Masked by Fire:
A Pilot Study Analyzing Perimortem Ballistic Trauma in Burnt Remains

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Fire is believed to destroy everything it comes into contact with, making it a popular choice for covering up crimes like murder. By warping and shrinking the bones, fire can pose quite a challenge to even the most experienced forensic investigator. To better understand the effects of fire on bodies it is common for forensic investigators to set up experiments to study these effects. In the case of my thesis I employed an experiment to look at the effects fire can have on remains that have been inflicted with ballistic trauma. Through careful examination of the skeletal remains, I have attempted to observe the morphological changes of the traumatic markers on the bones as they progress through the different stages of burning. It is my hope that my research will provide forensic investigators with a better understanding of how ballistic trauma changes in fire and how to identify the differences between the postmortem fractures of fire to the perimortem fractures generated by ballistic trauma.

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Chapter 1

Forensic Anthropology and Trauma Analysis and its Relevance to Public Issues

Murder is a crime that destroys families and can terrorize and haunt communities. It falls on the shoulders of law enforcement agencies and forensic investigators to ensure that when crimes like murder are committed, they are brought to a close as efficiently and as swiftly as possible, so that the victims family and community can return to their normal lives. Due to how destructive murder is, the public and the victims' families will have high expectations for law enforcement (Glassman: 2009, Sledzik et al: 2009, Saur: 2009). There is a common misconception that fire destroys everything it touches and so it is often employed by criminals to quickly cover up crimes like murder. It is imperative that forensic investigators, whether they are academics or law enforcement officers, tackle the challenges that fire scenes present. Furthermore, a victim's family can also expect law enforcement to be ethical with the victim's remains and to ensure that while the remains are in the hands of forensic investigators, like forensic anthropologists, those remains are not abused or mistreated in anyway (Dirkmaat: 2012, Glassman: 2009).

One of Forensic anthropology's roles is to assist in the solving of crimes where skeletal remains are present. However, forensic anthropology is not limited to dealing with dry bones. It can also be employed in identifying human remains in other types of scenes such as, mass disasters and fatal fires where although soft tissue may be present, in most cases it is often too heavily damaged to be used to provide an accurate understanding of the scene. In these contexts forensic anthropologists are utilized to reconstruct the story of the crime scene by examining the bones of the victim.

Forensic anthropologists can also assist law enforcement further through archaeology and taphonomy. By taking an archaeological approach to crime scenes, forensic anthropologists can assist law enforcement officers in recognizing some of the environmental effects that influence bone and estimate how long the remains have been exposed to the natural elements (Marks: 2009, Dirkmaat: 2012). Through meticulous recovery and analysis, forensic anthropologists can provide a detailed report that identifies fractures that occurred perimortem, and associated with cause of death, and fractures that occurred postmortem and associated with environmental causes (Marks: 2009, Dirkmaat: 2012).

I am comparing perimortem fractures associated with ballistic trauma with postmortem fractures that are often produced by the heat and flames of fire. By improving our knowledge on how to differentiate between these different types of fractures accuracy can be advanced during crime scene and laboratory analysis of the remains. My research reflects public issues through its affiliation with forensic anthropology; I see my research as a forensic experiment that looks to build upon existing knowledge within this field to improve academic and forensic investigator's skills when it comes to identifying trauma in burnt remains.

Careful recovery of the remains ensures that any potential evidence that may be present in the remains can be recovered, and not lost or destroyed. In fatal fire cases, remains are often very fragile due to dehydration and calcination of the bone. Any trauma present on the bone is equally fragile and can easily be lost or destroyed if proper care is not taken. Mishandling potential evidence can compromise the investigation. This can be very stressful and painful for the victim's family, as unsolved cases will leave them wondering if law enforcement did everything in their power to solve the case (Glassman: 2009). This emotional stress can result in an overall loss of faith in the justice system (Glassman: 2009).

In the end, my research is but a small part of trying to bring about information for those who have been killed, and closure to those who have lost someone they love. By equipping those investigating the case with the proper knowledge and understanding of how perimortem fractures are produced and how they can be altered by fire, and by also providing them with images showing the difference in appearance between perimortem and postmortem fractures commonly associated with fire. I hope to show to the public that every victim has a voice that can be heard no matter how brutal the carnage or how destroyed the scene may be. Even the most destructive natural elements like fire can be understood with accuracy if we simply take the time to *read* the bones carefully.

My research is a forensic-oriented experiment, and the journal I would like to submit my research to is the *Journal of Forensic Sciences*. This journal is published by the American Academy of Forensic Sciences, which is the leading forensic community in North America when it comes to publishing current forensic research, as well as setting the standards that forensic investigators across the disciplines of forensics must adhere to if they wish to be considered accredited experts in the field. By publishing with this journal it is my hope that my research will reach others studying burnt remains and provide possible insight to them on what I found when I was conducting my research. I also hope that my research may encourage other researchers to also set up and carry out their own experiments to study how fire can affect other forms of trauma.

Chapter 2

Masked by Fire: A Pilot Study Analyzing Perimortem Trauma in Burnt Remains

2.1 Introduction

With fire being capable of destroying and masking evidence, forensic experts need to have an understanding of how fire behaves, and how tissues and other materials break down in fire, and how trauma can be altered by the extreme heat that fire can produce. Recent work in forensic anthropology and forensic pathology has addressed the behaviour of fire, and its effects on the human body (Dirkmaat: 2002). Traditionally, it was thought that fire destroys everything and the recovery of trauma is nearly impossible because of how fire can warp and alter both the soft and hard tissues of the body, however, in recent years, experimentation has found that that despite all of the alterations trauma can still be detected as it can leave distinctive markers that stand out from natural burn markers (Symes et al: 2008, Dehaan: 2008,Dirkmaat: 2002).

