A COMPARISON OF VACUUM METAL DEPOSITION AND GUN BLUING FOR THE DEVELOPMENT OF LATENT FINGERPRINTS ON FIRED NICKEL-PLATED BRASS AMMUNITION

by

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DEDICATION

This is dedicated to my uncle, Jim Snyder, who supported me all throughout my undergraduate and graduate career- I will never be able to thank you enough.

This is also dedicated to my fiancé, Weifan Wu. Thank you for pushing me to apply to this Master's program and supporting me throughout this insane last semester. There is no one else I would have wanted to go through this with.

Lastly, this is dedicated to my mother who, to this day, still watches awful true crime TV with me when I come to visit.

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ABBREVIATIONS

ACE-V	Analysis, Comparison, Evaluation, Verification
BY40	Basic Yellow 40
CAE	Cyanoacrylate ester
CLPE	Certified Latent Print Examiner
GB	Gun blue/gun bluing
SOP	Standard operating procedure
USSS	U.S. Secret Service
VMD	Vacuum metal deposition

DEFINITIONS

Charged/spiked/groomed	Refers to the application of an extraneous substance (sebaceous oil, eccrine sweat, amino acids etc.) to the finger in order for a donor to deposit a high-quality latent print
Fingerprint matrix	The combination of water, salt, sweat, lipids, and amino acids that are secreted by the skin and form a latent fingerprint
Friction ridge detail	The combination of ridge flow and points of minutiae on the finger
Friction ridge skin	Characterized by alternating ridges and valleys on the fingers, palms, and soles of the feet that improve grip by enhancing the friction between the skin and the surface of an object; form the fingerprint
Latent fingerprint	The unintentional recording of a fingerprint; invisible to the naked eye but can be enhanced
Minutiae	Characteristic ridge detail that individualizes the fingerprint and makes it possible to compare and identify prints

ABSTRACT

Vacuum metal deposition (VMD) is a highly sensitive method for developing latent fingerprints on semiporous and nonporous surfaces with extensive research focusing on various classes of polymers. The relatively high cost of a VMD unit and the need for an experienced operator, has prevented the technique from replacing traditional methods, such as gun bluing, for developing latent fingerprints on spent cartridge casings. A literature review revealed that while VMD has the potential to be a powerful technique in the development of expended cartridge casings, there is a lack of comparison studies between VMD and other latent print development techniques on shell casings. The purpose of this study was to determine if there is a significant difference in the equality of latent fingerprints developed by vacuum metal deposition and gun bluing (GB) on fired cartridge casings. To accomplish this, a single latent print spiked using a sebaceous oil reference pad was deposited on 250 9mm nickel-plated brass ammunition samples and developed by either VMD or GB. From these 250 casings, 50 were treated in a brief preliminary study that subsequently guided the gun bluing process. As a result, a modified gun bluing protocol using a 20% Brass Black (Birchwood Casey, Texas, USA) solution was followed to process 100 casings while the remaining 100 were subjected to silver/zinc deposition in the VMD560 (West Technology Forensics, England, UK). All casings were photographed, examined, and graded on a 0-4 scale by a Certified Latent Print Examiner. Of the 200 casings developed, 115 samples failed to yield any ridge details (Grade 0) with 54.78% having been developed by VMD. There was limited ridge detail (Grade 1) present on 62 samples with comparable results from both techniques. Low quality detail (Grade 2) was visualized in 23 samples with 86.96% having been produced by GB. Using the Kruskal-Wallis H test with a 90% confidence level to determine statistical significance, the primary hypothesis that VMD would be the superior method was not supported. Therefore, it is recommended that nickel-plated brass casings be processed using the modified GB protocol.

Keywords: *Forensic science, fingerprints, latent fingerprints, vacuum metal deposition, gun bluing, cartridge casings, firearms*

I. INTRODUCTION

I.I. Biological aspects of fingerprints

Latent fingerprint examination and identification is based upon three premises: fingerprints are persistent, unique, and classifiable. Skin is composed of three layers: the epidermis, dermis, and hypodermis. The outermost layer, the epidermis, consists of five layers of tissue: the stratum corneum, stratum lucidum, stratum granulosum, stratum spinosum, and stratum basale. It is the bottom layer of the epidermis, or basal layer, that gives rise to the friction ridge skin that forms the fingerprint by acting as a blueprint. An undulating layer of cells at the basale layer, known as dermal papillae (**Fig. 1)**, provides structural support for the protrusion of friction ridges (Monson et al., 2019). Friction ridge skin is characterized by alternating ridges and valleys on the fingers and palms that improve grip by enhancing the friction between the skin and the surface of an object. The stratum basale also contributes to the persistency of fingerprints, as any wounding of the friction ridge skin will not permanently alter the friction ridges as long as the damage incurred does not reach this bottom layer.

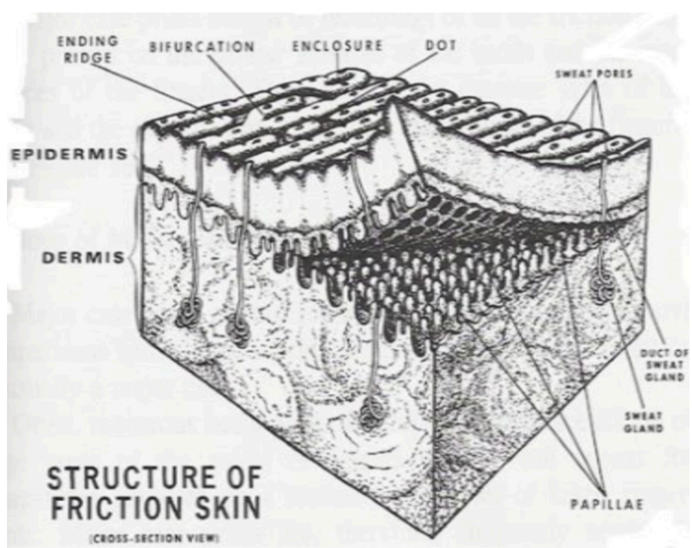

***Figure 1**. A cross-section of friction ridge skin (Mazumdar, 2014).*

The uniqueness of fingerprints stems from differential growth of the palmar and plantar volar pads during fetal development. The term "differential growth" refers to the random forces that act upon the developing ridge field during gestation. Between seven and eight weeks gestation, human fetuses develop swollen volar pads on the fingers, palms, and soles of the feet. Slight differences in genetics, mechanical stress, and timing of ridge development influence the exact location of minutiae points as the volar pads begin to exhibit ridge details. Due to the sporadic nature of these forces, and the areas upon which they act at a given moment, the patterns produced during friction ridge development are considered unique. Between 11 and 16 weeks of gestation, the swollen volar pads regress as the friction ridges continue to grow. The timing of events that occur during fetal development are assumed to have never been repeated between two individuals, thus, two individuals have never been recorded to have identical fingerprints.

There are three broad categories of fingerprints that allow for initial classification: loop, arch, and whorl prints. One can determine the pattern of a fingerprint by examining the core, or center, of the print as well as the delta, which is the triangular point where ridges diverge. Loop fingerprints will have both a core and a single delta. Whorl prints will have at least two deltas and arches will have no delta and no core. Beyond this initial classification, there are several subcategories of fingerprints that stem from these three possible patterns which further aid in analysis (**Fig. 2**).

Figure 2. *Fingerprint patterns. Top row (L to R): loop, double loop, central pocket loop. Bottom row (L to R): plain whorl, plain arch, tented arch. This list is not all-inclusive. (Hoover, 2016).*

Besides the core and delta, there are several unique characteristics, which result in a near-infinite combination of friction ridge detail. Within the print are many points of minutiae- the ridge detail that individualizes the fingerprint and makes it possible to compare and identify prints. Common minutiae points include bifurcations, ridge endings, ridge dots, lakes, spurs, and short ridges (**Fig. 3**). The spatial relationships between two, or more, points of minutiae are paramount in fingerprint identification.

