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Detecting GSR Indicative Particles on Decayed Bones using a Novel Field Kit

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-Sven Engling

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Abstract

Decomposed human remains are complex forensic puzzles, escalating in difficulty as the remains' age obscures evidence, like trauma. Research has shown that scanning electron microscopes with energy dispersive X-ray spectrometers (SEM-EDX) are capable of detecting and identifying gunshot residue (GSR) particles on bones. However, SEM-EDX work is time consuming, expensive, and not accessible to every forensic department. Therefore, a preliminary field test capable of detecting GSR indicative particles, like lead, could save departments money and assist in trauma identification. This study examines the viability of using either the 3M Lead Check Test swabs or a sodium rhodizonate solution as part of a field test to detect lead, a GSR indicative particle, on shot pork ribs that have been allowed to decay. Of the 60 buried ribs, 50 were recovered, and 25 ribs each were tested with the 3M Test Swab or the sodium rhodizonate solution. The success rate of the 3M swabs was much higher when compared to the sodium rhodizonate solution; 64% of samples tested positive for lead using the 3M swabs versus the 3.8% of samples that tested positive for lead with the sodium rhodizonate solution. The 3M swabs allowed for a more direct application to the trauma site and interreacted better with the bone medium than the sodium rhodizonate. The experiment shows that a preliminary field kit test shows promise in helping identify trauma that could be either ballistic or blunt force in nature, but further refinement of the test is needed before recommending it for use.

1. Introduction

A body, partly exposed in a marsh, is discovered by a hunter. The remnants of a human are stumbled upon by a hiker walking slightly off trail. A decedent bobbing down river is spotted by a fly fisher. Discovering deceased individuals who have had time to decompose present a multitude of forensic challenges to forensic scientists. Securing the site, recovering the remains, and identifying the identity of the individual along with their potential cause of death can be relatively tricky for a freshly deceased decedent. These steps become even more complex if the deceased individual has begun advanced stages of decomposition. Decomposition can truly complicate identifying the decedent and their cause of death. In the United States alone 4,400 unidentified remains are discovered on average per year (Hickman, Hughes, & Ropero-Miller, Strom, 2004), and after one year roughly 1,000 of those remains remain unidentified. Decomposition truly complicates the identification of both the individual and their trauma.

According to the CDC, 19,141 homicide deaths occurred in the U.S. in 2019, and 14,394 of those were firearm related (Centers for Disease Control and Prevention, 2020). Additionally, out of the 47,511 people who died due to suicide in 2019, 23,941 of those deaths were firearm related (Centers for Disease Control and Prevention, 2020). If any of the found human remains were homicide or suicide based, there is a good chance that ballistic trauma might be present somewhere on the body, but like individual identification, trauma identification can be obscured by decomposition, especially if its progressed to active or advanced decomposition (MacAulay et al., 2009). Ballistic trauma or gunshot wound trauma will differ by the type of firearm and by the distance from which that firearm was discharged. Generally, gunshot wounds are grouped into contact, loose contact, near contact, intermediate, and distant wounds (Di Maio, 1993; Shkrum & Ramsay, 2007). The trauma signs associated with each grouping will also change with the type of firearm used. By examining the entry wound for signs of the muzzle, soot staining patterns, tattooing/stippling around the entry wound, and abrasion rings at the wound site, forensic scientists can make determinations about the type of firearm used and the distance from which it was discharged (Di Maio, 1993; Shkrum & Ramsay, 2007). Decomposition, however, will exaggerate or obscure some of these clear trauma signs, making identification a great deal more difficult. While the stippling, abrasion ring, and some of the soot marks won't be easily wiped away, these signs will disappear when the soft tissue undergoes decomposition, carrying all signs of ballistic trauma away with it. Luckily, not all clues disappear with decomposition. Bones can carry a wealth of forensic information. Not only can they help with identifying the decedent, but they can also give clues as to the nature of the trauma that could have caused their death. Bones, being "a specialized form of dense connective tissue...composed of calcium salts embedded in a matrix of collagenous fibers (Di Maio, 1993)," decompose on a much different timeline from soft tissue allowing them to carry clues that forensic scientists, like forensic anthropologists, can interpret even well into the late stages of decomposition. When striking a bone, a bullet creates a temporary cavity as it penetrates and fractures the bone. As this cavity undulates, most of the fragments stay within the cavity, though some fragments will travel with the direction of the bullet. As a bullet penetrates a bone, it bevels out the bone in the direction the bullet was travelling (Di Maio, 1993). This beveling can help determine the direction the bullet took through the bone. Radiating fractures from the site of trauma in combination with this beveling can help forensic anthropologists identify ballistic trauma on bones.

Unfortunately, trauma on bones is not always clear as textbooks and research papers make it out to be. Sometimes it is difficult to differentiate ballistic trauma from blunt trauma (Berryman, Kutyla, & Russell Davis, 2010). For instances like this, it is useful to have tests that can help differentiate between the two when simple observational study is not enough. Using a scanning electron microscope equipped with an energy dispersive X-ray spectrometer (SEM-EDX) has slowly become standard when looking for evidence of gunshot wounds (Chang, Jayaprakash, Yew, & Abdullah, 2013). SEM-EDX's magnification is powerful enough to visually identify gunshot residue (GSR) particles on bones, and with its x-ray attachment it can chemically verify the particles by identifying the individual elements that make up a GSR particle. Characteristic GSR contains three metals, lead, antimony, and barium that originate as lead styphnate, barium nitrate, and antimony sulfide in the primer of a piece of ammunition (Di Maio, 1993). The primer is a concussive charge at the base of a piece of ammunition that the firing pin or hammer of a firearm strikes when the trigger is pulled. The concussive kinetic energy of the firing pin causes the primer to ignite which in turn ignites the gunpowder within a piece of ammunition. The chamber of the firing gun holds all this explosive energy within it, propelling the bullet of the ammunition forward away from its cartridge case and toward the one available exit to the bullet, the muzzle. Simultaneously, the cartridge case is pushed backward and is either expelled or left in place, depending on the type of firearm. During this heated event, the main ingredients of the primer, lead styphnate, barium nitrate, and antimony sulfide, are vaporized and some of this vapor travels behind the bullet as it shoots out of a firearm. As these primer gases hit the cooler air, they rapidly cool and form a microscopic semi-spherical alloy made of lead, barium, and antimony. We know this newly formed particle as GSR.

Past research has found that GSR can be detected on bone, but expensive and time-consuming tests, like SEM-EDX, were needed to find it. To the writer's knowledge no published research has seriously looked at creating or using a preliminary test to detect GSR on decomposed bones with inconclusive trauma to help identify potential deposits of GSR around trauma sites. This study will examine the possibility of using two different chemical color tests as a preliminary test to determine the efficacy of using them before committing resources to a confirmatory test, like SEM-EDX.

2. Literature Review

GSR is classically thought of as a combination of antimony, barium, and lead particles that arises from the condensation of primer vapors (Brown, Cauchi, Holden, Wrobel, & Cordner, 1999), and in today's forensic setting a particle combining all three of these metals would be classified as a unique GSR particle. Other inorganic particles, organic particles, and other combinations of the classical GSR metals, such as lead-barium, lead-antimony, or antimony-barium, are thought of as characteristic GSR particles or GSR indicative particles (Amadasi, Brandone, Rizzi, Mazzarelli, & Cattaneo, 2012; Berryman et al., 2010; Lindström et al., 2015). The goal of this research is to be able to detect GSR indicative particles on decayed pork ribs using a novel field kit employing a 3M lead test and a sodium rhodizonate test. This field test works as a preliminary test for GSR indicative particles, specifically for lead, as opposed to confirmatory tests like those that employ a SEM-EDX that prove the presence of GSR unique particles by identifying the characteristic elemental composition and the characteristic spheroidal morphology (Amadasi et al., 2015, 2012; Chang, Jayaprakash, Yew, & Abdullah, 2013; Spathis, 2017). The preliminary tests from the field kit will prove useful to investigators because histological examination of decayed remains' bone trauma can be exceedingly tricky. With these types of remains it is difficult to tell the difference between trauma caused by blunt force and trauma caused by a bullet (Amadasi et al., 2015; Gibelli et al., 2010; MacAulay et al., 2009; Taborelli et al., 2012)

Many GSR oriented literature reviews exist throughout forensic literature, but only three, Chang et al.'s, Blakey et al.'s, and Romolo and Margot's are relevant to the topic of this paper. The review by Chang et. al (2013) does a thorough job examining how GSR relates to a person and place, how GSR can help determine when a firearm was used, and how a variety of analytical methods can be used to find GSR. This information is then applied by Chang and co-authors to help with shooter identification, helping with estimating firing distance, helping with estimating the time since discharge, and helping relate a bullet to its injury through GSR examination. Chang et al.'s literature review was an invaluable source of information because it meticulously explains how both SEM-EDX functions, how sodium rhodizonate works, and the challenges decomposed tissue could present to identifying GSR. Blakey et al.'s literature review, on the other hand, was less broad, and focused on the behavior and fate of inorganic GSR once a firearm has discharged (Blakey, Sharples, Chana, & Birkett, 2018). This review analyzes how various literature examines how GSR distributes after a firearm discharges and how statistical models could be employed to estimate GSR distribution to help identify shooting distance, firing range, the persistence of GSR on various surfaces, and type of ammunition used by the firearm. It was helpful to understand how long GSR can survive on various surfaces and apply that knowledge to bones. The final literature review by Romolo and Margot (2001), reviewed techniques to analyze and interpret GSR by splitting analytical methods into two groups: inorganic and organic GSR analysis (Romolo & Margot, 2001). This team does a fantastic job outlining the various instrumental methods used to analyze both organic and inorganic GSR, while outlining the history of GSR research. They conclude that each case is unique, and the preferred method of detecting GSR depends on the situation of the case (Romolo & Margot, 2001). This is an important point because using the preferred SEM-EDX method to detect GSR might not always be the economical and appropriate choice. This inspired the goal of this literature review, which was to look at the research history of GSR on bones to find an applicable alternative to SEM-EDX. To date, no literature review has examined the numerous papers that analyze the association between GSR and bones, and this, therefore, might be the first review to attempt this. Several papers have been published about the relationship between GSR and bones in many different contexts, and in order to make it coherent, the information will be presented chronologically.

The basis for this research idea and the idea of GSR on bones goes back almost forty years when in 1986 Helmut Fischbeck and his research team published a paper that showed evidence that GSR indicative material can deposit on a victim's bone and persist. This case study involved the need to be able to identify a decedent based on a perimortem gunshot wound to the hand that had occurred in 1973. The decedent was found and exhumed in 1983, and investigators used proton-induced X-ray emission (PIXE) analysis to examine a portion of the right second metacarpal bone that showed signs of past trauma. Old hospital records indicated that the missing victim, that the decedent was suspected of being, had been shot in the right hand. PIXE analysis was able to detect lead residue around the trauma of the metacarpal bone, but no other traces of lead where found on any of other of the victim's phalanges (Fischbeck, Ryan, & Snow, 1986). Lead being found on a bone that had been both shot and buried years prior, showed evidence that GSR indicative particles are not just limited to being deposited on skin and clothing. This case additionally showed that it is possible for lead from GSR to persist in the human body, even once it has begun to decay.

Being able to detect lead from GSR after ten years is certainly telling of how persistent lead can be in a human body, and in his case report paper Alberto Amadasi and his team of researchers showed through their examination of five cases, just how persistent it can be. While their first few cases showed that a combination of GSR indicative particles can be recovered from skeletonized bodies that have decayed in a variety of places, their fifth and final case really proved the tenacity of lead in human bodies (Amadasi et al., 2015). The fifth case involved the historical examination of an Italian soldier from World War One who had been found in a mass grave. A gunshot entry wound was clearly visibly on the frontal bone, and it was examined with SEM-EDX. The authors were able to detect large amounts of lead particles around the wound's edges, even though the surrounding soil that the bone was found in had no traces of lead contamination (Amadasi et al., 2015). Ruling out lead contamination was vital to show that lead had not leached from the soil onto the frontal bone. These case reports support the idea that lead from GSR can survive in the human body well into the skeletonization process.

