EFFECT OF DECOMPOSITION AND PROCESSING ON RADIOGRAPHIC DETECTION OF GUNSHOT TRAUMA IN SKELETAL REMAINS

by

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TABLE OF CONTENTS

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF ABBREVIATIONS

Abbreviation	Description
BFT	Blunt force trauma
FARF	Forensic Anthropology Research Facility
FMJ	Full-metal jacket
GEFARL	Grady Early Forensic Anthropology Research Lab
GSR	Gunshot residue
GSW	Gunshot wound
HP	Hollowpoint
ORPL	Osteological Research and Processing Lab
PD	Post-decomposition
PM	Post-maceration
PT	Post-trauma
ROF	Radiopaque fragments
ROM	Radiopaque material
TXSTDSC	Texas State Donated Skeletal Collection

I. INTRODUCTION

Trauma patterns have significant importance for forensic anthropologists and within the general field of forensic science; as a precise understanding of trauma provides investigations with necessary contextual information about cause and manner of death. For both the medical examiner and forensic anthropologist, interpreting trauma as a gunshot wound (GSW) or blunt force trauma (BFT) can be difficult, especially when the remains are not complete, are highly fragmented (Langley et al. 2018), present atypical trauma patterns (Smith et al. 1993) or have been exposed to destructive taphonomic processes (Herrmann and Bennett 1999, Taborelli et al. 2012). In some of these cases, radiopaque materials, or ROM, (e.g., metallic fragments from the bullet observed on radiographs) can serve as an indicator of a gunshot defect, aiding in trauma interpretation.

The Scientific Working Group for Forensic Anthropology (SWGANTH) issued guidelines on conducting trauma analysis in 2011. Forensic anthropologists should practice careful and descriptive documentation methods including "descriptive text, photographs, diagrams and radiographs" when analyzing skeletal trauma (SWGANTH 2011). Soft tissue trauma is mainly reserved for the examination of a pathologist, whereas the forensic anthropologist examines bones and some cartilage (SWGANTH 2011).

While radiographs are commonly used by forensic anthropologists in the detection of opacities to confirm GSW, the validity of pursuing opaque material as an indicator of gunshot defects in skeletal remains has not been extensively examined. Specifically, few studies have examined how frequently opaque materials are observed on radiographs of GSW, and fewer studies have a focus on metallic particles embedded in the gunshot defects as evidence in cases presenting atypical trauma patterns. Understanding the reliability and validity of radiographic opacities is important for forensic anthropologists because radiography is an important method of trauma analysis involving high-velocity projectile trauma (SWGANTH 2011).

There are numerous scientific studies on gunshot residue (GSR) as related to firing hands, firing distance and weapon and ammunition distinctions, but not on radiopaque material detection in the bone for wound interpretation. Romolo and Margot (2001) conducted a thorough literature analysis of studies on GSR in forensic investigations. Of the 130 sources they cite, none of them focuses on opacities on gunshot defects. Several studies have included detection of lead or GSR on gunshot defects (Herrmann and Bennett 1999, Taborelli et al. 2012), while other mentions of lead wipe consist of vague case reports (Smith et al. 1993, Willey and Scott 1996). However, understanding the reliability and validity of radiographic opacities is important for forensic anthropologists because radiography is an important method of trauma analysis involving high-velocity projectile trauma (SWGANTH 2011).

The purpose of this study was to examine the reliability and validity of using ROM to detect gunshot defects in forensic anthropological cases. The study included an observational phase where human bones with known gunshot defects in the Texas State Donated Skeletal Collection (TXSTDSC) were radiographed to determine how commonly ROMs are present in a post-maceration collection. The second phase of the study involved an experimental phase using pig remains to determine the prevalence of ROM in GSWs after trauma and if the ROM persists following decomposition and maceration with low heat. Three primary questions were addressed: 1. What is the frequency of opaque material observable in gunshot defects in bone? 2. Is the frequency of observed radiopaque materials in gunshot defects affected by the decomposition/skeletonization process? 3. Is the frequency of the observed radiopaque materials in gunshot defects affects by the maceration process? and 4. Is the frequency of observed radiopaque materials in GSWs influenced by ammunition type?

When analyzing projectile trauma, the term used to describe any materials left by the bullet should be taken under careful consideration, but there is confusion in the literature as to the materials, particles, and fragments detected as relating to gunshot wounds. Common terminology includes "gunshot residue" (GSR), "lead wipe", and "lead spatter". Gunshot residue consists of lead, barium, and antimony particles from the primer and discharge of the gun (Berryman et al. 2010). These particles are small and typically remain on the superficial layers of the wound and may not be radiopaque. The terms lead spatter and lead wipe are more problematic because the metal detected in the radiograph can include lead, copper, or steel from the bullet. The SWGANTH guidelines recommend using the term "bullet wipe" rather than "lead wipe" because this material may include more than just lead (SWGANTH 2011). Therefore, for this thesis I will use the terms "bullet wipe" and "bullet spatter". The differences between the two are in the dispersion patterns with bullet wipe often following the wound tract of the bullet and bullet spatter being small fragments of metal from the bullet embedded or deposited in the hard and soft tissues (Berryman et al. 2010). Bullet wipe is defined as "lead particles from the bullet deposited and embedded in the bone defect and is commonly seen on defects when the firearm used by the shooter is not of high quality, leading to pieces of the bullet being shaved off when discharged" (DiMaio, 1999; p69). For this research, I use radiopaque, opaque materials, and opacities interchangeably to mean any material (bullet splatter or bullet wipe) in the gunshot defect that is denser than bone and radiopaque. Furthermore, I use the term “gunshot defect” to describe skeletal evidence of high-velocity projectile trauma. The term “wound” can imply a soft tissue element.

II. PREVIOUS LITERATURE

Ammunition

The design and structure of the bullet is an important factor which contributes to the amount of damage and trauma it can cause to the target. In her Master's thesis, Chapman (2007) describes different uses for various bullet types and how the bullets impact the target. Hollowpoint bullets expand upon impact with the target, allowing it to fragment in the wound cavity of the target (Chapman 2007; Fackler 1996). This expansion and fragmentation of the bullet increases the severity of the damage to the target by creating jagged edges in the wound tract of the bullet in the target. This characteristic of hollowpoint bullets also decreases the chance the bullet exits the target, making it more likely it becomes embedded and more difficult to remove (Chapman 2007). In contrast, full-metal jacketed, or round nosed, bullets may cause less widespread trauma upon impact with the target than do hollowpoint bullets (Fackler 1996). Since the full-metal jacketed bullet is not designed to fragment there is an increased likelihood of an exit wound and smoother wound tracts in the target (Figure 1) (Fackler 1986).

Figure 1. Visual comparison of 9mm semi-jacketed hollowpoint bullet (left) and full-metal jacketing (right) (Stephanopolous et al. 2014).

Trauma Interpretation Methods in Forensic Anthropology

Anthropological expertise in forensic cases may focus on and aid in trauma interpretations. Our job as anthropologists to assist in determining the manner of death (i.e., suicide, homicide, or accidental) and the understanding the cause of death (i.e., blunt force, sharp force, or ballistic) (Galloway 1999). Skeletal trauma should be assessed both prior to, and following the removal of any personal effects and soft tissue (SWGANTH 2011).