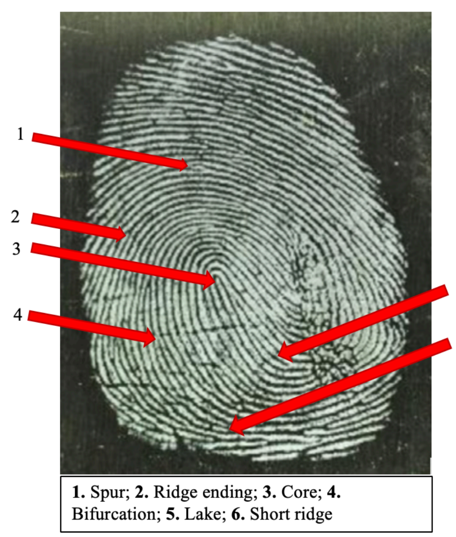

Figure 3. *An example of common minutiae points (Girelli et al., 2018).*

Upon touching a surface with an ungloved hand, the raised friction ridge skin of the finger leaves behind an impression created by the water, salt, sweat, lipids, and amino acids that are secreted by the skin. These residues are collectively referred to as the "fingerprint matrix." This unintentional recording of the friction ridge skin is known as a latent fingerprint and while it is invisible to the naked eye, it can be visually enhanced for examination and possible comparison.

I.II. Latent print examination

To determine the source of a latent fingerprint, examiners follow ACE-V methodology: analysis, comparison, evaluation, and verification. In the analysis stage, an examiner must assess the general ridge flow, the spatial relationships of visible minutiae points, and determine the orientation of the print. Examiners must also judge the quality and clarity of the print to determine if it is suitable for comparison. If the print is determined to be of value, then the examiner may begin side-by-side comparisons, to either another latent print or a record print, to determine if the details in both fingerprints are in agreement based on ridge flow, minutiae points, and spatial relationships.

In the evaluation stage, the examiner will reach one of three possible conclusions: the prints came from the same source (identification), the prints did not come from the same source (exclusion), or there is insufficient information in either the known or unknown print to make a determination (inconclusive). The final step in the ACE-V method is verification. A second examiner will repeat the ACE process and make a conclusion. Ashbaugh 1999 summed up the latent print examination process with his friction ridge identification philosophy: "Friction ridge identification is established through the agreement of friction ridge formations, in sequence, having sufficient uniqueness to individualize."

I.III. Recovering latent fingerprints on spent shell casings

In firearms-related crimes, expended cartridge casings can provide a wealth of information particularly if an examiner is able to develop the latent fingerprints of the individual who loaded the weapon. However, with the extreme physical changes a cartridge undergoes during discharge, fingerprints are exceptionally difficult to recover. A very common weapon recovered in firearms-related crimes is the 9mm handgun as it is relatively lightweight and easy to conceal. During the firing process of a semiautomatic gun, the trigger of the gun is pulled, releasing the hammer. The hammer then strikes the firing pin, which in turn strikes the primer cap on the cartridge. The striking of the primer cap initiates the burning of smokeless powder, which produces gas, and pressure as it burns. This gas pushes the bullet out of the casing and through the barrel before exiting out of the muzzle. After firing, the recoil generated by the fired cartridge moves the slide backwards, the ejector causes the cartridge to collide with the breechblock, and the spent cartridge casing is ejected from the gun. The compressed recoil spring drives the slide forward, pulling a new round form the magazine into the chamber.

Latent fingerprint visualization methods can placed in three general categories: methods that react with the residual fingerprint matrix, those that deposit a substance in between the ridges of the latent print, and those that involve some type of reaction with the surface of the substrate rather than the print itself (Najdoski, Oklevsi, and Stojkovis, 2015). Black powder dusting is a common technique for recovering latent prints on non-porous surfaces, especially those that are immobile. The black powder visualizes the print by adhering to the fatty and aqueous components in the fingerprint matrix and, thus, falls under the first category of techniques. While black powder works well on relatively fresh latent prints, the firing process destroys much of what would allow the powder to adhere to the print.

As mentioned, the options for developing latent fingerprints on expended casings are limited due to the explosive nature of firing. Therefore, most development techniques fall into the latter two categories: substances that deposit into the furrows of the print and reagents that undergo a chemical reaction with the surface of the substrate and enhance the background of the print. Two such techniques that could be used on cartridge casings are gun bluing and VMD.

I.III.I. Principles of gun bluing

Gun bluing solutions contain water, cupric sulfate, and nitric and selenious acids. Selenious acid is an oxidizing agent used to blacken various metal surfaces; however, it has also proven effective in the development of latent prints on ballistic metals. While volatile compounds are evaporated during firing, molten salts within the print corrode the surface of the shell casing and prevent the oxidation reaction (**Fig. 4**) from occurring at the same rate as the background. The result is a reverse fingerprint- the ridges of the print will remain unchanged while the background and furrows between ridges begin to darken because of the oxidation process.

Oxidizing reaction: $H_2SeO_3 + 4H^+ + 4e^- \rightarrow Se + 3H_2O$

Figure 4. *The oxidizing reaction of gun bluing (Morrisey, Larrosa, and Birkett, 2017).*

A process known as cyanoacrylate ester (CAE) fuming may be performed prior to the application of gun bluing. In a sealed fuming chamber, a small amount of cyanoacrylate- colloquially referred to as Superglue- is heated to approximately 130°F. The vapors released by the heated Superglue contain polymerized cyanoacrylate that adhere to the residues left behind by the friction ridges. A container of water inside the fuming chamber ensures that the humidity of the system reaches the desired 70-80%. This relatively high humidity is needed to initiate the polymerization process and will improve the quality of superglued prints by effectively “re-hydrating” latent fingerprints. Superglued fingerprints will take on a white, crusty appearance.

Though the sequential processing of shell casings using CAE followed by gun bluing is a common method among law enforcement laboratories, recent research is split on its effectiveness with some arguing that gun bluing as a singular process produces higher quality results. However, the sporadic results produced by gun bluing- either sequentially or alone- may be due to the inconsistency in the brands and concentrations used (Morrisey, Larrosa, and Birkett, 2017).

I.III.II. Principles of VMD

Vacuum metal deposition (VMD) is a highly sensitive method for developing latent fingerprints on semiporous and nonporous surfaces with current literature focusing on various classes of polymers. While the system has shown great potential in past research, the relatively high cost of a VMD unit has prevented it from replacing traditional methods.

In VMD, a small amount of metal is heated in a foil boat to the point of evaporation. The atoms are then freed to travel in the chamber's airspace, in a linear direction from the source boat, until the atoms reach a surface upon which to deposit. A vacuum pressure of $2.0*10^{-4}$mbar is required inside the chamber to prevent the metal atoms from colliding, or reacting, with any extraneous molecules. Generally, the initial metal deposition is either pure gold or pure silver, dependent upon the surface to be coated. The deposition of gold results in an incredibly thin layer, which is typically only visible on some porous surfaces such as paper. In contrast, a silver layer is visible to the naked eye and development is monitored in real-time through the viewing window. It should be noted that a gold layer cannot be over-deposited while a silver layer can be, so constant monitoring is required to prevent over-processing when performing a silver deposition.

When applying the initial layer, the metal will coat the surface uniformly as the atoms form agglomerates on the surface; however, areas containing residual fingerprint matrix will develop at a slower rate. An initial layer of gold requires a second deposition with pure zinc while silver can be enhanced by zinc deposition but it is not always necessary. Zinc atoms will preferentially deposit on the agglomerates that were formed by the first layer of gold or silver, further enhancing the background of the latent print. The result is a reverse print- the furrows of the latent fingerprint and the background of the surface will be coated in metal, leaving the friction ridge impressions untouched.

I.IV. Importance of this project

Though VMD has demonstrated success in a limited number of trials, a literature review revealed a lack of comparison studies between VMD and other latent print development techniques on cartridge casings, particularly on nickel-plated brass. With expelled cartridge casings providing such a high level of probative value if recovered from a crime scene, can VMD produce higher quality latent fingerprints than traditional methods? The primary objective of this study was to compare prints developed on fired 9mm nickel-plated brass cartridge casings developed using VMD to those developed following a gun bluing protocol using Brass Black. While it should be noted that no casings, regardless of development technique, were expected to produce identifiable latent fingerprints, a secondary objective of this study was to gain insight into how much detail within a latent fingerprint could survive the firing process. The results of this project could be used as a guide local and federal law enforcement agencies in the processing of fired nickel-plated brass ammunition recovered from crime scenes. The methodology of this study could also be used to guide future comparison studies.

