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Rapid Detection of Gunpowder Residue between a Pistol and a Revolver on Hands and Sleeves: A Field Method Using a Digital Scope with Microimaging Technology

John Z. Wang

Forensic Studies Program, School of Criminology, Criminal Justice, and Emergency Management, California State University- Long Beach, 1250 Bell Flower Blvd., Long Beach, CA, U.S.A.

Corresponding Author:** ***John Z. Wang, *Forensic Studies Program, School of Criminology, Criminal Justice, and Emergency Management, California State University- Long Beach, 1250 Bell Flower Blvd., Long Beach, CA, U.S.A.*

Abstract:

In the U.S., shooting-related incidents continue to rise. Both gunshot residue (G.S.R.) and gunpowder residue (G.P.R.) have long been used to detect their presence to determine the involvement of an alleged shooter, yet they are barely visible by the naked eye. While some methods have been reported, such as the Sodium Rhodizonate/Modified Griess methods and the Scanning Electron Microscope (SEM), they are either non-applicable on human skin at scenes or the SEM is a lab-based device and too expensive beyond most police crime lab budgets, which is an indicator of a lack of field-based devices to detect the G.S.R./G.P.R. on their dimensional differences on landing surfaces (hands and sleeves). Under a quasi-experimental design with purposive sampling, a digital device (the DM series) with microimaging technology was able to compare and differentiate the four stubs (N=4) between a pistol (Glock 19) and a revolver (.38 S&W) at the three morphological characteristics: unburnt, semi-, and completely burnt G.P.R. residues. Further, the digital device was also capable of differentiating the G.P.R. particles at three levels: between the pistol and the revolver, between two hands and two sleeves, and between the G.P.R. and associated fibers. The study findings indicate the digital scope can visualize the invisible G.P.R. particles on the hand and the sleeve and thus may provide a supplementary method prior to the Sodium Rhodizonate/Modified Griess methods and the Scanning Electron Microscope in a quick, real-time, non-destructive, and in-situ manner for a presumptive result.

Keywords: *Shooting-Related Investigation, Gunshot & Gunpowder Residues, Digital Scope, Microimaging Technology, Criminalistics, Gunshot Wounds*

1. Introduction

As shooting-related incidents continue to rise in the U.S., the challenge to determine a shooter's alleged involvement has become more serious because there is a lack of an effective device to perform such a task, especially at scenes. Another related issue is the conceptual confusion of describing the particle-based residues from a gun shooting, such as firearm discharged residue (F.D.R.), cartridge case discharged residue (C.D.R.), explosive primer residue (E.P.R.) and propellant residue (P.R.). While literature uses them interchangeably, this paper differentiates these terms into two sources: (a) the chemical components and (b) the firing mechanism. The first source of the residue comes from a common Sinoxid primer that contains lead styphnate as a shock-reactive explosive, barium nitrate as an oxidizer, antimony sulfide as a fuel, and tetracene as a sensitizer. For the sake of the discussion, the first three elements are targeted and briefly referred to as lead (Pb), barium (Ba), and antimony (Sb), which are housed in the three tiny pockets of the prime in a mixture at the bottom of a cartridge. Mechanically, once the firing pin hits the primer, the three shock-sensitive elements explode and cause a series of chemical reactions simultaneously: Sending sparks into the cartridge casing, igniting the gunpowder (propellant) in the casing to combust, producing huge high pressure of gas to expand, and propelling the bullet (projectile) out of the casing's mouth to enter the gun barrel and to eventually exit the gun barrel (muzzle). Therefore, these primer-based particles can be called gunshot residue (G.S.R.) due to the three elements.

The other source is gunpowder (propellant), a narrower term for smokeless gunpowder in contrast with the old black gun powder). It is an organic substance primarily made of nitrocellulose or cellulose nitrate mixed with nitroglycerin and other components. The gunpowder is usually produced in one of four shapes: flakes, discs, cylinders, or balls, with the flakes being the majority form of smokeless gunpowder. In most shooting circumstances, both the G.S.R. and G.P.R. residues can be found on the shooter's hands and the clothing sleeve. Depending on the type of firearm (pistols, revolvers, rifles, or shotguns), the G.P.R. particles can be divided into three morphological formats: unburnt (a circular shape), semi-burnt (larger but irregular shape), and/or completely burnt (soot) on the shooter's hands and sleeves. Finally, some tiny amounts of metallic particles from the casing and the bullet jacket may also accompany both the G.S.R. and G.P.R.