There are numerous methods and strategies used by anthropologists in interpreting trauma depending on the scenario and context of the scene and inflicted trauma, but taphonomic processes can make the interpretation of skeletal trauma difficult (Galloway 1999). THE SWGANTH guidelines provide detailed examples and considerations for forensic anthropologists tasked with identifying and interpreting perimortem trauma and postmortem damage.

Once skeletal defects are determined to be due to trauma and are not related to a pathological condition, forensic anthropologists must then determine the number of incidents and classify the trauma type. Methods of interpreting trauma can include but are not limited to the reconstruction of the bones, examining fracture patterns, and experimental studies. Additional practices may include high resolution computed tomography scanning, photography and graphics, histology, defect morphology, and radiology (Galloway 1999, p. 15).

Methods of classifying a trauma pattern as GSW consists of the presence of the bullet or projectile or the general morphology of the wound associated with the biomechanical characteristics of how bone reacts to high-velocity projectile impact. Fracturing and beveling from high and low-velocity impacts provide valuable information to reconstructing the skeletal fragments and gives insight about the possible weapon used (Bartelink 2015). While these can be accurate and useful in forensic investigations in which the skeleton is complete and well preserved, not all cases meet these requirements (Langley, et al. 2018).

In cases where the bone is not complete, is highly fragmented, or present atypical trauma patterns the presence of radiopaque material shows promise for aiding investigators in determining if the trauma is due to gunshot. Willey and Scott (1996), for example, examined ten soldiers from the Battle of the Little Bighorn for what they defined as the presence of “lead spatter”. The skeletons were radiographed, and six of the ten exhibited detectable lead particles associated with gunshot defects. Likewise, Langley and colleagues (2018) used the presence of GSR particles on a highly fractured cranium through the use of SEM-EDS to confirm the cause of death as being related to a firearm. GSR fragments located on these incomplete cranial fragments, exposed to the elements, confirmed the suspicions of the pathologist and forensic anthropologist that the fracturing was caused by the impact from a projectile. Likewise, Smith and colleagues (1993) identified gunshot trauma in two cases, both presenting atypical defects. The first case, shot from six to eight feet, presented a small piece of lead embedded in the defect as well as metal deposits. The researchers are vague in their descriptions of the particles and the quantification of the deposit amount. Interestingly, this large metal deposit was identified on the exit defect, whereas GSR particles and bullet wipe have only been present on the entrance wound (Ceccheto et al. 2012). The second case presenting atypical trauma patterns includes a woman shot with a 9mm pistol, but Smith and colleagues (1993) do not state the firing distance. Smith and colleagues (1993) also use the term “bullet wipe" to describe their findings but do not compare this to the large metal deposit or a small piece of lead radiographed in the first case. Berryman et al. (2010) is one which delves deeper into the GSW in search of GSR rather than focusing on superficial layers of skin and tissue. With a maximum firing distance of six feet, Berryman et al.'s (2010) experiment provide a significant find: the presence of GSR underneath the periosteal layer of bone.

Only a few studies have examined how taphonomic processes influence the observation of radiopaque materials associated with gunshot defects. A preliminary study conducted by Taborelli et al. (2012) finds that following the maceration process, gunshot residue can still be evident in the skeletal remains of both the animal and human samples. They located particles on the bone, specifically on the edge or very near to the edge of the defect. This is useful when the wounds cannot be accurately interpreted due to taphonomic processes or from fragmentation. The pigs were allowed to decompose and skeletonize, while the human samples were macerated using water, and let sit in distilled water soon after the shooting. Gunshot residue was found in all the human samples and four of the nine gunshot defects in pig samples. This difference in GSR detection between the two samples may be explained by the duration of decomposition of the pig samples, during which they were influenced by environmental factors. Similarly, Herrmann and Bennett (1999) radiographed pig femora after gunshot trauma was inflicted (i.e., before they were burned in a staged house fire) and were able to detect lead spatter. However, after burning the lead spatter was not present. This indicates that while radiopacity was useful in distinguishing BFT from GSW before burning, thermal alterations deemed them indistinguishable as the lead particles were lost.

The previous articles show that there is value in studying radiopaque materials to identify gunshot wounds and that it can be found even in skeletal samples that have been exposed to the environment. The presence of radiopaque materials (either GSR or bullet wipe/splatter) on skeletal material may be useful for forensic anthropology because remains are typically decomposed or skeletonized upon examination by the anthropologist and may provide valuable information on the type of trauma. The gap in the literature, however, consists of radiopaque materials in atypical trauma patterns for the interpretation of a GSW or gunshot defect. This perspective has not been detailed or documented in a scientific experiment, aside from Berryman et al. (2010) and Taborelli et al. (2012) but in these cases they use the term GSR not bullet wipe, leading to some confusion.

III. MATERIALS AND METHODS

The study was comprised of two different samples. The first included fleshed pig heads and ribs. The second sample consisted of human remains from the Texas State University Donated Skeletal Collection.

Pig Sample

The pig sample consisted of 15 fleshed heads and 8 skinless slabs of ribs purchased from local grocery stores. The heads and ribs were all of similar weight and size respectively. Pig samples were chosen for this experiment because of moral and feasibility concerns regarding the use of destructive analyses on human crania. The inexpensive cost and availability of pig heads and ribs also allow for a greater sample size than if human samples were used.

Human Sample- Texas State Donated Skeletal Collection

The frequency of opacities detected in bone subject to projectile trauma, from the TXSTDSC, were examined. A total of 18 donors have known GSWs, but only two have recorded weapon and ammunition type. One was shot with a .45 caliber handgun while the other was shot with a .22 caliber rifle. Of the 18 donors, twelve were recorded as having a head or cranial gunshot trauma. Three of these were intraoral gunshots and two were contact shots (Table 1).

Gunshot Trauma to Pig Remains

Each pig head (15) was shot three (3) times from different angles for a total of 45 GSW. Of the 15 pig heads, seven were shot using hollowpoint (HP) ammunition (total of 21 GSW). The other eight pig heads were shot using full metal jacketed (FMJ) ammunition (total of 24 GSW). There was a preliminary test shooting using one slab of pig ribs in which 6 HP and 6 FMJ bullets were used to test x-ray settings and detection. An additional 8 slabs of ribs were used, with half the rib samples shot with each ammunition type (4 HP and 4FMJ slabs). Each slab was shot 4 times (total of 16 HP and 16 FMJ GSW).

All shots were taken from the same firing distance of 8 feet. Dr Grady Early agreed to have the trauma portion of this study take place on his property. The shooting was conducted by Corporal Kassondra Raven, an investigator with the local San Marcos Police Department.

Weapon and Ammunition

The weapon utilized during this experiment was a 9 mm caliber Springfield XD handgun. The ammunition was 9 mm caliber hollowpoint bullet as well as full-metal jacketed rounds. A 9mm gun was chosen for its popular use in crimes involving firearms in the United States (Zawitz, M.W., U.S. DoJ, July 1995). Handguns are the most used gun in homicides involving firearms. Hollowpoint lead bullet ammunition was chosen for its property of expanding upon impact, creating more fractures and damage to the wound. This will increase fragmentation and atypical defects. Full-metal jacketed ammunition was chosen due to its comparatively cheaper price and its dissimilar target impact actions from those of hollowpoint bullets.