II. REVIEW OF RELEVANT RESEARCH

II.I. Introduction

The goal of this literature review is to provide fundamental knowledge regarding the principles of both vacuum metal deposition and gun bluing and their application in the development of latent fingerprints. Any research limitations will be discussed as well as possible future directions of each study. Furthermore, the lack of comparison studies between VMD and gun bluing will be highlighted and serve as justification for the overall research project.

Due to a gap in research, there are very few studies, currently, that focus on the processing of cartridge casings using the aforementioned methods, especially VMD. No projects were found to have examined nickel-plated brass ammunition, specifically; therefore, studies focusing on brass casings were reviewed to guide this project.

II.II. VMD for the development of latent prints on cartridge casings

Researchers G. Christofidis, J. Morrissey, and J. Birkett (2019) published *A preliminary study on vacuum metal deposition as a standalone method for enhancement of fingermarks on ballistic brass materials* in the Journal of Forensic Sciences' March 2019 issue. In this study, the authors conducted a preliminary study on flat, brass surfaces and subsequently examined 20 fired brass cartridge casings, each containing a single groomed fingerprint. Christofidis et al. (2019) focused primarily on three variables: the gender of the fingerprint donor, the effect time between deposition and firing may have on development, and different metal deposition processes.

The gender component of this study is particularly interesting since it has been argued that male donors have a higher concentration of lipids and fatty components in their fingerprint residue when compared to that of a female donor (Christofidis et al. 2019). Therefore, in their preliminary study, the authors had each of the six donors- three male and three female- deposit 12 groomed fingerprints across two clean brass plates, for a total of 24 plates per donor. For accurate comparison between the techniques, the authors performed a split-print analysis comparison by cutting the plate so that one-half of the print could be treated with gold/zinc and the other half with silver/zinc. Collecting prints in such a way ensures that the same conditions- fingerprint mixture and deposition pressure- are the same for the fingerprint and allows for side-by-side comparison. The 24 plates per donor were divided into four groups and allowed to age in dark, dry conditions for two, seven, 14, or 35 days. The samples were treated with either gold/zinc or silver/zinc in the VMD900 metal deposition system from West Technology.

Based on the results of the preliminary study, the researchers opted to develop the brass cartridge casings with silver/zinc and use four donors- two male and two female- for the primary experiment. After cleaning the cartridges with a 5% v/v Decon 90 solution and ethanol, each participant placed a single spiked fingerprint on five cartridges, for a total of 20 ballistic samples. After five days, the cartridges were then loaded into a .38 Smith and Wesson revolver, the revolver was fired, and the spent shell casings were collected. The casings were subjected to silver/zinc deposition and all developed prints (including the prints from the preliminary study) were graded on a 0-3 scale, with 0 indicating no ridge detail development and 3 indicating the development of identifiable ridge detail with clear characteristics. A second latent print examiner performed independent grading.

In the preliminary study using flat, brass plates, the male donors generally produced more identifiable prints than the female donors. Interestingly, one female donor produced no identifiable marks on the two, seven, and 14-day old samples, but produced a grade 2 print on the 35-day-old sample. This indicates that a fresh fingerprint may not always develop better than an older mark when utilizing VMD. Though the researchers chose to use silver/zinc deposition in their primary study, a Mann-Whitney test determined that there was no significant difference in the quality of prints developed with either gold/zinc or silver/zinc on the brass plates. Furthermore, out of 20 cartridge casings only four produced any evidence of touch, three of which displayed limited second level characteristics when enhanced. A limitation in this study was the availability of the firearms service that provided ballistic support, resulting in the 5-day gap between print deposition and firing, which may have allowed prints to degrade prior to discharge. This time gap should be shortened in future studies.

A research article titled, “The Capability of Forensic Vacuum Metal Deposition for Developing Latent Fingermarks on Fired Ammunition: A Preliminary Study Comparing Alternative Metal Processes” was conducted and written by Eleigh R. Brewer of West Technology Forensics and published in the July-September 2019 edition of the Journal of Forensic Identification. In this article, Brewer examined vacuum metal deposition (VMD) to determine its potential in the development of latent fingerprints on fired shotgun and rifle ammunition.

For the experiment, Brewer selected two firearms- a rifle and a shotgun- along with Winchester brass cartridges and Gamebore 12-guage cartridges. She divided the study into four experiments where each weapon would fire cartridges with both spiked and natural fingerprints. She used a single donor through the study to ensure that prints were deposited with comparable pressure. She described the steps the donor took before, during, and after each individual deposition for both the natural and charged samples. For each firearm type, 60 cartridges were fired, allowing 10 cartridges per process for the six metal sequences evaluated including a set of five natural and five spiked prints. She also described the aging process for samples as it relates to her study. For her control sample, she ran a white paper square containing a single charged fingerprint alongside the cartridge casings inside the VMD chamber.

Brewer described how the developed prints were graded following each process and stated that a fingerprint identification expert provided an independent review of the grades assigned to each print. This ensured confidence in the accuracy of this study and its translation into operational use. She acknowledged that while all metal processes developed some quality of ridge detail, gold was the best metal for developing brass casings but was least successful on the plastic shotgun casings and vice-versa was true for aluminum/zinc deposition.

Overall, this project functions well as a preliminary study that leaves several potential directions for future research. However, due to the use of a single donor, the small sample size, and the lack of repeated trials it cannot be said that this study entirely fills the gap in research the author initially identified. Further studies should include more metal processes, samples, donors, and trials as well as ammunition of varying composition and statistical analysis.

II.III. Gun bluing for the development of latent prints on cartridge casings

In 2015, Girelli et al. published *Comparison of practical techniques to develop latent fingermarks on fired and unfired cartridge casings* in Forensic Science International. The authors compared seven development techniques on fired and unfired 9mm cartridge casings and included an aging component as well. The seven processes, and their relevant application sequences, were:

- Cyanoacrylate fuming and regular powder dusting
- Cyanoacrylate fuming and magnetic powder
- Cyanoacrylate fuming and gun bluing
- Cyanoacrylate fuming and Basic Yellow 40 (BY40)
- Gun blue solution only
- Acidified hydrogen peroxide using glacial acetic acid (AHP1)
- Household vinegar (AHP 2)

The controls used in this study were 21 live 9mm rounds. These rounds were cleaned and received natural (i.e. neither spiked nor charged) fingermarks deposited by a single donor who washed their hands 20 minutes prior to deposition. These control samples were processed at the same time intervals as the experimental casings (24 hours, seven days, and 14 days). A total of 500 cartridges were "naturally" spiked by having donors load the firearms with ungloved hands while taking no special care during loading. Expended casings were collected using gloved hands and plastic tweezers. The researchers graded their results using Bandey's grading scale but modified the scale to assign a heavier weight to ridge detail located beyond the casing's base.

For the fired casings, each of the seven techniques were used to develop sets of 20 for each of the three time intervals for a total of 380 processed casings. Of these 380 casings, none displayed detail greater than, or equal to, Grade 2 on Bandey's scale. These poor results were attributed to the firing process during which the expansion of the cartridge maximizes friction between the casing's surface and the barrel's chamber (Girelli et al., 2015). Bandey's grading scale scores a print based on the total "area" of detail that developed. For example, a print exhibiting roughly 1/3 of detail would receive a grade of 2 but would not be considered identifiable. The sequential method that displayed the most consistent results was determined to be CAE, GB, and BY40 after the researchers applied this sequence to the CAE+ GB processed casings. Gun bluing produced better results than AHP 1, AHP 2, CAE followed by regular powder dusting, and CAE followed by magnetic powder dusting.

Morrissey, Larrosa, and Birkett (2017) examined 45 fired and 45 unfired 9mm brass Luger casings using three techniques- cyanoacrylate fuming followed by BY40, cyanoacrylate fuming followed by gun bluing, and gun bluing as a standalone technique. A single donor provided natural fingerprints for both the fired and unfired samples, though the donor alternated between two fingers. It is unclear how much time passed between deposition and firing but all casings, both unfired and fired, were processed within 12 hours. A 50% solution of Birchwood Casey Perma Blue and distilled water was used for the gun bluing protocol while the researchers followed CAST guidelines for CAE and BY40.