In 1999 Brown followed Fischbeck's case study by publishing a paper that used image analysis to inspect gunshot residue in entry wounds. While Fischbeck's work focused on a case, Brown and his team of researchers took a more in-depth approach to understanding how GSR can travel into a gunshot victim. This research involved shooting Andorran goat hides from ranges between contact and 60 cm with a Ruger .22 semiautomatic rifle using solid high velocity ammunition. Citing SEM-EDX analyzation as costly and time consuming (Brown et al., 1999), the researchers used a new technique to quantify the amount of GSR in the goat hide's wound track using a combination of Alizarin Red S (an organic dye, capable of staining barium and lead) light microscopy (LM), and automated image (AI) analysis of the stained skin. Brown and his team found their quantifying technique was simple, inexpensive, and able to quantify GSR on skin sections taken throughout the gunshot wound. Surprisingly, they found that there was little statistical difference between GSR deposition in the wound between contact range and up to 20 cm ranges (Brown et al., 1999). This is key because it shows that GSR can be deposited into the body by shots other than contact shots.

Brown's study was later further verified in 2012 by Cecchetto and his team of researchers. Cecchetto also tested for GSR in gunshot wounds, but he specially examined how much GSR was present in entry and exit wounds and compared the amount of GSR in those wounds between fresh and decomposed samples (Cecchetto et al., 2012). This study is unique because it is one of the few studies that uses human samples. It used sixty 6cm lengths of human calves that had been amputated for medical purposes, and each sample was shot with a Beretta Mod. 81 using full-jacketed ammunition. Twenty samples were shot at 5cm, twenty samples were shot at 15cm, and the remaining twenty were shot at 30 cm. After 15 days of decomposition, samples were fixed in formalin, and analyzed with a Skyscan High Resolution Micro-CT. Micro-CT analysis showed GSR present in the epidermis and dermis of the control (fresh) samples, while the decomposed samples only had high density GSR particles in the dermis layer (Cecchetto et al., 2012). The researchers found GSR in the entry wound for all fresh and decomposed samples, but found no GSR in any of the exit wounds (Cecchetto et al., 2012). This study verifies Brown's work that GSR does travel into the wound tract of a gunshot wound, and it can be reliably identified, even if the body has begun decomposition, through instrumental means like Cecchetto's micro-CT method or Brown's SEM-EDS method.

After Brown established that GSR can travel into the gunshot wound tract, Faller-Marquardt was able to hypothesize why this happened when he and his team observed soot staining on the bones of gunshot victims. This study used the data from 65 forensic autopsies along with data collected from an experiment that involved shooting a slaughtered calf's head from contact range and from 2 meters away. The autopsies were performed between 1992 and 2004, and the individuals died from contact gunshot wounds to the neurocranium. From the autopsy observations, the researchers found that 65 of the 68 contact shots showed bones blacked with soot around the bullet wound (Faller-Marquardt, Bohnert, & Pollak, 2004). They also found that the periosteum around the bullet wound was detached and folded over itself rather than being attached to the bone. Beyond the folding, the periosteum was detached and lifted for an additional 3cm zone around the gunshot wound (Faller-Marquardt et al., 2004). The experimental shots to the calf's forehead showed similar results. The contact shot showed black soot staining 2 to 5 mm radius around the gunshot wound while the periosteum was detached up to a 35 mm radius around the gunshot wound. This detached periosteum was also present on wounds from shots fired from 2 meters away (Faller-Marquardt et al., 2004). From this distance, the periosteum only detached for 2 to 4 mm around the gunshot wound. Faller and his team concluded that the shearing forces of the bullet travelling through the tissue causes the periosteum to detach, creating room for powder gases travelling in the bullets wake to expand when striking a flat bony surface (Faller-Marquardt et al., 2004). Faller-Marquardt's work was vital in showing that materials like soot and GSR can follow a bullet into the body, and they established a way for it to be deposited on the bone by showing that the periosteum is moved by the bullet's shearing forces. More importantly, he showed that shots from 2 meters away can still cause the periosteum to detach from the bone. This presents the opportunity for GSR to be trapped in these small openings.

Faller-Marquardt and his team of researchers, however, were not looking for any evidence of GSR. In 2010, Berryman and his team of researchers advanced this work when they were able to identify GSR on bones from various ranges. The study used six pork ribs, shot at a distance between one and six feet using a 0.45 caliber rifle with full metal jacket bullets. The ribs were then inspected for GSR using a SEM-EDX. The researchers found unique and indicative GSR particles on all the bones including those shot from six feet away (Berryman et al., 2010). Berryman and his researchers used Faller-Marquardt's work to theorize that the periosteum detachment, caused by the shearing forces of the bullet, allows bone to be exposed to GSR as the bullet travels through it. The travelling bullet acts as a vacuum, trapping vapor containing GSR particles behind it, and then depositing it along the wound tract and ultimately on the exposed bone (Berryman et al., 2010). Building on Faller-Marquardt's work, Berryman showed that GSR indicative materials could travel into the body, and ultimately be trapped on the bone itself.

Berryman and his team of researchers tested their ribs immediately after shooting them, allowing no time for decomposition. Gibelli and their team of researchers, on the other hand, focused on examining ways to assess gunshot lesions on body tissue that has been given time to decompose. This study, taking place just a few short months after Berryman's publication, used seven pigs that died independent of the experiment and shot them each in three similar locations around the head. Three pigs were allowed to decompose in the open air, three were buried 5 cm deep in the soil, and one pig was sampled and tested immediately as it was acting as the control. Every 15 days one of the gunshot lesions from each of the pigs was sampled, and each sample was examined through macroscopic observation, radiochemically tested through NAA on swabs, and histologically tested using sodium rhodizonate followed with a 5% HCl solution (Gibelli et al., 2010). The researchers found that there was a definite difference between the open air and buried samples. The open-air samples were well preserved after 16 weeks making the gunshot wounds easily identifiable macroscopically. The buried samples, however, went through decomposition and putrefaction, and after 8 weeks the gunshot wounds were not identifiable on the skin anymore (Gibelli et al., 2010). At this point researchers were forced to sample from the bone directly. Radiochemical analysis with NAA showed that samples from the buried pigs post 8 weeks still tested positive for antimony, though the open-air samples always tested for a higher concentration of antimony. Sodium rhodizonate tests showed traces of lead in all the open-air samples, but only one of the buried heads showed traces of lead using the combination of sodium rhodizonate and 5% HCl. The control itself tested positive for both antimony and lead around the gunshot wounds, while a skin sample away from the wounds tested negative for both lead and antimony (Gibelli et al., 2010). The important conclusion of this research is that while gunshot wounds are simple to identify in the early stages of decomposition, they become nearly impossible to identify once the body's tissues become fully degraded in the later stages of decomposition (Gibelli et al., 2010). This is vital to understand because bodies that have been allowed to decompose for an extended period of time begin to hide their trauma, and it is important to establish ways to help identify signs of trauma that have been masked by decomposition.

These results verified an earlier paper by MacAulay et al. (2009) that showed that gunshot wounds were still identifiable on pigs during the fresh decomposition stage through the bloated decomposition stage, but once active decomposition set in, gunshot wounds were morphologically harder and harder to identify, especially if the shots were taken from a distance away (MacAulay et al., 2009). Gibelli's results supported the results that MacAulay and his team found under similar testing parameters. Gibelli and their team of researchers also noted that

NAA testing was the most useful for conclusively showing the presence of GSR by showing that at least 0.2 µg of antimony was present, which the US Army Criminal Investigations Laboratory establishes is a threshold value for GSR (Gibelli et al., 2010). The researchers additionally point out that while the sodium rhodizonate was an unreliable test to conclusively prove the presence of GSR, it did perform well to verify the presence of lead around the gunshot lesions confirming the lesion to be a gunshot wound (Gibelli et al., 2010). This is vital because it shows the value of using the sodium rhodizonate test as a preliminary test for gunshot wounds on decomposed samples. Zoja and their team of researchers had already shown in 2006 that cadaveric skin, after being treated with formalin and embedded in paraffin blocks, could be treated with sodium rhodizonate and different solutions of triphenylmethane due, a connective tissue contrast staining dye, to detect GSR (Zoja, Lazzaro, Battistini, & Gentile, 2006). Gibelli expanded on this study by using decomposed samples rather than fresh cadaver skin, and was still able to use sodium rhodizonate to verify that the lesions on the body were the result of gunshots by detecting lead, making sodium rhodizonate a great preliminary test for GSR that can then be verified later with a conclusive test, such as SEM-EDX.

After Berryman's publication, more researchers began examining GSR on bones through the use of SEM-EDX. Taborelli's and her team of researchers' goal was to analyze the persistence of GSR on skeletonized gunshot wounds on decomposed pigs and macerated gunshot wounds on decomposed human bone using SEM-EDX (Taborelli et al., 2012). Taborelli combined two different samples into her study to examine the question of GSR persistence on bones. Her first samples were five pig heads shot a total of nine times with a Franchi revolver .38 special using full metal jacketed ammunition from a distance of 5 cm. Out of these nine gunshots, five decomposed in the open air while the other four decomposed buried in pots filled with soil. After

4 years, the samples were analyzed with a SEM-EDX, and only four of the nine gunshot wounds, two wounds from the open air and two wounds from the buried portion, tested positive for unique GSR (Taborelli et al., 2012). The other samples Taborelli used were human samples taken from gunshot victims who had been shot by various firearms at contact range. These samples were macerated in boiling water for a week to remove the soft tissue and were then analyzed with SEM-EDX. All of the humans samples tested positive for unique GSR particles (Taborelli et al., 2012). Taborelli and her team of researchers argued that the pig samples showed less unique particles because they were shot at a range of 5 cm as opposed to contact (Taborelli et al., 2012). This conclusion is doubtful, considering the previous studies that showed that it is possible to detect GSR-unique particles from ranges greater than 5cm. It is likely that the human samples were fresher and therefore more inclined to have more GSR unique particles. The pig samples were also stored in pots indoors for 4 years. The method of the indoor storage is unclear in the paper, which could have led to further discrepancies. Ultimately, this paper is important because it asks a very important question that had not been fully addressed in any previous papers: can GSR be detected on skeletonized samples?

This question was picked up by Lindström and her team of researchers. Initially, they investigated how well GSR can be detected in the wound tract of a gunshot lesion, but ultimately, they examined GSR’s persistence on bones. Lindström and her team of researchers first research project with GSR examined the difference between the amount of GSR residue present on entry and exit wounds of a suicide case in 2014 using a SEM-EDS (Lindström, Hung, Duncan, & Kieser, 2014). The decedent shot himself in the right auricular region using 9 mm ammunition. The suspected exit wound was the left auricular region, and careful analysis with the SEM-EDS showed GSR indicative particles on both the entrance and exit wounds. Notably, a higher concentration of GSR particles were found on the entrance wound when compared to the exit wound (Lindström et al., 2014). Unlike Cecchetto, Lindström was able to find GSR in the exit wound of gunshot lesions. This might be due to the fact that Lindström used a SEM-EDS to examine her samples as opposed to Cecchetto's micro-CT instrumental method. It could also have to do with the kind of samples they both used. While both used human samples, Lindström's samples had bones while Cecchetto sample used pure muscle (calves). It is possible that the sample and method difference allowed Lindström to detect GSR in the exit wound, while Cecchetto could not.

