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Project Title: Identification of Blunt Force Traumatic Fractures in Burned Bone

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Summary of Project

Forensic practitioners are often presented with burned human remains recovered from varied accidental scenarios ranging from plane crashes, vehicle fires, and wildfires, to structure fires and other intentional fires aimed at concealing a body or trauma to a body. Critical to their analyses of cause and manner of death is the ability to differentiate between thermal damage and any intentional sharp, blunt, or ballistic trauma. Initial attempts to differentiate the signatures of traumatic from thermal impacts indicated that such is possible (Hermann and Bennett, 1999; Pope and Smith, 2004). However, in 2009, Ubelaker provided a synthesis of the forensic interpretations, evaluations, and research involving burned skeletal remains and he concluded that, while previous studies indicated that some perimortem trauma signatures survive postmortem burning, "differentiating perimortem trauma from postmortem thermal-related alterations can be challenging" (Ubelaker, 2009:2). Similarly, Goncalves *et al* (2023) note that the examination of burned human remains lacks standard approaches that characterize anthropological assessments of unburned skeletal material.

Anthropological fire research has also explored expected burn patterns (Symes *et al* 2008, 2014), and more recently systems for descriptive classifications of burn damage (Galloway *et al* 2024; Pope *et al*, 2022; Williams, 2023), contributing to the complexity of isolating and identifying traumatic impacts to burned remains. Yet, the development of systematic, evaluative mechanisms for distinguishing perimortem trauma, particularly blunt force trauma, from thermal trauma is still lacking. The present study is a first attempt to move beyond the merely descriptive assessment of observable fractures in burned bones by using experiments with intact human remains burned in a controlled setting. This work provides guidelines for practitioners attempting to differentiate between perimortem blunt force and thermally induced trauma.

Given that most residential fires attain a maximum temperature of 650°C and automobile fires reach 950°C (Devlin *et al* 2004), the potential for impacts to bone tissue is dramatic. Exposing bone to heat alters bone's chemical properties and the relationship between the organic (collagen) and inorganic (hydroxyapatite crystals) compounds. In particular, the extraction of collagen dramatically increases the fragility of bone. Castillo *et al* (2013) noted that morphological changes in bone collagen can occur when exposed to temperatures as low as 100°C. While the remaining crystalline structure retains the gross contour of bone this material is brittle and the microstructural integrity is undoubtedly affected. These generally expected macroscopic and microscopic changes are further reflected in how the bone appears in terms of surface color and thermal fracture patterns, but also in the overall strength of the osseous material related to aspects of bone microstructure (mechanical strength and crystallinity).

The heat comprised mechanical properties and structural integrity of burned bone allow it to fail under less stress than unmodified bone. Simply, heat exposure will produce fractures in bone. Researchers Herrmann and Bennett (1999) outlined five fracture types commonly observed in burned bone:

1. Longitudinal- follow the long access of the bone and propagate with the grain;
2. Step fractures (straight transverse)- extend from the margin of longitudinal fractures and traverse against the grain

3. Curve transverse- in an arc formation across the grain and commonly found only at the epiphyseal/diaphyseal junction in long bones. They are commonly associated with the pulling away of soft tissue from bone with increasing heat and are regarded as indicators of pre-incineration condition as they have not been recorded in bone burned in a dry state.
4. Patina- affects the outer layers of cortical bone in epiphyseal regions and has a cracked appearance
5. Delamination- the peeling and flacking of bone layers. Often observed in cranial elements as the inner and outer tables separate along the diploe though it also occurs at the epiphyses.

An additional and well-documented signature of bone that has been affected by heat is a change in color. Following a spectrum ranging from unburned beige color progressing through dark brown, to black, followed by blue grey and white, exposed surfaces will exhibit these changes based on a combination of two factors: the duration and the intensity of the heat exposure. Other commonly observed, yet superficial, features of burned bone include the heat border and heat line. These attributes are transient and can only be found adjacent to areas that do not display any thermal alteration as both are proximate to and result from minimal heat exposure brought on by receding soft tissues (Symes et al 2008).

While the majority of these patterns and features are unique to thermally altered bone and are regarded as characteristics of heat exposure, fractures that follow longitudinal trajectories are not solely found in burned bone and can result from other traumatic forces. Similarly, radiating fractures known to characterize traumatic impacts may follow trajectories across bone that mimic thermal fractures.

Skeletal material is known to fail, i.e. fracture, when stressors exceed the strength of a bone. Most notably blunt force impacts on the human body produce expected and distinctive fracture paths and patterns in the hard tissues but can vary based on the condition and morphology of individual bones. For long bones, fractures are generally classified into one of three basic categories: simple, wedge, and complex. Subsequent descriptions may incorporate morphology and patterning such as transverse, oblique, butterfly, spiral, and comminuted. While blunt force fractures on unaltered (unburned) bone have distinct and signature appearances, this research focuses on whether these signatures survive and can be identified in burned remains; can they be differentiated from thermal fractures?

Major Goals and Objectives

This study focused on identifying patterns of, and differences between, perimortem blunt force traumatic fractures and thermally induced fractures. The issue at hand is two-fold: 1) documenting the survivability of perimortem blunt force fracture evidence following a burning event and 2) subsequently, where possible, providing tools to successfully guide practitioners in differentiating between blunt force and thermally induced fractures. Specifically, we sought to address whether it is possible to confidently, correctly, and reliably identify perimortem blunt force trauma in burned human remains.

The major goals of this research were focused on:

1. Documenting blunt force trauma fractures to the cranium, radius and ulna, and tibia prior to and after a burning event;
2. Comparing the fracture patterns (type and location) and their known etiology (blunt force or heat) to develop best practices for examining fractures observed in burned remains to contribute to manner and cause of death determinations.

Primary Research Question

1. Is it possible to identify fractures caused by blunt force in burned bone? That is, can blunt force fractures be differentiated from thermal fractures based on appearance and location.
    a. Does this differ between the upper limbs and lower limbs?
    b. Does a fractured limb produce a different burn pattern than its not impacted antimere?

Research Design

The goal of this research is to document and analyze blunt force trauma and thermally induced fractures on human remains. This research design had multiple overlapping stages in which human remains were mechanically impacted and thermally altered. The overlapping stages are described in detail below:

a. Research sample;
b. Blunt force trauma with a description of the Impact Device;
c. Thermal alteration with a description of the Forensic Pyre;
d. Fracture analysis

Methods

This study enrolled human donors from the Forensic Anthropology Center (FAC) Body Donation Program at the University of Tennessee, Knoxville. The FAC receives approximately 100 human donations each year for research. As part of the Body Donation paperwork, prospective donors indicated if they would like to be used for research involving trauma, including thermal trauma. Additionally, subjects were not autopsied, weighed less than 215 pounds, and were less than 6'1" tall. The presence of joint replacements or pacemakers were a disqualifying factor. A series of x-rays were collected to ensure no disqualifying attributes existed and to serve as baseline imagery. Digital radiographs were taken using a ULTRA 9030Hf Portable X-Ray Unit and scanned with VetRay Diagnostic software.