Each method was tested on 15 casings and development was graded on a 0-3 scale dependent upon minutiae and the ability to determine fingerprint pattern. Out of the fired casings examined, gun bluing alone produced the highest quality results with 60% of fingermarks scoring a grade of 3. CAE followed by gun bluing produced the worst results with 53.3% scoring a grade of 1 and 46.7% scoring a 0. It should be noted that the authors suggest that the casings processed with CAE may benefit from the use of a lighter fuming cycle (Morrisey et al., 2017).

In 2018, Girelli et al. extended their 2015 study and evaluated different fingerprint developers on naturally handled brass casings. The study also simultaneously examined the effects of time on latent print development by aging the casings post-firing for 24 hours, 7 days, and 14 days. The developers, and their application sequences, examined were:

- Cyanoacrylate fuming, gun blue, and basic yellow 40
- Cyanoacrylate fuming, gun blue, and ardrox
- Deposition of Prussian blue films
- Coating by electrolytes containing potassium permanganate and sodium bicarbonate

A total of 240 9mm brass casings were collected post-firing and separated into 12 sets of 20 samples, ensuring that every combination of aging interval and development method was evaluated. All results were graded on a 0-4 scale based upon the percentage of ridge detail developed. Girelli et al. 2018 determined that of the four possible development techniques, the application of cyanoacrylate fuming, gun blue, and fluorescent dye developed the best latent prints on the expended casings with ardrox and basic yellow 40 producing similar results (**Fig. 5**). In contrast, the application of potassium permanganate and sodium bicarbonate yielded the worst results and similar results were obtained by depositing Prussian blue film.

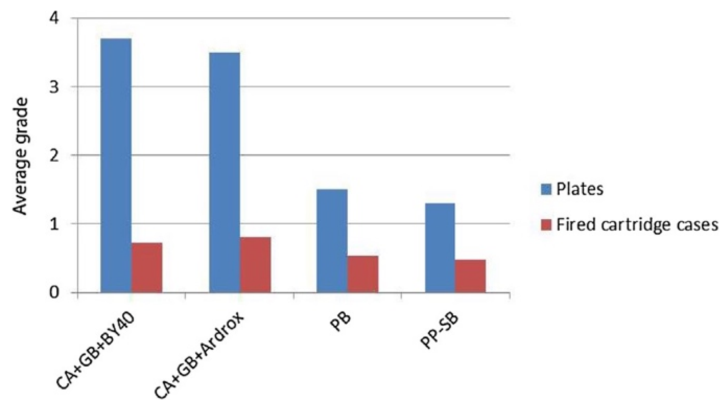

Figure 5. *Summary of results obtained by Girelli et al. (2018).*

Furthermore, Girelli et al. 2018 detailed the effects of firing on the expended casings by considering certain parameters such as bullet mass, muzzle velocity, and the length of the gun's barrel along with the visual examination of the effects of firing on latent prints. In this study, three donors prepared 15 cartridges each, including five cartridges with sebaceous prints, five with eccrine prints, and five natural, un-spiked prints. All 45 casings were collected and processed using cyanoacrylate fuming, gun bluing, and BY40. The results demonstrated that prints deposited near the base of the cartridge were less damaged with a clear phase separating the quality of ridge development (**Fig. 6**).


Figure 6*. An image from Girelli et al. 2018 depicting the zone of highest quality development near the base of the cartridge casings.*

The results of this study demonstrated that Prussian blue film and the application of potassium permanganate and sodium bicarbonate do not develop high quality latent prints on fired brass ammunition. While sequential processing with cyanoacrylate fuming, gun blue, and a fluorescent dye stain developed higher quality ridge detail, the average score for this process still fell below level 1 on the researchers' 0-4 scale. The researchers also determined that the blowback of hot gases during the firing process is the main source of damage to the fingerprint, resulting in distortion and destruction of ridge detail. Although the firing process is responsible for the majority of fingerprint deterioration, the data concluded that naturally handled shell casings generally produce poor results, likely due to the small surface area of the 9mm cartridge. This suggests that the firing process alone is not entirely responsible for the destruction of prints, leading to the variability of latent development.

The only limitation noted by the authors of this article reminds the reader that the use of sebaceous compounds in the laboratory trials does not necessarily represent a natural fingerprint deposition, as the skin on the fingers does not contain sebaceous glands, only eccrine. However, it is also important to acknowledge that sebaceous compounds are naturally deposited in fingerprints, in varying concentrations, due to the propensity of individuals to touch greasy body parts, especially their faces. Based on the results of this study, future comparison studies must be conducted to determine a more optimal method of latent print development. Further studies should also examine the effect of other external factors to simulate evidentiary ballistic samples. The study by Girelli et al. 2018 further justified the use of gun bluing in the current VMD comparison study as opposed to Prussian blue and potassium permanganate and sodium bicarbonate application.

III. MATERIALS AND METHODS

III.I. Ballistic support

Primarily, this project required 250 9mm nickel-plated brass cartridges. To obtain the necessary samples, two licensed DHS firearms instructors at the U.S. Customs and Border

Protection's Advanced Training Center in Harpers Ferry, West Virginia provided ballistic support on January 31, 2020. CBP provided 250 Winchester Luger 9mm JHP nickel-plated brass cartridges and all firearm handling for this study. While wearing latex gloves with a single finger exposed, the finger was charged on a sebaceous oil latent print reference pad (EVIDENT, Virginia, USA) and then rolled nailbed-to-nailbed on the cartridge casing. The result was a single spiked latent print covering approximately one-half of the casing's surface, oriented with the tip of the finger toward the tip of the cartridge and the base of the finger toward the primer cap. The finger was wiped on a clean kim wipe after each placement and was re-charged prior to laying the next print.

A Glock 19 Gen 5 MOS handgun was used by CBP personnel to fire the rounds, after which the Ammo-Up 18-Inch Brass Collector was used to collect the expended shell casings. While wearing latex gloves, the casings were transferred to 36-grid plastic organizer bins. The grids were equipped with wooden pegs so that the casings were held upright to prevent collision with the grid walls during transport and storage. Each grid was labeled sequentially and with what process the casings would be subjected to.

III.II. Fingerprint development techniques

III.II.I. Preliminary testing of gun bluing procedures

Brass Black (Birchwood Casey, Texas, USA) was chosen for use in this project based on U.S. Secret Service (USSS) standard operating procedure (SOP) for processing nickel-plated brass ammunition. Based on prior research by Girelli et al. 2018, the sequential processing of casings using cyanoacrylate ester (CAE) fuming, gun bluing, and a dye stain yielded superior results compared to CAE and gun bluing alone. Initially, 100 casings were to undergo sequential treatment with CAE, gun bluing, and dye staining. However, since this does not coincide with current laboratory protocol, a brief preliminary study was carried out to guide the processing of casings using this new gun bluing procedure. For this project, 250 casings were collected with the intention of reserving 50 casings for preliminary testing. Following laboratory protocol regarding the processing of nickel-plated brass ammunition, 24 of the excess samples were lightly fumed in an MCV3000 fuming chamber. The casings were loaded onto two custom racks- containing six hooks each. A section of a latent print card containing a single spiked latent print served as a standard and function check of the CAE fuming process. An aluminum weigh boat was filled with a quarter-sized dollop of Turbo Fuse Instant Bonding Adhesive and distilled water was added to the water reserve, if necessary. The chamber was ran on autocycle consisting of a 15-minute humidity cycle, a 10-minute fuming cycle, and a 20-minute purge cycle. Superglued casings were further processed by submerging the samples in a 10% solution of Brass Black in water. The full gun bluing procedure will be discussed in Section III.II.II.

Basic Red and Basic Yellow 40 dye stains were prepared using a digital scale, weigh boats, and ethanol and applied to casings using a plastic dropper. To compare dye stains, half of these samples were stained with BY40 while the other half were dyed with Basic Red. The stained casings were viewed under 445nm and 495nm light sources, respectively, using a CrimeScope CS-16-400. An additional five of the excess samples were not treated with CAE and instead were placed directly in a 30% solution of Brass Black. To achieve optimal development, the 30% solution was reduced to 20% and five more samples were processed. The results of this preliminary testing did not support the sequential processing of CAE, gun bluing, and dye staining and, therefore, only the gun bluing procedure was used.