I will contribute to this ongoing discussion of the preservation of trauma in burnt remains by presenting an experimental component that explores this issue. I hope to contribute to the development of a clear set of observations and criteria that clarify indications of trauma in burnt remains, and therefore contribute to the work of forensic investigators in determining whether or not trauma contributed to death.

2.2 Hypotheses

I hypothesize that in the early stages of the burning process, when tissue is still present, any trauma that has been inflicted on the body will only be obscured at the soft tissue level. The fire may conceal entrance and exit wounds in the body as soft tissues such as skin and organs shrink and dehydrate (Mayne-Correia: 1997, Symes et al: 2008). Furthermore, bullet trajectory paths through the soft tissue may also be altered due to the alteration of the soft tissue (Mayne-Correia: 1997, Symes et al: 2008). In these early stages, the alteration to the bone should be minimal, because the tissue mass protects the bones from being altered by the fire.

As the bones are left to burn longer in the fire the persistence of evidence should become more questionable, and I hypothesize that the loss of evidence for trauma will be dependent on the relationship between the size and age of the pig with the amount of time that has passed and the temperature of the fire (Dehaan: 2008, Dehaan: 2012, Devlin & Herrmann: 2008). As remains are exposed to heat the bones undergo a process known as calcination (Dirkmaat et al: 2012, Symes et al: 2008, Correia: 1997). During the calcination process, water evaporates and other organic material carbonizes. The results of the calcination process are remains that are left smaller and very brittle, because all that remains in the body is the inorganic components like the mineral crystals that provide the structural foundation for the bones (Symes-Dirkmaat: 2012, Symes et al: 2008).

<u>2.3 Materials and Methodology</u>

2.3.1. Brief Description of the Pigs

I burned nine pigs over a period of five months. The pigs were bought from a local farmer just outside of Alymer Ontario. The farmer owned two different farms, to keep the male pigs separated from the juveniles and the females; all of the pigs that I purchased were juvenile females with the oldest being no more than a year. These pigs had died of natural causes; none of the pigs were euthanized for purpose of this experiment. Because they died of natural causes, these nine pigs were not all the same weight, and ranged from thirty-five to ninety pounds (fifteen to forty kilograms) See table 1 below. Of the nine pigs that were burned, eight were inflicted with ballistic trauma, and one was used as a control. As these were juvenile pigs that were shot, the dimorphism of their bones are different compared to adult pig bones, this is important to note as it can influence the trauma patterns generated by the bullets.

<u>Pigs:</u>	**Pig Weight (lbs)& (Kgs)**	**Burn Duration**	**Estimated Temperature in Fahrenheit (ºF)**	**Trauma Location and # of Bullets**
Pig 1	55-60 (lbs) 24.94-27.21 (kg)	1 hour and 26 minutes	Charred Stage Peak Temp:972	3 right shoulder/upper arm 2 sternal region 1- right rear leg
Pig 2	50-55 (lbs) 22.67-24.94(kg)	1 hour and 28 minutes	Early Partially Calcined Stage Peak Temp: 1054	3- right shoulder upper arm 4- sternal region 1- right rear leg
Pig 3	45-50 (lbs)	1 hour 40	Late Partially Calcined	1- right shoulder upper

	20.41- 22.67(kg)	minutes	Stage Peak Temp: 1285	arm 2- sternal region 3- right rear leg
Pig 4	50-60 (lb) 22.67- 27.21(kg)	20 minutes	Charred Peak Temp: 1520 Average: 1000	4- right shoulder/upperarm 4- sternal region 4 -right rear leg
Pig 5	50-55 (lb) 22.67-24.94 (kg)	1 hour	Early Partially Calcined Peak Temp: 1513 Average: 950-1000	4- right shoulder/upperarm 4-sternal region 4- right rear leg
Pig 6	45-50 (lb) 20.41-22.67 (kg)	1 hour and 25 minutes	Late Partially Calcined Peak Temp: 1593 Average: 1050-1100	4-right shoulder/upperarm 4- Sternal region 4- Right Rear leg
Pig 12	80-90(lb) 36.28-40- 82(kg)	7 hours	Fully Calcined Peak Temp: 1500	15 - Right Shoulder Arm 6- Sternal region 5- Right Rear Leg Note: 2- 45 Calibre FMJ rounds 38 Special Rounds- 3 Upper arm/ 1 Skull 20- 45 Calibre hollow point rounds
Pig 13	40-45(lb) 18.14- 20.41(kg)	4 hours	Fully Calcined Peak Temp: 1500	6- right rear leg 6- Sternal region 5- right shoulder upper arm Note: 3- 38 special rounds 2 Upper Arm/ 1 Skull 14- 45 Calibre hollow point rounds
Control	35-40lbs	2 hours	Late Partially Calcined	No ballistic trauma was

	15.87- 18.14		Peek Temp: 1496	inflicted

Table 1: Pig Weights and Burn Temperatures- Temperature readings were measured in Fahrenheit

2.3.2 Ethics Approval and Handling of the Remains:

This research did require I complete a level A protocol form which address the how I should handle the tissue and dispose of it. However, other clearance was not required as none of the pigs I was working with were alive for the research I was not required to acquire permission from the CCAC (Canadian Council of Animal Care). When it came to handling and processing the remains all those working and handling the pigs were required to wear biohazard tyvek suites, medical gloves, ventilators and safety goggles to ensure that no bodily fluids, harmful bacteria or anything else that could be harmful transferred from the deceased pigs to me or the volunteers.