A total of 16 complete and intact human cadavers from the Forensic Anthropology Center (FAC) Body Donation Program (donors) were subject to mechanical impacts to several body regions and then thermally altered. The total sample consisted of 11 males and 5 females ranging in age from to 44 to 85 with a mean age of 68. The lowest weight was 100 and the highest was 201 with a mean of 151 pounds. In addition, the computed BMI for each donor can be seen in Table 1. Values between 18.5 to 25 are generally considered normal with those over 30 labeled obese (https://www.who.int/data/gho/data/themes/topics/topic-details/GHO/body-mass-index). As per the World Health Organization (WHO) categories, seven donors are classified as normal with three underweight, five overweight, and one obese. Once donors were enrolled in the project, they were subject to impact trauma.

Table 1: Sample demographics					
Subject #	**Sex**	**Age**	**Weight (lbs)**	**Height cm**	**BMI**
1	M	84	152	174.5	22.6
2	M	56	157	167	25.5
3	M	56	201	177	29.1
4	M	54	127	190	16
5	F	85	163	173	27.9
6	F	73	123	165	20.5
7	F	44	123	165	20.5
8	F	74	158	180	22.1
9	M	75	157	173	23.8
10	F	75	160	163	27.3
11	M	69	100	185	13.3
12	M	70	164	175	24.3
13	M	65	115	176.5	16.7
14	M	79	143	175	21.2
15	M	70	189	182.5	25.7
16	M	78	190	157	35
Mean all		68	151	174	23.22
Mean all males		66	154	176	23.02
Mean all females		70	145	169	23.66

Impact Device

Previous trauma experimentation relied upon investigator-powered blunt force trauma thus reducing the consistency of wounding (e.g. Herrmann and Bennett, 1999; Pope and Smith, 2004) or drop-weight towers (i.e. Kroman 2007, Powell *et al* 2012, Vaughan *et al* 2010). However, gravity driven devices (i.e. drop weight towers) are difficult to manipulate for impact location and research has shown that the force needed to fracture bones vary from 600 pounds (skull) to 1100 pounds (tibia) and up to 1760 pounds (humerus) (Kroman 2007, Nahum and Melvin 2002, Yoganandan and Pintar 2004). Therefore, use of a gravity-driven device to produce the impact forces necessary for the long bones is not ideal.

A specially designed pneumatically-controlled impact gantry system was built to allow researchers to control force (in psi), duration of impact, location of impact, and impact apparatus shape (square, rectangular, or spherical) (Figure 1). The gantry impact system was designed in conjunction with the Department of Mechanical, Aerospace, and Biomedical Engineering (MABE) at the University of Tennessee's Tickle School of Engineering. The pneumatic design of the gantry impact system allows investigators to control the necessary amount of force while the load cell records the time and amount of force was delivered. The impact gantry consists of the following five main components. Four of the features correspond to Figure 1 and are noted below as A-D.

A. The impact piston- The piston is a pneumatic cylinder that is affixed to the gantry and on which the impact heads are attached. The impact apparatus heads have three shape designs: square, spherical, and rectangular. The piston has a self-retracting spring on the release of air pressure and has a timer to control the impact duration.
B. An air supply system- The air supply system consists of an air compressor with an adjustable pressure regulator allowing for control of the impact piston force. The air cylinder can deliver a range of impacts between 400-2200 pounds with an input pressure of 25 to 150psi respectively. The air compressor is not illustrated here.
C. Adjustable gantry- The impact system is attached to the gantry which can be adjusted linearly along the length of the table as well as across the width of the base table. The angle of the impact piston can also be adjusted. The gantry design provides flexibility in positioning options.
D. Load cell and data acquisition system- A load cell is a sensor that records load, time, and energy dissipation and hence impact energy (recorded in J) and peak force (recorded in kN) generated by the impact block contacting the body. Data collected from the load cell will include magnitudes of impact drop energy and total contact duration of the impact.
E. Base table- A firm platform where the subjects are placed. The table size is consistent with standard autopsy tables.

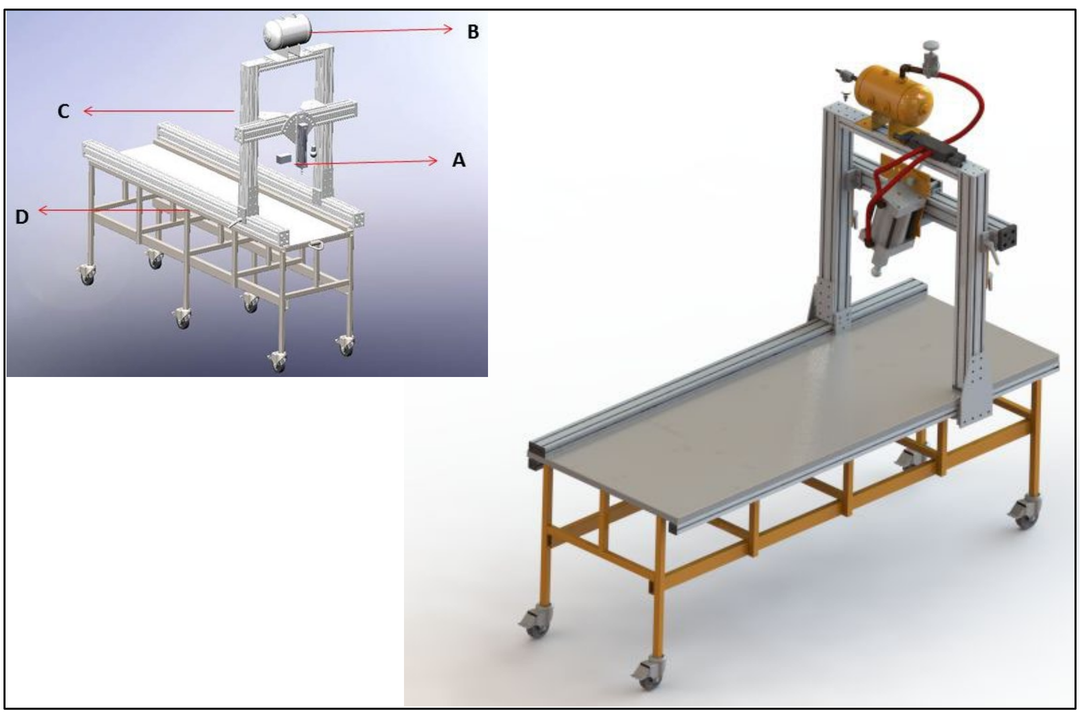

Figure 1 Impact table. Insert image details the four main components identified as A-D.