III.II.II. Modified gun bluing procedure

The 20% Brass Black solution was prepared in a 50mL glass beaker by first adding 8mL of Brass Black to the beaker and then filling the beaker with tap water to the 40mL line. A single casing was processed at a time by submerging the casing in the solution using plastic tweezers. Since the solution required constant agitation, it was stirred with the plastic tweezers for the duration of development. The casing was submerged until the surface of the casing began to blacken. Once this reaction started, the casing was removed and immediately submerged in a beaker of clean tap water to halt the development process. Development is sporadic and variable; therefore, it is not necessary to time the reaction or submerge the casing for a set amount of time (Cantu et al., 1998). Once the reaction was stopped, the casing was then allowed to air-dry. Once dried, the casings were transferred back to their corresponding grids in the plastic organizer box.

The solution was emptied and replaced every five to six samples, depending on the cloudiness of the used solution. To test the solution, a fired 9mm nickel-plated brass cartridge casing- not selected from the experimental samples- was spiked with a latent print and processed for each new batch of solution made.

III.II.III. Vacuum metal deposition

The same two six-capacity casing holders that were used in the CAE process were also used in the VMD560 (West Technology Forensics, England, UK) chamber. Each holder was loaded with five experimental casings while a single standard was loaded onto one of the hooks. The holders were attached to the ceiling of the evidence holder inside of the chamber using two magnets, each. The casings were positioned directly above and parallel to the front evaporation source.

For the silver/zinc process, a 2mm-long, 0.5mm diameter, silver wire of 99.9% purity was loaded into the third source boat and a single 250g zinc shot was loaded into the second (**Fig. 7**). When the chamber reached the correct pressure of $2.0*10^{-4}$mbar, the development process was started. To deposit the silver layer, the third boat, which contained the silver wire, was selected on the LCD touch screen and the current control knob was then slowly turned clockwise to begin heating the source boat. During silver deposition, the samples were constantly monitored until very faint fingerprint development was observed. To deposit the zinc layer, the second source boat was selected and, again, the control knob was slowly turned to heat the source boat. Due to the propensity of the zinc to "jump" out of the boat when it is heated too quickly, the zinc was monitored until it melted down. Once deposition was deemed sufficient, the current was shut off and the chamber was vented. Because of the behavior of molecules in a vacuum, three-dimensional objects must be rotated in order to process all sides. Therefore, each casing was carefully rotated 180 degrees and re-processed following the same procedures described above. Once complete, the casings were transferred back to their respective plastic grids for storage.

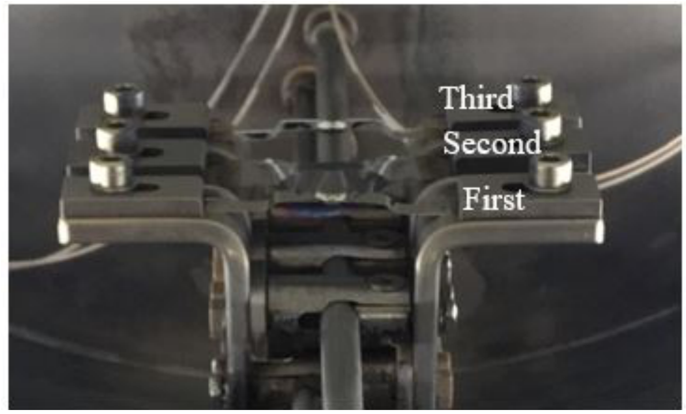

***Figure** 7. Evaporation source boats inside the VMD chamber. The evaporation source contains three smaller source boats- the first, second, and third boats.*

III.III. Photography

All 200 casings were photographed with a scale indicating the sample number, process, date of photograph, and initials of photographer. Photographs were taken with the Nikon D750 DSLR camera with a Nikon AF-S Micro Nikkor 60mm 1:2.8G ED lens. A Kaiser Copy Stand with an RA-1 arm was used to stabilize the camera and a Grip-It from Delta Photo Supplies was used to hold the casings.

All VMD samples were photographed using manual focus, an f-stop of F-11, an ISO of 100, and a 2.5" shutter speed with overhead fluorescent lighting. All gun bluing samples were taken using manual focus, F-11, ISO 100, and an 8" shutter speed. Furthermore, a black hood was used on the lens to block overhead light and prevent glare. All photographs were saved in JPEG format and digitally numbered and the single best photo of each casing was selected for scoring. All editing, including enhancing contrast, brightening shadows, and auto-toning, was done in Adobe Photoshop CC 2018.

III.IV. Print scoring

All fingerprints were graded to compare the quality of VMD and gun bluing and illustrate any differences. All cartridge casings were graded on the 0-4 scale described by **Table 1** below and a Certified Latent Print Examiner (CLPE) lent their expertise to provide a secondary score to each print. For statistical purposes, the scores assigned by the CLPE were used.

Table 1*. A summary of the grading scale used to evaluate latent fingerprint quality.*

GRADE	DESCRIPTION
0	No print development, no ridge detail present. Sample may have been over-processed.
1	Limited ridge detail may be present, but minutiae points are not visible and overall print pattern cannot be determined.
2	Low quality development, ridge flow is discernable and individual minutiae points are visible; could potentially be used for exclusionary purposes; beneficial but not "of value"
3	Moderate quality ridge detail is developed; overall pattern is discernable, but quality may be reduced due to poor contrast and/or voids in the print
4	High quality ridge detail is developed; ridge shape, direction, and spatial relationships are visible; minutiae points are crisp and clear; print is potentially identifiable

III.V. Data analysis and interpretation

The data is considered non-parametric and categorical thus the Kruskal-Wallis H test was chosen to interpret the results of this study as normality could not be assumed. However, to prove the data was not normally distributed, a Shapiro-Wilk test was performed. Nonparametric tests are conducted on ranked data and require the conversion of values to ranks, with the smallest value ranked as '1' (McDonald, 2014). The Mann-Whitney U test would normally be preferable for the comparison of two groups, but due to the varying ways software packages handle "tied" ranks, it was not selected. A statistically significant result would indicate that the difference in development between VMD and GB samples was not due to chance, but rather due to one process being superior.

$$H = \left[\frac{12}{n(n+1)} \sum_{j=1}^{c} \frac{T_j^2}{n_j} \right] - 3(n+1)$$

Figure 8. *The equation used to calculate the H statistic.*

The Kruskal-Wallis H test was used to determine if there is a significant difference in the development by VMD compared to GB by comparing the medians of each sample set (H_0= The medians are equal; H_1=The medians are not equal) at a significance of 0.10. The calculation for the H statistic where 'T_j' is the sum of the ranks in the 'j^{th}' sample (**Fig. 8**).

IV. RESULTS

Following the grading of the 200 images, a Certified Latent Print Examiner from the United States Secret Service's Fingerprint Laboratory provided secondary review. Generally, if individual minutiae were observed, only one point was seen (**Fig. 9**). The grades assigned by the CLPE were used for statistical analysis and interpretation. **Table 2** contains the overall results of the study; refer to **Tables A1** and **Table A2** in Appendix A for complete data tables.

Figure 9. *A visual of how casings were graded using Table 1 in Section III.IV.*

Vacuum metal deposition failed to develop any latent fingerprint in 63 out of 100 casings compared to gun bluing, which failed to develop latent prints on 52 casings. The development of Grade 1 latent prints was comparable between VMD and GB with 34 and 28 casings, respectively. The starkest difference between the two development processes was for Grade 2 prints with VMD developing three prints and GB developing 20. Neither VMD nor GB developed latent prints that scored above Grade 2 and no identifiable latent prints were developed by either method.