2. Technical Review

Detection of the presence of the G.S.R. and/or G.P.R. on an alleged shooter's hands and sleeves has long been used to indicate if he/she has fired a firearm [1, 2]. Currently, two methods are used separately on either G.S.R. or G.P.R., but not on both together, depending on a shooting situation.

The Sodium Rhodizonate Method is a chemical method that detects the presence of lead (Sb), barium (Ba), and antimony (Sb) components—the three components within a cartridge primer, also called G.S.R. The method produces the results in two steps using two types of chemical solutions. First, a red-brown color will appear if lead or barium is present on the area when a saturated sodium rhodizonate solution and a buffer solution are sprayed onto a suspected area, in this case the shooter's sleeve. A second spray is performed with 5% hydrochloric acid and the color becomes a purple-violet complex, which indicates the existence of lead [3]. Although this method is more applicable in testing certain surfaces by spraying, such as clothing, curtains, drywalls, or carpets, it is not recommended on a living person's skin due to its potential chemical toxicity and liability. In sum, this method suffers a few weaknesses: non-real-time results, non-friendly use, and non-human application, thus it is considered a non-human skin method.

The Modified Griess Method uses desensitized photographic paper (film) with a hypo solution (sodium thiosulfate ($Na_2S_2O_3$) to make the paper non-sensitive. Then, the paper is treated with a solution of sulfanilic acid in distilled water and alpha-naphthol in methanol, both of which can react with nitrite compound residue, which is a by-product of the combustion of the gunpowder. Next, the suspected item (a cut piece of sleeve) is pressed against the photographic paper in a face-down manner and the back of the clothing is heated with a steam iron that is filled with a diluted acetic acid solution. Finally, the heated acetic acid vapors penetrate the clothing for a chemical reaction: If the clothing contains any nitrite ions, some orange specks or dots will appear [3]. This method requires several chemical steps, according to the current agency protocol, cannot be applied to a living person's skin either, suffering the same disadvantage as the Sodium Rhodizonate method, and making it a non-human skin method. Another downside from this method is that the photographic paper reacts with both organic nitrite and nitrates for a higher false positive rate, meaning many household chemicals contain nitrite, e.g., nail polish removers, felt-tip markers, fabric protectors, fertilizer, or fireworks. In sum, these two semi-methods are complicated with multiple steps and only work on the G.S.R. or G.P.R. specifically, which is not ideal for crime scene processing.

The more advanced method is to use a standard stub and tap the hands and/or sleeves of an alleged person of interest or suspect at crime scenes. Then, the stub is sent to a police crime lab for a determination by a Scanning Electron Microscope (SEM). While the SEM is a more accurate and reliable device, the technology indicates some disadvantages. First, it takes several hours or even several days between a sample collection and an examination result due to the complex testing procedure. Second, the examiners must have specific skills with years of training and experience to operate the device and interpret the results. Next, the false positive rate is also relatively high due to the over-sensitivity at a microgram level by the SEM, causing possible wrongful convictions. Further, the SEM cannot display gunpowder residue in a grey scale image on the computer screen. Finally, the costs of the SEM, its annual maintenance, and its required personnel are far beyond most budgets of police crime labs. Therefore, a field detection method is needed to reduce the shortcomings by the three research questions. First, can a digital scope quickly detect and visualize the G.S.R./ G.P.R. on the hand and the sleeve at crime scenes? Second, if yes, are there any differences in the distribution patterns between a pistol and a revolver? Finally, can the device clearly differentiate the G.S.R./G.P.R. particles and other residues (fiber, blood)? The three research questions suggest some practical forensic values needed for novel device applications in the real-time, nondestructive, and *in-situ* manners for a presumptive result at scenes (the field forensics), in labs (the lab forensics), and/or during autopsies (the medical forensics).