Skeletonization of Pig Remains

The samples were placed in cages at the outdoor decomposition facility, known as the Forensic Anthropology Research Facility (FARF) at Texas State University in San Marcos, Texas. The cages protect the pig samples from scavenging while they naturally decompose at the facility. Two cages were used separating the samples by ammunition type, with the FMJ samples under one cage and the HP samples under the other. By placing the samples outside and exposed to variable environmental conditions, I was able to document how environmental conditions may affect opacity persistence in the defect. The radiographs and the maceration process for each sample were conducted at the Osteological Research and Processing Lab (ORPL).

Maceration with Low Heat and Processing

Decomposed samples were disarticulated at FARF and brought to ORPL for phases 2 and 3 of the x-rays and maceration with low heat. Maceration is the use water to break down soft tissue without the aid of heat or chemicals, however, to remove the soft tissues from the pig samples, low heat and tergazyme were added. For this study, I will refer to this process (with the additional ingredients of heat and chemicals) simply as maceration.

This process was completed using a large pot for the pig samples and a kettle for the human donors. These were filled with water and heated for nine (for the pig samples) hours. If the samples had more tissue than would come off with just heat and water, then 1 to 2 ounces of tergazyme would be mixed in the water. This increases the amount of soft tissue that is broken down during maceration, allowing the processing of the remains to be quicker. Processing the remains consists of removing all remaining soft tissue and cartilage from the bones using Dawn dish soap, a toothbrush, and metal utensils such as scalpels and tweezers.

Radiography

To conduct the radiographs for this study, I used a MinXRay portable x-ray machine. The elements were placed on the grid directly below the beam. Crania were placed on foam blocks, with autopsied human crania held together using dental wax. The settings used for each element are listed below in Table 1 and Table 2 lists the region of trauma observed for the donor samples and the elements I radiographed.

Table 1. X-ray Settings Used for Elements and Bone Conditions

Element	**Condition**	**Height of beam**	**kV**	**mAs/sec**
Human/ Pig Crania	Dry	40 cm	46	4.2
Human/ Pig Cranial fragments	Dry	33.5 cm	40	3.5
Human Vertebrae	Dry	40 cm	40	3.5
Human Ribs	Dry	40 cm	a) 46 b) 52	a) 4.4 b) 4.0
Pig Ribs	Decom-posed, mummified	40 cm	52	4.0
Pig Crania	Decom-posed, mummified	40 cm	46	4.2

Table 2. Regions of Trauma and Radiographs Taken

Donation	Region of Trauma	Elements x-rayed
D01-2009	Head	Reconstructed skull; lateral view; cranial fragments
D02-2009	Head	Reconstructed skull; lateral view
D49-2014	Head	Reconstructed skull; calotte only
D43-2014	Head- intraoral	Mandible; occipital; temporal; misc. cranial fragments
D39-2015	Head	Reconstructed skull; calotte only; mandible; misc. fragments
D52-2015	Head	Skull base only; lateral view
D19-2012	Head	Reconstructed skull; calotte only; base only
D02-2010	Chest	T10; left ribs; right ribs; left scapula
D10-2010	Multiple to chest	Left scapula; rib
D02-2013	Chest	Vertebrae; right ribs; left ribs
D16-2017	Head	Reconstructed skull; calotte only; base only
D32-2017	Head- contact shot	Base only; calotte only
D20-2019	Chest	Vertebrae; ribs; clavicles; misc. fragments
D72-2018	Chest	Right ribs; left ribs; vertebrae
D63-2017	Chest	Right ribs; left ribs; right scapula; vertebrae

Opaque Material Analysis

Analysis of radiopaque materials was conducted for both the human remains in the TXSTDSC and the experimental pig bones. For the human remains radiographs help to determine the presentation and location of radiopaque materials focusing on the manifestation as described below. This represents real-world examples of gunshot trauma observed in forensic anthropological investigations. Photographs and notes of decomposition and maceration took for each of the donations were used during the interpretation of the results for the persistence of opacities as well as the environmental conditions the donors were exposed.

My pig experiment, however, focused on three aspects of the manifestation of opacities on gunshot defects, including presentation, persistence and location (i.e. cranial or postcranial). A positive presence of opaque material is defined as being detectable by radiograph, which I termed "Radiographically Opaque Materials" or ROM. In this study, opaque materials include any substance (e.g., metal particles or gunshot residue) that are denser than the bone and therefore appear opaque on radiographs. Prevalence of detectable opacities in GSW or gunshot defect was scored as present or absent for each defect. Persistence of opacities is defined as whether the radiopaque material is detectable after decomposition/skeletonization and maceration. This aspect of my study examines the frequency of opaque material deposits on gunshot defects in the pig bones after decomposition and again after maceration to determine if taphonomic processes or the methods of cleaning remains negatively affect these material deposits. Each sample was x-rayed at ORPL in three phases. These phases include after gunshot trauma are inflicted, after decomposition, and after the maceration process.

For the pig crania, I counted the number of clumps, or groups, of ROM. These presented clear gunshot defects. I did not count the isolated particles or determine their relationship to the specific defect. For the pig ribs, I counted the number of isolated particles present, as large groupings of ROM were not present in the radiographs.

Statistical Methods

Radiographs post-trauma, post-decomposition and post-maceration were used to quantify the presence of ROM in the defect. To determine if there was a significant change from post-trauma to post-decomposition and then to post-maceration. A G-test goodness of fit was run using an expected 1:1 ratio. The G-test is a statistical method which analyzes observed and expected frequencies. The G-test was appropriate for this study because several of the expected frequencies were below a value of 5, causing a Chi-Square test to likely be inaccurate. To determine if there were differences between ammunition types, a Fisher's exact test was used. The Fisher's exact test is a statistical method which analyzed a data table and provides the probability of achieving those data patterns (Madrigal, 2012).

IV. RESULTS

Hollowpoint Hog Sample

For this sample, seven hog crania and four slabs of ribs were shot using hollowpoint ammunition. Twenty-one rounds were shot at the crania (three rounds in each head) and sixteen rounds were shot at the ribs (four rounds in each rib slab). Table 3 shows the initial ammunition total for each sample and if bullets or fragment groups persisted through the different phases of the project.

After the initial trauma infliction, all seven hog heads (100%) tested positive for ROM and each GSW could be detected in the radiograph by the presence of ROM, although the ROM was not re-associated with the entrance or exit wounds. After decomposition, four crania (57%) presented a total of six (6/21= 28.6%) embedded rounds which could be identified in the radiographs. Of the four crania with clear rounds, three of the crania each presented two clear gunshots and the other crania presented one clear gunshot (Figure 2).