Table 2. *A summary of the scores assigned to all 200 shell casings by the CLPE.*

Enhancement Method	Grade 0	Grade 1	Grade 2	Grade 3	Grade 4
VMD	63	34	3	0	0
GB	52	28	20	0	0

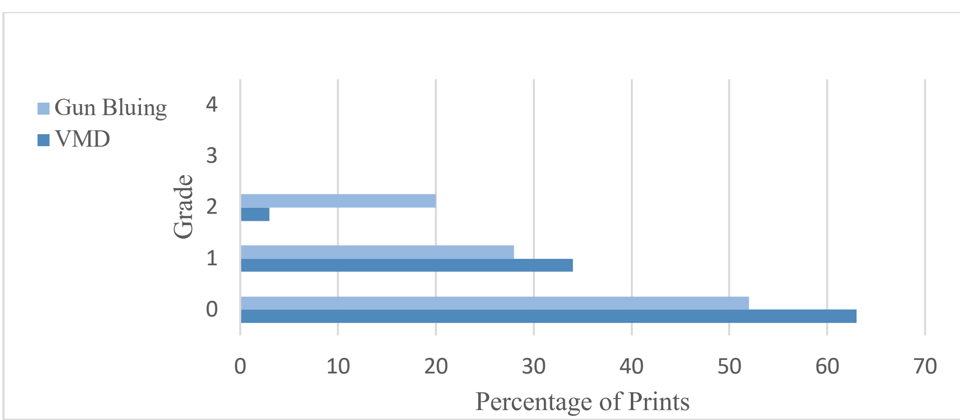

Figure 10. *A graph comparing the CLPE scores for VMD versus GB.*

The results in **Table 2** are further visualized in **Figure 10** above. Prior to performing the Kruskal-Wallis test, both data sets for VMD and GB were analyzed using the Shapiro-Wilk Test for Normality. Because the conversion of data to "ranks," as is necessary with the Kruskal-Wallis test, will inevitably result in a loss of data, a One-Way ANOVA or independent samples t-test is normally preferred. However, the independent samples t-test does not handle deviations from normality and therefore is only recommended for data that is normally distributed (McDonald, 2014). The results of the Shapiro-Wilk Test (**Table 3**) showed that the data was, in fact not normally distributed, so the Kruskal-Wallis test was deemed appropriate.

Table 3. *Results of the Shapiro-Wilk Test for Normality.*

Shapiro-Wilk Test

	VMD	GB
Mean	0.4	0.68
Median	0	0
b	4.459833	6.782759
W-stat	0.663004	0.744913
p-value	8.06*10^-14	6.88427*10^-12
alpha	0.1	0.1
Normal?	No	No

To illustrate the difference between the two processes, the scores for VMD and GB were ranked for comparison using the Kruskal-Wallis H test. Refer to **Table A3** and **Table A4** in Appendix A for complete data tables.

Table 4. *The ranked sum values calculated using the Kruskal-Wallis test.*

VMD	GB
$T_1 = 9202$	$T_2 = 10898$
$n_1 = 100$	$n_2 = 100$

The Kruskal-Wallis test was conducted to compare the ranked sum of the 100 casings treated with silver/zinc deposition in the VMD560 (T_1=9202) to that of the 100 casings processed via gun bluing (T_2= 10898) (**Table 4**). The *H* statistic (**Table 5)** was calculated as 4.2932 and the resulting p-value of 0.03827 was statistically significant at $p < 0.10$. Therefore, the null hypothesis (H_0) was rejected; there is a difference in the quality of latent fingerprints developed by vacuum metal deposition in comparison to gun bluing with Brass Black.

***Table 5**. Calculation summary of H statistic.*

Calculation Summary
H = (12/(N(N+1)) * (∑T^2/*n*) - 3(*N*+1)
H = 0 * 2034432.08 - 603
H = 4.2932

V. DISCUSSION

Many casings processed with both techniques exhibited the same "zone of development" at the base of the cartridge, near the primer cap (**Fig. 11**) which was described in Girelli et al. (2018). Interestingly, this zone on the VMD-processed casings did not always contain higher quality development while the opposite was true for gun-blued casings.

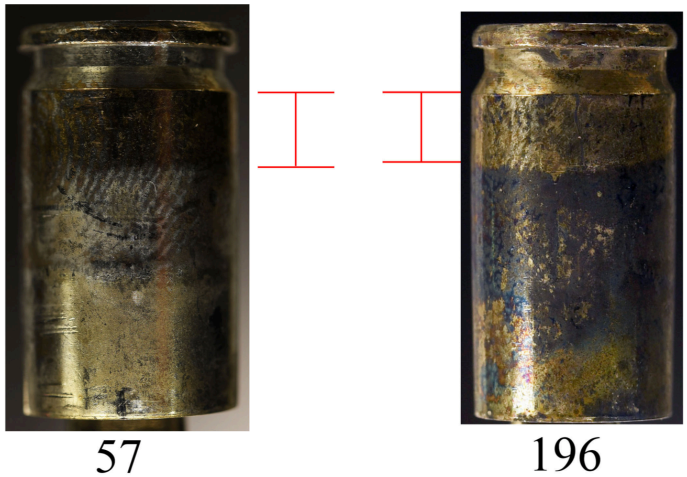

Figure 11. *VMD casings (left) and gun bluing casings (right) both exhibited a clear zone of development near the base of the cartridge.*

The results of the Kruskal-Wallis H test proved that the difference in latent print quality produced by VMD and GB was significant. Of the 115 latent prints that failed to be visualized (Grade 0), 54.78% were processed by VMD. Grade 1 prints were also comparable between the two processes: 54.84% were produced by VMD. Of the 23 Grade 2 prints, 86.96% were developed by gun bluing. From the data generated, it was clear that gun bluing was the superior method over vacuum metal deposition, which did not support the initial hypothesis of this study. However, the secondary hypothesis of the study was supported as neither process developed identifiable latent fingerprints. Gun bluing with Brass Black produced 86.96% of the total Grade 2 results of this study and since the Kruskal-Wallis test proved that the difference between the two processes was significant, it is easy to infer that gun bluing was the superior process for developing latent fingerprints on nickel-plated brass casings.

Based on a review of prior literature, VMD was expected to produce higher quality results. However, none of the studies focused specifically on nickel-plated brass casings and, instead, analyzed brass casings. While Brewer (2019) was able to develop identifiable fingerprints on brass using silver deposition, nickel-plated brass required more contrast than a silver layer alone could provide thus necessitating a second treatment with zinc.

V.I. Challenges and limitations

Perhaps the most pertinent limitation of this study was the use of a single donor. However, this was partially circumvented by having a second examiner score prints, which eliminated examiner bias. A second limitation rose from the use of a sebaceous oil reference pad when depositing latent prints prior to firing. While maintaining consistency was important to this study, this matrix is not necessarily representative of natural fingermarks. Another potential limitation was that the print donor did not load the magazines themselves- CBP personnel did. Because of this, the study did not mimic the natural loading process. While personnel did wear gloves while loading the magazines, there was no guarantee that the prints were not altered during handling. Considering the amount of pressure required to load the cartridges, it is certainly possible that some prints were at least partially destroyed during loading.

Most challenges faced were due to the behavior of atoms in a vacuum, only surfaces that are in a direct line from the evaporation source receive the necessary metal coatings. As a result, two challenges were encountered in the VMD processing phase. The biggest challenge in treating by VMD was angling the shell casings in the VMD chamber so that the entirety of the surface facing the evaporation source was coated. If this was not achieved, then portions of the latent print could be missed. The second challenge associated with working in a vacuum was the need to rotate the samples inside chamber without removing them from their hooks and without interfering with the deposited metal layer. By extension, the necessary re-processing of the casings frequently caused overlapping areas of deposition, resulting in heavy, uneven zinc accumulation. While it is possible to remove the metal coatings, at the time of writing, there is no validated way to remove excess metal deposits in a controlled manner.

V.II. Advantages and disadvantages

V.II.I. Vacuum metal deposition

The advantage to vacuum metal deposition, in general, is its sensitivity and ability to visualize latent prints on non-porous surfaces that have either aged significantly or have been exposed to adverse environmental conditions (Jones, et al., 2001), although this sensitivity was not observed in this particular study. While the enhancement of latent prints using VMD did not return the high quality results expected, the casings could still be further examined following metal deposition. VMD does not affect DNA (Bhoelai et al., 2011), which would allow for swabbing following latent print examination. Furthermore, the silver/zinc layer is easily removed with acetic acid and, while this would denature any traces of touch DNA, the casing could still be examined for unique striations.

Because processing in the VMD is observation-based, as items do not process for a set amount of time, the system requires extensive training and practice to gain proficiency. The same could be said for gun bluing, it does not have a set processing time either; however, one could argue that monitoring the casings and stopping the reaction is much easier. Another drawback of the VMD system being observation-based is that the samples need constant monitoring, as the deposition rate cannot be controlled. When evaporating a metal, the metal sample may jump from the source boat if the boat is heated too quickly. This means that the operator must monitor the source boat while simultaneously monitoring the sample for development, which occurs rapidly once the metal has melted. Because of this, it is also very easy to over-process a sample.