Blunt Force Trauma

Impacts were made in three locations: the cranium above the ear (landmark pterion), one side radius and ulna (the other side served as a control), and one side tibia and fibula (the antimere served as a control). The side was chosen based on ability to move and position the limb for impact.

Data on the load and time for each successful impact were recorded. The average psi for a fracture was approximately 87psi. Table 2 has the average psi and duration of impact for each body region

Table 2. Average PSI and time

Region	PSI	Time (sec)
Cranium	86.8	2.7
Arm	87.1	1.2
Leg	87.9	1.3

Once the donors were impacted, the fractured regions were x-rayed. Figures 2a, 2b, and 2c are examples of post-trauma x-rays.

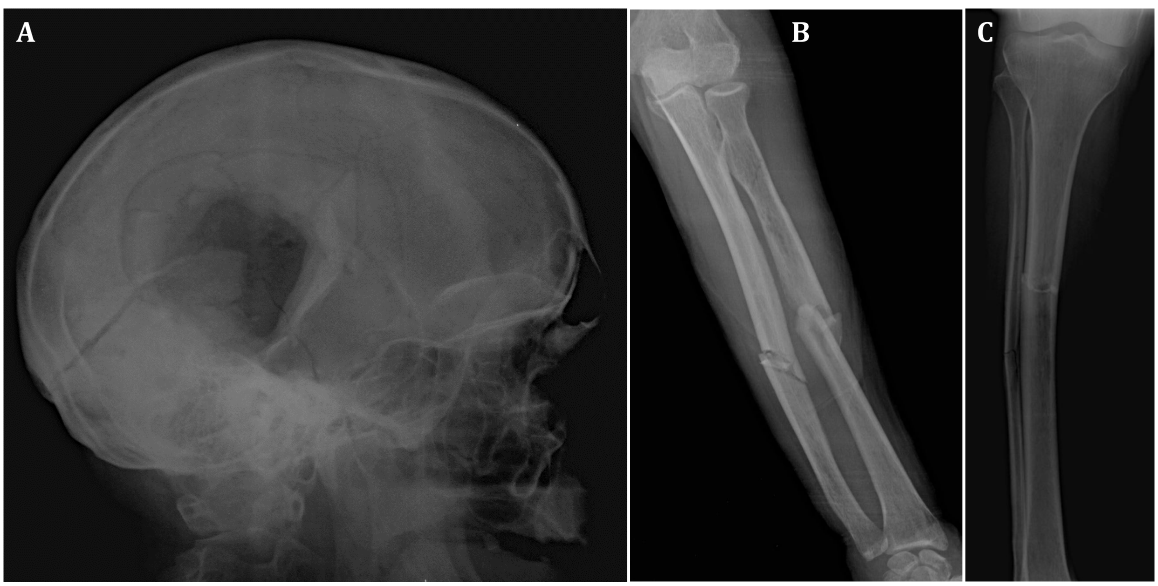

Figure 2 Examples of post impact radiographs. A cranial trauma, B forearm trauma, and C. for lower leg trauma.

Forensic Pyre

Following blunt force impact, all donors were exposed to thermal trauma using an outdoor forensic pyre. This research is the first known systematic study involving whole-body burning using the same situation (pyre) for each incident. The burning took place at a property owned by the University of Tennessee Institute of Agriculture. An area approximately 25x20m was cleared of any flora and covered with a layer of gravel. Each forensic pyre consisted of a 3-sided cinder block structure with an 8x4 foot steel perforated sheet on which donors were placed. See Figure 3.

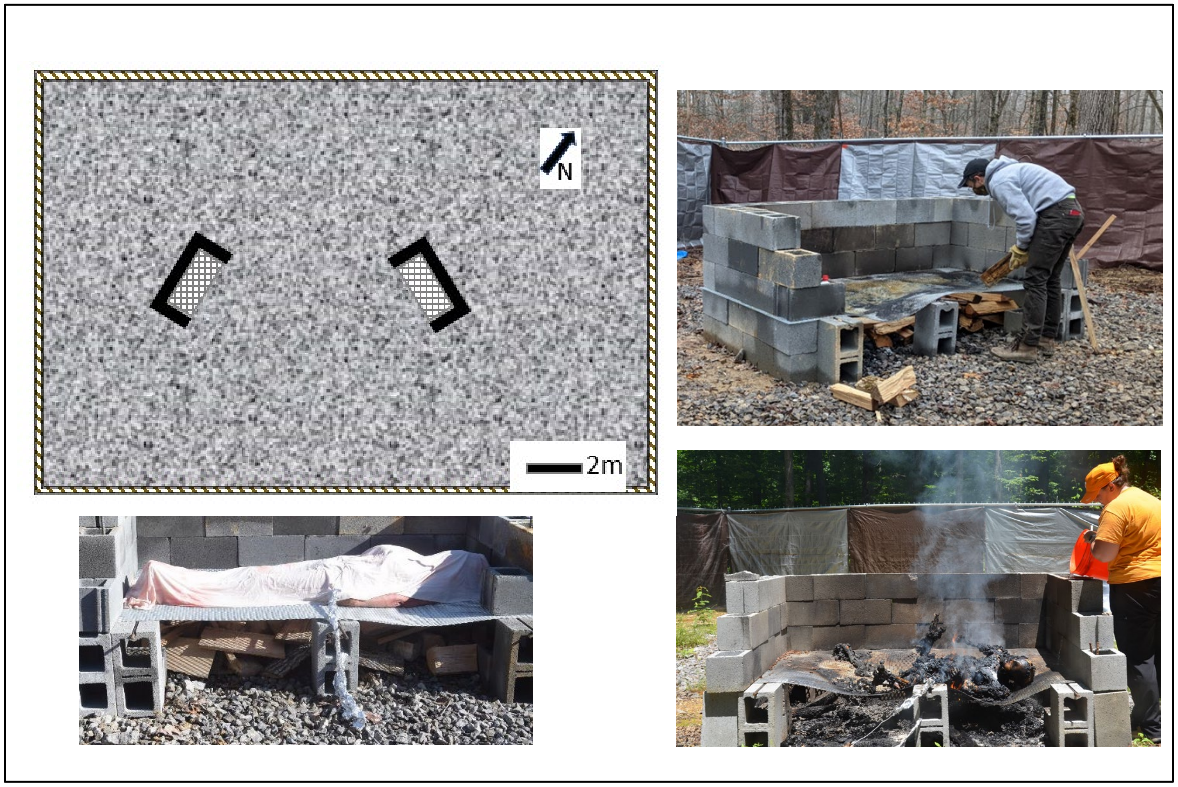

Figure 3 Forensic Pyre. Top left is schematic of pyre area. Clockwise images show pyre during preparation for a burn, lower right is cooling the block as part of heat suppression and lower left is prior to burn initiation. Foil wrapped around thermocouple wires.