The other three crania (43%) presented dispersed ROM fragments which could not be associated with individual defects or rounds (Figure 2). The ROM fragments in these three crania were not grouped in any certain way as to indicate the number of rounds present. All seven crania tested positive for ROM after decomposition presenting either embedded rounds or dispersed fragments. After maceration, only two of the heads (28%) were positive for ROM with 15 metal fragments detected (7 in one head and 8 in the other).

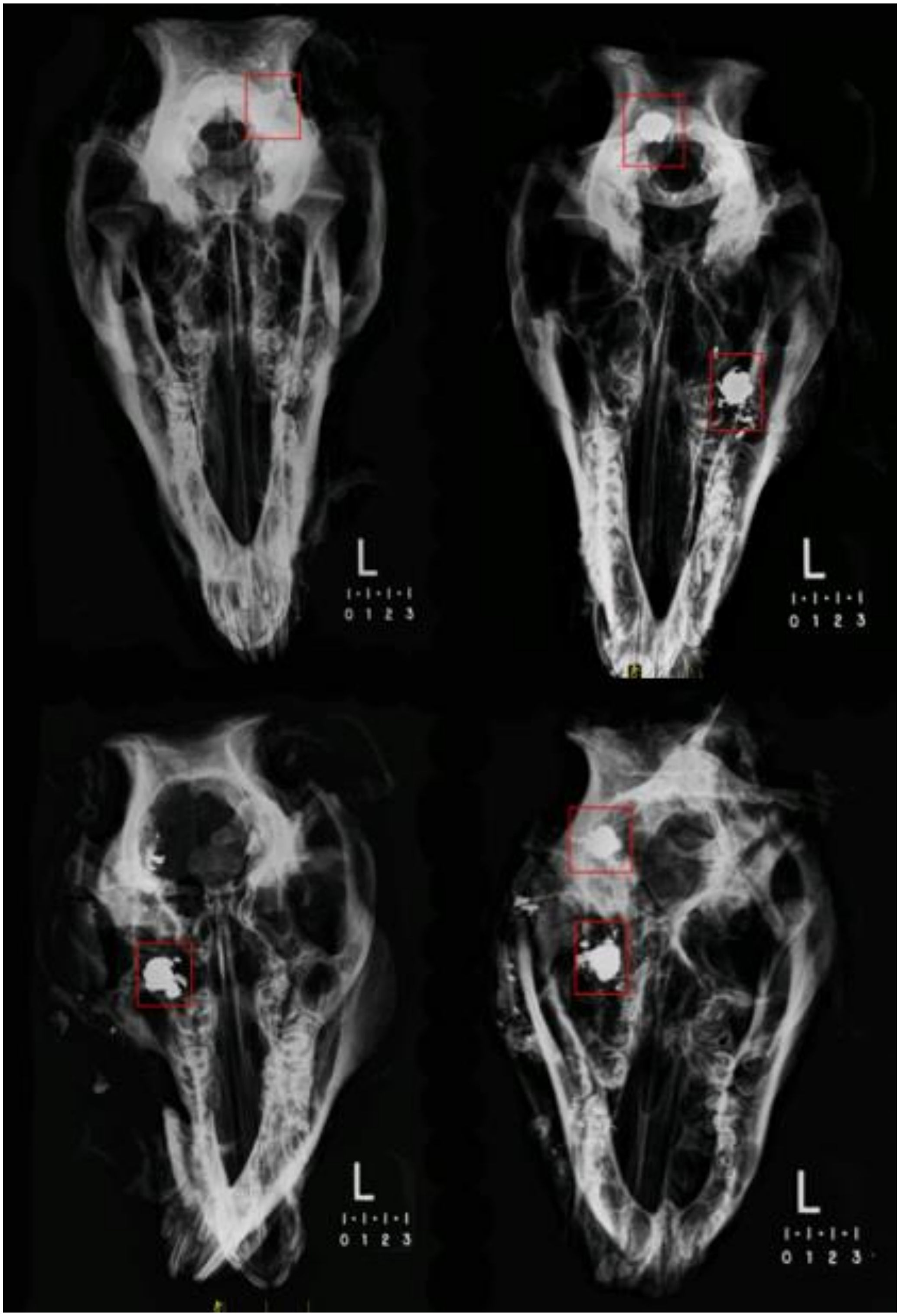

Figure 2. The four crania PD showing a total of 6 clear, embedded HP rounds.

Table 3. Detectable GSW by Postmortem Interval and Ammunition Type

Ammunition	Element PMI	Total
HP	Crania PT	21 rounds (3 x 7 heads)
HP	Crania PD	8 rounds (4 heads)
HP	Crania PM	15 fragments (2 heads)
HP	Ribs PT	16 rounds (4 x 4 slabs)
HP	Ribs PD	Scattered ROM, no clear group
HP	Ribs PM	No ROM
FMJ	Crania PT	24 rounds (3 x 8 heads)
FMJ	Crania PD	3 rounds
FMJ	Crania PM	1 round
FMJ	Ribs PT	16 rounds (4 x 4 slabs)
FMJ	Ribs PD	No ROM
FMJ	Ribs PM	No ROM

The hog heads were again radiographed after they were macerated and processed at ORPL. Two of the HP crania tested positive, with 7 ROM fragments present in one cranium and 8 fragments present in the other cranium (Figure 3). These fragments were not grouped to see individual gunshot defect. It should be noted that one of the crania in this sample was scavenged by vultures. This scavenged cranium was skeletonized when phase 2 of the radiographs were conducted and tested negative for ROM.

