JOURNAL OF FORENSIC SCIENCES

J Forensic Sci, May 2014, Vol. 59, No. 3
doi: 10.1111/1556-4029.12409
Available online at: onlinelibrary.wiley.com

TECHNICAL NOTE

CRIMINALISTICS

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Detection of Gunshot Residue on Dark-Colored Clothing Prior to Chemical Analysis

ABSTRACT: Detection of gunshot residue (GSR) is an arduous task for investigators. It is often accomplished with chemical tests, which can reveal elements and ions indicating the presence of GSR, but are likely to cause physical alteration to the pattern. In this study, the Spex Forensics Mini-CrimeScope MCS 400, along with 16 accompanying wavelength filters, was applied to various GSR patterns and target types. Three dark shirt materials, four ammunition calibers, and eight ammunition manufacturers, along with the primer residue of the different manufacturer ammunitions were tested. Results indicate the alternate light source wavelength of 445 nm to be the optimal setting. In addition, target material plays a large role in the preservation of GSR patterns as particles burn. Furthermore, it can be extrapolated that residue, observed from a full round and firing distance of six inches, is mostly composed of unburnt gunpowder residue, not primer residue.

KEYWORDS: forensic science, gunshot residue, gunpowder residue, primer residue, firearm, alternative light source

In 2010, there were 14,748 known murder cases in the United States. Of the cases to which additional data were available, 8,775 murders involved firearms; approximately 60% of all murder cases. In addition, there were 367,832 robberies and 778,901 aggravated assaults; of these, 127,521 and 137,857 cases involved firearms, respectively (1). Due to the common use of firearms in violent crimes, it becomes important to analyze such evidence in the search for information relevant to the reconstruction of the event. Gunshot residue (GSR) is an important type of firearm-related evidence but remains one of the most difficult subjects to study due to the many variables (e.g., target type, environmental conditions, firearm and bullet caliber, gunpowder and primer composition, etc.).

When searching for GSR at a crime scene, it can sometimes be problematic. A bullet entrance on the victim might be easy to locate, but the surrounding GSR cannot be seen due to the dark clothing on which it is located. The same challenges can be applied to the alleged shooter; dark-colored clothing easily masks traces of GSR. With the use of chemicals, it is possible to confirm the presence of suspected GSR on certain substrates. The modified Griess test (MGT) is one of the most commonly used techniques to test for nitrites generally known to GSR. To begin the MGT, a piece of desensitized photographic paper is treated with sulfanilic acid in distilled water, along with α-naphthol in methanol. The treated photographic paper is placed on the front of the sample to be tested, and the back of the sample is steam ironed with dilute acetic acid solution. If nitrites are present, a reaction between the chemicals on the front and back of the sample causes orange-colored specks to appear on the photographic paper (2). The examiner can then use the photographic paper to examine the size of the GSR pattern due to the imprint of nitrites. Once the MGT has been completed, the sodium rhodizonate test is commonly performed to test for lead. Other tests that can be used include the Harrison and Gillroy test, which tests for lead, barium, and antimony, or the Lunge test, which tests for nitrocellulose (3). Although many of these tests have traditionally been used for years, there are a number of disadvantages. Any GSR examination that is needed (e.g., sample to be placed in a scanning electron microscope for elemental composition) must be performed prior to chemical testing, because the chemical testing could be destructive; any pattern or physical sample that was present will most likely be destroyed. For example, a hypothesis of Bailey, Casanova, and Bufkin (4) was to use sodium hypochlorite or bleach to make patterns easier to see on dark- or multicolored fabrics. The MGT and sodium rhodizonate tests were then performed. This extensive application of chemicals may have initially provided necessary information for the researchers, but finally reduced the integrity of the evidentiary sample once all was completed; the sample cannot be returned to its original state for additional analysis.

This study focuses primarily on the ability to quickly and efficiently detect possible traces of GSR on dark-colored clothing in a nondestructive manner through the use of an alternative light source (ALS). For this purpose, it is hypothesized that results will identify an ideal wavelength of light while taking into consideration certain variables (i.e., fabric type, caliber/firearm type, and manufacturer differences of the same caliber). When using an ALS, it is postulated that different fabric blends will have varying results on the visualization of GSR. Primer residue will also be tested separately to identify any visual differences between gunpowder residue and primer residue in hopes of determining which may be fluorescing. Theoretically, once the assumed GSR patterns are located, multiple measurements and pictures can be taken in an effort to form preliminary inferences. It would then be feasible to take physical samples for analysis

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Received 14 Aug. 2012; and in revised form 15 Mar. 2013; accepted 24 Mar. 2013.

within the laboratory and perform chemical tests of a sample further confirming its identity as GSR.

