Fired Bullets and the Implications for Comparison During Different Stages of Human Decomposition: A Pilot Study

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ABSTRACT

This study examines the effect of decomposing human tissue on an examiner's ability to identify a fired bullet to a common source firearm. Full metal copper jacketed bullets were placed in various regions in and near the bodies of two human donors at the Northern Michigan University Forensic Research Outdoor Station (FROST) during the summer of 2019. Two bullets were placed in each of the selected regions so one could be left in situ (in position) during the entire data collection period, and one could be repeatedly removed and replaced to assess the effects of decomposition at shorter time intervals. Over time, individual characteristics in the land impressions became dulled and less distinct, and pitting became apparent in the copper jackets due to the exposure of decomposition byproducts and metal oxidation. Bullet location and the length of time of exposure to decomposition were analyzed for their relationships to changes in bullet condition.

Introduction

In criminal investigations, it is often critical to establish a physical link between the suspect and the victim. In cases involving firearms, this physical link can be established by identifying the fired bullets to a common source firearm. Numerous factors have the potential to affect an examiner's ability to link a fired projectile to a particular firearm, such as the composition of the bullet, alteration of the barrel of the firearm, or damage to the fired bullet. The environment in which a bullet is located after it is fired can have a significant effect on its condition and therefore its suitability for comparison to a source firearm **[1]**.

Decomposing human remains present a unique environment in which fired bullets may be located, and in which identification to a source firearm can be essential. The environment associated with decomposing human (or non-human proxies for human tissue) has been found to react with certain metals and to have a detrimental effect on the condition of fired bullets, especially when compared with other environments, such as being left in open air or buried in soil **[1, 2]**. Changes in the condition of fired bullets in decomposing tissue are attributed primarily to variations in pH and microbiological activity in the body during the decomposition process **[2]**. Prior research that has been conducted to evaluate the effect of decomposition on fired bullets involved the use of pig carcasses, which are often used as proxies for human remains in taphonomy research **[3]**. Recent research, however, has established that pigs are not perfect proxies for human remains and research that presumes to make statements about human decomposition should be conducted on human remains **[4, 5]**.

The amount of change that occurs to bullets in an environment of decomposing biological material is directly related to the bullet composition (e.g., aluminum-jacketed bullets are more resistant to change than bullet jackets made of copper or brass) **[6]**. Bullets tend to show a progression of oxidation the longer they are exposed to biological decomposition; however, the length of time a bullet is in contact with decomposing tissue is not known to be directly related to the suitability of a bullet for identification **[6]**.

The present study is inspired by and expands upon a study conducted by Smith et al. (1993), wherein the authors placed fired bullets into human cadavers and removed them when a pre-determined endpoint based on stage of decomposition was reached **[2].** In that study, all fired bullets remained in situ until the researchers determined that the donor was 90% decomposed or skeletonized (which resulted in a study period of 66 days) **[2]**. Smith et al. (1993) evaluated various bullet compositions (specifically, lead alloy, copper alloy jacketed, aluminum alloy jacketed, nickel plated copper alloy jacketed, and nylon coated bullets) and confirmed that the copper and nickel jacketed bullets were the most affected by contact with decomposing tissue; the aluminum and nylon jacketed bullets

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were found to be the least affected **[2]**. The bullets were placed in various locations within the body, including the head, chest, abdomen, muscle, and fat. The fat and muscle were found to have the greatest effect on the bullets. There was a black to green oxide buildup observed on the copper jacketed bullets in the chest. The lead bullets were most affected by the fat and muscle; the bullets could not be identified due to the severity of the oxidation. Other prior research dedicated to the evaluation of the effects of decomposition on the suitability of bullets for identification of a source firearm has focused on different environments **[6]**, human decomposition **[2]**, and collection after a certain amount of time **[2]**. The present study examines how individual characteristics on fired bullets are affected over time in decomposing human remains.

Decomposition

While the rate of human decomposition is highly dependent on temperature and moisture **[7]**, the progression through the stages of decomposition is somewhat predictable **[7, 8]**. The process of decomposition begins as soon as a living organism dies, although its effects may not be noticeable for hours or days, depending on the environment, body size, and numerous other factors **[7]**. Early stages of decomposition include changes in temperature (acclamation to ambient temperature) and color (e.g., the development of livor mortis in the dependent regions of the body), and the onset and passing of rigor mortis (the stiffening of the body for a period of time after death). Later stages of decomposition include more extreme color changes (e.g., brown, black, green), purging of fluids, bloating, and the release of abdominal gasses and subsequent sagging of the tissue **[7, 8]**. Advanced decomposition occurs post-bloat, and depending on the environment, may result in the eventual skeletonization or mummification of the body **[8]**.

Materials and Methods

Firearm

A Ruger, model P89, 9mm Luger caliber semiautomatic pistol from the Michigan State Police Metropolitan Detroit Forensic Laboratory's reference collection was selected as the firearm from which all test bullets would be fired. This specific firearm was chosen because after it was test fired by the primary author, it was found to leave individual, repeatable marks on fired bullets.