As to human visualization, the G.S.R and G.P.R. display some dimensional differences in size and shape after firing in their three inter-related burning results: unburnt (< mm), semi-burnt (> μm), and completely burnt (< μm) levels. These dimensional differences lay a technical possibility for some possible morphological characteristics under a digital scope [5, 6]. This study presents a rapid field detection method using a digital scope as an added presumptive method that can be used either before the Sodium Rhodizonate/Modified Griess methods or the SEM examination for three practical reasons: First, the increase of shooting-related incidents requires crime scene technicians/specialists (CST/S) to conduct a presumptive examination on- site, at least for a quick determination for exclusion of a suspect. Second, both the Sodium Rhodizonate and the Modified Griess methods are destructive, meaning it is a one-time testing process known as "get it or lose it," especially if the sample is limited (one gunshot only). In contrast, the digital scope device conducts an optical detection as a non-destructive method and does not interfere with the three methods, if that is the scheduled case flow. Finally, due to several unique functions, the digital scope can be used as a stand-alone and supplementary method; thus, the image quality can fulfill the presumptive requirements at scenes, in labs, and during autopsies, even if only one gunshot residue is available. To a certain extent, this method can even reach the standard of a confirmatory test, depending on which definition you are following.

3. Materials and Methods

The digital scope (DM series) is a palm-sized device utilizing microimaging technology with a 10 X ~1,000 X range of magnification that can display light colorful images via its attached screen (95 mm x 70 mm) and act as a stand-alone device using its internal battery. With a USB cable connecting the scope to a laptop screen, the device provides three levels of microimaging images: (1) The device has a screen (95 mm x 70 mm) with a LED light by adjustable knob control at a standard image resolution of high definition (HD:1080 x 720p or 2 megapixels); (2) When connecting to a laptop screen, the scope can obtain a full high definition (FHD: 1920 x 1080p or 4 megapixels); (3) Depending on the laptop's video card capacity, a quad high definition (QHD: 2560 x 1440p) can be achieved, which was employed for this study. Finally, the device can be housed on a stand with two side LED lights for oblique lighting and two goose-neck cables via a USB power cable to the laptop. The still image and video files can be saved for a live examination and comparison with two operational viewing positions to be adopted.

A. The Stage Position (Placing the stud directly under the scope)

a. Rapid detection in the same image frame for a real-time examination;
b. Color differentiation in the same image frame for a real-time comparison;
c. A distribution image of a particle account on unburnt, semi-burnt, and completely burnt particles; and
d. Two side LED lights on the stage for additional oblique lighting from the opposite direction at various angles via the two goose-neck cables.

B. The Free Position (Holding the scope onto any suspected surface)

a. Direct detection and differentiation with the above functions (a ~ c) in real-time and a real *in-situ* position on an entrance gunshot wound at scenes, in labs, and during autopsy;
b. Direct detection of tiny particles on the skin (the web area of the palm and back sides) and on the clothing (sleeves); and
c. This free-hand viewing position also allows for examinations on gunshot wounds/injuries in an *in-situ* manner, which is a unique function needed during an autopsy and was also employed by the author [4].

While a recent trend in forensic examination is to refocus on the crimes scene processing to reduce "garbage-in and garbage-out" situations, a portable device is being explored for rapid detection at scenes (the field forensics), in labs (the lab forensics), and during an autopsy (medical forensics). The traditional detecting methods of the Sodium Rhodizonate and the Modified Griess are limited to non-human skin situation due to their weaknesses mentioned above. On the other hand, the Scanning

Electronic Microscope (SEM), Atomic Absorption Spectrometry (AAS), and Gas Chromatography-Mass Spectrometry (GC-MS) are more scientific, accurate, and reliable; they are yet lab-based equipment (not field-based) for confirmatory examination. Further, the cost of the device and the maintenance are too expensive for most police crime labs even to consider.

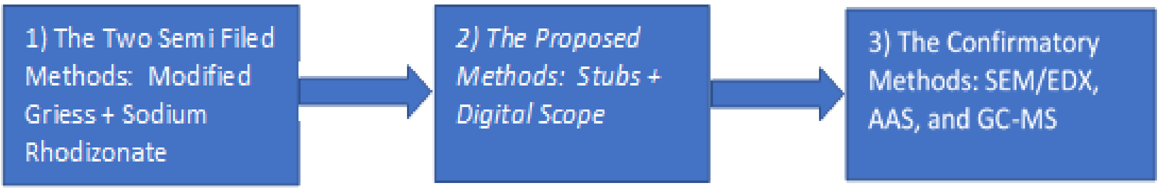

Figure 1. *A Comparison Perspective for the Stud0079*

This study provides an added or supplementary method that can be used as a stand-alone device in the field for the CST/S, as well as in labs and during autopsy. Due to the nature of the project, a quasi-experimental design was chosen to simulate a real shooting incident, which was carried out within an indoor shooting range. The design has been employed and accepted by several publications [7, 8].