2.3.3 The Shooting Phase

To ensure consistency in the analysis, all ballistic traumas were inflicted on the right side of the pig and done at a range of four meters (fifteen feet). The consistent range ensured that differences in distance from the cadavers would not affect the trauma observed. There were some differences in the number of bullets fired into each pig, and Table 1 reflects variation in number of shots and their distribution Pigs 1-3, were shot fewer times but when it became clear that many of the bullets were missing the bone, therefore in the second round of burns, Pigs 4-6, received four wounds in each region regardless of how promising the previous shot may have been, in order to ensure the bone was struck. As a result, it is very possible that multiple bullets striking the same region could have produced different trauma patterns in the bones of pigs 4-6. In the case of pigs 12 and 13 a different shooter was used. This new shooter was not a member of a professional police force, but a gun enthusiast at a local shooting range; his marksmanship were less reliable. Accuracy on the shooters part played a major role in determining whether or not the pig bones sustained any trauma. If the shooter missed, the bones would not be damaged. Furthermore, if multiple bullets struck bones, the trauma was different from that of trauma produced by a single gunshot wound.

Figure 1: 9mm handgun used to inflict trauma in Pigs 1-6 with hollowpoint round beside it.

2.3.4 The Burning Phase

I sought to replicate four stages of burning: charred, early partially calcined, late partially calcined and fully calcined which I define in Table 2 below. These four stages span the possible stages that law enforcement can encounter in a real life scenario. With the help of the Ontario Police College, and Fire Marshal Greg Olson for the Ontario Fire Marshal's Office, I was able to set up a pilot study using a burn cell located on the OPC's grounds.

Figure 2: Burning of Pig 6 (Late partially calcined stage)

Charred: Remains showed evidence of fire damage on the outer layers of soft tissue. Bones close to the surface, may show some discolouration due to the heating process. (Orange-brown/black colour) Pigs were removed from the fire when Charring/ blackening of the soft tissues, and the body was beginning to enter into pugilistic posture.	Early Partially Calcined: Remains will show extensive charring to outer layers of soft tissue. pugilistic posture setting in. Calcination process starting to appear. Bone colour changing from a black to a greyish-blue. The pigs were removed when the first signs of calcination and colour change.	Late Partially Calcined: Extensive charring to outer layers of soft tissue. Pugilistic posture is now starting to be destroyed due calcination taking place in the joint areas of the long bones. Colour change to white calcined bone should be noticeable on larger areas. Shrinking and post-mortem fire fractures should be observable. The remains were removed when the distal limb bones fractured off of the main body, and when extensive amounts of white calcined bone were noted.	Fully Calcined: Heavy calcination taking place across the body. Little to no soft tissue remaining. Bones will appear white in colour due to prolonged exposure. Bones will have severely shrunk in size and display common postmortem fire fractures on their cortical bone surface. Bones are extremely fragile and more fragmented.

Table 2: Definitions of Burning Stages

There were two forms of pyres that were created. For pigs 1-6 a sheet of plywood placed upon a metal frame formed the platform for these pigs to rest upon; cedar planks and chemically soaked fire logs were stacked around, under and on top of the pigs. The goal was to provide enough fuel to help the fire last until the fat within the pigs ignited and took over. 150 millilitres of gasoline was poured over and around the remains as an accelerant to start the fires. Once the fire was burning, additional cedar planks were added to sustain the high temperatures and to help shorten the amount of time needed to get to the desired burn stage. To get the temperature readings of the fire seen in Table 1, a thermal camera that Greg Olson had purchased for his own research was borrowed from time to time to give me an idea as to how hot the fires were. When the desired stage was reached, a team of firefighters extinguished the fire with water and fire suppressant chemicals. Pigs 12 and 13 were not burned at the OPC. Thanks to Dr. Maria Liston and a few volunteer students' help, a one-meter tall funeral pyre was constructed in a burn pit on campus and both pigs were place on it. The fuel consisted of cedar wood and dried splits of logs provided by the University of Waterloo. This pyre allowed me to completely destroy the soft tissue on the pigs and to calcine all of the bones.

2.3.5 The Recovery Phase

The recovery of each set of remains took place the day after the remains were burnt, allowing the remains to cool before handling and storage. An archaeological approach was used to recover as many bone fragments and pieces of tissue from the surrounding area. Helping me with the recovery of the fragments were 3 volunteers that consisted of both students from the University of Waterloo, as well as local fire fighters from the Township of Alymer. Using a forensic archaeological approach I learned from Mercyhurst University, the team and I used trowels, toothbrushes and screens to clear away and sift through the debris to locate and remove as much of the bone as possible. There were however, a few steps in this archaeological method that were skipped, because I had a limited amount of time to recover the remains and only 3 volunteers assisting me. The modifications to this archaeological approach overlooked the creating of a 1m by 1m grid square around the remains and creating a datum point, furthermore, I also did not assign a volunteer to sketch the remains while they were in situ.

For pigs 1, 2, 4 and 5, because the remains were not heavily fragmented from the fire, the archaeological recovery methods of using trowels and brushes was not needed to search for destroyed bone. The limbs that broke off still had a fair amount of soft tissue attached, and could be easily identified. For these earlier burn stages the archaeological recovery method was primarily employed to clear debris off the remains carefully.

For remains that were more heavily fragmented, such as pigs 3, 6, 12 and 13, the archaeological recovery methods had more value to the recovery, as we were now dealing with highly fragmented remains, that were also extremely fragile due to the calcination process. Using trowels, brushes, dental and surgical tools and ten millimetre screens, bone were carefully separated from the debris and charred wood, and then carefully placed into padded containers for transport to the university, where they would then be stored in the Osteology lab. Due to time constraints, fragments of bone that were smaller than half an inch were left behind so to ensure the recovery stayed on schedule, and also because I lacked the equipment to thoroughly examine fragments that size for trauma.