Bullets

Fifteen 9mm Luger caliber American Eagle Federal 124-grain full metal jacket (FMJ) bullets were test fired using the selected source firearm. All bullets were fired into a water recovery tank to ensure the entire bearing surface could be evaluated over time; for the purpose of this study, the bullets needed to be in pristine condition, even though that is not typical of evidence from crime scenes. The bullets were then collected and individually scribed with unique identifiers on each of their bases and ogives.

Prior to placement of any of the bullets in human donor remains, one of the 15 bullets was randomly selected as a control (subsequently marked as Item 1), and each of the other 14 bullets (subsequently labeled as Item 2 through Item 15) were compared to the control bullet according to standard examination protocol. All bullet comparisons were completed by the same examiner. Each of the land impressions (LIMPs) on each bullet were compared to the corresponding LIMPs on the control bullet and photographed (with the nose of the bullet pointing to the right). This preliminary examination was completed to ensure that all 14 of the test bullets could be identified to Item 1. After being compared, all 15 of the identified bullets (including Item 1) were indexed by inscribing a gross mark on the ogive above the corresponding LIMP of each bullet, which was then referenced as LIMP 1 in all comparisons.

Donors and Bullet Placement

This research was conducted at the Northern Michigan University (NMU) Center for Forensic Anthropology (CFA) from late June through July of 2019. The outdoor decomposition aspect of the research was carried out at the Forensic Research Outdoor Station (FROST); all examinations were performed at the Forensic Anthropology Research Laboratory (FARL). FROST is one of only a handful of facilities in the world that are devoted to the study of human taphonomy; FARL is the accompanying research laboratory where skeletal analysis and curation of donated human remains take place.

Twelve of the 14 fired bullets were placed in or near two human donors for the purpose of this experiment. The two human donors selected for this study were the most recently received/placed donors in the FROST facility. Bullet placement locations were designed to mimic locations of recovered bullets in homicide cases – head, abdomen, limbs (including placement of some bullets directly in contact with bone), and in the soil near the bodies. Two bullets were placed in each region. One bullet in each region was left in situ for the duration of the data collection period, and the other was removed at different time intervals to observe if there was a relationship between time in the body and the ability to identify individual characteristics. The expectation was that the longer the bullets are in contact with the products of decomposition, the more deteriorated they would be, and the

more challenging they would be to compare.

For this research, bullet "placement" refers to the insertion of bullets into the donors' soft tissue. This procedure was accomplished by using a scalpel to create a small incision in the donors' skin and carefully pushing the projectiles into the tissue until they reached their desired locations. Neither donor received any actual gunshot wounds for the purpose of this research. When bullets were retrieved on sampling days, they were retrieved and replaced through the same incision through which they were initially placed. This process was intended to minimize the number of incisions/entry points in the donor tissue.

Donor 1

Donor 1 was an elderly white male who was placed at the FROST facility in late March of 2019 according to standard FROST donor placement procedures and was covered by a metal wire enclosure to deter scavenger activity. Donor 1 remained untouched after being placed on the FROST property until the fired bullets were placed in late June of 2019. When the bullets were placed, Donor 1 was already in an advanced state of decomposition—partially skeletal with desiccated soft tissue.

Eight fired bullets (Item 3 through Item 10) were placed in four locations in or near Donor 1 **(see Figure 1)**. The bullets were placed so that they were not in contact with each other. The first two bullets were placed in the soil between the donor's thighs, where biological matter from decomposition was collecting. These were documented as "Right Soil" (Item 3) and "Left Soil" (Item 4). The two bullets in the soil were marked with PVC pin flags to indicate their location and to ensure they would be easily located and retrieved. Two bullets were placed in the left thigh, resting directly on the femur to determine if contact with bone would affect the individual characteristics of the bullets. When they were placed, the bullets were oriented so that the item numbers on the bases were upright with the noses pointed medially (toward the right thigh). These bullets were documented as "Proximal Leg" (Item 5), which was located closer to the torso, and "Distal Leg" (Item 6), which was located closer to the knee. Two bullets were placed in the abdominal cavity—one in the lower right quadrant and one in the lower left quadrant—by making small incisions in the abdominal wall and inserting the bullets through them. These were documented as "Right Abdomen" (Item 7) and "Left Abdomen" (Item 8). The final two bullets were placed in the eye sockets and were documented as "Right Eye" (Item 9) and "Left Eye" (Item 10).

Donor 2

Donor 2 was also an elderly white male whose death and placement at the FROST facility were in late June of 2019. Donor 2 was also placed according to standard FROST donor placement procedures and was covered by a metal wire enclosure to deter scavenger activity. Bullets were placed in and near Donor 2 two days after his placement at FROST, which facilitated data collection through the entire decomposition process, from nearly fresh through advanced decomposition.