An Overview of Gunshot Residue

Gunshot residue analysis provides information that can be critical to the outcome of a criminal investigation: (a) determination of entry and exit wounds, (b) estimation of shooting distance, (c) establishment of the type of ammunition used, (d) the trace of the projectile trajectory, (e) relation of an individual to the shooting incident, and (f) incorporation of all the above elements into the reconstruction of the crime scene (5). Primer residue and other GSR escape the gun in the form of gases. Once the gases condense, due to the high temperature and pressure created from firing, it will form spheroidal-shaped sediment on the firearm and surrounding objects, usually 0.5 to 5.0 μm in diameter (6). Previous studies have shown that people standing three feet or closer to the side of the shooter will probably have GSR on their hands, whereas people standing 10 feet or further in the same direction will likely not have GSR on their hands (7). There are a number of factors that could affect the availability of GSR on the victim or shooter: distance, caliber, types of propellant, type of weapon, target material, and muzzle-to-target angle (4).

The majority of GSR consists of burnt and unburnt particles from the propulsive charge and primer used by the individual or manufacturer. Typically GSR is a composite of lead styphnate (initiator), barium nitrate (oxidizer), and antimony sulfide (fuel) (8). The propellant mixture and the primer particles encompass most of the organic compounds, including nitrocellulose (NC) and nitroglycerine (NG). Smokeless gunpowder is single, double, or even triple based. Single-based powders contain NC as the explosive component, while double-based contain both NC and NG. A portion of the NC/NG mixture is replaced with nitroguanidine in a triple-based powder. Inorganic compounds such as aluminum, tin, or calcium silicide are primarily found in the primer mixture (3).

Analysis of inorganic primer particles requires the use of high-end equipment such as the scanning electron microscope with energy-dispersive X-ray spectrometry (SEM-EDX), the most popular method since the 1970s. With experienced use, an SEM-EDX can observe the morphological characteristics and elemental content with no damage to the GSR. Prior to examination, GSR particles must be removed from the evidential source using either some sort of an adhesive tape or a prepackaged aluminum stub, which possesses a sticky end for GSR collection and can be readily placed in the SEM specimen chamber (5). In a study by Oomen and Pierce (9), SEM-EDX was used to analyze American types of lead-free ammunition. Lead-free ammunition has become prevalent over the last few years, as it poses less of a risk to human health through inhalation and contributes less to environmental pollution. On the other hand, it presents a problem for traditional detection methods, which require lead (Pb), barium (Ba), and antimony (Sb), along with a particular morphology, to result in a positive identification of GSR. Primer residue is assigned to certain chemical classes depending on the proportions of Pb, Ba, and Sb present. The frequency and type of chemical class a primer is assigned help to differentiate the various types of ammunition (10).

In addition to SEM-EDX, a number of other methods exist to analyze the organic and inorganic elemental makeup of GSR. Berendes et al. (11) used a millimeter-X-ray fluorescence analysis (m-XRF) spectrometer to analyze lead-free ammunition similar to Oomen and Pierce (9). This technique was able to produce elemental mapping of GSR from various sources (e.g., skin and fabric); however, m-XRF is limited to flat sample sizes of 20×20 cm and can take 3–4 h to process.

Alternative Light Sources

Sunlight, which makes up the electromagnetic spectrum, is composed of (a) visible light, 400 nm to 700 nm; (b) infrared light, greater than 700 nm; and (c) ultraviolet light, less than 400 nm. Ultraviolet (UV) light can be further broken down into three categories: (a) UV-A (or black light), 320 nm to 400 nm; (b) UV-B, 290 nm to 320 nm; and (c) UV-C, less than 290 nm. To utilize any of these wavelengths for the purpose of examining evidence, certain filters must be applied, such as long-pass, short-pass, or band-pass filters. Long-pass filters allow longer wavelengths through the filter while blocking shorter wavelengths. Short-pass filter alternatively allows shorter wavelengths to pass through while blocking longer ones. A band-pass filter allows only a narrow band of wavelengths through. The interaction of light with matter can be important for enhancing the visibility of evidence at a crime scene. The absorption of light occurs when a given wavelength is absorbed by a molecule's electrons and causes the molecule to appear darker than the surrounding environment. This is commonly seen when detecting bloodstains on fabric substrates. Reflection of light occurs because the free electrons within the matter do not permanently absorb the light and instead release it almost immediately. Scattered light is a form of reflection: light is reflected in random directions due the roughness of the surface to which it is applied (e.g., dust particles, hair, and fibers scatter light in various directions). As electrons of an object do not interact with incoming light, but merely pass through, transmission takes place. Substrates such as glass and clear plastic allow transmission of light. The final type of light–matter interaction and the most important for this research is fluorescence. Fluorescence occurs if a given wavelength is absorbed by a molecule and later followed by light emission from the molecule but at a longer wavelength than that which was initially applied (12). A filter is required to screen out any reflected incident light or competing light so only the fluorescing light is observed. The goggles worn by the ALS operator are placed on the camera to serve as long-pass filters, allowing only light above a certain wavelength to be visualized (13). Collectively, the different forms of light and matter interaction are applied to the detection of latent fingerprints, body fluids, hair and fibers, bruises, bite marks, wound patterns, shoe and foot prints, drug traces, questioned documents, bone fragment detection, and for the purpose of this study, gunshot residue.