An advantage to the VMD was the ability to process the casings in batches of 10 and since the processing time was under a minute, processing all 100 samples was not too time-consuming. However, the VMD560 takes 100 minutes for initial start-up and if, for whatever reason, the machine needs to be shut down and restarted, the operator must wait the 100 minutes before processing. The VMD unit also requires frequent boat changes, regular deep-cleaning of the evidence chamber, and daily scrubbing of evidence shelf and greasing of the viewing window. In short, the machine is relatively high maintenance.

While the cost per run is inexpensive, the main drawback of VMD is the incredibly high cost of the equipment as the VMD560 from West Technology retails for over $100,000. The cost of consumables including pure silver, pure zinc, evaporation source boats, and cleaning reagents along with the cost of man-hours required for performing maintenance on the machine must also be considered.

<u>V.II.II. Gun bluing</u>

Like vacuum metal deposition, there is no set amount of time a sample needs to process as both methods are observation-based. It generally took between 20 and 30 seconds to develop a casing in 20% Brass Black and the reaction was very easy to halt once development was observed. Likewise, due to the simplicity of the process, gun bluing requires very little training in order to become proficient. The low cost of reagents, coupled with the fact that no specialized equipment is required, gives gun bluing its greatest advantage. One 3-ounce bottle from Birchwood Casey, purchased for $10.00, processed all 100 casings even when changing the solution every five or six casings, depending on cloudiness.

Figure 12. *A casing processed in 20% Brass Black exhibiting uneven development.*

However, unlike VMD, because development is not always uniform (**Fig. 12**) only one sample can be processed at a time. This uneven development may cause areas of the print to be over- or under-developed, possibly marring the print.

VI. CONCLUSIONS

This project further demonstrated the difficulties of recovering latent fingerprints from spent cartridge casings. The initial hypothesis predicted that vacuum metal deposition would prove to be the superior process based on the limited prior research available. This hypothesis, however, was not supported as submerging the spiked, spent shell casings in a 20% Brass Black solution produced higher quality results that proved to be statistically significant. Although the latent fingerprints enhanced by gun bluing were generally assigned higher scores than VMD, it should be noted that neither method produced prints higher than Grade 2. This supports the secondary hypothesis that identifiable latent prints would not be developed during this study. Although the all latent prints were score Grade 2 or below, gun bluing with Brass Black should be utilized for nickel-plated brass shell casings.

VI.I. Impact to the field

Since the donor's finger was spiked on a sebaceous oil latent print reference pad prior to every fingerprint deposition, the results of this study are not necessarily applicable to casework. However, this project was conducted to provide foundational knowledge regarding the capabilities of VMD in comparison to gun bluing. The results were intended to guide law enforcement in the processing of nickel-plated brass shell casings recovered as crime scene evidence and, based on these results, silver/zinc deposition with VMD is not recommended as an enhancement technique.

VI.II. Future directions

Only one type of shell casing treated with a single type of metal deposition was examined in this study- nickel-plated brass treated with silver/zinc. There are a multitude of shell casing compositions and metal deposition sequences that may be compared. Shell casings of various calibers and metal compositions, such as aluminum and lacquered steel, could be studied in the future. Furthermore, future method optimization studies should be conducted to determine if VMD and gun bluing might be used in conjunction with one another to produce higher quality results.

The use of a sebaceous oil reference pad for spiking the fingerprint, and having the magazines loaded by a second individual, did not mimic the natural handling of the ammunition or loading of the firearm. In future studies, a donor could deposit their fingerprint naturally by loading the magazines themselves. This is likely to reduce the smudging of prints during loading.

An issue that was encountered in the treatment of casings in the VMD chamber was the over-deposition of zinc in overlapping areas of shell casings following their rotation. Because the metal layers can be removed with acetic acid, more research should be conducted to determine a method of controlled metal layer removal that can be used as a "spot" treatment. However, if DNA collection is to be conducted following VMD, acetic acid cannot be used as it denatures DNA molecules. In this respect, acetic acid is a viable option to remove metallic layers prior to firearms analysis only. More research could be conducted to develop a method of removal that does not interfere with DNA collection.

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APPENDIX A

Raw data tables.

Table A1. *Raw data table for samples 1-100, processed in the VMD560 using silver/zinc deposition.*

Vacuum metal deposition - silver/zinc processing								
Sample Number	Researcher's Grade	CLPE's Grade	Date processed		Sample Number	Researcher's Grade	CLPE's Grade	Date processed
1	0	0	2/21/20		51	1	0	3/6/20
2	0	1	2/21/20		52	0	0	3/6/20
3	0	0	2/21/20		53	0	0	3/6/20
4	1	0	2/21/20		54	0	0	3/6/20
5	0	0	2/21/20		55	0	0	3/6/20
6	0	0	2/21/20		56	1	1	3/6/20
7	0	0	2/21/20		57	3	2	3/6/20
8	1	1	2/21/20		58	3	2	3/6/20
9	1	1	2/21/20		59	2	1	3/6/20
10	0	0	2/21/20		60	1	1	3/6/20
11	0	0	2/21/20		61	0	0	3/6/20
12	0	0	3/3/20		62	0	0	3/6/20
13	1	1	3/3/20		63	1	0	3/6/20
14	1	1	3/3/20		64	1	1	3/6/20
15	2	1	3/3/20		65	1	0	3/6/20
16	0	0	3/3/20		66	0	0	3/6/20
17	0	0	3/3/20		67	1	1	3/6/20
18	0	0	3/3/20		68	1	1	3/6/20
19	2	1	3/3/20		69	0	0	3/6/20
20	1	1	3/3/20		70	0	0	3/6/20
21	0	0	3/3/20		71	0	0	3/6/20
22	0	0	3/3/20		72	0	0	3/6/20
23	0	0	3/3/20		73	0	0	3/6/20
24	0	0	3/3/20		74	0	2	3/6/20
25	0	0	3/3/20		75	0	0	3/6/20
26	0	0	3/3/20		76	2	0	3/6/20
27	0	0	3/3/20		77	0	0	3/6/20
28	0	0	3/3/20		78	4	1	3/6/20
29	0	0	3/3/20		79	1	0	3/6/20
30	0	0	3/3/20		80	2	1	3/6/20
31	1	0	3/3/20		81	1	1	3/6/20
32	0	0	3/3/20		82	1	0	3/6/20
33	1	0	3/3/20		83	0	0	3/6/20
34	1	1	3/3/20		84	1	1	3/6/20
35	1	1	3/3/20		85	0	1	3/6/20
36	2	1	3/3/20		86	1	1	3/6/20
37	0	0	3/3/20		87	0	0	3/6/20
38	0	0	3/3/20		88	0	0	3/6/20
39	1	0	3/3/20		89	0	0	3/6/20
40	0	0	3/3/20		90	0	1	3/6/20
41	0	0	3/3/20		91	1	0	3/6/20
42	3	1	3/3/20		92	1	1	3/6/20
43	1	1	3/3/20		93	1	0	3/6/20
44	1	1	3/3/20		94	1	1	3/6/20
45	1	1	3/3/20		95	2	1	3/6/20
46	2	1	3/3/20		96	0	0	3/6/20
47	0	0	3/3/20		97	1	1	3/6/20
48	0	0	3/3/20		98	0	0	3/6/20
49	0	0	3/3/20		99	0	1	3/6/20
50	0	0	3/3/20		100	0	0	3/6/20

Table A2. *Raw data table for samples 101-200, processed in a 20% Brass Black solution.*