For each burn event, the ignition source was a drip torch applied to locally sourced wood positioned under the steel sheet. No accelerant was placed on the bodies. Wood was continuously applied throughout each burn event to maintain the fire. Two thermocouple wires recorded temperature data during each burn. One wire focused on fire temperature while the other was on body temperature. These devices recorded the temperature at five-minute intervals throughout the burn. Additionally, a camera was mounted on a tripod and set to take a single photograph each minute through the thermal event. In addition, the length of each burn was.

Each burn event ceased when donors reached a Pope *et al* (2022) stage 4A/4B: charring of all body regions, major portions of the limbs are disarticulated, bone is exposed, and heat fractures are present. Bodies were not scored using the Pope *et al* system however, the scoring descriptors were used to standardize the level of burning across the project. Fuel was removed from the pyre by raking out embers and water was poured into the pyre structure. No water was applied directly to the burned skeletal remains. The remains were documented while still on the pyre and isolated bone fragments were recovered and packaged by element or body region. Once the body reached ambient temperature, it was transferred to a wooden tray for transport. At the lab, the fractured areas were x-rayed again and skeletal elements with trauma were set on trays. Elements or body regions with soft tissue were placed at the FAC outdoor decomposition facility (ARF) in protective settings.

Fracture data collection

The PIs documented the location of each blunt force impact and associated fractures based on the post-trauma x-rays. While the documentation of the blunt force impacts applied only to impacted limbs, post-burn assessments were applied to the impacted and the controls. Figure 4 illustrates the x-ray and completed diagram of the right radius and ulna of Donor 12 and the bones after thermal alteration.

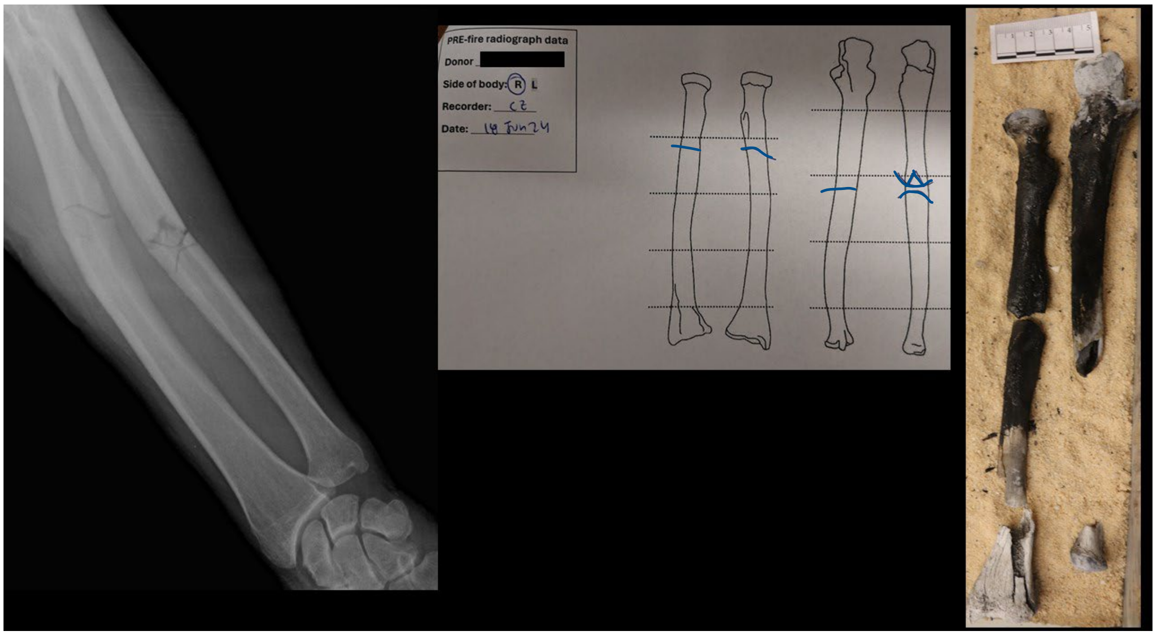

Figure 4 Example of data collection for donor 12. Left is pre-incineration radiograph. Center is documentation of location of blunt force impact and associated fractures. Far right depicts recovered burned bones.

All observable long bone fractures, whether the etiology was heat or trauma, were assessed using the combined Orthopaedic Trauma Association Committee for Coding and Classification and Muller AO classification of fractures (AO/OTA Fracture Classification), (Meinberg *et al*, 2018). Although a method to classify fractures in the craniomidface exists (Buitrago-Tellez *et al* 2002), it does not include the necessary components to describe blunt force trauma on the cranium, most importantly whether the fractures are concentric or radiating. Therefore, we will design a numerical system for the cranial elements (i.e. parietal = 1, occipital=2) and the fractures (A=linear, B=diastatic, C=stellate, D=depressed, E=comminuted). The AO/OTA system provides an alphanumerical code that conveys the type and complexity of bone fractures. The fracture type is indicated by letters A, B, C. The diaphyseal fracture type is further evaluated by group (1, 2, 3) to describe the fracture geometry (Table 3). This system generates a code that describes the type, group, and subgroup of fractures across five segments of each long bone. The segments are: proximal end, proximal 1/3, middle 1/3, distal 1/3, and distal end (Figure 5).

Table 3. AO/OTA Fracture Classification system for long bone diaphyseal fractures

Type	1	2	3
A- Simple	Spiral	Oblique	Transverse
B- Wedge		Intact Wedge	Fragmentary
C- Complex		Intact Segmental	Fragmentary segmental

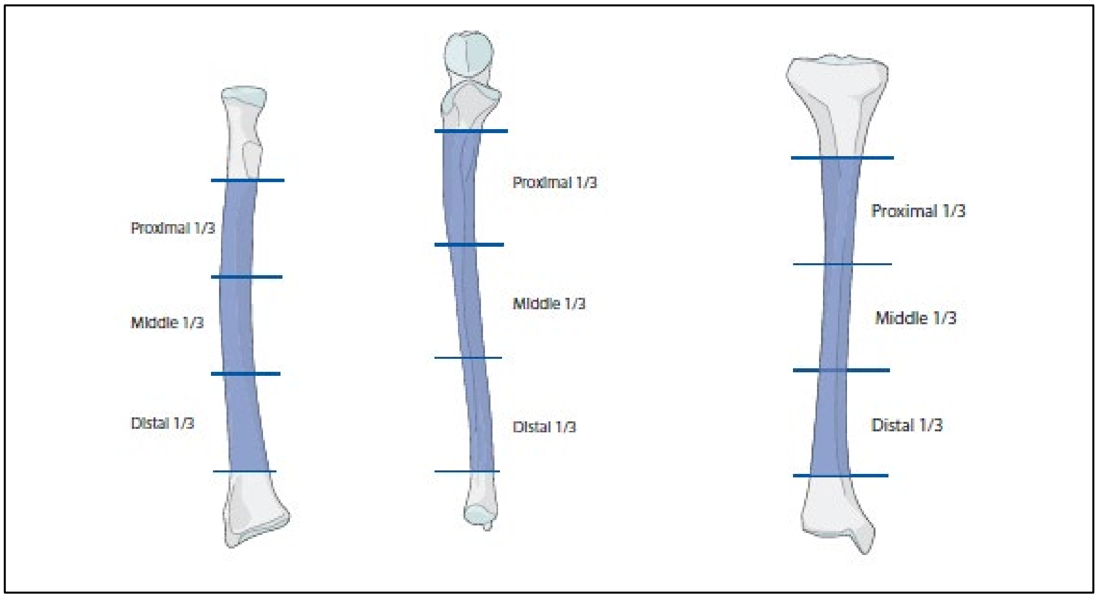

Figure 5 The five bone segments as set by the Orthopaedic Trauma Association Committee for Coding and Classification for each of the three long bones evaluated. From left to right: radius, ulna, and tibia.