Figure 3: Using an archaeological recovery process to separate debris and bone for pigs 12-13

2.3.6 The Dissection Phase

The dissection phase can be broken down into two separate phases. First, there was the "post-burn recovery phase" and second came the "cleaning phase". The post-burn recovery phase also took place the day after the remains were burned. Because of time restraints this recovery phase needed to be done efficiently and so only the right shoulder and upper arm, the right rear leg, and the sterna region were removed from the cadavers, as these were the regions chosen to be inflicted with trauma, if I discovered other areas where bone showed evidence of fracturing then those bones would also be removed as well. Pigs 1-3 were dissected using scalpels, but this approach proved to be too time consuming; to cut down on time, for pigs 4-6 portions of the burned carcass were removed with a power saw. Because this method was more risky, rather than cutting close to the trauma, sections of the body were removed instead to ensure the power saw blades did not come close to the areas suspected to have trauma. Once the sections of tissue containing trauma were separated from the main body of the cadaver, they were stored in labeled plastic bags. Because these sections had a lot of soft tissue on the bone, the plastic bags were put into coolers containing ice to keep the soft tissue from decomposing any further. The bags were drained of any bodily fluids and water before leaving the burn site, and then transported to the University of Waterloo where they were stored in a freezer until further processing.

2.3.7 Cleaning and Examination Phase

The second stage of processing was to remove the tissue from the bone, so that a careful examination could be done to identify what kind of ballistic trauma was left behind in the bones, and to see if there were any destruction due to heat and flame exposure. Here medical scalpels and scissors were used to remove as much of the tissue as possible, and to avoid damaging the bones. Once the bulk of the tissue was removed, the bones were placed into clear plastic show boxes that were left outside in my backyard for the months of September and October. Temperatures were cooler during these months and this did affect the rate of decomposition and insect activity. To optimize and speed up the decomposition process, during the daytime the lids of the boxes would be left partially open to allow insects to scavenge the remains, and when the sun had set the boxes would be sealed to promote moisture build up, I then covered the boxes with a tarp to protect the boxes from animals, and rainfall. The bones were then soaked in a diluted solution made up of 200 millilitres of 3% hydrogen peroxide to four liters of water. These baths removed any remaining soft tissue, and kill any harmful bacteria. As many of these bones still had a strong odour associated with them I decided to soak the bones for a day in a diluted bleach bath of 250 milliliters of bleach to 4 liters of water. After the bones were removed from the bleach, they were placed back into the plastic shoe boxes where they would be left to air dry for several days. After being left to dry I brought the bones to the lab to be examined.

2.3.8 Photography

During the shooting and burning phase, photography and video recordings were used to help capture images of the bullet wound locations, whether there were any exit wounds visible on the body, and to document the intensity of the fires that were burning the pigs. In the later stages, macro and microphotography was used to record the ballistic trauma and fire damage seen in the bone.

2.4 How Fires Affect the Body:

2.4.1Time and Temperature Relationship

In cremating a body, time and temperature interact to produce the results. When you make adjustments to one the other will also reflect those changes as well (Dehaan: 2008, Dehaan: 2012, Symes: 2008, Walker et al.: 2008). When there is an abundance of fuel and oxygen the fire will tend to burn hotter as there is more fuel to sustain the higher temperatures. When this happens, and hotter temperatures are being sustained this in turn can affect the amount of time needed to pass for the remains to go through the different stages of burning (Dehaan: 2008, Symes & Dirkmaat: 2008, Walker et al: 2008). Human and pig remains are rich with fats and other fuels that contribute to the burning (Dehaan: 2008, Dehaan: 2012, Symes: 2008 Dirkmaat & Symes: 2008). During my burns this was something very noticeable especially when comparing the first set of burns with the second set. If we compare Pigs 1 and 4 in Table 1, the time and temperature differences are remarkable and the reason for this is because of the amount of oxygen present during the burn that helped catalyze the reaction between the heat of the fire with and the fuel sources. This reinforces the notion that with a hotter fire the rate of destruction of the remains will be quicker in relation to the amount of time passed.

As a fire consumes a body, the patterns of destruction are often predictable. Parts of the body that have little soft tissue protecting like the knee, or parts of the face will be consumed by the fire early on, while areas like the pelvis or head of the femur that have organs and a lot of soft tissue will last longer in the fire even if temperature fluctuations occur, because the soft tissue itself must first be consumed (Dehaan 2008, Dehaan: 2012, Symes et al: 2008). Areas that are particularly vulnerable to fire include areas such as the skull, sections of the ribs, the distal ends of long bones, along with carpals and tarsal bones. As the body burns and dehydrates, it contracts, causing pugilistic posture. As the muscles contract they will pull inwards towards the trunk of the body and in turn pulls the limbs into positions where they are flexed and further exposing the distal ends of the long bones (Dehaan: 2008, Dehaan: 2012, Symes et al: 2008, Dirkmaat et al: 2012, Mayne- Correia: 1997, Buikstra: 1984).

Figure 4: Pig 3- another fracture commonly associated with fire damage.

2.5 Understanding Fractures

There are many different kinds of fractures in bone and many kinds of things that affect how fractures are produced and how bone reacts. A fracture occurs when bones experience a failure in their ability to absorb the kinetic forces being applied to them (Chapter 3; Galloway: 2014, DiMaio: 1999, Pope & Symes: 2009, Chapter 7 Warlow: 2005). When this failure happens it creates a fracture that reflects the amount of kinetic force applied to the bone. Minor transfer of kinetic energy such as the force produced from a fall, may only produce an incomplete fracture, while something like a car accident or bullet wound will produce a complete fracture (Chapter 3 Galloway: 2014, Pope: 2007).