Four fired bullets (Item 11 through Item 14) were placed in Donor 2 **(see Figure 2)**. Two bullets were placed in the arms/biceps by making small incisions through the skin and inserting the bullets into the soft tissue. These were documented as "Right Arm" (Item 11) and "Left Arm" (Item 12). Two bullets were also placed in the left thigh, resting directly on the femur. The bullets on the femur were placed by making small

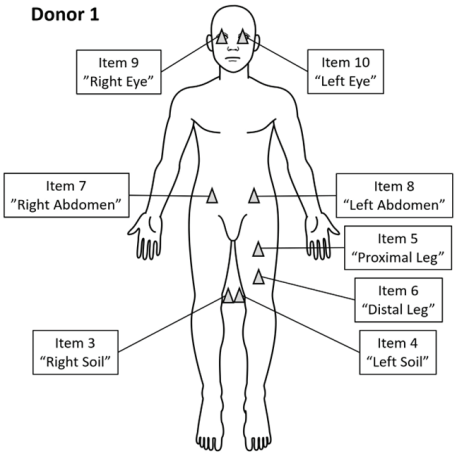

Figure 1: Donor 1 bullet placement locations

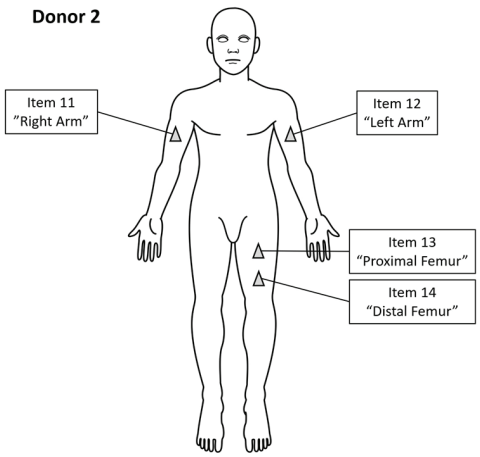

Figure 2: Donor 2 bullet placement locations

incisions through the skin and inserting the bullets so that they were in the same orientation as the bullets placed in the thigh of Donor 1. These bullets were labeled, "Proximal Femur" (Item 13) and "Distal Femur" (Item 14). Bullets could not be placed in the abdomen of Donor 2 because of the potential for disruption of another study focusing on the gut necrobiome.

Data Collection

The bullets from each donor were examined weekly or semi-weekly, depending on accessibility and availability of researchers. Bullets in Donor 1 were removed from the donor body and examined eight times over a one-month period (five weekends). The first comparison took place two days after bullet placement. Bullets in Donor 2 were sampled four times over 24 days. Donor 2 quickly became bloated, and maggot activity precluded the ability to locate and remove bullets until 10 days post-placement, when the bloating and maggot activity decreased.

Bullets with even item numbers were selected to be removed weekly (or semi-weekly, when possible) for examination, while bullets with odd item numbers were selected to be left in situ for the duration of the data collection period. The bullets removed for weekly or semi-weekly comparisons included the bullets on the left side of both donors where there was bilateral placement, as well as the distal femur bullet (Item 6) of Donor 1 and the proximal femur bullet (Item 13) of Donor 2. The even-numbered femur bullets were placed distally, and the odd-numbered femur bullets were placed proximally. The odd-numbered bullet was removed for periodic evaluation from Donor 2, contrary to what had been pre-established procedure for this study, because the distal bullet (Item 14) could not be located on the first retrieval date. The remaining odd-numbered bullets and Item 14 were left in place for the duration of the experiment. Items 2 and 15 were never placed in the donors; Item 2 was kept as a second control and Item 15 was not needed, due to limited options for bullet placement.

The bullets were removed with the assistance of NMU CFA staff who were familiar with human anatomy and were comfortable handling human remains in advanced states of decomposition. Stainless steel forceps with rubber-coated tips and wooden dowels were used for removal to ensure that the removal process would not generate any incidental marks on the bullets that could obscure the striations in the LIMPs. Metal forceps with small teeth at the ends were necessary on one occasion to retrieve the left soil bullet from Donor 1 (Item 4) because the soil was slippery, and the teeth were needed to grip the bullet. When examined under magnification, the examiner found that the metal teeth from the forceps did not impart any noticeable marks on the bullet.

In accordance with the standard Michigan State Police Laboratories' cleaning protocol, once the fired bullets were removed from the donors, they were placed in a plastic cup containing a sufficient amount of Envirocide™ (ready to use surface disinfectant/decontaminant cleaner) to completely submerge the bullets. The bullets were allowed to soak for a minimum of 30 minutes prior to being cleaned. When the bullets that had been left in situ were finally removed, they had to be soaked again after the initial 30 minutes due to heavy layers of patina (greenish-blue film produced on metal from oxidation) that developed. The physical changes and conditions of the bullets were noted when removed and after cleaning. The bullets were cleaned with a soft bristle toothbrush under tap water and Envirocide™. After cleaning, the bullets were placed back in EnvirocideTM for an additional 10 minutes prior to being dried and compared.

Using a Leica FS M comparison microscope, the removed bullets were individually compared to the control bullet (Item 1), according to standard comparison methods. LIMPs 1 through 6 on the removed bullets were compared to the corresponding LIMPs on Item 1. Each LIMP comparison was photographed, and observations were noted. After the comparisons, the bullets were placed back into the donors, in the same orientation as their initial placement, until the next sampling.