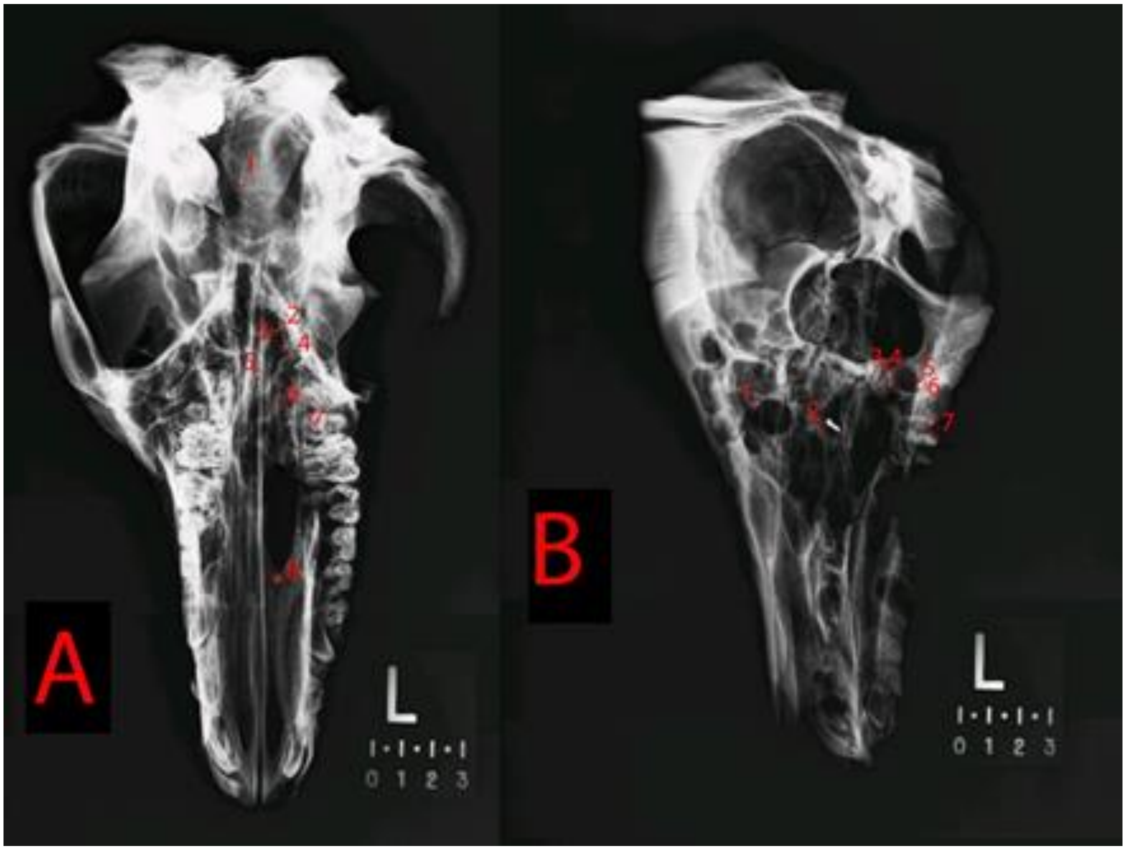

Figure 3. Two hog crania which tested positive for ROM in Phase 3. These were shot with HP ammunition. 8 ROM fragments persisted after maceration in the skull in image A, and 7 ROM fragments persisted in the skull in image B.

After the initial trauma infliction, the four slabs of hog ribs tested positive for ROM, indicating the 16 gunshots inflicted. Once the ribs progressed through the decomposition process at the Forensic Anthropology Research Facility, the slabs of ribs could not be kept together in their respective groups due to commingling in the field, and so these results will be for the rib sample as a whole, not for each slab. After decomposition, 18 fragments were present with no clear groupings of ROM to indicate the number of gunshots. There was no ROM present once the ribs were macerated and processed (See Tables 1 and 2).

Full-metal Jacket Hog Sample

For this sample, eight crania and four slabs of ribs were shot using full-metal jacketed ammunition. The crania were shot a total of 24 times (3 rounds in each head) and the ribs were shot a total of 16 times (4 rounds in each rib slab). The eight crania tested positive for ROM after the trauma was inflicted, and all 24 gunshot defects could be identified in the radiographs by ROM groupings. After the decomposition process, six of the crania tested positive (6/8= 75%). There were three intact bullets and 20 individual ROM fragments present in the crania during this phase of the project. One cranium with an intact bullet had no other ROM fragments, another cranium with an intact bullet had many fragments, and the other had two fragments. The three crania without intact bullets had one, eight, and nine fragments respectively. The sample with eight total fragments had five of those fragments near the skeletal defect. After the crania were macerated and processed, four tested positive for ROM (4/8= 50%). One cranium retained the intact bullet and no fragments. The other crania presented two, one, and one fragment respectively. Three of these samples were located near the gunshot defects. The ribs presented negative results after decomposition, and subsequently after the maceration process.

Changes Due to Decomposition and Maceration

A G-test for Goodness of Fit was run to determine if there was a significant difference in ROM detection in the hog crania between each stage (PT=post-trauma, PD= post-decomposition, PM= post-maceration). Table 4 shows a significant drop in ROM detection from PD to PM for both HP and FMJ hog crania samples, but this is because of the loss of ROM with maceration.

Table 4. G-Test for Goodness of Fit 1:1 Ratio

Bullet	**PMI**	**G**	**P 2 tail**
HP	PT -> PD	0	1
HP	PT -> PM	2.942	0.086
HP	PD -> PM	2.942	0.086
FMJ	PT -> PD	2.87	0.592
FMJ	PT -> PM	3.855	0.05
FMJ	PD -> PM	2.093	0.148

Effect of Ammunition Type

The number of crania with ROM detected immediately following (1) trauma, (2) decomposition and (3) maceration was statistically analyzed using a Fisher's Exact test to determine if the bullet type influenced the detection pattern through time. The data were run using the SAS statistical program.

There were no significant differences between bullet type and ROM at any treatment phase (PT, PD, PM) for the crania (Appendix A). Regardless of bullet type, the pattern of ROM evidence loss is consistent from PT to PM for the crania. In addition to the ROM frequency, Fisher's Exact was used to examine differences in the number of radiopaque fragments (ROF). As expected, the HP ammunition produced more ROM fragments which decreased in detection frequency from PT to PM but at a slightly slower rate than the HP ammunition. Finally, the ribs presented a different pattern. The pattern of ROM detection in the ribs is very significantly different for HP and FMJ rib samples between the post-trauma and post-decomposition phases because no material was found in the FMJ rib sample after decomposition. For the HP there were still detectable ROM until after maceration. This difference is also probably due to the reduced fragmentation of the bullet in FMJ ammunition.

Texas State Donated Skeletal Collection

Eighteen donors in the Texas State University Donated Skeletal Collection are documented as having a gunshot defect(s). Three of the donors tested positive for presenting ROM after they have been macerated and been curated in the collection. One donor was x-rayed after decomposition and presented a positive result for ROM detection. After the donor was macerated, the detection was negative. Therefore, 16.7% (3/18) of gunshot defects in the collection exhibited ROM after maceration. The six donors who were recorded as having postcranial gunshot defects were also x-rayed. The location for this trauma was primarily in the chest and consisted of either one or two recorded gunshots. All of these donors tested negative for any ROM present in the radiographs. The percent frequency for the presence of ROM detected in the curated donors in the Texas State Donated Skeletal Collection is 16.7%. The percent frequency for the presence of ROM detected after decomposition is 22.2% (4/18).