Lindström furthered her research on GSR that very same year with her team of researchers in New Zealand by examining how decay can influence GSR on bone. Lindström and her team investigated the ability to detect GSR on rib bones that had been allowed to decompose in different marine environments. The study involved the shooting of 93 young adult bovine ribs with a 0.22 caliber rifle using lead hollow point bullets. The ribs were either fleshed or defleshed before shooting. After shooting they were allowed to decay in either a minimum depth of 1.5 meters in the ocean, in the intertidal zone, or in the supraorbital zone. Ribs were periodically examined after 3, 10, 24, and 38 days of decomposition using an SEM-EDX and ICP-MS. Lindström and her team found that useful GSR evidence could be recovered from bones even after having experienced exposure to marine environments (Lindström et al., 2015).They found traces of lead in all bone samples even after 38 days of exposure. GSR-indicative particles (Pb and Ba) were observed on bone samples in the supralittoral zone throughout the testing time, and GSR unique particles were observed on the bones samples after three days of marine exposure (Lindström et al., 2015). GSR indicative particles were lost in the submerged samples of the intertidal zone, and the researchers discovered no clear pattern as to when the particles left the samples. The researchers concluded that SEM-EDX was able to detect GSR- indicative particles on bony wounds even if the samples had been allowed to decompose in a variety of marine environments. The results of this research were groundbreaking. Not only could GSR be detected on bones once they've been allowed to decay, but GSR could be detected on bones that have actively been exposed to water while decaying. Even in these adverse conditions, GSR can persist on bones.

As researchers began to accept that GSR is deposited on bones, they began to use that fact to examine cases. In 2018 Langley and her team of researchers used this fact to analyze a case that used SEM-EDS to examine a cranial bone fragment to confirm gunshot trauma by detecting GSR. The initial case involved the discovery of a shallow grave in 2014 by a couple of hunters. Severe decomposition led the remains to be analyzed by a forensic anthropologist who found linear and diastatic fractures on the skull bones, while the rest of the skeleton was mostly intact (Langley, West, Kunigelis, & Boggs, 2018). These skull fractures were analyzed with SEM-EDS, and GSR unique particles were found on the skull fragments. This discovery lead the cause of death to be ruled disruptive head trauma and the manner of death was ruled to be a homicide (Langley et al., 2018). This case report showed that GSR on bones has become enough of an accepted fact that unique GSR on bone alone is enough to rule a cause and manner of death.

Throughout this time another important aspect of GSR persisting on bones being examined was the question of how well GSR survived on cremated samples. One of the first researchers to comprehensively look at how cremation affects the ability to detect GSR on bodies was Amadasi and his three studies that examined this question. In his first paper regarding this subject Amadasi's goal was to detect GSR on charred remains using SEM-EDX, and if it was possible to identify the type of ammunition used by identifying the metallic residues of copper and zinc

(Amadasi et al., 2012). The study used sixteen bovine ribs, eight of which were fleshed while the other eight were defleshed by macerating them in boiling water. Each rib was shot by a Beretta type 98 FS 9mm using either unjacketed or full metal jacket ammunition at near contact range. Once shot each bone underwent a charring cycle in an electric oven that lasted for 24 hours. During this cycle the bones were heated to 800 degrees for the first twelve hours, and then left to cool off for the final twelve hours. The bones were then examined with a SEM-EDX, and the team of researchers found no GSR on the control samples, found that there was less GSR unique particles in the entrance wound of charred samples when compared to fresh samples, and that GSR unique particles were found on all charred samples, especially those shot by unjacketed ammunition (Amadasi et al., 2012). Notably the most common element found on the samples was lead, and that the amount of GSR particles on the samples was more dependent on the type of ammunition then it was on whether or not the samples were fleshed (Amadasi et al., 2012). The fact that lead is the most common metal found on the samples, regardless of the other variables, makes it a good element to focus on when trying to identify whether or not trauma found on a decomposed body is the result of a gunshot.

In 2013 Amadasi repeated this same experiment, but instead of using SEM-EDX to look for GSR unique particles, Amadasi and his team of researchers employed a different instrumental method, inductively coupled plasma optical emission spectrometry (ICP-OES), that only requires swabbing the lesion to function (Amadasi et al., 2013). Once the bovine rib samples were calcified using the methods outlined in their previous experiment, the samples were swabbed with swabs that had been soaked in 4M nitric acid and were then analyzed through ICP-OES. Amadasi found results similar to his first study. All samples showed signs of GSR, there was more GSR unique particles on fresh samples versus charred samples, and no trace of GSR was found on the control samples (Amadasi et al., 2013). These two studies show hard evidence of how persistent GSR on bones can be. The ability of GSR to survive on bones, even after thorough charring, makes it a good indicator to look for to determine whether or not a particular trauma was caused by gunshot as opposed to some other means.

Finally, in 2014 Amadasi examined soot soiling on bones caused by gunshots and how the charring process affects it (Amadasi, Merli, Brandone, & Cattaneo, 2014). Like Faller-Marquardt in 2004, Amadasi found signs of soot soiling on his bovine rib samples during his previous two charring research projects. Amadasi explains that the soot of a gunshot is the result of the complete combustion of the primer and the gunpowder (Amadasi et al., 2014), and that like Faller-Marquardt concluded, soot soiling on bone is related to firing distance and its color and extent is dependent on the composition of gunpowder in the ammunition. To examine this further, Amadasi repeated his previous two experiment parameters to see how the charring cycle affects the soot soiling. After the charring cycle the researchers found that the soot soiling was still present and had taken on a yellowish-gritty quality. Researchers believed that the gray soot was turned into a grittier yellow color when the metallic oxides in the soot were pyrolyzed in the charring cycle (Amadasi et al., 2014). Soot soiling was clearly present in all samples shot with unjacketed ammunition, while full jacketed ammunition did not produce a single example of soot soiling on the bovine rib samples. This lead researchers to conclude that evidence of soot soiling could help identify what kind of ammunition was used (Amadasi et al., 2014). Additionally, Amadasi also further verified his previous findings when his team found more GSR on the fresh samples versus the charred samples. This study not only validates Faller-Marquardt previous work, but it further proves how resilient left-over combustibles are on human bones. Evidence of previous gun-related trauma can survive on bones even after extensive charring as long as researchers know what to look for.

Amadasi's work was followed recently by West in 2019. The aim of his study was to be able to quantify the GSR in decomposed and burnt tissue using ICP-MS and ICP-OES to analyze the trace inorganic metals in the samples associated with GSR (West, n.d.). In this study two of three euthanized pigs were shot with a Smith and Wesson .357 Magnum revolver, while the third pig was stabbed twelve times to attract similar insect activity to the other two pigs. One of the pigs was shot with unjacketed ammunition, while the other pig was shot with jacketed ammunition. Then each pig was transferred to a research field, placed in separate wired cages, and allowed to decompose. Over a period of 49 days samples were then taken from each pig and analyzed with ICP-MS. GSR unique particles, lead, barium, and antimony, were found on all the shot tissue samples, no matter what stage the decomposition was (West, n.d.). West also found a higher amount of copper in samples shot with jacketed bullets and a higher amount of lead in those samples shot with unjacketed ammunition. This shows that lead, out of all the GSR trace metals, is incredibly tenacious, and is able to survive under various conditions. Even though the bones were not being tested in this part of the study, the fact that lead was able to survive on decomposing tissues speaks to its potential to survive on bone once decomposition is further along. This point is further proven by the next part of West's study. He tested for GSR on burnt samples by shooting sixteen bovine ribs, eight of which were fleshed and eight of which were not. The shot ribs underwent the same charring cycle outlined by Amadassi, and West then sampled the charred samples with swabs soaked in 2mL of 30% nitric acid to analyze the samples through ICP-OES. West further proved Amadasi's original findings that GSR unique particles could be found on charred remains through ICP-OES instrumental analysis, and that more GSR unique particles existed on fresh samples when compared to the charred samples (West, n.d.). West and Amadasi clearly show that GSR can survive on bone through adverse conditions, like decomposition and charring, making it a great way to determine whether or not morphologically unclear trauma was caused by gunshot or by some other violent act.

While the work cited above inspired this research, the goal was to use a simple, field-based (or, as designated, Point-of-Care) tests, like sodium rhodizonate, to look for GSR, since SEM-EDX work is an investment in both money and time (Boracchi et al., 2017; Brown et al., 1999; Walker & Rodacy, 2002). An important point to consider is the cost and the ease of use of the test being used to detect GSR. Chemical color tests, like sodium rhodizonate, are both relatively cheap and easy to use. Walker and Rodacy attempted to devise a portable field test kit for gunshot residue to provide immediate information on the presence of GSR back in 2002 that was both cheap and portable. Their two versions of their portable field kit were based on colorimetric tests. One field kit used diphenylamine (DPA) Test, which is a solution of DPA and sulfuric acid that changes from a clear solution to a blue color when residual nitroglycerine and nitrocellulose from gunshot residue oxidizes the solution. The second field kit used sodium rhodizonate solution to detect lead and barium from the gunshot residue (Walker & Rodacy, 2002). Both kits used swabs to rub an area exposed to GSR, and then each swab was treated with the chemical for its respective colorimetric field test. After testing both kits at Sandia National Laboratories and commercial shooting ranges, the researchers determined that the DPA field kit was easier to use because the color change was more evident during the field tests. Their tests also showed that DPA was able to detect GSR from weapons that were discharged only once about 75% of the time while weapons that were discharge multiple times were 95% (Walker & Rodacy, 2002). These field kits relied on the researchers being able to see a color change on a small swab, which could absorb the GSR and make the color change even more difficult to see. It is this researcher's hope that by using a wipe designed to attract lead that GSR will be easier to spot on a larger flat surface as opposed to a small swab.

Another important point to consider is how apt to contamination the sodium rhodizonate test is when test samples decay in the open air. In 2017 Boracchi and his team of researchers investigated this question. They examined decedents who had not passed away from gunshot wounds and had decomposed in Milan. Milan has a heavy and prolonged air pollution that consists of heavy articulate matter like lead particles (Boracchi et al., 2017). Researchers wondered if bodies exposed to this heavy air pollution would react positive to sodium rhodizonate tests. Skin samples were taken from the decedents who had decomposed for variable lengths of time ranging from 10 days to 3 years and from exhumed corpses who had been allowed to decompose for 11 years. This team of researchers found that lead pollution from the air and the soil did not cause any positive results when tested with the sodium rhodizonate test (Boracchi et al., 2017).

The goal of this research is to build upon all this prior work and be able to detect GSR indicative particles on bones that have been allowed to decompose in the open air using a proposed preliminary portable field kit deploying 3M Lead Test and a sodium rhodizonate test. The hypothesis of this research is if a majority of decayed rib bone samples test positive for lead, then it can be assumed that a commercially available lead-detecting kits will be able to detect enough lead from a GSR indicative particles on decomposed bone samples to serve as proper preliminary tests.

3. Methods and Materials

3.1 Field Kit Assembly

The GSR Preliminary Field Kit Test (henceforth the field kit) is contained in a small easy to carry padded bag. The bag contains three small opaque glass bottles, a pack of 3M Instant Lead Test swabs, Hygenall LeadOff Wipes, and gloves. The opaque spray bottle contains a five percent solution of hydrochloric acid (Firearms Manager, 2017). The opaque bottle keeps the strength of the acid consistent, since it can diminish under direct sunlight (OXY, 2016). The other two opaque bottles contain 50 mL of water and 0.5 g of sodium rhodizonate powder respectively.

3.1a) Field Kit General Procedure

The field kit has two tests that can be utilized. To use the field kit's 3M, wipe area of suspected GSR with the Hygenall LeadOff wipe. Allow the wipe to dry out (about 10 minutes) and apply the 3M swab to the Hygenall wipe that touched the bone and onto the bone itself. To apply the 3M swab, squeeze areas A and B on both ends of the swab. This breaks the glass vials within the 3M Tube that were separating the active ingredients. After shaking the tube to mix the active ingredients, the tube is squeezed until a little liquid can be seen at the soft sampling end of the 3M tube. Once this occurs the tester has ninety seconds to apply the 3M swab because that is how long the solution is active (3M, 2012). If the brownish yellow testing liquid turns pink/red on the bone or on the wipe it is a positive test for lead (3M, 2012). This serves as a preliminary test for GSR. Once lead is shown to be present a SEM-EDX test should be done to conclusively prove that GSR particles are present.