The examination of the bullets involved examining each LIMP independently and reaching a conclusion. Three possible conclusions could be reached during the examination: identification (I), similarities (inconclusive) (S), or unsuitable (U). These are standard conclusions for firearms examiners. First, prior to a comparison, the LIMPs were examined independently to determine if they were suitable for comparison. If there was too much deterioration to the LIMP, it was deemed to be unsuitable for comparison. If the LIMPs were suitable for comparison, then LIMPs were compared to the control bullet. If there was sufficient agreement between the two LIMPs being compared, then the result would be an identification. When there was some agreement, but not sufficient agreement for identification, similarities were noted. The bullets were then assessed as a whole to determine if they could be identified or not, despite damage to some LIMPs.

Results

Tables 1 through **6** show the results for each bullet comparison; **Tables 1** through **4** present the conclusions reached for each item placed in Donor 1 and **Tables 5** and **6** present conclusions for items placed in Donor 2. The left column shows the accumulation of days since the bullets were placed. The column labeled "Bullet" indicates the conclusion

reached for the bullet as a whole. The remaining columns are the conclusions reached for the individual LIMPs of the bullets. The last row of results represents the results of the bullet that was left in situ.

Data on individual bullets is presented in the following section. Results for bullets that were removed on a weekly or semi-weekly basis are presented first, followed by results for bullets that were left in situ for the duration of the study period.

Donor 1

The bullets from Donor 1 had copper jackets that appeared to have a dulled finish and the dulling increased throughout the weeks **(see Figure 3)**. Each time the bullets were sampled, a patina was observed on the surface, except for the bullet in the soil (as explained below). The patina varied in distribution and quantity for each sampling **(see Figure 4)**. The bullets that were left in situ in Donor 1 all had a thick layer of patina that covered the entire bullet and was not easily cleaned from the surface. The bullets were soaked, cleaned with a soft bristle toothbrush, soaked again, and then cleaned again to remove the patina to view any individual characteristics.

Figure 3: Representative depiction of dulled finish and marbling effect observed on one of the bullets

Figure 4: Representative depiction of patina observed on one of the bullets

Soil

The left soil bullet (Item 4) could be identified each time it was sampled, but the number of identifiable LIMPs decreased over time. LIMP 1 could be identified for every data collection date over the five-week period, but by the fourth week, LIMPs 2 and 5 were found to be unsuitable, and by the fifth week, LIMP 3 was also found to be unsuitable. The right soil bullet (Item 3) was unsuitable for comparison when recovered the final week. All of the LIMPs on Item 3 were determined to be unsuitable for comparison due to corrosion or deterioration.

During the second week of sampling, new marks were observed on Item 4 in some of the LIMPs. The origin of these marks is unclear. Additional marks continued to be observed throughout the remaining weeks. Some of these marks obscured the individual marks that were previously used for comparison. These new marks were observed the most in LIMP 6 **(see Figure 5)**. During the fourth week, the marks obscured the individual characteristics enough that an identification could not be concluded for the LIMP; similarities were still observed, however. No such additional marks affected Item 3.

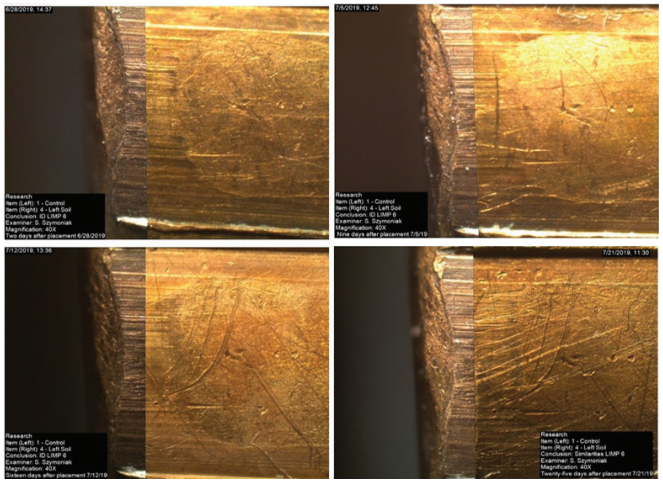

Figure 5: LIMP 6 from left soil bullet (Item 4) – New marks observed over time. Top left-2 days after placement; top right-9 days after placement; bottom left-16 days after placement; bottom right-25 days after placement

Patina was observed on the surface of Item 4 in the first and fifth weeks of sampling. Interestingly, no patina was observed on Item 4 in the second through the fourth week of sampling. During the first sampling of the fourth week, the copper of Item 4 showed a spotted, greyish discoloration and some areas with a darker reddish-brown discoloration **(see Figure 6)**. These markings were not present for the second sampling during week four.

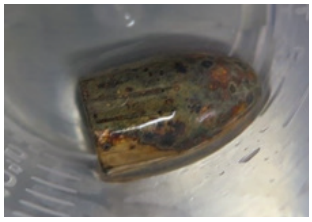

Figure 6: Left soil bullet (Item 4) during week 4 – gray spotted discoloration that was absent the next sampling

Thigh (Femur)

The bullet from the distal femur (Item 6) could be identified for the first five samplings (up to 16 days after placement). During the fifth sampling, only LIMPs 4 and 5 could be identified, while the remaining four LIMPs only displayed similarities. When Item 6 was examined on day 23, there was distinct pitting observed in several of the LIMPs, and LIMPs 2 and 4 were found to be unsuitable. On day 25, LIMPs 3 and 5 were also found to be unsuitable. In the final week of sampling, LIMP 5 was found to display similarities; LIMPs 1 through 4 and 6 were unsuitable for comparison. The bullet became more corroded as time progressed. The bullet that was left in situ on the proximal femur (Item 5) could still be identified by sufficient agreement in LIMPs 5 and 6.