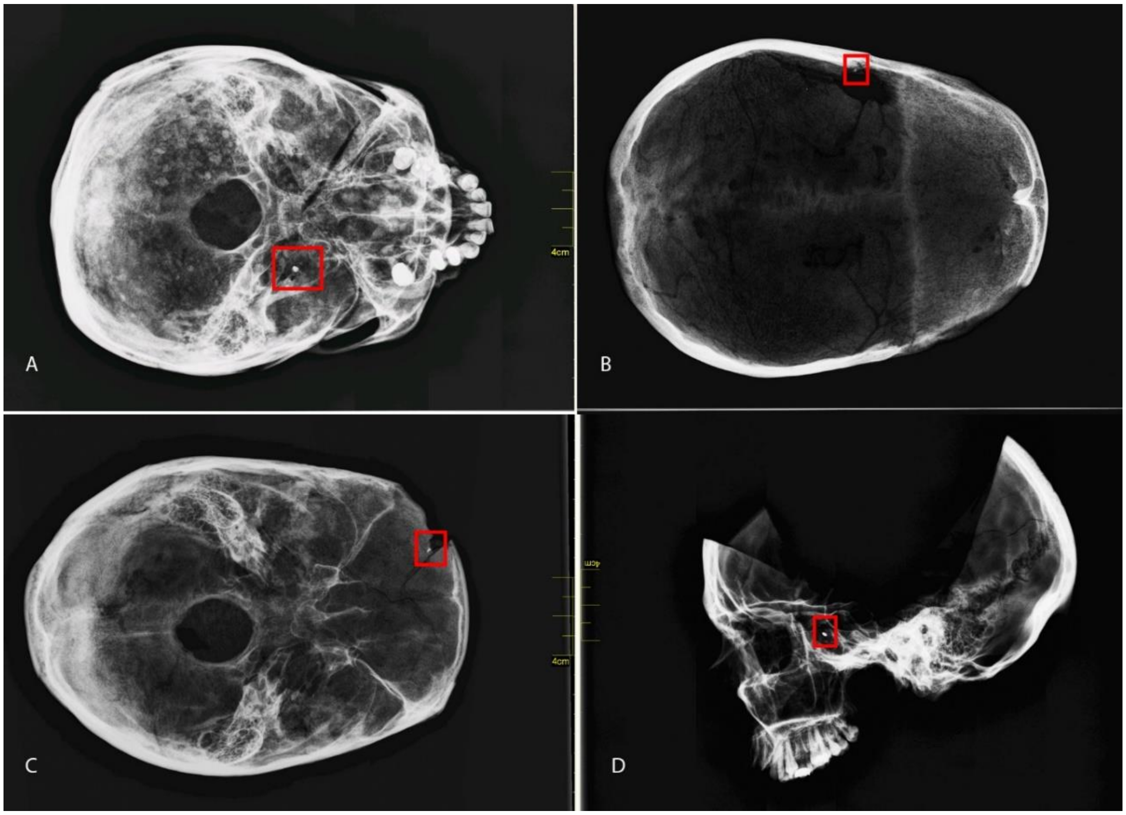

Figure 4. Radiographs for the four crania from separate donors which tested positive for ROM. Image A, a positive ROM detection post-decomposition, then tested negative post-maceration. Images B-D are positive, post-maceration radiographs.

V. DISCUSSION

It is important for forensic anthropologists to accurately interpret trauma patterns when investigating forensic cases. Anthropological interpretations of trauma can impact the investigation by providing useful information about the cause and manner of death. However, the accuracy of trauma interpretations can decrease due to several factors which were tested in this study. This study focused on trauma interpretations of atypical gunshot defects using the widely used method of radiography. The validity of this method was tested on highly fragmented, decomposed and environmentally-exposed samples of gunshot trauma.

According to DiMaio (1999), lead shavings from the bullet may embed themselves in the gunshot wound if the bullet and barrel are not in perfect alignment. Lead shavings may embed in the skin surrounding the wound if the bullet was shot from a poorly-made revolver or handgun (DiMaio 1999, pg 39-40). The fragments come from the bullet but not from misalignment with the barrel but its impact with the target and the design of the bullet's jacketing. My results further do not align with DiMaio's statements that fragments embed in the skin because I detected ROM embedded in the deeper soft tissue and bone structures. Also, poor craftmanship of a gun may have some impact on how the bullet responds and reacts to target impact, but my thesis also shows that where the bullet penetrates in the body, the type of ammunition used and the condition of the remains during analysis also play important roles in the detection of ROM in gunshot defects.

Effect of Decomposition and Maceration

The results of this study demonstrate that the reliability of radiographs in detecting ROM for trauma interpretation to be significantly affected by the decomposition and maceration processes. With each phase (PD, PM) the frequency of ROM decreased for both types of ammunition and in both crania and ribs. The biggest decrease occurred during the maceration process. This suggests that forensic anthropologists should always conduct radiographic analyses before maceration. The statistical results for the pig crania sample showed a significant difference in ROM detection from post-trauma to post-maceration. The rib sample showed a greater decrease in reliability of accurate trauma interpretation based on radiographic detection of ROM compared to the crania sample.

It was expected that decomposition would reduce the accuracy of radiographic detection of ROM because it was hypothesized that much of the ROM would be embedded in the soft tissue which degrades during the decomposition process. However, due to the summer environment of San Marcos, Texas, the hog carcasses mummified, preserving the soft tissue and the ROM which had embedded in those tissues. Based on the results after maceration, ROM detection could have decreased if there was not soft tissue desiccation. This indicates the loss of soft tissue, not necessarily the maceration process, could be responsible for the lower detection of ROM.

The pattern of ROM embedded in soft tissue rather than bone was further observed in the hog cranium which was scavenged by vultures. The complete loss of soft tissue on the scavenged sample can explain why ROM was not detected PD. A decomposition study conducted in 2009 at FARF observed the effects of vulture scavenging on decomposition rates, using hog carcasses (Reeves 2009). Reeves (2009) observed American Black vultures and turkey vultures accelerating the rate of decomposition. Similar to the results of Reeves (2009), the hog crania which was scavenged by vultures was the first to skeletonize, whereas the samples which were not scavenged mummified. If ROM embedded in the bone, it would have been detected after decomposition. However, this was not the case and it presented negative ROM results.

While decomposition can decrease radiographic ROM detection reliability, maceration had an even greater effect on the reliability of this method in this study. This supports the statement by Rogers (1992) that radiographs should be taken before maceration and processing of remains suspected of having gunshot trauma, especially if soft tissue is present. Taking radiographs of remains before the removal of soft tissue increases the preservation and detection rate of radiopaque evidence of gunshot trauma. The preservation of the soft tissue could explain why the frequency of ROM PD was higher than expected and why maceration had a more significant impact on the removal of ROM evidence.

Figure 5. Radiograph of a hog cranium PD with an intact FMJ bullet located in the soft tissue of the ear, rather than embedded in the bone.

Figure 6. Comparison of HP sample conditions from PT (top) to PD mummification (bottom) and preservation of soft tissue.

Effect of Ammunition Type

Hollowpoint and FMJ gunshot defects were mostly able to be identified by the structure of the ammunition upon impact with the samples. Full metal jacketed ROMs were mainly grouped after trauma infliction and decomposition, compared to the more dispersed HP ROM samples. There was a significantly greater amount of ROM fragments in the HP sample than in the FMJ sample. This result was expected because a metal jacket covers the entire bullet, including the tip in FMJ bullets, whereas the tip is not covered in HP bullets which allow the bullet to deform and fragment upon impact (Hollerman et al. 1990). The hollowpoint bullets expand into a star or "mushroom shape" creating a larger amount of tissue destruction and bullet deformation and fragmentation (Hollerman et al. 1990).