To use the sodium rhodizonate test, wipe the area of suspected gun trauma with the LeadOff wipe. Then add the water from the marked bottle to the bottle containing the 0.5 grams of sodium rhodizonate powder. Shake this solution thoroughly, and then employ the sodium rhodizonate solution as quickly as possible, since the shelf life for it is short (Zoja et al., 2006). Once mixed, spray both the bone and the wipe with the solution. If lead is present small pink or red colored dots should appear on the wipe or the bone. To confirm for lead, each pink or red colored area is treated with five percent hydrochloric acid solution by spraying each wipe with the hydrochloric acid from the kit. If the pink coloration turns purple then the presence of lead is confirmed (Feigl & Suter, 1942; Firearms Manager, 2017).

3.2 Field Kit preliminary Tests

The following tests were done to verify the validity of the field kit. The tests focus on the 3M Lead Swabs, since plenty of past research establishes sodium rhodizonate's ability to detect lead (Feigl & Suter, 1942). All tests were done at the residence of the graduate student due to covid lockdown procedures.

3.2 a) Testing 3M Instant Lead Test and LeadOff Wipes Interaction

The 3M Instant Lead Test was applied to a fresh out of the pack LeadOff wipe in multiple locations to see if a wipe would cause a positive reaction to the 3M swab in absence of lead. Application of the 3M swab followed the instructions stated in 2.1a. The wipe was then observed for 10 minutes. Color left behind by the 3M swab was noted upon application while the wipe was wet and once again when the wipe was dry.

3.2 b) Testing 3M Instant Lead Test and LeadOff Wipe on Known Lead Substances

3M is a common testing device for lead that is cheaply sold online and it is EPA approved to test for the presence lead at home. Both electrical soldering wire and the lead bullet portion of a piece of ammunition are two objects confirmed to have lead. Both were tested directly by applying the 3M swab to them. The color change on the swab end of the 3M test was observed.

The lead bullet was then used to scratch a piece of shipping cardboard. This scratch was tested with the 3M swab to check for the presence of lead. This test was then repeated but the scratch was instead wiped with the LeadOff wipe. The LeadOff wipe was then tested with the 3M swab.

3.2 c) *Testing 3M Lead Test and LeadOff Wipe on Bone Material*

Pork ribs were purchased from a local supermarket. A rib was manually defleshed by hand, and then directly tested with a 3M swab to check for the presence of lead. Additional ribs were then manually defleshed by hand and scratched with lead bullet. Some of the scratched defleshed bones were tested directly with the 3M swab while others were wiped with the LeadOff wipe that was then tested with the 3M swab.

Fleshed ribs were also scratched by the lead bullet by roughly pushing the bullet through the rib's flesh and onto the bone. These bones were defleshed by hand and through boiling water maceration. Once defleshed each bone was wiped with the LeadOff Wipe, and then the wipe was tested with a 3M swab.

3.2 d) Field kit preliminary Test with Freshly Shot Samples

20 fleshed pork ribs were shot with a 9mm caliber firearm using 9mm ammunition (total jacketed) at a distance of one meter. The rack of ribs were individually separated with a knife, and held in place by clamps constructed from wood. Each shot was aimed towards the middle of the fleshed rib using a laser sight on the 9mm caliber firearm. After each shot, notes were made on the status of the rib, and each rib was collected in a small, labeled plastic bag to be analyzed at the researcher's home later that day. One rib was lost to the wild. Upon being hit by the bullet, the rib flew off the clamp and landed somewhere in thick snow, out of sight. After several minutes of searching, the bone was not recovered. Each rib placed in a bag was immediately placed in a cooler packed with ice so the sample would stay relatively fresh until it was transported back to the graduate student's apartment to be tested.

At the graduate student's residence, the were ribs divided into 2 different testing sections. The first ten ribs were tested directly without stripping the remaining flesh of the bones. These ribs were tested both by a direct application of the 3M lead test and by wiping the area of gun trauma with a LeadOff wipe and testing the wipe. The other 9 ribs were individually boiled in pots of water for 30 minutes, then allowed to cool for 10 minutes, before being manually defleshed.

These bones were then tested with both the 3M swab directly and by wiping the area of the gunshot wound with a LeadOff wipe which was then tested with a 3M swab.

3.3 Field Kit Test on Decaying Remains

3.3 a) *Soil Test*

The soil where the eventual shot bones would be buried was tested by a soil scientist for traces of lead. Four shallow holes were dug using a two-handed pothole digger. Samples of soil from these holes were combined with water in small vials and then tested with Soil Lead Check. The four holes were resampled and retested with SCITUS Lead Test Swabs.

3.3 b) *Field Kit Test*

Ten racks of pork ribs were bought from Wegmans, totaling roughly 75 individual pork ribs. They were separated with a knife into individual ribs. Five ribs were randomly chosen and immediately tested for traces of lead using the 3M Lead Check test swabs to verify that the samples were lead free. The remaining 70 pork ribs were then taken to a forest in Pennsylvania during the month of June.

Seventy of the ribs were shot by a 9mm caliber firearm using 9mm total jacketed bullets. Each rib was shot from one meter away. The ribs were held in a clamp constructed from wood and metal clamps, while the firearm rested on a mount. The distance between the clamp and mounted firearm was measured with a meterstick, and the distance between the clamp and the firearm was checked periodically to ensure that the shooting distance was kept consistent. Of the 70 ribs that were shot, 10 were used for a related undergraduate experiment, and 60 were placed in a shallow burial pit in the forest floor to allow for decomposition. After being buried, the ribs were surrounded by a home-built chicken wire cage held in place with heavy duty tent screws to prevent any scavenging predators from altering or relocating the bones. These 60 ribs were then allowed to decompose for 35 days. After roughly one month each rib was tested for lead in the field using the field kit. The first 25 recovered bones were tested with the 3M lead check test, numbered 1-25, and the next 25 recovered ribs were numbered 1-30. Any positive signs for lead were taken as a qualifying sign for GSR, and signaled further tests needed to be done to confirm the presence of GSR. As the sun was setting, it became difficult to recover the remaining samples.

3.4 *Field Kit Applications on Charred Bones and How Insect Activity Affects the Field Kit*

An attached undergraduate study using the field kit on shot pork ribs examined the application of the field kit on charred remains and how insect activity affects the application of the kit. Five bones were shot and underwent a charring cycle in a firepit, and five ribs were allowed to decompose in a tank with blowfly larvae to ensure heavy insect activity. The charring cycle consisted of 30-minute exposure to large well-built bonfire. before being tested by the field kit. The other set of ribs were allowed to decompose for 31 days in the tank exposed to blowflies before being tested by the field kit.

3.5 *Materials*

- 3 amber glass bottles
- 50 ml water
- 1 Waterfly Fanny pack from Waterfly Direct based in USA
- Gloves from Amazon.com Services LLC
- Wood from Home Depot based in Hawthorne, NY
- Woven Wire Mesh from Z&H Lifestyles based in
- (60) 3M Instant Lead Test from Amazon.com Services LLC
- 7Penn Spiral Ground Anchors from 7Penn Store based in South Dakota
- 60 Hygenall LeadOff Wipes from Hygenall Corportation based in Hunstville, AL
- Sodium Rhodizonate powder from HazTech Systems Inc based in Mariposa, CA
- Industrial Test Systems SenSafe 480311 Lead Soil Test Strips from Industrial Test Systems based in Rock Hill, SC
- Hydrochloric Acid from LabChem Inc based in Zelienople, PA
- 75 pork ribs purchased from Wegmans based in Harrison, NY
- Maxxtech 9mm Ammunition PTGB9MMB 115 Grain Full Metal Jacket 50 rounds purchased from Outdoorlimited.com based in High Point, NC
- SCITUS Lead Test Swabs from Spirochaete Research Labs LLC based in Brooklyn, NY

4. Results

4.1 *Preliminary Results*

4.1a) *Testing 3M Instant Lead Test and LeadOff Wipes Interaction Results*

The LeadOff wipe by itself showed no positive signs for either the 3M Lead Test or the sodium rhodizonate spray.

4.1b) *Testing 3M Instant Lead Test and LeadOff Wipe on Known Lead Substances Results*

Both the electrical soldering wire and the lead bullet tested positive for lead when tested by the 3M Lead Test. Additionally, the cardboard scratched by the bullet and the wipe that rubbed that scratch both tested positive for lead when tested by the 3M test.

4.1c) *Testing 3M Lead Test and LeadOff Wipe on Bone Material Results*

Manually defleshed pork ribs themselves did not test positive for lead. When scratched with a bullet these scratches tested positive for lead, and so did the wipe. When the fleshed ribs were attempted to be scratched by roughly pushing the bullet into the fleshed rib, no positive results were found on the bone or on the wipe that was later used to wipe that area.

4.1d) *Field Kit Preliminary Test with Freshly Shot Samples Results*

Nineteen bones were tested with the 3M lead test to assess the feasibility of using 3M lead check in the field. The results are depicted in table 1.

Table1: Preliminary test results using the 3M testing method

Test Result Category	Labeled Bones	Total
Positive Result	10, 11, 12, 13, 14, 15, 19	7
Maybe	1, 2, 3, 17	4
Negative Result	4, 6, 7, 8, 9, 16, 18	7
Rejected	5	1

4.2 *Main Experiment*

4.2 a) *Soil Test Results*

Lead Soil Check showed weak positive results for the four sample holes. A follow up lead test using the SCITUS Lead Test Swab showed strong negative results for all four holes.

4.2 b) Field Kit Test on Decaying Remains Results

The following results were collected from the shot bones that were recovered from the burial site. Each result was divided into one of five categories: a positive result, a strong maybe, a weak maybe, a negative result, and a rejected result. Clear positive results indicated a clear result for the presence of lead, a strong maybe indicated a harder to interpret result that showed probable evidence of a positive result, a weak maybe indicated a result that showed weak signs of a positive result, a negative result was a sample devoid of any positive results, and a rejected result could not be interpreted due to heavy dirt matting, heavy saponification, or lack of a before/after test pictures that allowed for clear comparison. Bones 1 through 25 were tested with the 3M lead check and bones 31 through 55 were tested with the classical test, sodium rhodizonate spray. The results are shown in Table 2.

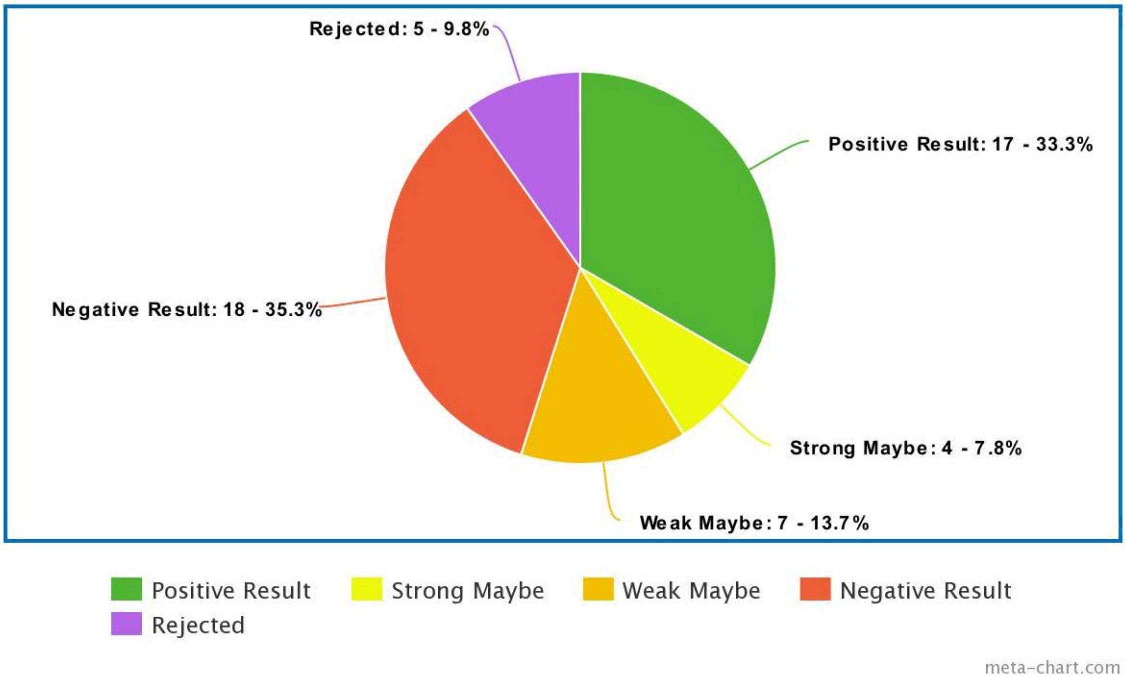
Table 2: Field kit test results for each labeled bone for both methods