When examining the area of the bullet that had been in prolonged direct contact with the femur, the area was lighter in color than the remainder of the bullet **(see Figure 7)**. Discoloration was observed on both the distal and proximal bullets. However, there does not appear to be a direct relationship between the persistence of the individual characteristics and placement of the bullet on the bone. The LIMPs resting on the bone were similarly affected as the other LIMPs not in contact with the bone.

Figure 7: The lighter area on the bullet from the distal leg from Donor 1 – LIMPs 1 and 6

Abdomen

During the first two samplings, two and four days after placement, all the LIMPs of the left abdomen bullet (Item 8) could be identified. Two additional samplings and comparisons were conducted after nine and eleven days. During the first examination, half of the LIMPs could be identified (LIMPs 1 through 3), and the other half displayed similarities (LIMPs 4 through 6). Two days later, two LIMPs could be identified (LIMPs 2 and 6), two showed similarities (LIMPs 1 and 3), and two were unsuitable for comparison (LIMPs 4 and 5). The remainder of the exams resulted in only one land impression being able to be identified (LIMP 2); the others either showed only similarities or were found to be unsuitable. The bullet that was left in situ, the right abdomen bullet (Item 7), did not have any LIMPs with identifiable marks, and only one LIMP displayed some similarities (LIMP 6).

Eye

During the first week, the bullet from the left eye socket (Item 10) was examined twice. LIMP 1 could be identified during the first examination; however, two days later, the LIMP was observed to be heavily pitted and did not have any striations suitable for comparison. During the first week, there was sparse maggot activity in the eye socket. After the first week, Item 10 was no longer able to be identified, but similarities could still be observed. Item 9, the bullet in the right eye socket (left in situ), could still be identified by LIMP 1 at the completion of the study. LIMP 2 showed similarities, while all other LIMPs were unsuitable for comparison.

Donor 2

The bullets from Donor 2 could not be sampled until 10 days after placement due to bloating of Donor 2 and heavy maggot activity restricting access to the bullets. These bullets were sampled four times over three weekends. **Tables 5** and **6** indicate the conclusions reached for each Item placed in Donor 2.

The copper jackets on the bullets in Donor 2 displayed the same marbling effect that was observed on the bullets recovered from Donor 1. It was not until the second and third weeks of sampling when patina was observed on the exterior of the bullets. During the second week of sampling, maggot activity was also observed to be diminished when compared with the previous week, potentially allowing the patina to form. The bullets from the arm/bicep displayed patina more concentrated on the portion of the bullets that was exposed to the interior environment of Donor 2. The portion that was exposed to the exterior environment did not appear to have as

Days from Placement	Bullet	LIMP 1	LIMP 2	LIMP 3	LIMP 4	LIMP 5	LIMP 6
2	I	I	I	I	I	I	I
4	I	I	I	S	I	S	I
9	I	I	S	S	I	S	I
11	I	I	U	S	I	S	I
16	I	I	U	S	I	U	I
23	I	I	U	U	S	U	I
25	I	I	U	U	S	U	S
30	I	I	U	S	U	U	S
30 Untouched	U	U	U	U	U	U	U
The results in the table are represented by an I for identification, S for similarities/inconclusive, and U for unsuitable.							

Table 1: Results of bullets from soil placed in Donor 1 – Items 3 (untouched) and 4

Days from Placement	Bullet	LIMP 1	LIMP 2	LIMP 3	LIMP 4	LIMP 5	LIMP 6
2	I	I	I	I	I	I	I
4	I	I	I	I	I	I	I
9	I	I	S	I	I	I	I
11	I	I	S	I	I	I	I
16	I	S	S	S	I	I	S
23	S	S	U	S	U	S	S
25	S	S	U	U	U	S	U
30	U	U	U	U	U	S	U
30 Untouched	I	U	U	U	S	I	I
The results in the table are represented by an I for identification, S for similarities/inconclusive, and U for unsuitable.							

Table 2: Results of bullets from leg placed in Donor 1 – Items 5 (untouched) and 6

Days from Placement	Bullet	LIMP 1	LIMP 2	LIMP 3	LIMP 4	LIMP 5	LIMP 6
2	I	I	I	I	I	I	I
4	I	I	I	I	I	I	I
9	I	I	I	I	S	S	S
11	I	S	I	S	U	U	I
16	I	S	I	S	U	U	S
23	I	S	I	S	U	U	S
25	I	S	I	S	U	U	S
30	I	S	I	U	U	U	U
30 Untouched	U	U	U	U	U	U	S
The results in the table are represented by an I for identification, S for similarities/inconclusive, and U for unsuitable.							