Under the design, a purposive sampling method was adopted, which has also been recognized by several publications [9, 10, 11]. The sampling method followed an operational standard due to the availability of the firearms at the shooting range or a simulation of real shooting incidents: (1) Two shots were fired by each type of firearm (a 9 mm pistol by Glock 19 and a revolver by .38 S&W) for two collections (the hand and the sleeve); (2) Three tapings were applied on each target area (the hand and the sleeve); and (3) Approximately 30 minute-interval was spent between each shooting, tapping, and the detection of the digital device. The variables for the study include: (1) the types of firearms (pistols or revolvers), (2) the sampling area tapped (the hand or the sleeve), and (3) the type of residues (G.S.R. or G.P.R.) A summary of both the collection and examination steps of the study is described below:

Collection Steps

1. Two types of firearms were purposively selected: One 9 mm pistol (Glock 19) and one revolver (.38 S&W) were purposively chosen because they are the commonly encountered weapons in most gang-related drive-by-shootings, home invasions, robberies, and murders.
2. Only one shot of each type of firearm was fired and collected at an indoor shooting range to maintain a higher level of consistency, accuracy, and safety.
3. After the shooting, the "shooter" came out of the restricted shooting area and the two research assistants conducted the tapping with washed hands and gloves.
4. Two sampling areas were targeted: (a) the web area between the thumb and the index finger (skin-based) of the back of the shooting hand and (b) the sleeve area (fabric-based) of the shooting hand (about 6″ from the wrist). Each tapping was repeated three times on the shooting hand or the sleeve by two separate standard stubs.
5. The stubs used were the standard collector made of a specially alloyed aluminum with a carbon adhesive material mount. The research assistants tapped the hands and the sleeves, producing a total of four sampling stubs (N= 4).
6. The interval time between the shooting and the tapping was around 30 minutes in average, which was approximately similar to the period of time of a 911 call and a crime scene team's arrival for collecting G.S.R./G.P.R. on an alleged shooter.

4. Results

While the shooting and the tapping each hand and sleeve lasted about 30 minutes, the field-testing procedure took about 15 minutes with six steps: (1) Place each stub back into the vial and then an evidence envelope, seal it, and label it with the required information; (2) Open the envelope, place the stub under the digital scope that is connected to a laptop using a higher definition (QHD: 2560 x 1440p), turn on the two oblique LED lighting for the best contrast; (3) Adjust the focus to detect and visualize the particle residue under the stage position on the spot; (4) Compare the dimensional differences and the morphological characteristics of the G.S.R. and G.P.R. residues; (5) Save the image to the laptop for future uses; (6) Record and interpret the examination results.

The following results were observed via the digital scope by using the microimaging software (the higher definition) and connecting with a laptop at a consistent working distance (50 mm) between the surface of the stub (D=13 mm) and the opening (D=20 mm of field of view) of the scope protector in order to maintain a consistent optical calibration.

Digital Scope Examination of the Pistol's Stub

The Pi. 1 was the stub on the shooting *hand* where a 9 mm Glock 19 fired a 9 mm Luger PAG. The digital device detects successfully by converting the invisible G.P.R. particles on the stub into a clear image with a dimensional pattern for a particle count: around 16 un-burnt particles (uniform circular), 15 semi-burnt particles (larger but irregular), and six completely burnt particles (tiny dots). However, no G.S.R. and no fiber were observed on the stub.

The Pi. 2, was the stub on the shooting *sleeve* by the same pistol. The digital device also detects successfully by converting the invisible G.P.R. particles on the stub into a clear image with a dimensional pattern. Approximately, 10 un-burnt particles (uniform circular), 9 semi-burnt particles (larger but irregular), and five completely burnt particles (tiny dots) were noticed. Again, no G.S.R. was noticed, but a heavy presence of fiber was observed on the stub from the sleeve.