Test Result Category	Labeled Bones	Total
Positive Result	2, 3, 4, 5, 6, 7, 10, 11, 12, 13, 16, 18, 19, 20, 21,23, 43	17
Strong Maybe	22, 37, 39, 42,	4
Weak Maybe	25, 34, 35, 36, 40, 44, 53	7
Negative Result	1, 8, 9, 14, 24, 31, 32, 33, 37, 38, 41,46, 47, 48, 50, 52, 54, 55	18
Rejected	15, 17, 45, 49, 51	5

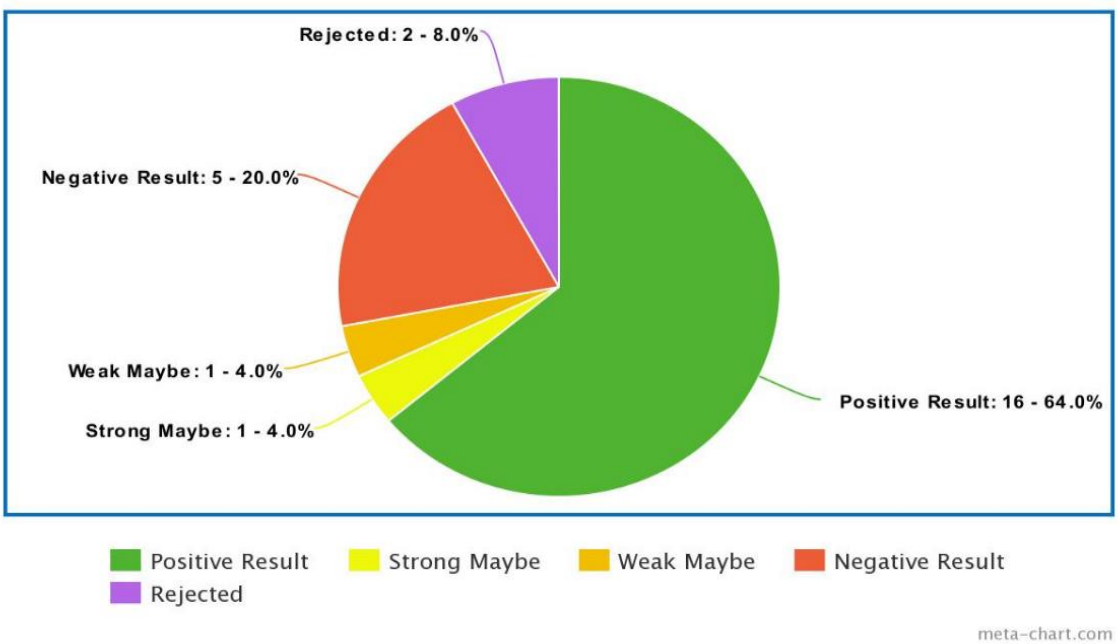
The data gathered above shows that 33.3% of all tested samples tested positive for lead, 7.8% showed a strong maybe for the presence of lead, 13.7% showed a weak maybe for lead, 35.3% showed a negative result for lead, and 9.8% of the rib samples needed to be rejected. This percentages are visualized using a pie chart in Graph 1.

When examining only the results from the rib samples tested with the 3M Lead Swabs (ribs 1-25) the percentages change. For ribs tested only with the 3M Lead Swabs 64% tested positive for lead, 4% tested as a strong maybe for lead, 4% tested as a weak maybe for lead, 20% tested negative for lead, and 8% of samples needed to be rejected. These percentages are visualized as a pie graph in Graph 2.

Graph 1: Test results from all recovered bones

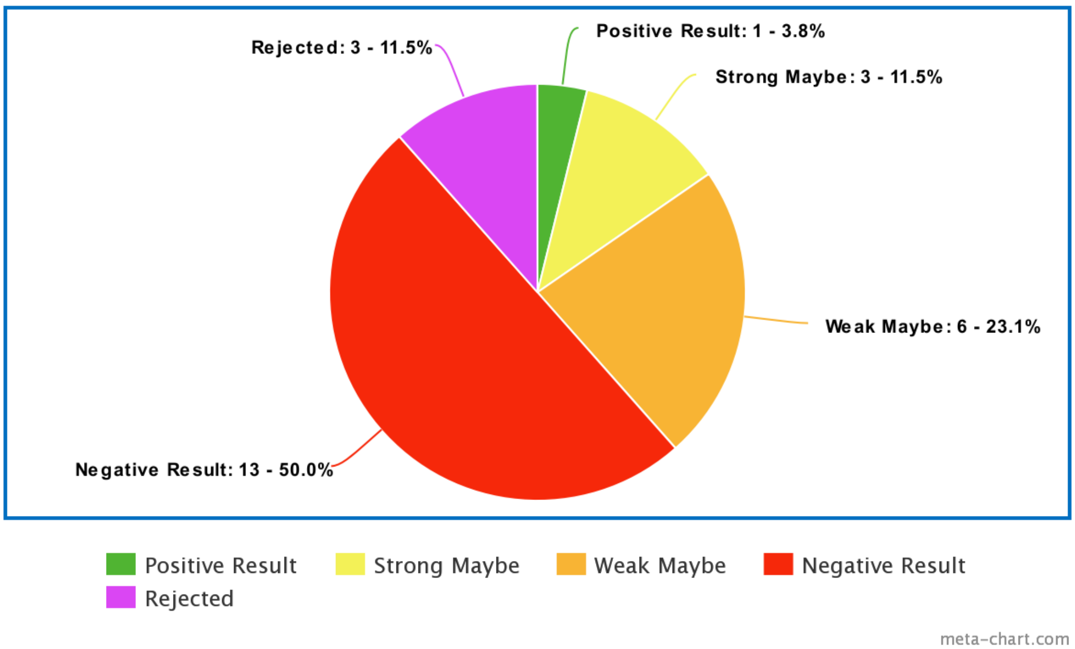


Graph 2: Test Results from samples only tested with 3M Lead Check Swabs (ribs 1-25)



When analyzing only the results from the rib samples tested with the sodium rhodizonate solution (ribs 30-55) the percentages change yet again. For ribs tested only with the sodium rhodizonate solution 3.8% tested positive for lead, 11.5% tested as a strong maybe for lead, 23.1% tested as a weak maybe for lead, 50% tested negative for lead, and 11.5% of samples needed to be rejected. These percentages are visualized as a pie graph in Graph 3.

Graph 3: Test results from samples only tested with sodium rhodizonate solution (ribs 30-55)



5. Discussion

5.1a) *Testing 3M Instant Lead Test and LeadOff Wipes Interaction Results Discussion*

A fresh wipe straight out of the package was not expected to test positive for lead, so the results were not particularly surprising. It would be expected that a wipe, designed to clean your hands, would not be covered in lead residue, especially if it was made to take GSR of your hands after discharging a firearm. The fact that the results were clearly negative, confirmed that the wipe would be useful part of the field kit. The wipes themselves also contain some mild acids like citric acid, sorbic acid, and levulinic acid, which should help sodium rhodizonate solutions react to the presence of lead. Additionally, the wipe itself is a rectangular shape made up of smaller squares. It is easy to identify a portion of the wipe by assigning each square a numerical value. This was later done in the observations notes for analyzing the recovered ribs that were tested with the field kit.

5.1b) *Testing 3M Instant Lead Test and LeadOff Wipes on Known Lead Substances Results Discussion*

While the EPA already showed that the 3M Lead Check test swabs function as advertised, it was good to confirm it for this experiment as well. It was further good news to see that the test was sensitive enough to pick up traces of lead on a LeadOff wipe that was used to wipe an area of known lead. This further confirmed that both testing elements would be good inclusions in the field kit.

5.1c) *Testing 3M Lead Test and LeadOff Wipe on Bone Material Results Discussion*

Testing direct scratches caused by bullets on bones was the next logical preliminary test for the 3M tests and LeadOff wipes. It was reassuring to see that it was possible to test for lead using both the 3M test directly and when using a wipe and LeadOff wipe. It was unsurprising that when testing the fleshed ribs that the results for lead on the bone came back negative. The bullet was pressed as hard as possible into the rib meat by hand with the hope that it would push through the meat and scratch the bone. The bullet did not have enough force behind it to manually push it through the meat or transfer lead traces to the bone. The fact that the bone did not test positive for lead with the test was not discouraging for the field kit, only for the self-esteem of the researcher who realized they did not possess the finger strength they thought they had.

5.1d) *Field Kit Preliminary Test with Freshly Shot Samples Results Discussion*

Testing freshly shot bones was an unexpected challenge. A positive test with the 3M swab occurs when the testing liquid from the swab or the swab itself turns from brownish-yellow to a bright red/pink. On bones that are still covered in pink flesh, fat, cartilage, and filled with fresh marrow around the bone's trauma site, looking for a positive pink/red test results was exceedingly difficult. The leftover marrow was by far the most difficult challenge. It quickly stained the wipe and the 3M swabs red, masking any result, be it positive or negative. This obscuring of results made testing the first half of the preliminary results difficult. Testing the latter half of the preliminary bones became easier because the bones were individually boiled before being tested by the 3M swab for lead. Testing the boiled bones made seeing both positive and negative results much clearer, and results became more consistent. Positive results were seen both on the wipe, on the bones, and on the swabs themselves from the boiled preliminary samples.

Carefully examining the boiled preliminary bones led to a concern. Some of the positive results found on the bones were found along fracture lines radiating away from the site of trauma. It is very likely that there would be lead in these fractures, but a concern arose that there is a possibility that enough testing liquid in a fracture could create a false positive. If enough 3M testing liquid pooled within these fractures, could it look more like a positive result than negative? To investigate this issue, fresh rib bones were purchased. These bones were put into individual plastic bags, and these bags were wrapped in a kitchen towel. The rib bones were then repeatedly smashed with a hammer to induce the ribs to break and produce fractures that radiated from the trauma site. These bones were then boiled in the same manner as the preliminary shot bones were. Once boiled, 3M test swabs were used to swab along fracture lines. The test showed that most fractures do not produce false positives. A couple of fractures, that were red initially due to the red marrow beneath the fracture showing through, appeared to be positive when tested. Although this was expected, since we were applying the chemical test onto a surface that had red on it, it is logical to assume that the chemical test would then also appear red. This however was noted, and it is why it was important to have before and after pictures of all future rib bone tests to make sure that fracture lines would be visible before applying the test. This was done to ensure that during the actual experiment that fracture line positives would not be false positives.

It was already assumed that sodium rhodizonate in combination with a follow up application of HCl could detect lead from GSR, since there is a copious amount of research literature that demonstrates this, starting with Feigl's work 80 years ago. Old research shows that sodium rhodizonate is more sensitive than 3M swabs. Sodium rhodizonate can detect 0.1 micrograms of lead, while the 3M swabs can only reliably detect lead at 1.0 mg/cm² (Buehler & Rhoda, 2012; Feigl & Suter, 1942). While concentration of lead in GSR can vary, to one study used inductively coupled plasma optical emission spectroscopy has shown that a concentration of lead in GSR is about 3,158μg L^{-1} from a firearm discharged at 0 cm, and decreases to a concentration of 81.52μg L^{-1} from a firearm fired from 200cm (Vanini et al., 2015). Using that information, it can be estimated that a concentration of about 1,620μg L^{-1} of lead will be found in GSR from a firearm discharged at 100 cm (the distance of this test). This should be easy to detect for the classical sodium rhodizonate test, while just on the verge of possible for the 3M test, though no previous literature has ever attempted to use the 3M swab test to do this. That is why the 3M lead swab was the main focus of the preliminary tests. The plausibility of using the 3M swab tests needed to be tested before being included as a kit option. Since the results were not fully negative, it was determined that the 3M lead swabs are capable of detecting lead in GSR, and therefore could be used in the main experiment. The main drawback during the preliminary tests was the difficulty of testing fresh ribs that had been shot, since the soft organic material on the bone interfered with interpreting the results. It was determined that this would not be an issue in the actual test, since the bones would be partially decomposed. There would not be any red or pink tissue left on the ribs. That being the case, the 3M was approved to be a viable component of the field kit alongside the established lead chemical test, sodium rhodizonate.