Table 3: Results of bullets from abdomen placed in Donor 1 – Items 7 (untouched) and 8

Days from Placement	Bullet	LIMP 1	LIMP 2	LIMP 3	LIMP 4	LIMP 5	LIMP 6
2	I	I	S	S	S	S	I
4	I	U	S	S	S	I	I
9	S	U	U	S	U	S	S
11	S	U	U	S	U	S	S
16	S	U	U	U	U	S	S
23	S	U	U	U	U	S	S
25	S	U	U	U	U	S	S
30	U	U	U	U	U	S	U
30 Untouched	I	I	S	U	U	U	U
The results in the table are represented by an I for identification, S for similarities/inconclusive, and U for unsuitable.							

Table 4: Results of bullets from eye sockets placed in Donor 1 – Items 9 (untouched) and 10

Days from Placement	Bullet	LIMP 1	LIMP 2	LIMP 3	LIMP 4	LIMP 5	LIMP 6
10	I	U	S	U	U	U	I
17	U	U	U	U	U	U	U
19	U	U	S	U	U	U	U
24	U	U	U	U	U	U	U
24 Untouched	U	U	U	U	U	U	U
The results in the table are represented by an I for identification, S for similarities/inconclusive, and U for unsuitable.							

Table 5: Results of bullets from arms/biceps placed in Donor 2 – Items 11 (untouched) and 12

Days from Placement	Bullet	LIMP 1	LIMP 2	LIMP 3	LIMP 4	LIMP 5	LIMP 6
10	I	I	S	U	U	U	U
17	U	U	U	U	U	U	U
19	U	U	U	U	U	U	U
24	U	U	U	U	U	U	U
24 Untouched	-	-	-	-	-	-	-
The results in the table are represented by an I for identification, S for similarities/inconclusive, and U for unsuitable.							

Table 6: Results of bullets from femur placed in Donor 2 – Item 13

much patina.

Arm/Bicep

During the first sampling, only one LIMP from the left arm/bicep (Item 12) could be identified (LIMP 6), one displayed similar characteristics (LIMP 2), and the others were unsuitable. The rest of the samplings all resulted in unsuitable LIMPs for comparison, except for the third sampling, in which LIMP 2 showed some similarities. All LIMPs on the bullet recovered from the right arm/bicep at the end of the study (Item 11) were found to be unsuitable for comparison.

Thigh (Femur)

The results from the proximal femur bullet (Item 13) were similar to that of the left arm/bicep (Item 12); only LIMP 1 could be identified, one LIMP (LIMP 2) displayed similarities, and the remaining four LIMPs were unsuitable for comparison. All LIMPs were unsuitable for comparison in the last three samplings.

The area on the bullet that was in direct contact with the bone was also examined. The LIMPs that were supposed to be in contact with the bone were LIMPs 1 and 2, based on placing the scribed numbers on the base upright. However, an area of lighter discoloration was observed around LIMPs 5 and 6, an area adjacent to LIMPs 1 and 2. The discoloration was inconsistent with observations documented regarding the bullets recovered from the femur of Donor 1.

Due to unknown circumstances, the distal femur bullet (Item 14), the bullet left in situ, could not be recovered. The left thigh of Donor 2 and the surrounding ground were searched visually and using a metal detector, without finding the bullet. The most plausible explanation for the missing bullet is scavenger activity. Despite FROST/FARL staff's efforts to deter scavenger activity, trail cameras in the facility have documented numerous occasions of small scavengers (primarily skunks) burrowing under the cages to consume maggots, insects, and human tissue. The trail camera focused on Donor 2 captured images of a skunk entering the cage and the left thigh showed evidence of scavenger activity. Because Item 14 was never recovered, no results for this bullet can be reported.

Discussion

This study was conducted to observe the effects of decomposition and environmental factors on the suitability of fired bullets for identification to a common source firearm. Twelve bullets were placed in six locations in and near two human donors. Two bullets were placed in each location. One bullet from each location was removed and replaced repeatedly over the data collection period to assess the effects of decomposition over short time periods. The other bullet was left in situ during the entire data collection period. The bullets were examined to observe how the degradation of the bullets progressed over time. At the beginning of this study, all LIMPs on the fired bullets had distinct striations that were suitable for comparison, and all LIMPs were identified to the control bullet. These distinct striations could still be observed in the first week of sampling from Donor 1 for most of the LIMPs and in one LIMP from both bullets from Donor 2. As time progressed, however, the striations became dulled and less distinct, as if they had been abraded. Some LIMPs were found to be unsuitable for comparison once the striations were nearly indistinguishable or became completely obscured. When the LIMPs were exposed to decomposition long enough, the LIMPs displayed pitting. The pitting made the bullets unsuitable for comparison.

The location of the bullets in or near the body does not appear to have a predictable effect on bullet degradation. The pairs of bullets from Donor 1 had split results from each of the four locations. For example, two bullets (Items 4 and 8) could be identified each week they were sampled from the soil and abdomen; however, the corresponding bullets (those left in situ, Items 3 and 7) could not be identified. The opposite results occurred for the bullets in the leg and eye sockets. Removing and cleaning the bullets each week could account for the variations in the results. The bullets from Donor 2 all had the same results of escalated deterioration – resulting in striations being unsuitable for comparison.