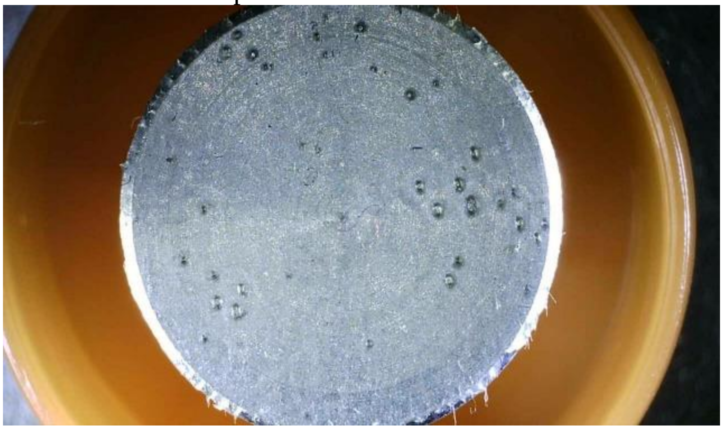

Figure 2. *The stub hand image of the G.P.R. distribution by the morphological characteristics by the pistol (Glock 19).*

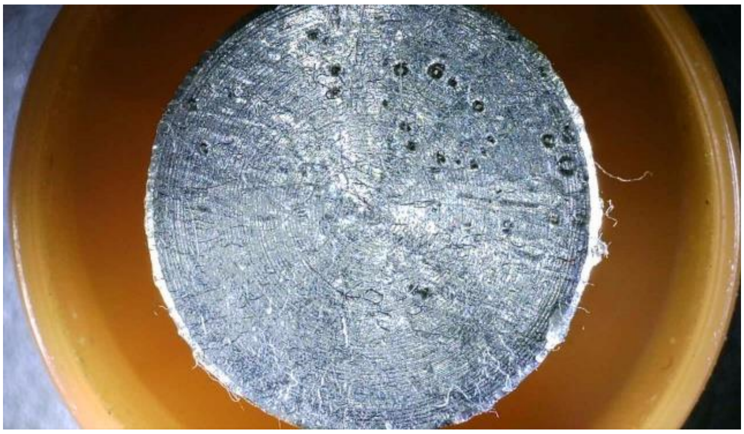

Figure 3. *The stub sleeve image of the G.P.R. distribution by the morphological characteristics by the pistol (Glock 19).*

Digital Scope Examination of the Revolver's Stub

The Re. 1 was the stub on the shooting hand by a S&W 686 revolver that fired a .38 Special PAG. Again, the digital device was able to depict the G.P.R.s on the following accounts: about six un-burnt particles (uniform circular), 15 semi-burnt particles (larger but irregular), and 7 completely burnt particles (tiny dots) were recorded.

However, no G.S.R. and no fiber were observed on the stub. The Re. 2, alternatively, was the stub on the shooting *sleeve* by the same revolver. The digital device also displays successfully by converting the invisible G.P.R. particles on the stub into a clear image with a dimensional pattern and morphological features. Approximately, eight un-burnt particles (uniform circular), 13 semi-burnt particles (larger but irregular), and seven completely burnt particles (tiny dots) were seen. Again, no G.S.R. was noticed, but only a lighter presence of fiber were observed on the stub from the sleeve.

Figure 4. *The stub hand image of the G.P.R. distribution by the morphological characteristics by the revolver (.38 S&W).*