Data collection was standardized using a specially designed Google Form (Appendix A). Each bone segment was evaluated for bone color, presence of impact trauma, and recognizable heat fractures. Specifically, visible bone colors were documented whether they were primary or secondary across the segment: 1) unburned, white yellow, 2) yellow/brown, 3) carbonized black, 4) grey-blue, and 5) calcined white. Known blunt force impacts and associated fractures were scored with the AO/OTA coding scheme and other fractures were therefore deemed heat-related. Fire breakage and fractures were noted as present or absent using standard terminology: 1) longitudinal thermal fractures, 2) step thermal fractures, 3) transverse thermal fractures, 4) patina thermal fractures, 5) splintering and delamination thermal fracture, 6) heat line fractures, 7) curved transverse thermal fracture, 8) heat line/border present, and 9) post-fire breakage.

Data Analysis Techniques

The data from the Google form were exported to a spreadsheet for data analysis. Each bone segment was coded (i.e. proximal end = 1, proximal third = 2, etc.) for more detailed assessments. Simple statistics were computed to characterize the assemblage. These include frequency of fracture type, pattern of isolated segments, color of segments, and blunt force fracture types. These data aid in documenting the survivability of perimortem blunt force fracture evidence. The aim is to identify any patterns to aid practitioners in their assessment of burned human remains.

Expected Applicability of the Research

The expected applicability of the research is to: 1) provide descriptive and quantitative data on expected post-burn fracture patterns of individuals without perimortem blunt force trauma; and 2) provide descriptive data on expected post-burn fracture patterns of individuals with blunt force trauma. The target audience includes medical examiners, coroners, and forensic anthropologists. Much of the information on burned remains and trauma patterns results from casework and experience but our systematic approach with the use of fleshed human donors and a gantry impact system will provide the criminal justice community with realistic and directly applicable fracture analysis and data for forensic casework. The skeletal remains from this project are curated by the Forensic Anthropology Center allowing continual trauma fracture training for students and professionals. The digital x-rays will also be available for future training and research allowing continual refinements and methodologies in trauma research.

Participants and other Collaborating Institutions

1. The gantry impact system was designed in conjunction as part of an undergraduate senior project in the Department of Mechanical, Aerospace, and Biomedical Engineering (MABE) at the University of Tennessee's Tickle School of Engineering.
2. The Forest Resources AgResearch and Education Center (FRAEC) at the University of Tennessee Institute of Agriculture (UTIA) in Oak Ridge, TN, provided the outdoor facilities for forensic fire burn research area. Specifically, Kevin Hoyt, the FRAEC Director, and Martin Schubert, Manager of the FRAEC.
3. Dr. Amy Mundorff, Associate Professor of Anthropology, and Caroline Znachko, Anthropology graduate student, assisted in burned bone data collection.
4. Multiple training opportunities also extended from this project.
    a) A graduate student assisted us with the x-ray protocol allowing her to become familiar with x-ray settings and how to produce x-rays in a medicolegal setting.
    b) Multiple graduate students and two forensic anthropology professionals observed the actual burns spurring several conversations regarding related research questions.
    c) Two graduate students assisted in the cleaning of burned remains, which resulted in a poster presentation at the American Academy of Forensic Sciences, Orlando, Florida, detailing how to process burned remains (see **List of Products**)
    d) An entomology post-doctoral fellow and an undergraduate research assistant sponsored by the University of Tennessee Office of Undergraduate Research and Fellowships assisted with collection of entomology samples and decomposition descriptions of four burn donors to compare the oviposition to unburned. This resulted in a publication (see **List of Products**).

Changes in Approach

The initial research design included impacting the thorax (ribs) in addition to the cranium and the long bones of the lower arms and legs. However, during the first burn event, we recognized that we were not able to maintain a Pope *et al* 2024 burn level 4B for the thorax. This region regularly exceeded the Pope *et al* 2024 5A stage; the ribs became too fragmentary, and identification of the blunt force fractures was not possible.

In addition, we had planned to collect data on bone mineral density of all donors. Unfortunately, the bone densitometer stopped working after three donors and the company that provided this machine were not able to fix it before the end of the project. Known bone mineral density may have provided insight into observed fracture patterns.

Outcomes

Activities

Over the course of 18 months, 16 donors were enrolled in the project. The 16 donors were burned on nine separate dates (Table 4). A total of ten crania (six controls), ten right lower arms and six left lower arms, nine right lower legs and six left lower legs were impacted.

Table 4. Donor activities summary

Research #	Bones fractured	Burn	Placement at ARF
1	R Radius	Jan 13 2021	January 19 2021
2	glabella, R arm, R leg	Jan 22 2021	January 26 2921
3	R pterion, L arm, L leg	Feb 25 2021	March 2 2021
4	L pterion, R arm, R leg	Feb 25 2021	March 2 2021
5	L pterion, L arm, L leg	May 5 2021	May 7 2021
6	L pterion, L arm, L leg	May 5 2021	May 7 2021
7	L pterion, L arm, L leg	June 30 2021	July 1 2021
8	R pterion, R arm, R leg	June 30 201	July 1 2021
9	R pterion, R arm, R leg	March 31 2022	April 1 2022
10	L pterion, R arm, R leg	March 31 2022	April 1 2022
11	R arm, R leg	April 7 2022	April 9 2022
12	R arm, R leg	April 7 2022	April 9 2022
13	R arm, R leg	May 31 2022	June 1 2022
14	L pterion, L arm, L leg	May 31 2022	June 1 2022
15	L arm, L leg	July 11 2022	July 12 2022
16	R arm, R leg	July 11 2022	July 12 2002

Results and Findings

We have analyzed fire temperature and time data and have evaluated ten left and right tibias (for a total of 100 analyzed portions) and seven left and right radius and ulnas (for a total of 140 analyzed portions: 70 for the radius and 70 for the ulna).

<u>Burn time and temperature</u>

Burn durations ranged from 86 to 202 minutes with an average time of 134 minutes (Figure 6). Across all burns, the body temperatures ranged from 77°C to 576°C. Average fire and body temperatures across 14 donors are illustrated in Figure 7.