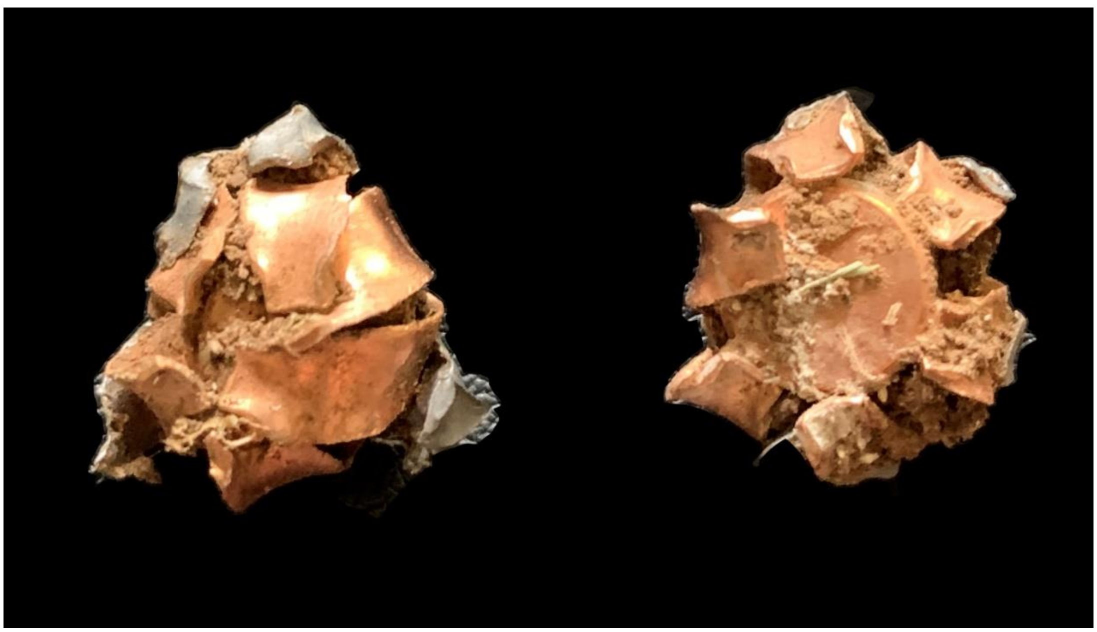

Figure 7. Two HP bullets recovered from Phase 1 trauma infliction. Note the flower/mushroom shape of the rounds after impact described by Hollerman and colleagues (1990).

Visible in the radiographs, the defects and groupings of ROM were more clearly grouped than in the HP radiographs. While the pattern of radiographic detection of ROM between the two ammunition types was not significantly different, the morphology and structure of the ROM were mainly distinguishable according to ammunition type (Figure 8). The HP ROM could be distinguished by the deformed shape of the bullet in addition to ROM fragments. The FMJ bullets embedded in the soft tissue structures less frequently than HP bullets and created fewer fragments due to the structure of the bullet jacket. Six HP gunshot rounds followed this pattern (Figure 1). The ROM from HP rounds PD still created groupings of fragments with many fragments but did not have embedded rounds. In contrast, four FMJ rounds were identified in the radiographs PD but they were not as deformed as the HP rounds and had less, or no, fragments grouped around them (Figure 8).

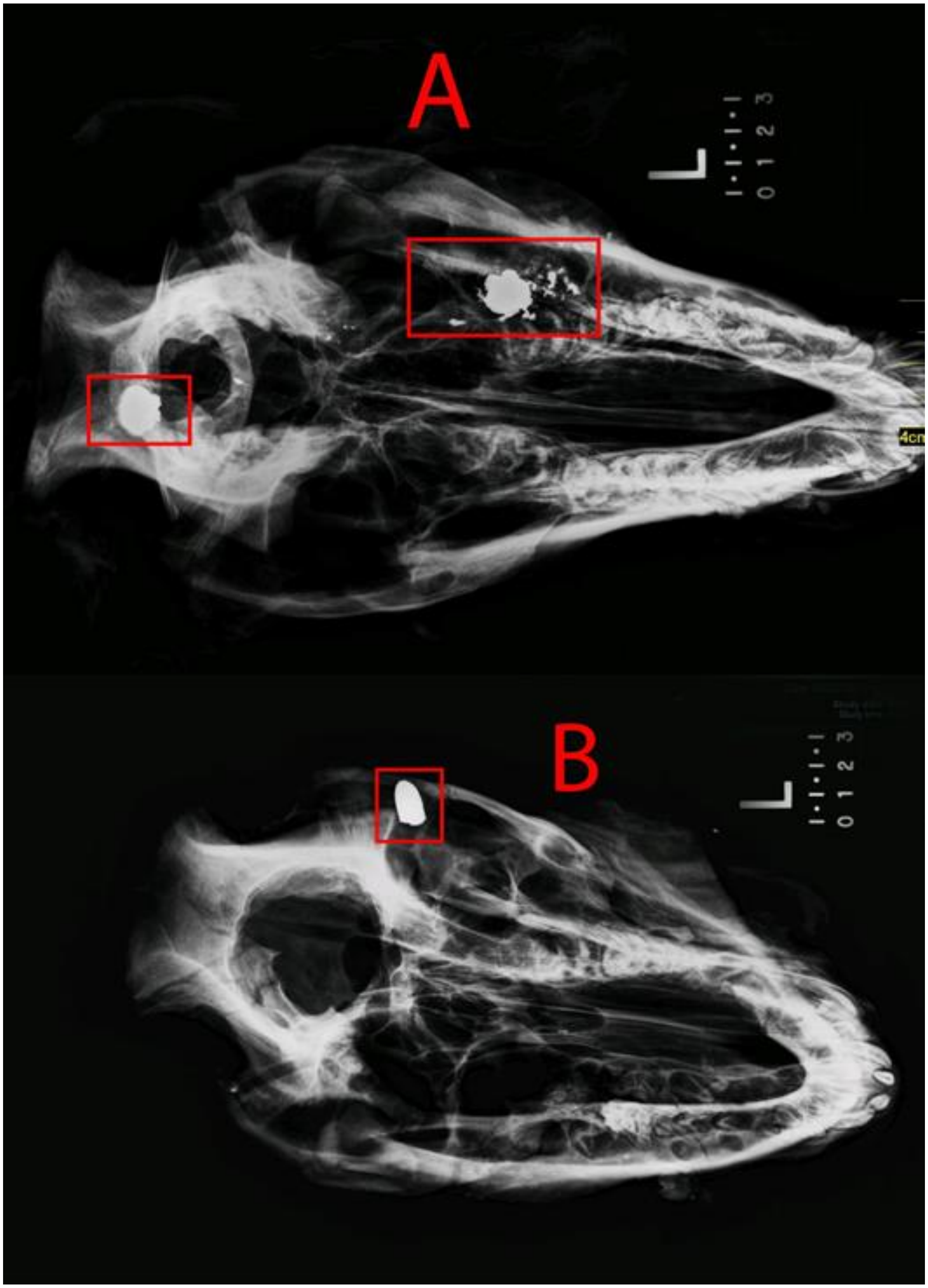

Figure 8. Radiographic comparison of HP and FMJ bullets. Image A (top) is an example of a Phase 2 radiograph (post-decomposition) of a hog cranium shot with hollowpoint ammunition. Image B (bottom) is an example of a Phase 2 radiograph of a hog cranium shot with full metal jacketed ammunition. Note the difference in morphology of the ROM in each image. The FMJ bullet is intact, compared to the HP bullets, which are less intact and surrounded by several ROM fragments.