Bullets were placed resting on the bone to determine if the bone had an influence on the individual characteristics. Contrary to expectations, there was not a distinct difference in the ability to identify the bullets from the LIMPs that were in direct contact with bone and the bullets not in contact with bone. The two bullets from Donor 1 that were resting on the femur were not consistent. The bullet removed weekly had similar results for the LIMPs that were in contact with the bone and the LIMPs that were not. However, the LIMPs in contact with the bone of the bullet that remained in situ were unsuitable for comparison, while the other LIMPs displayed characteristics that could be compared.

While direct bone contact did not affect the comparability of bullets, there was a direct relationship between location of bullet on bone and discoloration of the bullet jacket. The discoloration was observed on both bullets from Donor 1. There was discoloration observed on Donor 2; however, the discoloration was adjacent to where it was expected. A slight

rotation of the bullet could account for the discoloration being adjacent to where it was expected (the area in contact with the femur), which may have been the result of human error in not placing the bullet in exactly the correct position when it was replaced following examination, or it is possible that the bullet's position shifted between sampling events. It is also possible that the discoloration is simply not related to whether the bullet is in contact with bone. Further research is needed to evaluate this relationship.

Replacing the bullets after the weekly and semi-weekly examinations may have changed what specific biological tissues were in direct contact with the bullets from week to week. The bullets placed on the femur were strategically placed in a specific orientation each time; however, other bullets were simply placed back in the environment, not in a specific orientation. Item 10 was sampled twice during the first week. The first time the bullet was examined, LIMP 1 could be identified. When Item 10 was sampled again two days later, LIMP 1 was unsuitable for comparison. The LIMP displayed heavy pitting and the striations were no longer visible **(see Figure 8)**. The condition of the individual characteristics on Item 10, observed during the first week, could have resulted from it being in contact with a new or slightly different area within the incision.

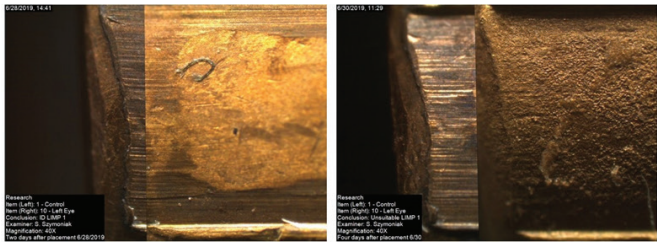

Figure 8: Item 10 during the first week of sampling – left photo is the first sampling and right is the second. LIMP 1 became unsuitable for comparison just after two days of being placed back in Donor 1.

The bullets in the donors each displayed patina throughout the weeks of sampling. When copper is exposed to air it will start to corrode. If it is exposed for a short period of time, the copper can change color from a reddish orange to a reddish-brown color. However, if it is exposed longer, patina will form to protect the copper from additional corrosion **[9]**. Through cleaning the bullets these layers were removed from the sampled bullets each week. The bullets left until the end of the data collection period were more heavily corroded with patina than those that were removed and cleaned over time **(see Figure 9)**. The thick layer of patina from these bullets was difficult to remove.

During the fourth week, the left soil bullet (Item 4) had spotted discoloration that was grayish brown in color and some areas that resembled rust. However, when the bullet was sampled two days later it did not display the same discoloration. The exact cause of this discoloration remains undetermined, though it is possible that the copper changed color from short-term exposure to different environmental factors. Recent research presented observations of a similar pattern on copper-plated steel jacketed bullets, in which the bullets eventually rusted due to the steel jackets **[10]**. The bullets used in this experiment were not composed of steel, and therefore, did not rust.

When bullets are exposed to environmental factors, they can become damaged by their surroundings, in addition to corrosion. When comparing the left soil bullet (Item 4) to the control, new marks were observed weekly on some of the LIMPs. The origin of these marks is unclear. The bullet was examined microscopically after the use of metal forceps during recovery and new marks were not observed. When the right soil bullet (Item 3) was recovered at the conclusion of the study, no additional marks were observed.

Furthermore, it was observed that the bullets that were recovered from Donor 2 had an accelerated degradation. The bullets from Donor 2 became unsuitable for comparison sooner than the bullets from Donor 1, who was already past the earlier stages of decomposition when the bullets used for this study were placed. The bullets in Donor 1 were not exposed to maggot activity or the early and extensive microbial activity associated with decomposition because the donor was already nearly desiccated when the study began. In contrast, Donor 2 was in early stages of decomposition when the study began, and passed through all stages of active decomposition, in addition to experiencing a high level of maggot activity, especially in the wounds, during the data collection period for this study. The presence of maggot activity and active decomposition may have played a role in the bullet deterioration.

When bullets are exposed to decomposition and environmental factors, the resulting corrosion can cause deleterious changes to the individual characteristics in LIMPs, which in turn will affect an examiner's ability to analyze the bullets. The results of this study demonstrate that the quantity and quality of discernable striae, after exposure to decomposing human tissue, differed according to the length of time the bullet was exposed to decomposition and the stage of decomposition to which the bullet was exposed.