5.1e) *Soil Results Discussion*

The soil scientist used The Lead Soil Check Test purchased by this author and tested four separate small patches of soil dug out by a rusty pothole digger around the area that would eventually make up the burial pit for the bones. The results showed weak positives for all four holes. Even before testing the soil, the soil scientist quickly pointed out that the inexpensive lead soil test would show false positives if other heavy metals are present in the soil like iron, zinc, copper, cadmium, and chromium and feared this might give false positives. After the results were evaluated, it was concluded that the weak positive results might be interference due to the rust from the pothole digger or from other heavy metals in the ground. Additionally, the positive result for this test was the same general color as the soil itself. Making it possible that these results are not positive, but just the color of clay heavy soil. The holes were resampled and retested using SCITUS lead tests, a non-soil lead test that would not test positive for heavy metals, besides copper. All four holes were sample and tested again with each test showing clear distinct negative results for lead. The simplest explanation is that there was not enough lead to cause any interference with the eventual results. Any prior weak positive results were likely false positives due to the limitations of the initial soil tests.

5.2 *Bone Results Analysis*

On the day of recovery, it was found that grass had grown thickly around the area of the burial site. Luckily, the rib cage prevented any scavengers local to the area from digging up and disturbing the bones. The soil itself was damp and had retained a lot of water from the previous few storms that had come through the area. The bones were buried roughly 8 inches down, and after the first six inches were removed with a shovel, the last two inches of soil were carefully removed using a small trowel. The last two inches contained a high number of beetles, worms and slugs. When the last two inches of soil was excavated a clear smell of decomposition wafted up from the burial site, and there were obvious signs of saponification on a large majority of the bones. Saponification is a decomposition process that turns excess fats on decomposing material into soapy substances under the right environmental conditions, like the waterlogged soil of the burial site. Each bone was carefully removed from the burial site and was laid down in a numbered box on butcher's paper to be carefully examined later.

Carefully recovering the bones from the burial site took longer than anticipated. By the time the bones were recovered, it was a lot later in the day than planned. Due to the waning sunlight each bone was photographed, tested, quickly analyzed, and then photographed again. These before and after pictures were later carefully analyzed, and the majority of the data in the results came from the photos' interpretation. It was the researcher's fear that the sun would fully set before each bone was carefully examined by hand, and that led to the decision of using before and after photographs as the foundation of the data.

While analyzing the pictures, it became clear that the bones could not simply be ruled positive or negative for lead. Additional categories had to be added due to the lighting of the pictures, the angle of the pictures, and sometimes the strength and/or weakness of the result itself appearing in the pictures. In addition to positive and negative results, the categories strong maybe, weak maybe, and rejected were established to help paint a clearer picture of the test results of the bones. The five categories can be summarized as follows:

- Positive result: a clear positive result from either the 3M or the sodium rhodizonate spray around the trauma site. A clear red/pink streak on the bone or the wipe
- Strong maybe result: Result has a strong possibility of being positive but due to the clearness of the picture it is difficult to conclusively say that it was a positive
- Weak maybe result: A probable positive result but a combination of dirt, a faintness of the reaction, and/or clearness of the photograph made the result difficult to confirm a positive
- Negative result: a test with no sign of color change
- Rejected sample: The bones either had a missing before picture or the bone had an excess amount of fatty residue and dirt on the bone combined that completely obscured results. These bones were rejected since it would not give conclusive results

The notes of each recovered rib were combined with the photo interpretations to place each rib into one of the five established categories. What follows is a quick synopsis of each bone's notes and why it was placed into a certain category.

- Rib 1: This bone was easily wiped clean with a LeadOff wipe, and the area of ballistic trauma was easy to spot once cleaned off. After application of the 3M test, there is no sign of a positive result on the bone or on the wipe itself.
- Rib 2: The bone was easily cleaned off with a LeadOff wipe, and once cleaned the area of ballistic trauma was easy to identify. Once the 3M test was applied there were signs of a positive test, a brighter red color, both on the wipe amongst some of the dirt areas and on the bone itself. After some time passed, the red color persisted on both the bone and on the wipe, while the rest of yellowish-brown testing liquid from the 3M test dissipated.
- Rib 3: This rib was shot in half and a hefty amount of clay and soil clung to the leftover portions of meat on the bone. The area of the trauma caused by bullet impact is clear, since there is bullet wipe present around the trauma area along with clear beveling. While there was no positive reaction for the 3M test on the wipe, there were signs for a positive reaction on the bone along fracture lines originating at the site of ballistic trauma and around the trauma site itself.
- Rib 4: Both halves of ribs were recovered along with a smaller bone fragment that had come from the same rib. This rib underwent heavy saponification, which caused a lot of wet soil to stick to the bone. The LeadOff wipe was able to wipe away a little bit of this layered fatty dirt from the trauma site, but a large portion of the bone remained matted in dirt, much to the delight of the larvae wriggling around in it. While the wipe itself had no

positive result to speak of, the bone around the area of trauma had a positive red result for lead. Both halves of the bone had positive results around the area of trauma.

- Rib 5: Both halves of rib were recovered, and both were relatively clean of fatty residue and wet soil. The site of the ballistic trauma is very obvious, and after the site had been wiped with the LeadOff wipe, the wipe itself did not show any signs of a positive test. The bone, however, had clear signs of red around the trauma area leading to a positive result.
- Rib 6: The two halves of the ribs were recovered. The bones were mostly clear of fatty residue, but saponification had clearly taken place because both halves were very greasy. The ballistic trauma on the bones is clear, and even after decomposition had taken place there is a clear example of bullet wipe on the bone's trauma site along with bevelling from the bullet impact. While the wipe had no result, the bone itself had a clear red mark near the site of trauma and along a fracture line that radiates away from the site of trauma.
- Rib 7: Both halves of rib were recovered. While there was not a lot of greasy residue, both bones were heavily stained by dirt. Trauma area is present, though it is not a clear example of ballistic trauma. While the wipe does not have any positive results, the trauma area on the bone has clear signs of red positive results for lead.
- Rib 8: The two rib halves were recovered, though it is likely that both halves might not have originated from the same rib bone. Both bones were heavily matted with wet dirt and fatty grease. Once wiped away, the area of ballistic trauma is clear, showing signs of bullet wipe around the trauma area. Both the ribs and the wipe, that cleaned the rib, were negative for lead residue when tested with the 3M lead test.

- Rib 9: Two portions of the ribs were recovered, and they were heavily matted with layers of greasy fatty residue and wet soil. The area of trauma is clearly ballistic in nature, but there is no sign of a positive result around the area of trauma on the bone nor is there any positive sign on the wipe itself. This was a clear negative result.
- Rib 10: This rib was only grazed during the shooting, and it is one of the few bones that was recovered whole. The whole bone was heavily caked with grease and wet soil, and even after wiping the bone down with the LeadOff wipe there were maggots present on the bone itself. The area of trauma is not as clear as on the previous examples, since the bullet only grazed the bone. The bone itself did not have any clear positive results but there is a clear thin red streak on the wipe that probably rubbed a small amount of GSR on the bone near the top of the wipe. The streak stands out from the regular dirt, and the straight line suggest that I was caused by the tester when they had the wipe slightly folded while rubbing the area of trauma. This was ruled a positive test.
- Rib 11: Two ribs halves were recovered for Rib 11, though it is likely they did not originally come from the same rib. Both ends of the halves were heavily layered with grease and wet dirt, concealing the area of trauma until it was wiped. The trauma site is clearly ballistic in nature with fractures radiating away from the area of trauma. One of the halves still had a slight charred end where the bullet impacted the bone. The wipe itself seems to be free of any positive tests, but the bone itself has clear positive signs of lead at the edges along the site of trauma, and probable signs of positive in one of the fractures radiating away from the sign of trauma.
- Rib 12: Two halves of rib were recovered, and these halves were heavily covered in layers of greasy fat and wet soil. Once wiped, the area of trauma became clear. There was

evidence of ballistic trauma as there were signs of a bullet wipe on trauma site of the bone along with beveling from where the bullet had impacted and pushed through it. The 3M test showed a clear positive result for lead in one of the fractures radiating away from the site of trauma and just slightly along the edge of the site of trauma on the other bone. Additionally, the wipe had two faint streaks of red on the left top portion of the wipe.

- Rib 13: Both halves were recovered for rib 13, and like previous bones it was covered in layers of wet soil. Once wiped the area of trauma was clear, but it was not clearly ballistic trauma. After the area of trauma was wiped there were signs of positive results on both the wipe and on the bone itself. The wipe has traces of red in the center and top of the fifth square, while the bone itself had areas of red indicating the presence of lead around the site of trauma.
- Rib 14: Rib 14 was recovered as a whole bone, since this rib was only grazed by a bullet. This bone was relatively free of dirt and fatty grease, which made the site of trauma easily visible, even before wiping it. The were no signs of a positive test on the bone itself nor on the bone, making this a clear negative result.
- Rib 15: The two halves of rib 15 were heavily mattered with dirt that clung to the bone through fatty residue caused by saponification. While there are clear signs of positive results on the wipe, no before picture of the wipe exists, causing the bone to be rejected.
- Rib 16: Two halves of the rib were recovered, but there was a large amount of greasy fat and wet soil on the bone itself. The layers were thick enough for many larva and maggots to actively move around the bone even once it was removed from the burial site. The trauma site is nearly invisible until it was wiped free of dirt. Even once visible, the trauma site is not clearly ballistic. There were likely red smudges on the wipe in squares

one, two, four, and eight. Additionally, there was a clear positive result for lead on a bone fragment on the edge of the trauma site. Some of the red smudges became more visible once the rest of the testing liquid evaporated. The red color from the positive test also persisted on the bone. This bone was ruled a positive result.

- Rib 17: Only one half of a rib was recovered for this rib. The rib was relatively clean of grease and dirt upon recovery with a clear sign of trauma, though the trauma was not clearly ballistic in nature. While there are signs of red indicating a positive result for lead, this sample had to be rejected because there was no before picture. Making it impossible to compare the wipe and bone before and after the test.
- Rib 18: Both halves of the bone were recovered for this rib, though it is likely that these bones were not originally from the same rib. Both rib halves were heavily covered in layers of grease and wet soil. The site of trauma on the bone is visible, but it is not clearly ballistic trauma. While the bone itself does not have a clear positive result there are multiple clear positive red results on the wipe itself. There are signs of red in square one, two, three, four, five, and ten on the wipe. The clearest mark is on square ten, while the other marks in the other squares are a little fainter.
- Rib 19: A whole bone was recovered for this rib, and it was heavily layered with fatty grease and wet dirt that needed to be wiped off to identify the site of trauma. While the wipe had few faint smudges of red on it, a clear positive result was on the bone itself near the site of trauma. There is a clear red portion near the site of trauma, though the trauma is not clearly ballistic.
- Rib 20: Two halves were recovered for rib 20, and bones were completely covered in thick fatty grease residue caused by saponification that caused wet soil to stick to it. The

wipe was needed to be able to identify the site of trauma that was clearly ballistic in nature. There are very faint red smudges of red in square two of the wipe, in addition to more clear positive result on the bone itself. There are clear positive red results on the bone itself near the site of trauma and within a fracture that radiates away from the sign of trauma.