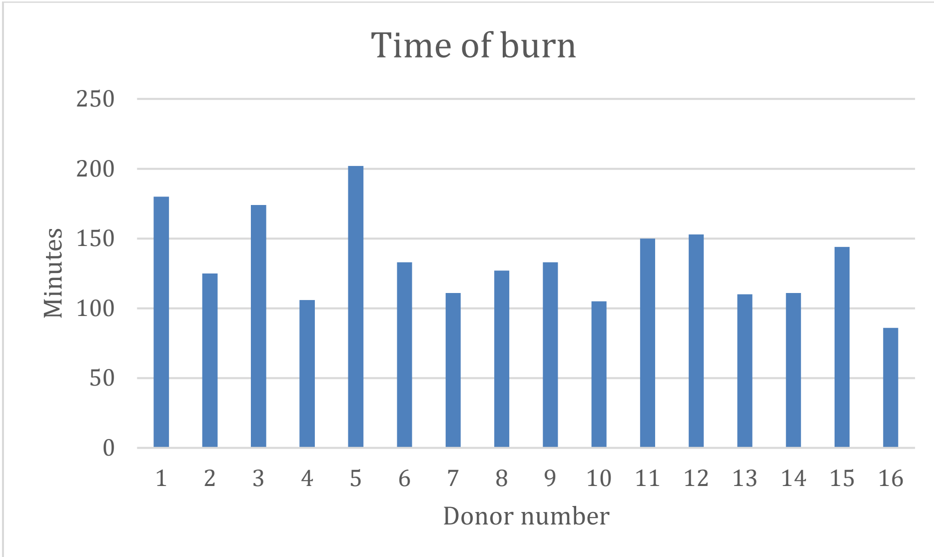

Figure 6. Time of burn durations in minutes

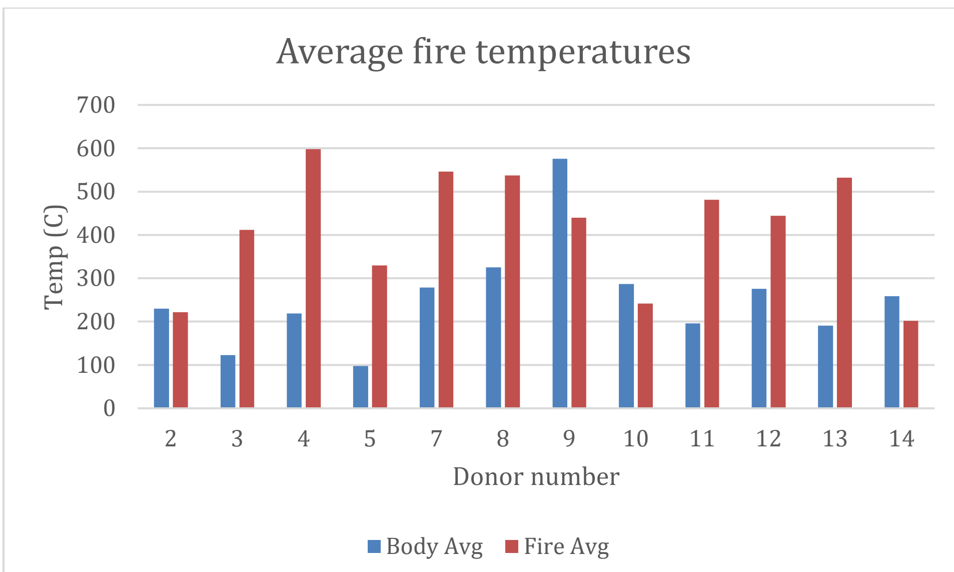

Figure 7. Average fire and body temperatures

Average fire temperatures are relatively constant across the project, most likely due to consistency in fuel type. The average fire temperature exceeded the average body temperature by several hundred degrees except in four burn events where the average body temperature exceeded the average fire temperature; however, the difference in these values is negligible. The duration of burns fluctuated across the research period but for many of the burns, there is a clear indirect relationship between average fire temperature and fire duration: for longer burn events, average fire temperature is lower (eg. donor numbers 3 and 5) and for shorter burns, average temperatures are higher (e.g. 4 and 7). Seasonality (i.e. ambient air temp) and BMI do not appear to affect fire time and temperature but will be explored with further research.

Thermal fracture analysis

Long bone thermal fractures will be presented by element: tibia as one and radius and ulna as a pair. Thermal fractures are present on 77% of tibial segments (164 thermal fractures). The most common thermal fracture recorded was longitudinal (37%) followed by heat line fractures (19%). Although often discussed in the literature, curved transverse comprised only 3% of total thermal fractures recorded. 42% of the segments had heat lines or borders present.

Thermal fractures were present on 72% of combined radial and ulnar segments (136 thermal fractures r). The most common thermal fracture recorded was longitudinal (45%) followed by transverse fractures (22%). As in the tibia, curved transverse comprised only 2% of total thermal fractures. Heat lines or borders were present on 31% of the segments.

Blunt force fracture analysis

The most seen AO/OTA fracture types on tibias are A3 (simple transverse, n=4) and B3 (complex wedge, n=3). Blunt force trauma was most easily observed when the impact or associated fractures traversed unburned bone segments. Table 5 documents the assessment of the blunt force impact to the tibia; note the primary burn level and how the fractures were identified. Even though the PIs and data collectors were aware of the location of the blunt force trauma, we found instances when we could not comfortably assign an etiology of blunt force trauma, especially in charred or calcined bone.

Table 5. Summary of tibial blunt force fractures

Donor	**Tibia-side**	**Bone segment**	**Primary burn level**	**How fracture identified**
2	Right	Middle 1/3	Unburned	Clear fracture on unburned with radiating fracture lines
3	Left	Middle 1/3	Unburned	Clear fracture on unburned
4	Right	Middle 1/3	Grey/Blue	From x-rays; portion is incomplete however fracture margins are not consistent with thermal fractures
6	Left	Proximal 1/3	Unburned	Clear wedge fracture on unburned
7	Left	Middle 1/3	Grey/Blue	Not identifiable on bone
8	Right	Middle 1/3	Carbonized/Black	Not identifiable on bone
9	Right	Proximal 1/3	Unburned	Clear fracture on unburned
10	Right	Middle 1/3	Unburned	Clear fracture on unburned
11	Right	Proximal 1/3	Unburned	clear fracture on unburned
12	Right	Proximal 1/3	Unburned	Clear fracture on unburned

Our observations include:

1. The distal most segment of the tibia tends to separate from the rest of the diaphysis, likely associated with calf muscle contraction. Thirteen of the 18 distal segments (72%) are isolated portions. The segmentation is not due to blunt force trauma.