Bones react differently to kinetic energy depending on whether it is living and fresh or dead and desiccated. This results in different fracture patterns (Chapter 3; Galloway: 2014, Pope: 2007, Chapter 7 Warlow: 2005). Perimortem refers to a time interval that occurs just before or at the time of death through to the time period just after death. In this period bones remain moist and retain their elasticity and flexibility due to the presence of collagen in the bone (Chapter 3; Galloway: 2014, Pope: 2007, Walker et al: 2008). This is important to note because the retention of moisture and collagen can influence the surfaces, texture and angles of fractures, by affecting how much kinetic energy is required to generate the fractures in the first place and the path of force through the bone. Fractures produced in fresh bone are often smooth, and the angles are often obtuse or acute, with secondary fractures known as radiating and concentric fractures branching away from the impact site (Chapter 3 Galloway: 2014). Once these primary fractures are produced, the kinetic energy will run along the fracture line until either the kinetic energy itself is expended or the fracture reaches another tissue or bone that can absorb the remaining kinetic energy in the tissue that has been compromised (Galloway: 2014, DiMaio: 1999).

In contrast to this, fractures associated with post mortem dry bone often break at right angles, and will often have no evidence of secondary fractures. With the moisture evaporated from the remains, and the collagen destroyed, dry bones are then very brittle, and this brittleness can lead to a "crumbled" or "compressed" look of the fractures walls, and contributing to the overall roughness and jaggedness appearance of the fractures generated in dry bone (Chapter 3 Galloway: 2014, pg: 51). One final observation that is unique to post mortem dry bones is the fragmentation of the bones themselves. In dry bone, bone fragments are often very fragile and are easily susceptible to shattering under small amounts of force and are less likely to adhere to the main fracture, while fragments associated with perimortem wet bones tend to adhere to the main fracture and can make the reconstruction of the trauma much easier (Chapter 3 Galloway: 2014, Pope: 2007).

Because the fire is affecting the dehydration process by speeding it up and removing the collagen and moisture from the bones, fractures in bones that are subject to heat modification will appear similar to postmortem fractures in nature. (Chapter 3 Galloway: 2014, Pope: 2007, Walker et al: 2008). Fire can also leave behind other unique fractures patterns that are a result of the physical changes the bone undergoes during the incineration process. The rapid dehydration process can lead to delamination, a process in which the outer surface of the cortical bone loses its smoothness, and displays small patina micro-fractures that penetrate the outer layers of the cortical bone surface. As well as the splintering and fracturing of the bone as the soft tissue retracts across the bones (Herrmann & Bennett: 1999, Drikmaat & Olson: 2012, Chapter 3 Galloway: 2014). Fractures patterns typical of fire damage include transverse, curved transverse, longitudinal and step fractures (Dirkmaat & Olson: 2012, Herrmann & Bennett: 1999). The jagged fracture edges and rough surface should still be similar to that of dry bone; however, the compression and crumbled effects of the fracture walls may be more pronounced, the bones will be extremely fragile due to the complete loss of moisture from the heat, and right angled fractures should be noticed because most if not all the collagen providing structure to the bones would have been destroyed (Walker et al: 2008).

There is also a change in bone colour as the bones' organic component is burned away, until there is nothing left but the inorganic mineral matrix (Dirkmaat & Olson: 2012, Herrmann & Bennett: 1999, Symes: 2008, Devlin: 2008, Walker et al: 2008).

2.6 Ballistic Trauma in Bone

Bullets are designed to shred and crush any material that they come into contact with and at the same time they also fling that same material outward into the surrounding tissue, creating a larger wound concavity than the actual circumference of the bullet itself (DiMaio: 1999). The size and shape of the wound cavity in the body depends on the amount of kinetic energy lost by the bullet while it travels through the different tissues (DiMaio: 1999).

Researchers have found that bullet wounds that are shot into areas like the long bones generate similar fracture patterns to those shot into cranial bones where the effects have long been documented (Pope & Symes: 2009, DiMaio: 1999). Entrance wounds tend to have smooth edged defects with radiating and concentric fractures produced by the energy transfer from the bullet to the bone. Where the difference lies is in the exit wounds. Because the surface of a long bone is much smaller than that of a cranial bone, it requires less time for the secondary radiating and concentric fractures to reach the dorsal side of the bone, resulting in a compromised matrix of the trabecular bone before an exit wound is even generated by the bullet (Symes & Pope: 2009). Because of this compromise in the trabecular structure, when the bullet exits the long bone, the exit wound is often not recognizable because the fragments of bone produced by the radiating and concentric fractures will have already been displaced into the surroundings areas of the limb by the kinetic force generated by the bullet (Pope & Symes: 2009). Bullets do not necessarily need to make contact with the bone to generate a fracture. In areas such as the ribs, a bullet only needs to pass through the space between the ribs to generate a fracture; this is because the areas ability to absorb kinetic energy is much lower than other regions of the body (Chapter 7 Warlow: 2005).