West et al. (14) were reportedly some of the first researchers to apply these principles using an ALS to physical wound pattern detection. When these molecules release the light at a longer wavelength of less intensity than the applied wavelengths (i.e., fluorescence), it is referred to as Stokes shift. The theory of Stokes shift allows patterns on and below the skin to be photographed. Most light is reflected and scattered from the surface of the skin, while some light is transmitted below the surface and absorbed by certain types of tissue molecules. The varying degrees of absorption and fluorescence allow the observation of healthy versus diseased or traumatized tissue.

Schuler et al. (15) sought to study bloodstains in a manner that was noninvasive. Similar to GSR, it is important to take note of bloodstains prior to chemical analysis because there are many physical characteristics which can be useful, for example stain size, shape, distribution, location, overall appearance, and the interrelationship between the stain and the substrate upon which it is located. Schuler et al. (15) chose to use near-infrared hyperspectral imaging (NIR HSI) as their method for analysis. Although it served their purpose, the drawback to this method is that the maximum imaging field is only 10 × 10 cm with an entire sample enclosure of only 30.5 × 38.1 cm, making it time-consuming to process large substrate surfaces. It was concluded that NIR HSI would be best used in conjunction with ALS to quickly identify areas of interest. In a study by Lin et al. (16), they also chose to use the NIR region of the electromagnetic spectrum to test for the visualization of various types of evidence including GSR. Their method required the images to be captured by a video or digital camera with a charge-coupled device (CCD) array sensitive to IR.

Schulz et al. (17) used the Spex Mini-CrimeScope MCS 400 to locate skin particles left behind on various substrates such as sand, fibers, and soil. Alternative light source was able to effectively cut in half, the amount of time used to discern the skin cells from the surrounding environment. Alternatively, Vandenberg and van Oorschot (13) used the Polilight PL500 by Rofin as a screening tool to detect biologic stains (i.e., seminal, saliva, and blood stains). The Polilight produces a narrow band of light at wavelengths between 310 nm and 650 nm. It was noted that fluorescent detection is sometimes dependent upon the nature of the substrate upon which the stain is deposited. There is often difficulty in detecting a stain on a highly absorbent, dark-colored, or strongly fluorescent material. Brighteners in detergents and fabric softeners can also cause unwanted background fluorescence under UV light. Vandenberg and van Oorschot (13) ultimately found that a wavelength of 415 nm while wearing yellow goggles was good for observing stains on dark clothing. Still another type of ALS is the Video Spectral Comparator 2000 by Foster and Freeman, used in a study by Atwater et al. (2). The video comparator is primarily used for the examination of questioned documents but was used by Atwater et al. (2) to look at GSR on dark-colored clothing. Although it appears to work well, the drawbacks are similar to that of the NIR HSI. With a maximum field of view of only 210 × 160 mm the video comparator requires an attachment to a desktop monitor for viewing and operating.

It should be reiterated that use of an ALS source only aids in the detection of suspected GSR. Alternative light source, as it is utilized in this study, is meant to provide an efficient method of gaining preliminary data to aid in the formation of an investigation. It is not meant to replace chemical testing such as the MGT or sodium rhodizonate test and should not be solely relied upon for a conviction. It is acknowledged that environmental sources of GSR do exist and can also be detected by an ALS. The study by Dalby et al. (3) included a section on environmental sources of inorganic GSR-like particles. They included stud guns, lead smelting, and car brake and battery mechanics. Anyone who comes into contact with these materials for extended periods of time may be found to possess particles of Pb, Sb, and/or Ba elemental composition, indicative of GSR-like particles. On the other hand, there is always the possibility of GSR loss due to the activities of the shooter postfirearm discharge. Dalby et al. (3) reported that GSR can be detected on the shooter's skin anywhere from one to seven hours after the act but can be detected up to 2 months later on fabric that is left undisturbed. All of this depends on the shooter's general hygiene and how often they wash their hands or even their clothes. In short, an examiner should be weary of what evidence is present and that which is not.