2. A clear border between burned and unburned bone is not indicative of perimortem trauma. Figure 8 illustrates a clear differential burn pattern between the proximal half and distal half of a tibia. This tibia was not impacted.

Figure 8. Differential burn pattern on a non-impacted tibia

Although the radius and ulna are adjacent elements, in two instances, the ulna did not fail (donor 9 and 14) and in one instance, the radius did not fail (donor 10). The most seen AO/OTA fracture types on the radius and ulna are A2 (simple transverse, n=3) and B3 (complex wedge, n=5), often identified via x-rays (Table 6). Due to the normal burn pattern, the radius and ulna were often missing the distal two segments and were incomplete making blunt force fracture identification not possible.

Table 6. Summary of radial and ulna blunt force fractures

Donor	Radius side	Ulna side	Bone segment	Primary burn level	How fracture identified
3	Left		Distal 1/3	Unburned	Clear fracture on unburned
3		Left	Distal 1/3	Unburned	Clear fracture on unburned
4	Right		Distal 1/3	Carbonized/Black	Boundary between unburned and burned
4		Right	Distal 1/3	Carbonized/Black	Smooth oblique fracture on carbonized bone
6	Left		Proximal 1/3	Unburned	Clear fracture on unburned
6	Left		Middle 1/3	Unburned	Fragments of the impact site are missing; only confirmable via x-ray
6		Left	Middle 1/3	Unburned	Clear fracture on unburned
9	Right		Middle 1/3	Unburned	smooth margins
9		Right	Middle 1/3	Unburned	Not fractured
10	Right		Middle 1/3	Carbonized/Black	Not fractured
10		Right	Middle 1/3	Unburned	Appears as wedge fracture, wedge not recovered; x-ray confirmed
12	Right		Middle 1/3	Carbonized/Black	Wedge fragments missing; x-ray confirmed
12		Right	Middle 1/3	Grey/Blue	Complete fracture site not present; x-ray confirmed
14	Left		Middle 1/3	Unburned	Clear fracture on unburned
14		Left	Middle 1/3	Unburned	Not fractured

Our observations include:

1. Thermal damage impacts the distal most segments more frequently than the middle segments. As a result, the distal portion may experience thermal fracturing that may obscure or, to a novice practitioner, mirror blunt force trauma. Figure 9 demonstrates the radius and ulna from the same donor. The left side was blunt force impacted while the right side was not. The isolated damage seen on the distal right ulna and middle third of the radius is due to thermal damage.

Figure 9: Left and right radius exhibiting comparable thermal and blunt force damage patterns. Box indicates enlarged view at right.

2. A clear border between burned and unburned bone may be indicative of perimortem trauma. This observation differs from tibial patterning. Figure 10 illustrates a clear differential burn pattern between the left and right radius of the same donor. While the right radius exhibits the juxtaposition in color (burned and unburned) between adjacent fragments, the non-impacted left bones are fragmented but those fractures traverse burned areas. The radius on right is a result of blunt force trauma, the left radius is a result of thermal trauma. Of note is the simple fracture on the left radius (thermal) and the absence of the distal ulnar ends.

Figure 10. Left and right radius and ulna of donor 10 with similar burn pattern; right side was impacted. The elements on the right side of image are from the right side.

3. Due to the morphology and overall size of the radius and ulna, it is more difficult to confidently identify blunt force trauma. In addition, for these elements thermal trauma may be misinterpreted as blunt force. Figure 11 demonstrates a left ulna with a differential burn pattern as well as an apparent wedge fracture but was not impacted.

Figure 11. Left ulna with varied adjacent burn colors and apparent wedge fracture. No impact trauma. The image at right is an enlarged view of the boxed portion.

Limitations

Limitations of this research include the inherent issues involving burned bone (fragmentation, shrinkage). The fragmentation of bone impacts the ability to recover 100% of the remains. Although this research was conducted in a controlled setting designed to maximize recovery, some of the blunt force fractures are complex and produce small and unidentifiable fragments. However, this limitation reflects real-world forensic situations. Another limitation was the rigidity of the adhering burned soft tissues. This required innovative, and time-consuming, processing which led to an extended data analysis timeline. Finally, the outcomes of this research cannot be extended to cremated remains, however that can be a future research avenue.

Artifacts

List of Products

Devlin, J and Vidoli, G. "Observations from Experimental Burning" Presented as part of Workshop 23: The Impact of Burning on Skeletal and DNA Evidence American Academy of Forensic Sciences Annual Meeting, Denver CO

Hayden McKee-Zech, MSc; S. Fatula, MA; G. Vidoli, PhD; J. Devlin, PhD "A Technical Note on Recovery and Processing of Burned Human Remains" Poster presentation at the American Academy of Forensic Sciences Annual Meeting, Orlando, FL, February 2023

McKee-Zech, H., Fatula, S., Devlin, J and Vidoli, GM (2023). Recovery and Processing of Burned Human Remains. Podium presentation at the 24th Annual Conference of the British Association for Biological Anthropology and Osteoarchaeology. 15-17 September, London.

Owings, C., McKee_Zech, H., Orebough, J., Devlin, J., Vidoli, G. (2024) The utility of blow fly (diptera: calliphoridae) evidence from burned human remains. *Forensic Science International* 356: doi: 10.1016/j.forsciint.2024.111962

Vidoli, G., & Devlin, J. "Thermal Alteration and Trauma in Human Bones". In *20th congress of the International Federation of Association of Anatomists*. Istanbul, Turkey. August 5, 2022

Vidoli G.M. and Devlin, J. "Bone Trauma and Thermal Alteration of Human Remains". Paper presented at the National Institute of Justice Forensic Science Research and Development Symposium. February 14, 2023

In review McKee-Zech, H., Fatula, S., Devlin, J and Vidoli, GM "Protocols for the recovery, processing, and curation of burned human remains" Submitted to PLOS One

Data Sets generated

1. Radiographic images of pre-trauma, post-trauma, and post-fire of the crania, both radius and ulna, and both tibias of 16 donors
2. Timed photographs of each burn- one photograph per minute of the burn. This equates to an average of 134 photographs per burn
3. Temperature data for 14 of the burns
4. Force data all the impacts, recorded in psi, impact energy, and peak force
5. Primary and secondary burn colors for each diaphyseal segment
6. Thermal fractures present on each diaphyseal segment

Dissemination Activities

Since this project initiated, we have provided thermal trauma lectures to numerous groups of professional crime scene investigators including over 200 FBI Evidence Recovery Team members, more than 100 crime scene investigators from Mexico, 15 forensic anthropologists from Colombia and 80 law enforcement from around the United States. This has also provided opportunities to discuss the impact of fire on the body and they have had the opportunity to observe the burned remains at the ARF and the bone fragments in the FAC lab.

References

Buitrago-Tellez, C. H., Schilli, W., Bohnert, M., Alt, K., & Kimmig, M. (2002). A comprehensive classification of craniofacial fractures: postmortem and clinical studies with two- and three-dimensional computed tomography. [Research Support, Non-U.S. Gov't]. *Injury, 33*(8), 651-668.