The suggested velocity required to compromise most organs and bones in the body is around 800-900m/sec (DiMaio: 1999). However, for rounds such as hollow points a lower velocity of around 500-600 m/sec is enough because of the bullet's design (DiMaio: 1999). Hollow point bullets can be expected to cause significant damage to bone in particular because they are designed to stay within the body. Another important note to take from this is that handguns are considered to be low velocity weapons and bullets fired from these kinds of firearms must make direct contact with the bone in order to produce this kind of trauma. The trauma that can be expected then from a hollow point round fired from a handgun is an area of bone that has been literally obliterated because of the velocity of the gun itself. The bullets will not likely generate enough kinetic energy to push the bullet through the body to generate an exit wound. When a bone is struck and stops the bullet from going any further, the bone trauma could almost be described as a "bursting" effect. Where the bone simply explodes under the amount of force striking it, and the surrounding area is heavily "mangled" due to the additional trauma being generated from the fragments of bone being pushed outwards, and the shards separating from the bullet itself (DiMaio: 1999, Warlow: 2005) The physical appearance of the fragments of bones will still show similar characteristics of perimortem fracture fragments mentioned above with potential jaggedness in appearance due to the shredding effect of the bullet (DiMaio: 1999, Galloway: 2009). Chipping and minute compressions can also be evidence and are suggestive of ballistic trauma. These forms of trauma could be the product of secondary debris produced from the bullet impact striking other areas with enough force to cause incomplete fractures or, when the bullet exhausts all of its energy and deflects of the bone. In the case when deflections of bullets occur, superficial perforating entrance and exit wounds may be observable. Or small oval defects also known as “keyhole” fractures or “plug and spall” fractures can be punched into the bone and then deflect out of the body or be a short distance away from the point of impact (DiMaio: 1999, Galloway: 2009).

Figure 5-6: Entrance and Exit wound of hollowpoint round shot through the Sternum of Pig 5

2.7 Observations:

The patterns of ballistic trauma and fire damage varied with each pig. Table 3 summarizes the gross observations on each specimen.

Table 3: Observations of Trauma in Bone in Various Regions Recovered

Pigs	Trauma in Rear Right Leg	Trauma in Right Shoulder and Upper Arm	Sternal Region	Fire Damage to Bone
Pig 1- Charred	Trauma was noticed in the proximal end of the right tibia with the epiphysis- impact point where bullet struck.	Perimortem was observed on the blade of the right scapula. Inward bevelling and chipping. Trauma is suspected	No evidence of ballistic trauma present in bone.	No fire damage noted on the bones.

	Radiating Fractures were observed. Fragmentation from bullet impact. Outwards bevelling in the cortical bone Distal Epiphysis of Tibia shows stress fracturing due to the enormous energy transfer.	to be secondary fracturing produced by bullet shard		
Pig 2- Early Partially Calcined	Trauma noticed in the proximal epiphysis of the Tibia, as well as the distal epiphysis of the Femur. The bullet struck the knee joint. Large radiating longitudinal fractures through the diaphysis of the Tibia and the distal epiphysis of the Femur.	The right humerus and scapula are severely damaged. The diaphysis of the humerus is destroyed leaving only the distal epiphysis that is easily recognizable. The cortical bone shows obtuse and acute angling in the fracture walls of the cortical bone. Fragmented scapula blade and articular surface.	Shearing and bevelling could be in some of the ribs. No ribs show any direct contact with a bullet. Fractures are a result of stress overloading. Sternum also shows these similar fractures.	Patina and traverse fractures seen on the diaphysis of the right tibia. Colour Change seen in the fracture walls.
Pig 3- Late Partially Calcined	Right Tibia displays radiating fractures in both proximal and distal epiphyses. Diaphysis is mostly missing or fragmented. Upheaval in the Tibia suggesting energy transfer. Acute and Obtuse fracture angles in the cortical bone of the epiphyses.	Right Scapula possible secondary fracture, semi impact site on the blade. Produced by either a bullet shard or bone debris from the humerus. The diaphysis of the humerus heavily damaged, with the distal epiphysis showing radiating fractures. The proximal epiphysis bone upheaval and fragmentation. The right ulna and	Sternum and ribs show signs of shearing and bevelling. Possibly stress overload on the bone. No evidence of a bullet striking the bones directly.	Radius and Ulna, Tibia, Fibula and parts distal portion of Femur have calcination or colour change. Fractures include (Patina & Traverse fractures across the shaft, and Curved Traverse across the shaft of the bones)

		radius suspected to have secondary trauma Radiating fractures and splintering seen in Radius and Ulna.		
Pig 4 Charred	Femur comminuted fracture fragmentation and bone loss of diaphysis. Acute and obtuse angles on fractures walls of cortical bone. Diaphysis was a possible impact point for a bullet. The Proximal epiphysis of the Tibia has fragmentation and bevelling of bone. Diaphysis of the Tibia has a longitudinal radiating fracture. With acute and obtuse angles visible in the walls of the cortical bone.	Damage to the diaphysis of humerus. Fragmentation of diaphysis and the distal epiphysis of the humerus Shearing in cortical bone of the Ulna. Acute and obtuse angles also observable in Ulna and Humerus The blade of the scapula has secondary trauma from the fracturing of the humerus or bullet shard.	Distal end of the sternum displays bevelling in the bone. Ribs and vertebra that were extracted show signs stress overload fractures. Fragmentation occurring on vertebra, secondary trauma from a bullet shard.	No evidence of Fire damage occurring in any of the bones.
Pig 5 Early Partially Calcined	In Left & Right Femura, have comminuted fracture fragmentation of diaphysis and bone loss. Acute and obtuse angles in the cortical bone. The proximal epiphysis of Tibia has radiating fractures as well as fragmentation and bone loss	Humerus displays fragmentation and bone loss of diaphysis and distal epiphysis. The radius and ulna both show signs of stress fractures in the proximal epiphyses. The scapula has inward bevelling and compression fractures along the blade.	Sternum has two gunshot wounds visible, both with entrance and exit wounds. Entrance wounds are jagged and rough, with outward bevelling noticeable. Radiating fractures seen too. Bone fragmentation seen near exit wound.	Right Fibula and Tibia display patina, traverse fractures travelling across the shaft of the bone and also longitudinal fracturing. Left rear leg also has fire damage at the knee joint, and raises questions about possible fracturing observed in the left fibula.
Pig 6 Late Partially Calcined	Distal epiphysis of femur has bone loss and fragmentation. radiating fractures suspected to be	Ulna and Humerus display fragmentation, bone loss and acute and obtuse angles in the	Sternum was not recovered. Ribs display stress overload fractures. Ribs were also	Colour change, and heat fractures are seen in the Scapula, Ulna, Radius and the distal epiphysis of the Humerus. Right Most of the