Limitations and Future Research

The authors recognize that there are limitations associated

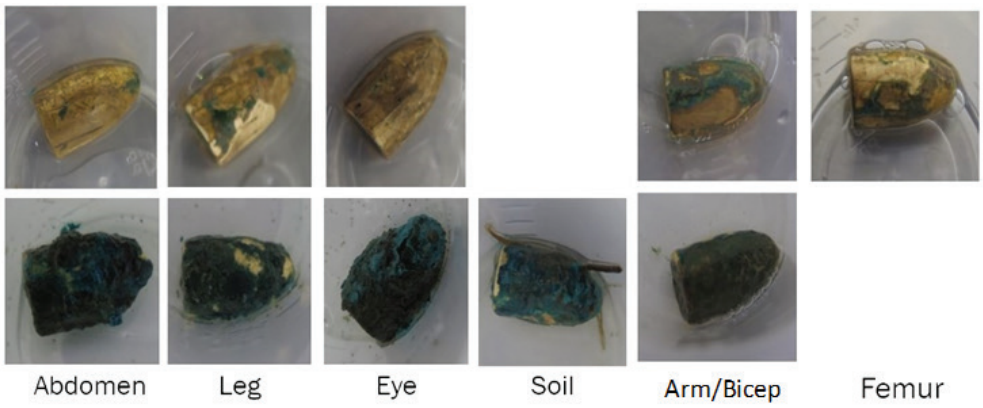

Figure 9: Final removal of bullets–for each pair of photos, top group of photos are the bullets continuously removed weekly (soil bullet not photographed), bottom group of photos are bullets that were left in situ (femur unrecovered)

with this pilot study. The two donors used for this study were selected based on availability and were not intentionally selected based on any specific criteria. The donors were not at the same stage of decomposition, and this study did not take into account a number of intrinsic (e.g., donor health, body size) or extrinsic (weather, temperature, soil pH, microbial activity) donor variables or bullet variables (e.g., bullet composition) that may have affected both the rate of decomposition and the observed changes to the bullets **[7, 6]**. Ambient temperature is also critical for calculating accumulated degree days (ADD), which is a standard in taphonomy studies for presentation of conclusions regarding postmortem interval **[8]**. This study considers only chronological days, not ADD, which may affect conclusions regarding the effects of time and environment on the comparability of fired bullets recovered from decomposing human tissue. While ADD were not used, the values were calculated and are displayed in **Tables 7** and **8**, as a reference.

There are also a variety of techniques that can be used to clean bullets. The technique employed in this study was specific to a particular laboratory; other laboratories may have different procedures that may affect the outcome. Evaluating the relationship between the cleaning procedure and the effects of decomposition on the bullets was beyond the scope of this study. Also, the cleaning technique was not used on the control bullet as a control for the application of cleaning solution, so it is unknown at this time whether that technique affected the bullet striations.

Additionally, there was not a verification process conducted throughout the experiment, which would have been completed in traditional casework. All exams were conducted by the same examiner throughout the project, which could introduce bias. Ideally, an examiner removed from the details of the experiment would be chosen to complete the comparison. However, due to geographical constraints, a second examiner was not available. In future work, it would be beneficial if an additional examiner were to complete the comparison and/or if a 3D scanning system was used, such that an examiner could review the bullets later. Depending on the scanning system used, the system could also provide a numerical value to the similarities observed between the bullets and the control. Future planned research will seek to address and account for these limitations.

Conclusion

While there were limitations regarding the available research subjects and applicability of methods during this pilot study, several findings stand out that cannot be ignored. First, bullets that were placed in a body that had already passed through the active stages of decomposition (e.g., Donor 1 bullets) did not degrade or develop patina to the same degree as the bullets located in areas with large amounts of soft tissue (e.g., the arm and thigh of Donor 2), which progressed through all stages of decomposition during the course of the study. This supports prior findings that exposure to the products of active decomposition of human tissue can have a detrimental effect on the comparability of fired bullets. Therefore, when fired bullets are recovered from biohazardous conditions, it is imperative to promptly remove biohazardous material from the surface to ensure minimal deterioration of individual characteristics. Second, though contact with bone does not appear to affect the comparability of striae, there does appear to be a relationship between prolonged contact with bone (or near bone) and the discoloration of the copper jackets of fired bullets. This may be significant and warranting further

exploration. Finally, location of bullets in the abdomen, arm, thigh, or skull does not seem to affect the deterioration of the bullets in a meaningful way. The findings from this pilot study justify the need for further investigation into the effects of decomposition on the condition and comparability of fired bullets and the implications those effects may have on the outcomes of homicide cases involving gunshot wounds.

Days from Placement	ADD Base0 From DOD	ADD Base0 From Placement (At FROST)	ADD Base0 From bullet placement
	36.66	NA	NA
	764.46	727.8	NA
2	801.13	764.47	36.67
4	838.09	801.43	73.63
9	945.04	908.38	180.58
11	976	939.34	211.54
16	1077.95	1041.29	313.49
23	1233.68	1197.02	469.22
25	1273.03	1236.37	508.57
30	1380.54	1343.88	616.08

Table 7: Accumulated Degree Days for Donor 1

Days from Placement	ADD Base0 From DOD	ADD Base0 From Placement (At FROST)	ADD Base0 From bullet placement
	25	NA	NA
	85.91	60.91	NA
10	284.67	259.67	198.76
17	440.4	415.40	354.49
19	479.76	454.76	393.85
24	587.26	562.26	501.35

Taable 8: Accumulated Degree Days for Donor 2

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