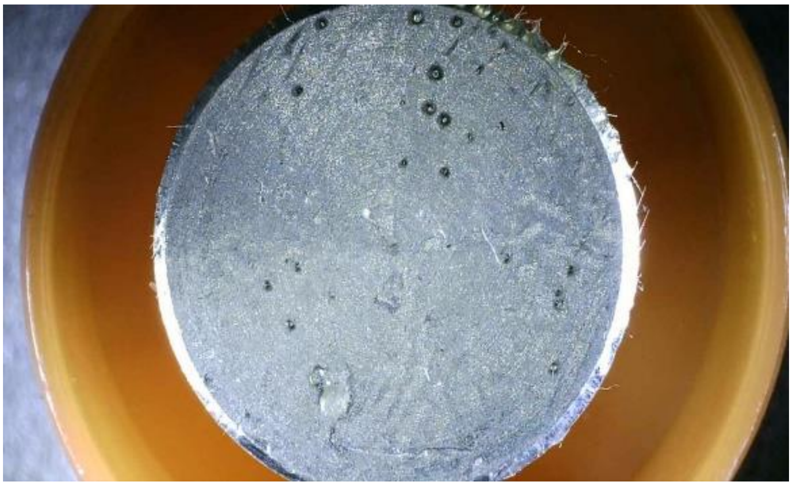

Figure 5. *The stub sleeve image of the G.P.R. distribution by the morphological characteristics by the revolver (.38 S&W).*

Based on the examination using the digital scope, several summaries and interpretations can be made here. First, the palm-sized device was able to detect the G.P.R in a clear image within 30 minutes, during which the collection time takes about 20 minutes, and the examination time needs approximately 10 minutes on each stub in a real-time manner on the spot. All the digital images can be further adjusted based on the working distance, ranging from the whole area of the stub (D=13 mm) to a specific particle via a zooming-in function, thus qualifying the scope as a real field-testing and a stand-alone device.

Second, the device was able to differentiate the morphological characteristics of the G.P.R. residues by quantifying the number of black particles based on their burning degree: unburnt particles as circular flakes, semi-burnt as larger but irregular shapes, and completely burnt as tiny dots or soot. This function allows the CST/S to observe directly the existence of the G.P.R. particles, which can be used as a supplementary testing method before both the Sodium Rhodizonate and the Modified Griess methods and the SEM test to reduce the cost and the potential false positive rate. Next, based on the two images on *hands*, the G.P.R. residue of the unburnt particles (16) from the pistol (the 9 mm Glock 19 pistol) appeared much more in number than that (6) from the revolver (.38 S&W).

This phenomenon can be attributed to the fact that the revolver uses an open cylinder that allows the larger G.P.R. particles to disperse in every direction into the air, thus reducing the larger G.P.R. particles from landing on the "shooter's" hands in its immediate area, which may be used to differentiate the types of weapons (pistols or revolvers) involved. By the same mechanical principle (a semi-close chamber vs an open cylinder), the heavy presence of fiber from the pistol stub and the lighter fiber presence from the revolver stub can be used as an indicator to differentiate the stubs between the pistol and the revolver. Further, the two images on the *sleeves* did not show too many differences in the G.P.R. residue.

This could be explained by the distance that the sleeves were located farther from the firing firearm and the three levels of unburnt, semi-burnt, and completely burnt residues receive the same momentum in the backward direction from both firearms. Finally, no G.S.R. particles (the yellow particles) were found on the four stubs. One explanation may count for this phenomenon: The boxer design primer in both 9mm Ruger (the pistol) and .38 S&W (the revolver) burns and exhausts completely the three elements (lead (Sb), barium (Ba), and antimony (Sb) after their combustion (the trigger blast), which may be only visible under a SEM.

Table 1 provides the statistical summaries and comparisons of the G.S.R. and G.P.R. of the four stubs from the pistol and the revolver.

Table 1. *Statistical summaries and comparisons of the G.S.R. and G.P.R. of the four stubs from the pistol and the revolver.*

Residues / ***Firearms***	**G.P.R. (No. of Black Particles on *Hand*)**	**G.S.R. Particles on *Hand***	**G.P.R. (No. of Black Particles on *Sleeve*)**	**G.S.R. Particles on *Hand***	**Fiber Residue on Sleeve**
Pi. 1 (9 mm Glock 19) on 9 mm Luger	-Unburnt = 16 -Semi-burnt =15 -Completely burnt=6	-Unburnt = 0 -Semi-burnt = 0 -Completely burnt= 0	-Unburnt = 10 -Semi-burnt = 9 -Completely burnt= 5	-Unburnt = 0 -Semi-burnt = 0 -Completely burnt= 0	Heavy Presence
Re. 1 (.38 S&W) on .38 Special	-Unburnt = 6 -Semi-burnt =15 -Completely burnt=7	-Unburnt = 0 -Semi-burnt = 0 -Completely burnt= 0	-Unburnt = 8 -Semi-burnt = 13 -Completely burnt= 7	-Unburnt = 0 -Semi-burnt = 0 -Completely burnt= 0	Light Presence

5. Limitations and Discussions

A few limitations were also observed. First, the number of G.P.R. particles by the digital scope can only be used as a presumptive result to prove a possible involvement of a shooting action. Second, from a probable cause perspective, the presence of the G.P.R. cannot exclude three situations of a secondary transfer circumstance where the alleged shooter (a) shakes hands with a real shooter, (b) picks up a discharged gun, or (c) touches anything from the shooter's discarded belongings (gloves, clothing, or shoes). These limitations are similar to the methods by the Sodium Rhodizonate, the Modified Griess, and the SEM.