	present. Fragmentation of Tibia as well. Femur and Tibia although overbleached, still show evidence of acute and obtuse angles in the cortical bone.	cortical bone. Radiating fractures observed on the diaphysis of the humerus.	fragmented. No contact with bullet.	Tibia and Distal diaphysis and epiphysis of the Femur are heavily calcined and show traverse, curved traverse and longitudinal fractures. Left side, humerus and distal long bones also display colour change and heat fractures.
Pig 12 Fully Calcined	Right proximal femur head possible evidence of perimortem trauma due to obtuse and acute angles in the cortical bone.	Difficult to determine if trauma is present because of calcination fractures.	Difficult to distinguish trauma from calcination fractures.	Heavy fire damage on all of the bones recovered. Postmortem fractures (travesrse, curved traverse, longitudinal, patina and delamination) are visible on many of the fragments recovered. The bones have been reduced to white calcined bone. Highly brittle they must be handled with extreme care.
Pig 13 Fully Calcined	Heavy fire damage made it difficult to assess for trauma.	Peculiar angles in the cortical bone of some of the long bones associated with the front arm.	Difficult to distinguish trauma from calcination fractures.	Heavy fire damage on all of the bones recovered. Postmortem fractures (travesrse, curved traverse, longitudinal, patina and delamination) are visible on many of the fragments recovered. The bones have been reduced to white calcined bone. Highly brittle they must be handled with extreme care.

Control Late Partially Calcined	No trauma inflicted	No trauma inflicted	No trauma inflicted	Soft Tissue is heavily charred and has in some areas split open. Calcination is seen taking place on the skull as well as on all of the limb bones. All the distal limb bones (Tibii and Fibuli, Radii ad Ulni have all separated from the main trunk of the body. Evidence of post mortem longitudinal and traverse fire fractures are observable on the calcined distal limb bones as well as some of the wrist and ankle bones.

Figure: 7-8 Left: An example of patina fractures commonly associated with fire damage. Right: Example of Shearing of cortical bone commonly associated with perimortem trauma. Note the angles of the walls. Both images are of bones from Pig 2.

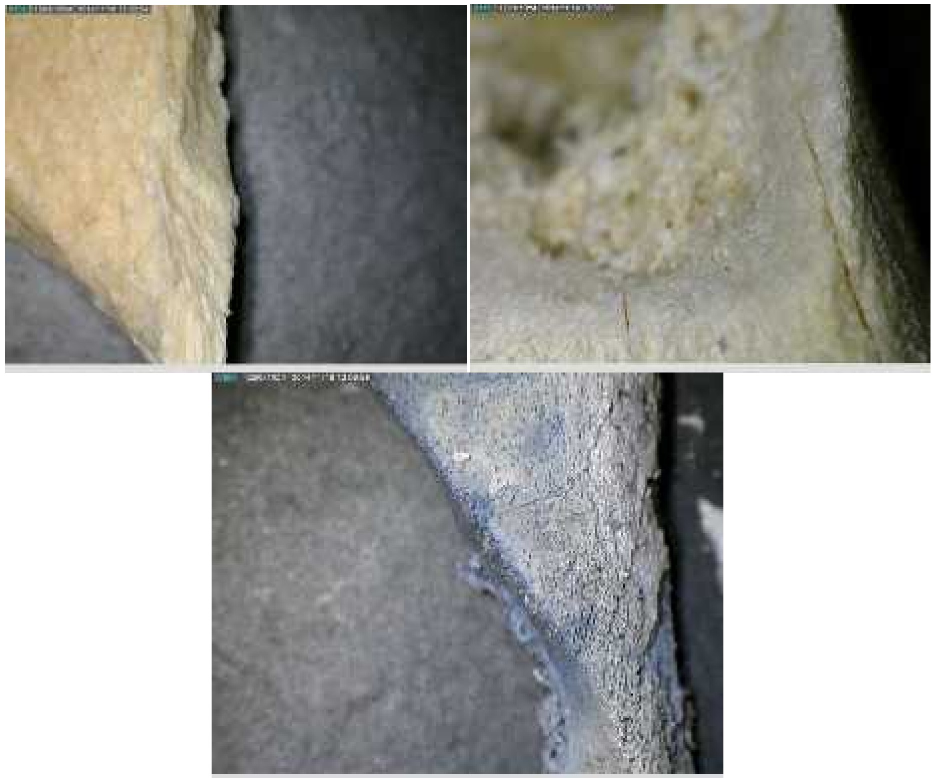
2.8 Discussion

A number of factors can influence the appearance and preservation of trauma in burned remains. First, areas of bone with trauma should be at more risk of being destroyed by burning, due to the fact that the trauma has already compromised the structure of the bone before it was exposed to the fire (Symes-Dirkmaat: 2008& 2012). As a result when soft tissue destruction finally reaches the area of trauma, the fractured bones should fall apart by the flames. Second, any disturbances or shifting of the body that takes place while the remains are burning could also cause the evidence of trauma to be destroyed, as the calcination process would have rendered the bones too brittle to resist further stresses (Dehaan: 2008, Symes et al: 2008).

2.8.1 How Trauma Appears After Burning

What I found when examining the remains was that in all stages there were always indications associated with perimortem fracturing, and that these indicators can survive incineration and calcination. These included acute or obtuse fracture angles in the cortical bone as opposed to right angle fractures more commonly seen in dry bone, radiating fractures stemming away from an impact site, or changes in colour along the inside of the fracture walls. Each of these clues was preserved in every stage of the burning process. Their resilience and form however gradually worsened the longer they remained in the flames.