Method

Materials

Three targets of dark fabric material were obtained from three different shirts: a black polo shirt of 100% cotton; a dark navy police issued uniform shirt of 75% polyester, 24% wool, and 1% Lycra; and a blue polo shirt of 60% cotton and 40% polyester. All firearms and corresponding caliber of ammunition are listed in Tables 1 and 2, respectively. It should be noted: (a) the Winchester Super-X was the only hollow point used—all others were full metal jackets, (b) S&B, PPU, and Wolf were the only European manufactured ammunition tested, (c) only the Wolf ammunition possessed a Berdan style primer—all others had Boxer primers, and (d) Remington UMC and PPU were the only one's not of 115 gr. weight. A Kinetic Bullet Puller (Quinetics Corp., San Antonio, TX) was used for the dismantling of bullets.

The ALS source used during this study was the Spex Forensics Mini-CrimeScope (model: MCS 400). The light source within the CrimeScope consists of a 400 Watt DAYMAX metal halide lamp with a ceramic reflector. The CrimeScope comes with a six-foot long, 10-mm active diameter liquid light guide to which the two selectable wavelength thumbwheels can be attached. The first thumbwheel (model: W8A-8F) possesses eight wavelengths to choose from: "300-400", 390, 415, 445, 455, 475, "CSS" (short-pass, approximately 400–520 nm), and 495 nm. The second thumbwheel (model: W8B-8F) has an additional eight wavelengths: 515, 535, 555, "SP575" (short-pass, *c.* 400–575 nm), 575, 600, 630, and "White" or "000" (UV light).

To provide eye protection and improve visualization of the sample, goggles possessing the four filter colors were used: UV, yellow, orange, and red. A Nikon D90 digital SLR camera was used to capture all photographs of the setup, materials, and samples under the various wavelengths. Depending on the wavelength used, the exposure and aperture diameter were adjusted to capture the best image most representative of what was seen by the naked eye while wearing the necessary eye protection. Also depending on the wavelengths most used, one to two of the respective filter was placed on the camera: Tiffen 67 mm Yellow #12 and Orange #21 filters.

Procedure

To begin the first part of the experiment within the shooting range, a large remnant of cloth was cut from either the front or back of each of the three shirt types. The pieces were then arranged on cardboard backing and stapled along the edges while smoothing out any large wrinkles or slack within the

TABLE 1—*Firearms used.*

Manufacturer	Model	Caliber/Action	Barrel Length (in.)
Glock	19	9 mm semiautomatic	4
Ruger	P89DC	9 mm semiautomatic	4.5
Ruger	GP100	.357 Magnum revolver	4
Springfield	XD40	.40 S&W*semiautomatic	4
Taurus	85	.38 Special revolver	2

*Smith and Wesson.

TABLE 2—*Ammunition used.*

Brand	Caliber	Grain Weight	Jacket Type
CCI Blazer	.40 S&W	165	FMJ*
Remington	.38 Special	130	FMJ
Winchester Super-X	.357 Magnum	145	Silvertip hollow point®
Federal Champion	9 mm Luger	115	FMJ
Hornady Custom	9 mm Luger	115	FMJ
PMC (Precision Made Cartridges) Target	9 mm Luger	115	FMJ
PPU (Prvi Partizan, Serbia)	9 mm Luger	158	FMJ
Remington UMC (Union Metallic Cartridge)	9 mm Luger	124	FMJ
S&B (Sellier & Bellot, Czech Republic)	9 mm Luger	115	FMJ
Speer Lawman	9 mm Luger	115	TMJ RN†
Winchester	9 mm Luger	115	FMJ
Wolf (Russia)	9 mm Luger	115	FMJ

*full metal jacket.
†total metal jacket, round nose.

fabric. Each of the targets were hung in the indoor shooting range located within the Forensic Firearms Division of the Austin Police Department (APD). All three targets were shot one time from a distance of six inches using the Ruger P89DC and Winchester 9 mm Luger ammunition. The targets were then removed from the hanging position, loosely covered with large pieces of white butcher paper, and stacked horizontally for safekeeping. This routine allowed for better preservation of any GSR patterns that might be present and offered protection from contamination during transportation.