Gun bluing technique - 20% brass black								
Sample Number	**Researcher's Grade**	**CLPE's Grade**	**Date processed**		**Sample Number**	**Researcher's Grade**	**CLPE's Grade**	**Date processed**
101	2	2	2/21/20		151	2	2	3/2/20
102	3	0	2/21/20		152	1	0	3/2/20
103	3	2	2/21/20		153	2	2	3/2/20
104	1	1	2/21/20		154	1	2	3/2/20
105	0	0	2/21/20		155	1	2	3/2/20
106	1	2	2/26/20		156	0	0	3/2/20
107	1	0	2/26/20		157	2	1	3/2/20
108	1	1	2/26/20		158	1	1	3/2/20
109	1	1	2/26/20		159	1	1	3/2/20
110	0	0	2/26/20		160	1	1	3/2/20
111	0	0	2/26/20		161	0	0	3/2/20
112	0	0	2/26/20		162	1	1	3/2/20
113	2	1	2/26/20		163	0	0	3/2/20
114	1	1	2/26/20		164	0	0	3/2/20
115	1	1	2/26/20		165	1	0	3/2/20
116	1	0	3/2/20		166	4	2	3/2/20
117	1	0	3/2/20		167	0	0	3/2/20
118	0	0	3/2/20		168	4	2	3/2/20
119	1	1	3/2/20		169	2	2	3/2/20
120	0	0	3/2/20		170	1	0	3/2/20
121	2	1	3/2/20		171	0	0	3/2/20
122	0	0	3/2/20		172	0	0	3/2/20
123	0	0	3/2/20		173	2	2	3/2/20
124	1	2	3/2/20		174	0	0	3/2/20
125	0	0	3/2/20		175	0	0	3/2/20
126	1	0	3/2/20		176	0	0	3/2/20
127	0	0	3/2/20		177	0	0	3/2/20
128	1	0	3/2/20		178	1	2	3/2/20
129	1	1	3/2/20		179	0	0	3/2/20
130	1	1	3/2/20		180	0	0	3/2/20
131	1	1	3/2/20		181	0	0	3/2/20
132	3	2	3/2/20		182	0	0	3/2/20
133	1	1	3/2/20		183	1	0	3/2/20
134	1	0	3/2/20		184	1	1	3/2/20
135	0	0	3/2/20		185	1	0	3/2/20
136	0	0	3/2/20		186	2	2	3/2/20
137	2	1	3/2/20		187	3	1	3/2/20
138	1	1	3/2/20		188	2	1	3/2/20
139	1	1	3/2/20		189	0	0	3/2/20
140	2	2	3/2/20		190	3	2	3/2/20
141	0	0	3/2/20		191	0	0	3/2/20
142	1	0	3/2/20		192	3	1	3/2/20
143	0	0	3/2/20		193	0	0	3/2/20
144	0	0	3/2/20		194	1	0	3/2/20
145	0	0	3/2/20		195	2	2	3/2/20
146	3	2	3/2/20		196	1	0	3/2/20
147	1	1	3/2/20		197	1	1	3/2/20
148	0	0	3/2/20		198	1	1	3/2/20
149	0	0	3/2/20		199	1	1	3/2/20
150	0	0	3/2/20		200	3	2	3/2/20

Table A3. Rank values for samples processed in the VMD560 as calculated by the Kruskal-Wallis test.

Sample #	CLPE Score	Ranks (VMD) T_1	Sample #	CLPE Score	Ranks (VMD) T_1
1	0	58	51	0	58
2	1	146.5	52	0	58
3	0	58	53	0	58
4	0	58	54	0	58
5	0	58	55	0	58
6	0	58	56	1	146.5
7	0	58	57	2	189
8	1	146.5	58	2	189
9	1	146.5	59	1	146.5
10	0	58	60	1	146.5
11	0	58	61	0	58
12	0	58	62	0	58
13	1	146.5	63	0	58
14	1	146.5	64	1	146.5
15	1	146.5	65	0	58
16	0	58	66	0	58
17	0	58	67	1	146.5
18	0	58	68	1	146.5
19	1	146.5	69	0	58
20	1	146.5	70	0	58
21	0	58	71	0	58
22	0	58	72	0	58
23	0	58	73	0	58
24	0	58	74	2	189
25	0	58	75	0	58
26	0	58	76	0	58
27	0	58	77	0	58
28	0	58	78	1	146.5
29	0	58	79	0	58
30	0	58	80	1	146.5
31	0	58	81	1	146.5
32	0	58	82	0	58
33	0	58	83	0	58
34	1	146.5	84	1	146.5
35	1	146.5	85	1	146.5
36	1	146.5	86	1	146.5
37	0	58	87	0	58
38	0	58	88	0	58
39	0	58	89	0	58
40	0	58	90	1	146.5
41	0	58	91	0	58
42	1	146.5	92	1	146.5
43	1	146.5	93	0	58
44	1	146.5	94	1	146.5
45	1	146.5	95	1	146.5
46	1	146.5	96	0	58
47	0	58	97	1	146.5
48	0	58	98	0	58
49	0	58	99	1	146.5
50	0	58	100	0	58

Table A4. *Rank values for samples processed via gun bluing as calculated by the Kruskal-Wallis test.*

Sample #	CLPE Score	Ranks (GB) T_2	Sample #	CLPE Score	Ranks (GB) T_2
101	2	189	151	2	189
102	0	58	152	0	58
103	2	189	153	2	189
104	1	146.5	154	2	189
105	0	58	155	2	189
106	2	189	156	0	58
107	0	58	157	1	146.5
108	1	146.5	158	1	146.5
109	1	146.5	159	1	146.5
110	0	58	160	1	146.5
111	0	58	161	0	58
112	0	58	162	1	146.5
113	1	146.5	163	0	58
114	1	146.5	164	0	58
115	1	146.5	165	0	58
116	0	58	166	2	189
117	0	58	167	0	58
118	0	58	168	2	189
119	1	146.5	169	2	189
120	0	58	170	0	58
121	1	146.5	171	0	58
122	0	58	172	0	58
123	0	58	173	2	189
124	2	189	174	0	58
125	0	58	175	0	58
126	0	58	176	0	58
127	0	58	177	0	58
128	0	58	178	2	189
129	1	146.5	179	0	58
130	1	146.5	180	0	58
131	1	146.5	181	0	58
132	2	189	182	0	58
133	1	146.5	183	0	58
134	0	58	184	1	146.5
135	0	58	185	0	58
136	0	58	186	2	189
137	1	146.5	187	1	146.5
138	1	146.5	188	1	146.5
139	1	146.5	189	0	58
140	2	189	190	2	189
141	0	58	191	0	58
142	0	58	192	1	146.5
143	0	58	193	0	58
144	0	58	194	0	58
145	0	58	195	2	189
146	2	189	196	0	58
147	1	146.5	197	1	146.5
148	0	58	198	1	146.5
149	0	58	199	1	146.5
150	0	58	200	2	189

APPENDIX B

This appendix consists of edited images of casings processed with silver/zinc VMD. Examination quality photographs were taken of each casing and the single most representative photograph of each casing was selected.

1 2 3 4 5 6 7 8 9 10

Figure B1. *Samples #1-10.*

11 12 13 14 15 16 17 18 19 20

Figure B2. *Samples #11-20.*

21 22 23 24 25 26 27 28 29 30

Figure B3. *Samples #21-30.*

31 32 33 34 35 36 37 38 39 40

Figure B4. *Samples #31-40.*

41 42 43 44 45 46 47 48 49 50

Figure B5. *Samples #41-50.*

51 52 53 54 55 56 57 58 59 60

Figure B6. *Samples #51-60.*

61 62 63 64 65 66 67 68 69 70

Figure B7. *Samples #61-70.*

71 72 73 74 75 76 77 78 79 80

Figure B8. *Samples #71-80.*

81 82 83 84 85 86 87 88 89 90

Figure B9. *Samples #81-90.*

91 92 93 94 95 96 97 98 99 100

Figure B10. *Samples #91-100.*

APPENDIX C

This appendix consists of edited images of casings processed with brass black. Examination quality photographs were taken of each casing and the single most representative photograph of each casing was selected.

101 102 103 104 105 106 107 108 109 110

Figure C1. *Samples #101-110.*

111 112 113 114 115 116 117 118 119 120

Figure C2. *Samples #111-120.*

121 122 123 124 125 126 127 128 129 130

Figure C3. *Samples #121-130.*

131 132 133 134 135 136 137 138 139 140

Figure C4. *Samples #131-140.*

141 142 143 144 145 146 147 148 149 150

Figure C5. *Samples #141-150.*

151 152 153 154 155 156 157 158 159 160

Figure C6. *Samples #151-160.*

161 162 163 164 165 166 167 168 169 170

Figure C7. *Samples #161-170.*

171 172 173 174 175 176 177 178 179 180

Figure C8. *Samples #171-180.*

181 182 183 184 185 186 187 188 189 190

Figure C9. *Samples #181-190.*

191 192 193 194 195 196 197 198 199 200

Figure C10. *Samples #191-200.*