Acute and obtuse angles of fractures found in the cortical bone could be observed in every stage of the burning process, and this was because of the angle of the fracture wall itself survived the incineration process. The acute and obtuse angles of the fracture walls could be detected at both the macroscopic level as well as with a dino-lite microscope with 220 magnification. However, despite their resilience, mishandling can still erase some of the details these angled fracture walls may offer.



Figures 9-10-11: Left: Angling in the cortical bone of Femur (Pig 4- Charred) no fire damage. Right:(Pig 6- Late Partially Calcined) slight angling in cortical bone of Humerus. Center Fragment for Pig 12 (fully calcined) bevelled femur shaft fracture suggestive of possible perimortem trauma.

Radiating fractures and concentric fractures are another reliable clue as they can survive to the end of the burning process; however they are more vulnerable to the heat the longer they stay in the fire. Radiating fractures in particular are good indicators for possible perimortem trauma, because they tend to be not only larger than fractures commonly associated with fire, but often travel through different sections of a single bone. This is important because the size and length of radiating fractures are often influenced by the amount of kinetic energy transferred into them. The more energy, the longer the fracture becomes and the more likely the radiating fracture will either terminate into a section of the bone which may be protected from the fire or it will transfer into a completely new bone that could potentially be even more sheltered by soft tissue than the initial traumatized bone. If a bone is then recovered with a section of the long bone that has a radiating fracture in an unburnt or undamaged section, it can safely be assumed that that fracture is a perimortem fracture, because postmortem fractures associated with the burning process will only affect the immediate areas that the fire has come into contact with.

Figure 12: Radiating fracture travelling through both unburnt and burnt bone. (Pig 2)

The third observation that I noted was colour change in the fracture walls, although this was more difficult to evaluate. When a bone is compromised, the shearing and splitting apart of the bone generates a new bone surface that will go all the way to the marrow cavity or will completely separate the bone into two pieces. This new surface can then be subject to modification by fire. How this can be useful in determining perimortem trauma, is that when a perimortem fracture is generated by a bullet, the fracture is compromising the bone before the exposure to fire. When the fire does reach the fracture, it will affect the fracture in the same way as it affects the outer layers of normal cortical bone. As such, the walls of the fracture should reflect the same colour as the cortical bone that is being damaged by the fire.

This is very useful in the early stages of the burning process because many of the fire fractures produced in the earlier stages are too small and will only affect the upper layers of the cortical bone. As such cortical bone that is near marrow cavity will not show colour change. Colour change however, becomes less reliable in the later stages of the burning process because now the bone becomes calcined. Once the bone becomes fully calcined both the outer and inner surfaces of the cortical bone will have been altered significantly by the fire, changing the colour to a white.

Figure 13: Left: Example of Colour Change in Fracture Wall (pig 3)

2.9 Conclusion

By understanding how post-mortem and perimortem fractures are produced, and recognizing what these fractures look like, are the only clues forensic anthropologists can rely upon when they are dealing with burnt remains that are believed to have trauma present (Buikstra: 1984, Bass: 1984, Dirkmaat et al: 2012, Symes et al: 2008, Herrmann & Bennett: 1999). Rather than looking for entrance or exit wounds or for highly fragmented bones, we must look at the cortical bone surfaces, the colour patterns of the bone and at the walls of the fractures. By focusing on these areas and investigating anomalies in the angles of the fracture walls or the size and location of the fractures as well as recognizing abnormal colour patterns in the bone we can uncover evidence that can indicate that trauma is present. My experiment has shown that perimortem indicators for trauma can survive incineration and endure up until the final stages of calcination even if the burning process has altered their appearance (Symes et al: 2008, Symes-Dirkmaat: 2008 & 2012, Dirkmaat et al: 2012, Bass: 1984, Buikstra: 1984, Mayne-Correia: 1997, Devlin: 2008, Walker et al: 2008).

What I have found is that it has been possible to recover evidence of perimortem trauma throughout all of the stages that I burned the remains to. However, as the bones progress towards the fully calcined stage, my accuracy in detecting trauma decreased, however, if a more experienced physical/ forensic anthropologist were to look at the remains their conclusions may be different. As such when it comes to examining bones burned to the fully calcined stage, I cannot definitively state I observed trauma in all areas of the body that were shot, and this is due to the design and purpose of hollow point bullets function. The "bursting" appearance and the high degree of fragmentation of the trauma generated by hollow points can easily be masked and destroyed by the dehydrating effect that fire has on the bone as it progresses to the fully calcined stage. Nevertheless, it is clear that fire does leave clues behind despite the common belief that it destroys everything it touches. The greatest challenge that fire poses to the forensic anthropologist is its ability to mask the trauma. So long as extreme care is taken when recovering, processing and examining the remains, and the forensic anthropologist is familiar with how fractures are generated, fires greatest strength at masking trauma can easily be rendered useless.

Appendix

AP1: Example of fragmentation of diaphysis from ballistic trauma: Pig 4

AP 2: Example of shearing of the bone and acute and obtuse angles in the cortical bone (Pig 4)

AP3 & AP4: Examples of Radiating Fractures travelling through both burnt and unburnt bone (Pig 3 Tibia)

AP5: Example of acute angling and colour change in the fracture walls. (Pig 3)

AP6: Example of ballistic trauma in the scapula (Pig 3)

AP 7: Examples of entrance wounds in the sternum (Pig 5)

AP 8: Example of acute angling calcined bone (Pig 12)

AP 9: Examples of acute angling in Calcined long bone fragments (Pig 12)

AP10: Pyre built to burn Pigs 12 & 13.

AP 11: Example of Ballistic trauma survived the calcination process

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