Effect of Trauma Location on Body

When studying trauma in various locations on the body, from the harder cranial vault to the thicker femora and thinner ribs, biomechanics plays a critical role in how typical (or atypical) traumatic defects appear on the skeleton. The same type of trauma can present different patterns depending on which of the 206 bones in the human body is affected. In this study, the ribs from the hog sample had a higher rate of evidence degradation than the cranial samples (rib FMJ= negative PD, HP= negative PM). The donors from the TXSTDSC which tested positive for ROM PD and PM all had documented cranial GSWs. While the exact conditions under which the human samples were subjected to trauma were not documented, multiple factors could explain this difference in ROM detection between cranial and post-cranial skeletal elements (Bartelink 2015).

Bartelink (2015) describes extrinsic and intrinsic factors which can influence trauma interpretations of skeletal material. The extrinsic factors for the hog crania and ribs were controlled, such as ammunition type, shooting distance and the direction of the shots fired. Therefore, the intrinsic factors such as “shape, size and density” are what most likely impacted the ROM detection in the hog sample (Bartelink 2015). The extrinsic factors which would have influenced the trauma patterns observed in the TXSTDSC were not controlled since these represent real-world scenarios. However, it is also likely that the same intrinsic factors which influenced the hog sample also played a role in the TXSTDSC donors because the similar pattern was observed. Though Bartelink (2015) explains how various factors influence blunt force trauma, the same factors can influence GSW. The postcranial trauma mainly consisted of ribs and vertebrae, which are softer structures than cranial vault bones and could explain why there is a difference in ROM detection between cranial and post-cranial elements. Though this was not tested in my study, it can be hypothesized that harder bones, (i.e., femora) will have a higher persistence rate of ROM than softer bones (i.e., ribs, vertebrae). It was verified for all human donors and pig samples that the bullet hit bone and would leave skeletal evidence of gunshot trauma.

VI. CONCLUSION

According to CBS News and the Gun Violence Archive (GVA), mass shootings in the United States reached a new record of 417 in 2019 (Silverton 2020) This was the highest number of mass shootings since the GVA began counting in 2014. In addition to mass shootings, the GVA also maintains a count of homicides, suicides and accidents each year. In 2019 alone, the GVA recorded 15,381 gun-related deaths not involved in a mass shooting (Gun Violence Archive). As the prevalence of gun-related incidents increases, it is important for medical examiners and forensic anthropologists to accurately interpret gunshot trauma necessary for investigations. Understanding how decomposition and macerations affect radiographs of skeletal defects from GSWs is important because the radiographic analysis is a commonly used method in trauma interpretation. Anthropological interpretations of trauma can have substantial significance in forensic investigations, making it necessary to test the soundness of radiographic analytical methods in trauma interpretations and how various factors can affect this method's reliability.

DiMaio states that lead shavings from the bullet may embed themselves in the gunshot wound if the bullet and barrel are not in perfect alignment. Lead shavings may embed in the skin surrounding the wound if the bullet was shot from a poorly-made revolver or handgun. I mostly disagree with this statement. I agree that material can be embedded in the soft tissues because my results show fragments embed in the skin and bone structures. I also agree that the fragments do come from the bullet, however, they do not come from misalignment with the barrel but its impact with the target and the design of the bullet's jacketing. Poor craftsmanship of a gun may have some impact on how the bullet responds and reacts to target impact, but my thesis shows that where the bullet penetrates in the body, the type of ammunition used and the condition of the remains during analysis also play important roles in the detection of ROM in gunshot defects.

Suggestions for Best Practices

Anthropologists typically work with decomposed or skeletal material which has been exposed to different environments and conditions. This study highlights that radiographs for trauma interpretation should be conducted before the removal of any soft tissue elements because by modifying with and removing soft tissue, the radiographic detection rate of ROM decreases. The positive detection of ROM is evident of gunshot trauma, but the absence of ROM does not necessarily mean there is no gunshot trauma when examining skeletal remains. There is a 33% chance that ROM will not be detected if it were a cranial gunshot and decomposed. Therefore, forensic anthropologists must use ROM in conjunction with other methods to correctly interpret trauma.

Another suggestion would be to utilize either a portable metal detector or magnet at the scene to locate and retrieve possible bullets or bullet fragments. This may be especially useful under the skull where some of the small fragments could have fallen to the ground as the soft tissue decomposed.

Other factors to consider which may affect the detection of ROM via radiographs include the region of the trauma on the body (cranial versus postcranial), the bullet type used, the environment the body was found and the amount of soft tissue present upon discovery and analysis. Each of these factors can affect the reliability of radiographs for interpreting gunshot trauma and should be taken into account should court testimony include trauma interpretation.

Future Directions

While this thesis answered the four primary research questions set forth at the beginning, it raised a few questions as well. This study has opened up various future directions of study such as looking primarily at how scavenging can affect radiographic detection of ROM. Further studies could also include a wider range of ammunition types such as semi-jacketed and/or soft-nosed bullets. In addition, different guns could be tested, including rifles, shotguns, and other handguns or pistols. Further examination of the various factors which may influence radiographic detection of skeletal gunshot defects continues to be of utmost importance to forensic anthropologists as gun-related crimes in the US continues to have large impacts on society.

APPENDIX SECTION

Appendix A

Table 5. Table of Fragments in Crania by Bullet Type and PMI				
PMI		FMJ	HP	Total
PT	Frequency	36	102	138
	Expected	33.379	104.62	
	Percent	13	36.82	49.82
	Row Pct	26.09	73.91	
	Col Pct	53.73	48.57	
PD	Frequency	26	93	119
	Expected	28.783	90.217	
	Percent	9.39	33.57	42.96
	Row Pct	21.85	78.15	
	Col Pct	38.81	44.29	
PM	Frequency	5	15	20
	Expected	4.8375	15.162	
	Percent	1.81	5.42	7.22
	Row Pct	25	75	
	Col Pct	7.46	7.14	

Fisher's Exact Test

Table Probability (P) 0.0179

Table 6. Table of Crania with ROM based on bullet type and PMI				
PMI		FMJ	HP	Total
PT	Frequency	8	7	15
	Expected	7.9412	7.0588	
	Percent	23.53	20.59	44.12
	Row Pct	53.33	46.67	
	Col Pct	44.44	43.75	
PD	Frequency	6	7	13
	Expected	6.8824	6.1176	
	Percent	17.65	20.59	38.24
	Row Pct	46.15	53.85	
	Col Pct	33.33	43.75	
PM	Frequency	4	2	6
	Expected	3.1765	2.8235	
	Percent	11.76	5.88	17.65
	Row Pct	66.67	33.33	
	Col Pct	22.22	12.5	

Fisher's Exact Test

Table Probability (P) 0.0752

Table 7. Table of Ribs with ROM based on Bullet Type and PMI				
PMI		FMJ	HP	Total
1	Frequency	25	39	64
	Expected	19.512	44.488	
	Percent	30.49	47.56	78.05
	Row Pct	39.06	60.94	
	Col Pct	100	68.42	
2	Frequency	0	18	18
	Expected	5.4878	12.512	
	Percent	0	21.95	21.95
	Row Pct	0	100	
	Col Pct	0	31.58	

Fisher's Exact Test

Table Probability (P) 0.0005

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