Future research directions should be considered as follows to expand this pilot study. While the gunpowder in this study all belongs to the flake shape, future tests should be extended to the three other gunpowder shapes: discs, cylinders, and balls. Another line of thinking is to test the remaining two types of firearms: the rifle and the shotgun. Next, the. 22 Long Rifle cartridges with the rimless firing system should be explored and tested for a more comprehensive database. Moreover, the test should be applied to more complex circumstances, such as the G.S.R./ G.P.R. mixed with blood and/or dirt [12, 13]. Finally, the author is looking for case works for a Dauber Rule evaluation at trial and eventually for an application for ISO 17025 recognition.

6. Conclusion

The digital device possesses several advantages over the Modified Griess and the Sodium Rhodizonate methods, and to a certain extent, the SEM. First, it is a portable device for a presumptive result, allowing a CST/S to perform on the spot, at least for a quick exclusion of a suspect, thus reducing the lag time between the sample collection and the examination results. Second, the device provides a real-time result with colorful images for direct G.P.R. counts by morphological characteristics (un-, semi-, and completely burnt particles) with a higher resolution so that the CST/S or even a police officer can operate with short training. Next, since the magnification can be ranged at 10 X ~1,000 X, depending on the working distance needed, the moderately enlarged image of the G.P.R. particles reduces the oversensitivity issue for the false positive rate, a common issue with the SEM. Further, the device can provide colorful images of tiny residues between the mm and μm levels, such as, fiber/paint chips, blood, and human tissues. A SEM usually generates only intensity value per pixel under the electron beam with a grayscale image (black and white), whereas the digital scope is photons-based and can pick up color as well. Finally, the digital scope is more affordable, friendly, straight forward, and time-saving.

Gunshot residue (G.S.R.) and gunpowder residue (G.P.R.) from a discharged firearm are usually deposited on the shooter's hands, clothing sleeves, body parts, and any nearby surfaces or bystanders. Therefore, both the G.S.R and G.P.R. have long been used to determine an alleged shooter's involvement, at least, as a positive indicator. While the two semi-field and non-human skin methods cannot provide a rapid, real-time, and friendly user-field method, the SEM is too expensive for most police crime labs. As a result, if shooting-related incidents continue to rise, a field-testing method is much needed or even demanded.

Based on this quasi-experimental design with purposive sampling, this study introduces a novel method: A digital scope with microimaging software has achieved several promising results: Quickly detect G.P.R. particles in real-time crime scenes from a pistol and a revolver; Distinguish the morphological characteristics of the G.P.R. at the three different levels between the two firearms; Differentiate the fiber cluster pattern between the two sleeves by the two firearms. In sum, the digital device is capable of rendering the invisible G.P.R. residues on hands and sleeves into a visible image with a quick, real-time, nondestructive, and even an *in-situ* manner for a presumptive on-site result. Due to the increasing challenges at cross examination, the future scope and direction of forensic science should be more open-minded to promote more field-testing-based methods, simply because the field forensics is the first line in controlling the quality of evidence and the chain of custody. Otherwise, the phenomena of "the backlog time" and "the garbage-in and garbage-out" may continue, the very two lessons learned from so many exonerated cases [14]. As new technologies are being invented and applied, such as artificial intelligence and forensic genealogy for the future forensic science community worldwide, using a digital scope with the microimaging technology is not far away to the broader forensic community by promoting academic education, advancing research, and sound practices.

DECLARATION OF COMPETING INTEREST

I declare that I have no financial and personal relationships with other people or organizations that can inappropriately influence my work, and that there is no professional or other personal interest of any nature or kind in any product, service and/or company.

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