Castillo, R. F., Ubelaker, D. H., Acosta, J. A. L., & de la Fuente, G. A. C. (2013). Effects of temperature on bone tissue. Histological study of the changes in the bone matrix. *Forensic science international*, *226*(1-3), 33-37.

Devlin, J.L., Dalton, M., Kennamer, D.C. (2004). Vehicle Fires: Actualistic Investigations. In *Proceedings American Academy of Forensic Sciences Annual Meeting Dallas, TX 2004* p. 176-177

Galloway, A, C Juarez, and E Pope (2024). How human bodies burn. The process of Thermal Damage, Body Movement, and shifting Fuel Loads. In The Path of Flames, Understanding and responding to fatal wildfires. Kendell, Galloway and Milligan eds. CRC Press. Taylor Francis Group, Baco Raton, FL. Pp:147-157.

Goncalves, D., C. Makhoul, MT Ferreira, and E. Cunha. (2023). The First References Collection for the Research of Burnt Human Skeletal Remains Stemming from the 21st Century Identified Skeletal Collection (Portugal). In Burnt Human Remains, Recovery, Analysis and Interpretation. S. Ellingham, J. Adserias-Garriga, S. Zapico and D. Ubelaker eds. John Wiley and Sons Ltd., Hoboken, NJ. pp:13-36.

Herrmann, N. P., & Bennett, J. L. (1999). The differentiation of traumatic and heat-related fractures in burned bone. [Research Support, Non-U.S. Gov't]. *J Forensic Sci.*

Kroman. A. (2007) Fracture biomechanics of the human skeleton. PhD Dissertation, University of Tennessee, *Knoxville*, TN.

Meinberg E, Agel J, Roberts C, et al. (2018). Fracture and Dislocation Classification Compendium. *Journal of Orthopaedic Trauma,* 32(*1)* Supplement.

Nahum, A. M., & Melvin, J. W. (2002). *Accidental Injury: Biomechanics and Prevention*. New York: Springer.

Pope E. (2023) Fire Environments and Characteristic burn patterns of human remains from four common types of fatal fire scenes. In Burnt Human Remains, Recovery, Analysis and Interpretation. S. Ellingham, J. Adserias-Garriga, S. Zapico and D. Ubelaker eds. John Wiley and Sons Ltd., Hoboken, NJ. pp:13-36.

Pope, E., C Juarez and A. Galloway, (2022). Refined classification system for thermally damage human remains by body segment. Forensic Anthropology 5(1): 57-72.

Pope, E. J., & Smith, O. C. (2004). Identification of traumatic injury in burned cranial bone: an experimental approach. [Research Support, Non-U.S. Gov't]. *J Forensic Sci, 49*(3), 431- 440.

Powell, B. J., Passalacqua, N. V., Baumer, T. G., Fenton, T. W., & Haut, R. C. (2012). Fracture patterns on the infant porcine skull following severe blunt impact. *Journal of forensic sciences*, *57*(2), 312-317.

Symes, S, C. Rainwater, E. Chapman, D Gipson and A. Piper. (2008). Patterned thermal destruction of human remains in a forensic setting. In the analysis of burned human remains. C.Schmidt and S. Symes eds. Academic press, Elsevier, Amsterdam. Pp:15-53.

Symes, S. A., L'Abbé, E. N., Stull, K. E., LaCroix, M., and Pokines, J. T. (2014). Taphonomy and the timing of bone fractures in trauma analysis. In *Manual of forensic taphonomy*(pp. 341-365). Boca Raton, Florida: CRC Press.

Ubelaker, D. H. (2009). The forensic evaluation of burned skeletal remains: a synthesis. [Review]. *Forensic Sci Int, 183*(1-3), 1-5. doi: 10.1016/j.forsciint.2008.09.019

Vaughan, P. E., Vogelsberg, C. C., Vollner, J. M., Fenton, T. W., & Haut, R. C. (2016). The Role of Interface Shape on the Impact Characteristics and Cranial Fracture Patterns Using the Immature Porcine Head Model. *J Forensic Sci, 61*(5), 1190-1197. doi: 10.1111/1556- 4029.13111

Williams, A. (2023). Methods for analyzing burnt human remains. In Burnt Human Remains, Recovery, Analysis and Interpretation. S. Ellingham, J. Adserias-Garriga, S. Zapico and D. Ubelaker eds. John Wiley and and Sons Ltd., Hoboken, NJ. pp:75-98.

World Health Organization https://www.who.int/data/gho/data/themes/topics/topic-details/GHO/body-mass-index; Accessed 27 June 2024.

Yoganandan, N., & Pintar, F. A. (2004). Biomechanics of temporo-parietal skull fracture. *Clinical Biomechanics, 19* (3), 225-239. doi:10.1016/j.clinbiomech.2003.12.014

Appendix A: Burn data collection form

Burn Bone data collection Feb 2024

* Indicates required question

1. Donor number (no D required) *

2. Data collector initials *

3. Bone

Check all that apply.

	Left	Right
Radius	☐	☐
Ulna	☐	☐
Tibia	☐	☐

4. AREA OF ANALYSIS 1 *

Mark only one oval.

- ◯ Proximal End (41)
- ◯ Proximal 1/3
- ◯ Middle 1/3
- ◯ Distal third
- ◯ Distal end
- ◯ Other: ____________

5. Is this portion an isolated segment? *

Mark only one oval.

- ( ) Yes
- ( ) No

6. What Color is the bone?

Check all that apply.

	I White/Yellow	II Yellow/Brown	III Carbonized/Black	IV Grey/Blue	V Calcined/White
Prriimarry	☐	☐	☐	☐	☐
Secondarry	☐	☐	☐	☐	☐

7. Was this segment impacted (BFT)? *

Mark only one oval.

- ( ) Yes *Skip to question 8*
- ( ) No *Skip to question 9*

BFT Scoring

8. Type of BFT Fracture (AO/OTA code)

____

Taphonomy

9. Are there any radiating BFT fractures traversing on this segment? *

Mark only one oval.

- ( ) Yes
- ( ) No

10. Does the area display thermal or postfire breaks? *

Mark only one oval.

- ( ) Yes- continue to next question
- ( ) No- skip next question

11. What type of breaks? Pick all that apply

Check all that apply.

- [ ] F1 Longitudinal Thermal fracture
- [ ] F2 Step Thermal fracture
- [ ] F3 Transverse Thermal fracture
- [ ] F4 Patina Thermal fracture
- [ ] F5 Splintering and delamination Thermal fracture
- [ ] F6 heat line fractures Thermal fracture
- [ ] F7 curved transverse Thermal fracture
- [ ] Heat line/border present
- [ ] Post-fire breaks
- [ ] Other: ____________________

12. Other comments