- Rib 21: A whole rib was recovered for this bone with the trauma site clearly visible at the end of the bone. The bone itself had minimal amount of fatty residue and wet soil clinging to it, and the trauma site was not strictly ballistic looking in nature. While there is no positive result on the bone itself, there is a clear positive result on the wipe near the bottom right corner of the fifth square. It is a line of red that has a slight amount of dirt with it that probably got onto the wipe when it was used to clean the trauma site of the bone. This red color persisted, even when the rest of the testing liquid on the wipe evaporated.
- Rib 22: One half of a rib was recovered for this bone, and it was heavily covered in damp dirt and fatty residue. The ballistic trauma is clear on this rib, and as in some previous bones, there is a bullet wipe present with beveling on the edge of the trauma on the bone that likely came from the impact of the bullet. The bone itself seems to have some residual positive red coloring that indicates a positive test, but the lighting on the photo makes it hard to ascertain whether or not this is from a positive test or from the bone itself. When comparing the tested bone to the pre-tested bone, the bone is slightly darker from dirt near the trauma site, but it is unlikely that this would cause the yellowish test liquid to appear red. Additionally there are some positive red smudges on the wipe in squares two, four, five, and eight, with the smudge in square eight being the clearest. The

positive shaded smudges in combination with a likely red positive shade on the bone rules this bone a strong maybe as opposed to a clear positive.

- Rib 23: Both halves of a rib bone were recovered. While the halves were covered in fatty residue, residual decomposing meat, and damp soil, the area of trauma was readily visible and clearly ballistic in nature. Bullet wipe is still present on one of the bone halves. The area around the trauma site had a clear positive red result along with a fracture radiating away from the trauma site that also had a positive red color within it. The wipe itself contains a few examples of positive red smudges. While not as clear as the bone positive result, red smudges on the wipe can be seen on squares four and five. The positive red color on the bones persisted, even when a lot of the other yellowish testing liquid evaporated. The reddish smudges also became a little easier to see once the other testing liquid evaporated. This was ruled a positive result.
- Rib 24: The two halves of the ribs were recovered, and both were heavily obscured with thick layers of damp soil and fatty grease. The trauma site is clearly present, but it is not clearly ballistic in nature. Once tested neither the wipe nor the bone showed any traces of a positive result, making it a clear negative result.
- Rib 25: Both halves of the bone were recovered with both rib halves heavily layered with dirt and grease. The trauma site is clearly visible, and it looks to be ballistic in nature. The test results for the 3M lead check show results that were difficult to interpret. There is a redder shade of the testing liquid present around the trauma site, but it is not as clear and evident as past examples have been. There are minor spots of red along the trauma site edge on the bone that are hard to see in the picture that could show a clearer result if the camera was at a slightly different angle. Additionally, there are some very faint

smudges of red in squares seven and eight on the wipe. Since there are faint and poor indicators of a positive result, this result was ruled a weak maybe.

- Rib 31: Two bone halves were recovered for rib 31, and both had undergone heavy saponification. A large amount of fatty grease stuck to the bones which caused a large amount of wet soil to cling to them as well. The trauma site on the bone is readily visible, and it presents with trauma consisted with ballistics as indicated by bullet wipe and beveling of the bone. While there are a few red dots barely visible on the fatty residue after applying sodium rhodizonate, these small dots are far away from the trauma site. Based on past research, GSR should not be able to travel further than 35 mm away from the site of trauma for a contact shot and no further than 4mm from the impact site for a shot fired from 2m away because those are the max distances the periosteum around the bone's trauma site will detach due to ballistic trauma(Faller-Marquardt et al., 2004). Even with a generous estimate of five centimeters away from the ballistics site, the red dots is too far from the trauma site to be counted, which caused this result to be ruled a negative.
- Rib 32: While two rib halves were recovered for rib 32, it is unlikely that both originally belonged to the same rib. Each half was heavily layered with greasy fat and wet soil that made it difficult to initially inspect the trauma site. The trauma site was visible once it had been wiped, and it was clearly ballistic trauma. Once tested both the bone and the wipe itself seemed to be free of any redness that would indicate a positive result. This rib was ruled a negative result because of this.
- Rib 33: Only one half of the rib was recovered for this rib and it was only lightly covered in grease and soil. The rib was easy to clean off, and while the trauma site is easy to see it is difficult to immediately rule this as ballistic trauma. Careful inspection of the bone and

the wipe did not reveal any redness causing this result to be ruled as a negative result for lead.

- Rib 34: Two rib halves were recovered that still had a fair amount of decomposed flesh in addition to fatty grease and dirt on them. The trauma site was clear, though not readily identifiable as ballistic in nature. There was a slight evidence of bullet wipe at the edge of one of the trauma sites that might have been caused by the impact of the bullet. There seems to be a faint redness on the bone near the trauma site and a faint red shadow on the wipe in square four. It is difficult to tell if this is the light in the photograph making the color appear red or if it is a truly positive result. Due to the faintness of the result and the probability that it might be a trick of the light in the photograph, this result was ruled a weak maybe.
- Rib 35: Only half of the rib was recovered for this sample and compared to other bone samples this one was relatively clean. There is a very evident trauma site, though it is hard to conclude that it is ballistic trauma. Inspection of the bone, once the sodium rhodizonate spray was applied, shows a faint redness near the trauma site and along the fracture radiating away from the site of trauma. This color change, however, is faint compared to other samples, and is therefore ruled a weak maybe. This faint color change persisted once the other yellow test liquid had a chance to evaporate.
- Rib 36: Both halves of the rib were recovered for this sample, and each half was heavily covered in layers of fatty grease and damp soil. Even after cleaning off the bone with a wipe, the trauma site is not fully visible, and it is cannot be clearly ruled as ballistic trauma. Once tested, the wipe was clear of any positive results for lead, while the bone itself had a slight red shadow on some of the leftover decomposed matter left on the

bone, very close to the trauma site. This faint red shade persisted even when other portions of the test liquid evaporated, and this sample was ruled a weak maybe.

- Rib 37: Two rib halves were recovered that were relatively clean of dirt and grease, but still covered in some decomposing organic matter. The trauma site was clear and looked to be of a ballistic nature. After careful examination of the wipe and the bone, no traces of red could be found causing this to be ruled a negative result.
- Rib 38: Both rib halves were recovered for rib sample 38, and both were heavily matted with layers of fatty residue and wet soil. The trauma site is evident, though it is not clearly ballistic. After careful examination, there is no sign of redness on either the wipe or on the bone, ruling this a clear negative result.
- Rib 39: Two rib halves were recovered for this sample, and both samples were mostly clear of both fatty residue and wet soil. There was a little bit of organic decomposed matter near the end of the bones away from the trauma site. The trauma is clearly caused by ballistic event. The trauma site itself has beveled bone where the bullet had pushed its way through it. On the edges of this beveling there is evidence of bullet wipe that could have been caused by the bullet passing through. While the wipe seems free of any red positive result, the bone itself has a little red on the edge of the trauma site amongst some small fractures and on the fulcrum portion of a piece of chipped bone where the chipped bone is still attached to the rib half. Due to focusing of the camera it is difficult to clearly see the positive result causing this to be ruled a strong maybe.
- Rib 40: A whole rib was recovered for this sample, and it was relatively free of any fatty grease and soil. The trauma site was a large fracture along the center of the rib where the bullet had grazed it. While the wipe and the bone seem to be relatively clean of any

positive redness, there is a very faint redness along a fracture that radiates away from the site of trauma. It is difficult to tell if this redness in the fracture is due to the wet bone interacting with the light of the camera. Due to that fact that it is very faint, and only visible in one photograph this sample was ruled a weak maybe.

- Rib 41: Two rib halves were recovered for sample 41, and these halves were mostly clean when they were recovered out of the burial site. The trauma site is readily visible and ballistic in nature. One of the rib halves presents with evidence of bullet wipe on the edge of the trauma site that maybe have occurred when the bullet penetrated it. Upon inspecting the bone and wipe after testing with the sodium rhodizonate spray, both materials were free of lead. This sample was ruled a clear negative result.
- Rib 42: Only half of the rib was recovered for this sample, and there were thick layers of greasy fat and damp dirt clinging to the bone. Once the sample was wiped clean, the trauma site became more visible, and it looked to be ballistic trauma. Evidence of bullet wipe could be seen at the end of the trauma site that could have been caused by the bullet passing through the bone. Once the spray was administrated redness can be seen along the edge of the trauma site and along a fracture that radiates away from the trauma area. The photo that shows this is unfortunately a little blurry, and therefore this photo was ruled a strong maybe instead of a clear positive. This red color persisted in a later photo, once the other yellow testing liquid had evaporated. Unfortunately, this photo was also unclear since the lighting made the red area difficult to see clearly.
- Rib 43: The whole rib was recovered intact for this sample, and the sample was clear of any greasy residue with a minimal amount of dirt on it. The site of trauma was faint, since the bullet only grazed this bone. After careful inspection there is a positive red

result for lead near the site of trauma. The wipe has a few faint shadows of red, but the more compelling evidence is on the bone itself, which caused this sample to be ruled a positive. These faint red shadows persisted when the rest of the testing spray began to evaporate.

- Rib 44: Two rib halves were recovered for this sample, and both were heavily matted with layers of grease and damp soil. The site of trauma is clear, though it is not evident that the trauma is ballistic. Careful inspection of the wipe and the bone showed a very faint redness on the edge of the bone and on square four on the wipe. All three instances of positive lead test for this sample were very feint and hard to make out, which ruled this sample as a weak maybe. The faint redness on the bone persisted after some time was allowed for the rest of the liquid to evaporate.
- Rib 45: Both halves of the rib were recovered, but they were heavily matted in thick layers of greasy fat and damp soil. The layers were so thick they obscured most of the result on the wipe and on the bone. The grime was too thick to make any clear conclusions on these bones causing this sample to be rejected.
- Rib 46: Two rib halves were recovered for sample 46, but it is unlikely that they originated from the same rib. Both halves were covered in wet soil clinging to the fatty residue on the bone itself. There was also plenty of decomposing organic matter still on this rib as well. After testing the wipe and the bone halves, none of the material gave any indicators for lead, making this a negative result.
- Rib 47: Two rib halves were recovered for this sample, though it is improbable that they came from the same rib. Each half had minimal amount of dirt on it, but it had a heavy amount of greasy residue clinging to the bone. The site of trauma was easily identifiable,

but it was immediately identifiable as ballistic. Careful inspection of both the wipe and bone showed no signs of lead, and the sample was ruled a negative.

- Rib 48: Both halves of the rib were recovered, and there was a heavy amount of damp soil mixed with greasy residue and leftover decomposing matter sticking to the bone. Once a wipe was used, the area of trauma became visible, and it looked like it was ballistic in nature. After testing the wipe and the bone with sodium rhodizonate spray, neither surface tested positive for lead, making this a negative result.
- Rib 49: Both rib halves were recovered, but due to the heavy saponification a large amount of damp soil, fatty residue, and decomposing organic matter clung to the bone. Even after being cleaned by a LeadOff wipe the bone was still incredibly dirty. The area of ballistic trauma was clear, but even after testing the results were difficult to interpret due to the thick layers of grime on the bone. This sample was rejected due to how dirty it was upon testing.
- Rib 50: Two rib halves were recovered for this rib, but it is unlikely they originated from the same rib. Both halves were heavily matted with damp soil and fatty residue. The area of trauma is not readily visible, and it is difficult to judge whether or not it is ballistic in nature. Examination of the bone and wipe, after applying the sodium rhodizonate spray, show positive reactions for lead, making this a negative result.
- Rib 51: Two rib halves were recovered for this sample, but they were both heavily matted with a combination of dirt, greasy fat, and decomposing organic matter. The trauma site was visible, and it was possible to judge that this trauma was ballistic in nature. The results were too difficult to judge because of the heavy amount of dirt and grease that stained both the wipe and bone causing this sample to be rejected.

- Rib 52: One rib bone was recovered for this sample, and like previous samples it was heavily matted with dirt. The trauma was not readily visible, and it took careful inspection and cleaning with a wipe to be able to identify it. The trauma was not readily identifiable as ballistic. The bone and the wipe did not test positive for lead, and this sample was ruled as a negative result.
- Rib 53: Two rib halves were recovered for this sample, and after taking a lot of greasy damp soil of the bone an area of ballistic trauma was revealed. Careful inspection after applying the sodium rhodizonate spray revealed some faint red patches near the trauma site on the bones. These areas were minute and hard to see, which caused this sample to be ruled a weak maybe.
- Rib 54: Two rib halves and a small fracture of one of the rib halves were recovered for this sample. Each bone was heavily matted with dirt and grease, and the trauma site was revealed after wiping the bone halves with the LeadOff wipe. The trauma site did not appear to be ballistic in nature. Careful inspection of both the bone and the wipe did not reveal any positive results for lead, ruling this sample as a negative result.
- Rib 55: The two rib halves recovered for this sample are unlikely to have originated from the same bone. Both halves were heavily layered with greasy fat and damp soil. The trauma site, once revealed, did not appear to be caused by a ballistic event. Neither the testing wipe nor the bones had any positive results for lead causing this sample to be ruled a negative.

5.3 *Bone Results Discussion*

While preliminary results hinted that some positive results were likely, it was nevertheless a pleasant surprise to see positive results on multiple bones. It was anticipated that any positive results that were found would be hard to see, since only a minute amount of GSR gets deposited on the bone when the bullet causes the periosteum to blow up from impact (Faller-Marquardt et al., 2004). It should not be assumed that every sample had a detectable amount of GSR indicative particles, since only a small amount of GSR ends up on bones. Additionally, when sodium rhodizonate was employed in an experimental field kit in a past study, it was found that positive results for the sodium rhodizonate on a sample swab were very small and hard to see (Walker & Rodacy, 2002). Those field kits tested for GSR on the hands of people after they had discharged a firearm one time. The amount of GSR deposited on bones would theoretically be even less, so it was expected that there would not be the same immediate and obvious results that normal sodium rhodizonate test produces when used for distance estimation. That meant, in order to see a positive result for lead, a great deal of patience and careful observation would be required. This was the reason why the data was solely based on the examination of the before and after tests of the rib bones. By inspecting the photos of each bone, each result could be reviewed with plenty of time, with no fear of the results being masked as the light waned with the sun, and no result would be missed because an inspection had to be rushed.

Looking at the results as a whole, it is clear that it is possible to chemically test for lead as a means for preliminarily testing for GSR. Both test kit methods were able to provide positive results, in addition to a couple of results that were strong maybes. As a preliminary test, this chemical method needs more refinement before it can be employed full time in the field. The kit itself made use of the two different methods to chemically test for lead, the 3M swab and the sodium rhodizonate spray. Comparing the results for both of them, it is clear that the 3M lead swab gave clearer results and, as a whole, more positive results. The sodium rhodizonate spray test gave more maybe results than the 3M swab did, and, as the whole, it produced more negative results. This is interesting because sodium rhodizonate is classically the chemical color change test used to detect lead. It was originally expected that it would produce more consistent results than the 3M test would. The actual results of the experiment show the exact opposite of what was expected.

It is likely that the direct application of the 3M swab to the bone and the wipe allowed the 3M's testing fluid to come into direct contact with a surface that held lead more easily than the spray could. The sodium rhodizonate was sprayed on the wipe and the bone. Spraying the sodium rhodizonate solution is nowhere near as precise as applying a solution to an area by hand. The 3M's direct application to the site of suspected trauma might have caused there to be clearer results than a spray that misted the general area of trauma because it ensured that the areas of trauma were directly introduced to lead detecting chemicals. The spray's wide distribution did not allow for such pinpoint precise application. Instead, one had to hope that the sodium rhodizonate solution soaked into the areas where lead was suspected of being to get a positive result.

Another factor that might have contributed to why the 3M swabs gave more consistent and clear positive results might be with how the two chemical tests interacted with the bone itself. The 3M liquid seemed to stay on the bone more and was more readily absorbed as compared to the sodium rhodizonate spray. The spray, being mostly water, dripped off the bone and evaporated rather quickly. It did not stay on the bone as long as the 3M lead check liquid did. Since the 3M swab testing liquid clung better to the surface of the bone, this could have created more chances of the testing liquid and the lead to interact, giving 3M better chances to give clearer results. The reason the sodium rhodizonate solution probably did not interact well with the bone has to do with the saponification that happened with the samples. The bones were covered in fatty and soapy residue that was still present, even after wiping the bone with the LeadOff wipe. This means a thin layer of fatty residue existed around the sample bones, which likely repelled the sodium rhodizonate solution. Due to hydrophobic forces, the mostly water sodium rhodizonate solution likely could not find any purchase on the bone samples, and therefore dripped off before interacting with any GSR particles.

Interestingly enough, this study was not the only one to experience problems with the interactions of sodium rhodizonate and bone as a medium. In late 2020 Gentile et. al released a study that sought to use a histochemical test to test for GSR on decalcified bones (Gentile et al., 2020). Part of this study tested bones from 11 decedents who had died from firearm related trauma. SEM-EDX confirmed GSR to be on bones of all eleven decedents, but when sodium rhodizonate was applied to these samples, only one of the eleven samples tested positive. Additionally, the one positive reaction could not be confirmed because the addition of HCl did not cause the usual red to purple color reaction that would confirm the presence of lead (Gentile et al., 2020). While it is hypothesized that hydrophobic forces caused sodium rhodizonate to be less effective in this study, Gentile’s study points to the fact that there might be a more immediate problem. Perhaps the bone is a poor medium for sodium rhodizonate and therefore not conducive to this chemical color test. 3M might be more effective because it is designed to be used on a variety of surfaces ranging from wood to vinyl to metal, lending it to be more successful with unusual surfaces like bone.

One limitation of these results is that the proposed test is not be able to distinguish between lead from GSR and lead residue from the swipe of a bullet, or another source of lead. This being only a preliminary test, the goal was to test for the presence of lead. A further confirmatory test would need to be completed to ensure that the lead that was detected was actually from GSR. Though it should be noted using a preliminary test to detect lead at the trauma sites of bones does not need to be able to distinguish between the two. If the goal is to confirm whether or not a trauma site is caused by ballistic trauma, then being able to detect lead at the site of trauma is already significant clue as to how the trauma occurred, especially if combined with histological observations of that trauma site.

5.4 *Challenges and Future Suggestions*

This study came with its fair share of challenges. The 3M Lead Check swabs are solely designed to test for lead, which is a great preliminary test for GSR. The 3M swabs are EPA approved to find lead. In this study we looked for very minute amounts of lead. The 3M swabs are a reliably test for lead, but as previously stated the amount of lead in GSR that the 3M swabs are testing for are near the limits of what the EPA found the 3M swabs can reliably detect. While no one has measured the amount of lead that deposited on bones from ballistic trauma, it is safe to assume that it is not a lot. It is assumed that the 3M swabs are just at the very limit of being able to reliably test for the lead portion of GSR.

Sodium Rhodizonate spray is classically reliable when it comes to testing for lead, especially when used in conjunction with HCl. It was surprising that its results were not as clear as the 3M tests, and that none of the positive results were able to be confirmed with the HCl spray. During the experiment, the sodium rhodizonate spray was tested on a card that was known to contain lead. The spray worked on the card, but when the follow-up HCl spray was used, an immediate brilliant color change from red to purplish-blue that's normally associated with the interaction of HCl and lead-positive sodium rhodizonate, did not occur. After a few seconds passed, a color change was seen on the lead check card. It is possible that the HCl used during the test was too weak to give proper confirmatory results for the bones. Caution, however, should be used in putting stronger HCl into a spray bottle for a field kit meant to be used in any condition. A stray breeze could prove dangerous to the field kit user, if the strong vaporized HCl from the spray bottle went rogue. Proper PPE would need to be included to protect the field kit user from this happenstance. There is also a chance that the lack of HCl and positive sodium rhodizonate interaction was not due to a weak HCl solution. As mentioned earlier, Gentile's study also had trouble using HCl to confirm a positive sodium rhodizonate test on bones (Gentile et al., 2020). It is possible that the bone medium itself might be causing an unknown problem that's interfering with their normal reaction.

Additionally, the sodium rhodizonate spray seemed to interact poorly with the bone samples due to the fatty residue around the bones. This challenge could be overcome by wiping the sample area more vigorously or by changing the solution itself. Perhaps adding a touch of dish soap could help. Dish soap brands, like Dawn, are used to break up fatty molecules on dishes when rinsed with water. Perhaps a drop of Dawn in the sodium rhodizonate solution could help break up the fatty molecules, allowing the solution a better chance to interact with the lead on bones. This, of course, needs further experimentation to confirm if such an idea works.

Overall, there were a couple of challenges that were common to both test kits. Testing decomposed ribs that had been covered in soil was a clear challenge. None of the preliminary tests involved testing samples that had decomposed or that had been covered in soil for any period of time. The combination of these two factors created a scenario in which the bone's results were difficult to interpret due to the large amount of soil smeared onto the bone and held in place by greasy fat. It is entirely possible that a combination of grease and dirt masked a small quantity of lead on the bone preventing the chemical test from interacting with it. If the test could be repeated, it could be helpful to have the bones decompose in the open air to eliminate the additional level of difficulty that soil and saponification adds to interpreting the chemical lead test results. This solution brings its own challenges because bones decomposing outside naturally attract scavengers that could scatter the bones.

Another recommendation for a future version of this study would be to perform subsequent SEM-EDX analysis on each sample that tested positive. SEM-EDX work is expensive and time consuming, and this study could not afford to test its samples in this manner. SEM's expense is one of the reasons that this study on preliminary test options for GSR on bones was done in the first place. That being said, if this test was fully funded and repeated, it would be highly recommended to analyze each bone that tested positive with SEM-EDX. This would allow for a clearer judgement of how well both preliminary tests worked, giving further points of comparison.

Other future tests could look more closely at how harder organic material interacts with these chemical tests. Not a lot of research literature exits on the subject of how the 3M swab liquid or sodium rhodizonate interacts with bone. Observations from this experiment showed that the spray while covering the bone did not adhere to the bone as well as the direct application of 3M testing liquid. The 3M testing liquid is designed to be used on multiple surfaces ranging from wood to vinyl, while the sodium rhodizonate testing spray is primarily used on clothing, occasionally skin, and paraffin blocks. Perhaps boiled bones (to avoid the rare false positives from marrow) could be shot, and then directly tested to get a better idea of how each chemical test interacts with bone to better understand which chemical test gives a better result.

An additional future test could make use of expert photography. By taking clearer pictures of each bone with proper lighting, a computer program could be used to analyze the pictures for color changes. Instead of relying on people to carefully examine each picture, and potentially making incorrect observations, a computer program could be written that looks for a certain shade of color in each picture. This would help find positive results more quickly and could potentially reduce any bias a researcher might have when looking through the photos for a positive sign.

6. Conclusion

The goal of this experiment was to develop a field kit capable of acting as a preliminary test for GSR on decomposed remains. The field kit is only able to detect lead, a GSR indicative material, making it a good preliminary test. The experiment indicates that it is possible to detect lead on decayed remains using the field kit, but the method needs further refinement. Examination of two different lead testing methods for the field kit, 3M Lead Test swab and sodium rhodizonate, were performed and showed considerable variation in the results. The data shows that more positive results came from the 3M tests. A majority of the 3M test results were positive, while nearly a majority of the sodium rhodizonate test results were negative. It should not be assumed that every rib had enough lead deposited on the bone to be detectable, since a single shot deposits only minute amounts of GSR on bone. Therefore, it is unlikely that every bone would test positive for GSR indicative materials even if more sensitive chemical tests were used. 3M lead check was able to detect lead on 64% of the samples. While this might not sound impressive, but considering it is unlikely that 100% of the bones had lead on them, this percentage is certainly significant. Had this experiment only focused on using 3M lead swabs it would be likely that the overall positive results would have been higher.

3M lead check swabs are much cheaper than developing samples for SEM-EDX testing or hiring a company to do SEM-EDX testing. Refining the 3M kits into proper forensic field kits would be a cheap viable preliminary test that could reduce the amount of samples to be processed through expensive confirmatory test, like SEM-EDX. Not every forensic department has the funds to have a professional forensic anthropologist on staff or have a lab with an SEM-EDX, but they could afford this field kit. Decomposed remains are a complex forensic puzzle, and every hint, even those that come from a preliminary test, can serve the ultimate goal to understanding pre-mortem events and determine cause and manner of death.

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