The second portion of the experiment consisted of four targets, all made similar to the first part of the experiment but using only black polo shirts made of 100% cotton. Each target was shot one time, from a six inch distance, with the Taurus 85, Ruger GP100, Glock 19, and Springfield XD40 pistols, and using the Remington .38 Spl, Winchester .357 Magnum, Winchester 9 mm Luger, and CCI Blazer .40 S&W ammunition, respectively. The calibers and firearms were chosen for use in this experiment based on the most common type of firearm evidence submitted to APD.

The third portion of the experiment involved eight targets, each shot from a six-inch distance using the Ruger P89DC and a 9 mm Luger round of a different brand per target (i.e., Federal, Hornady, PMC, PPU, Remington, S&B, Speer, and Wolf). All targets were again made from black polo shirts of 100% cotton. Similar to the previous portion, these ammunition manufacturers were chosen based on their local popularity. As with the first two phases of the experiment, the targets were covered and set aside for later analysis.

The final phase of experimentation within the shooting range was designed to examine only the primer residue of the 9 mm Luger ammunition used in the phase prior (i.e., Federal, Hornady, PMC, PPU, Remington, S&B, Speer, and Wolf). The Kinetic Bullet Puller was used to disassemble the unfired bullets from their cases, and the bullets and gunpowder were set aside from the cases containing live primers. Eight additional targets were cut using the black polo shirts of 100% cotton. In the center of each target, a silver dot was drawn with a felt-tip marker to provide a specific aim point and later provide a specific area to locate possible primer residue. This was not necessary for the previous sets of targets as a bullet hole is relatively easy to locate. Once the targets were hung, the Ruger P89DC was used to shoot all eight of the various dismantled brand cartridges. Prior to each cartridge discharge, the pistol barrel was briefly cleaned out using a bore brush, dry bore mop, and a clean cotton patch. Once finished, the targets were covered and set aside for later analysis.

Before all targets could be analyzed with the Mini-CrimeScope, it was necessary to test all 16-labeled wavelengths on a single GSR target. This allowed such a broad range of wavelengths to be narrowed down to only those that best visualized the GSR present. For this purpose, the target containing GSR from the CCI Blazer .40 S&W ammunition was examined. This caliber of ammunition is generally known to emit a large amount of residue and gunpowder particles onto surrounding surfaces and thus would serve as a prime specimen for the initial testing of all the wavelengths. To begin use of the CrimeScope, the equipment was set up in a small room with no windows to provide a completely dark area in which to work. The Nikon camera was placed on a vertically adjustable camera mount attached to the desktop; the CrimeScope was also placed on the desk to provide ease and comfort of use. Researchers wore corresponding eye protection (i.e., UV-, yellow-, orange-, or red-filter goggles), along with gloves and a laboratory coat for additional protection against the harmful wavelengths. The wavelengths were then tested in sequential order beginning with the "300-400" setting. Once all 16 wavelengths had been tested, it was found that the range of 445 to 495 nm, including the "CSS" setting, proved to be the most successful at visualizing GSR with the largest amount of contrast and the least amount of background fluorescence.

All 23 targets possessing the different variables previously described were analyzed using each wavelength setting of 445 nm, 455 nm, 475 nm, 495 nm, and CSS. A photograph was taken at each wavelength for each target, and camera settings were adjusted as necessary to provide the most realistic photograph in addition to attaching the filter lens that corresponded to the wavelength in use. White butcher paper was slipped between the shirt and cardboard target to make the bullet defect easier to see with the camera. The area containing GSR was illuminated in a painting motion, with the hand-held light guide in an effort to produce the best photographs of the entire GSR area. Each photograph contained a black-and-white scale, along with a label containing the type of shirt material, firearm, and ammunition used. Once all photographs had been taken, they were downloaded to a computer for analysis. The photographs for each wavelength, in conjunction with notes taken during the use of the ALS, were examined and rated using a one to five scale, with one being the worst (e.g., cannot see the particles, poor contrast) to five being the best (e.g., easy to see the most particles, most contrast). The scores were totaled and the wavelength with the highest score was found to be the best wavelength for efficiently identifying GSR on dark-colored clothing.

Results

The first part of this study was designed to compare all 16 wavelengths with the Spex Forensics Mini-CrimeScope. Wavelengths 415 nm and below illuminated little to no GSR but greatly illuminated the surrounding lint and other particles not part of the experiment. Beginning with 445 nm, the lint and other particle fluorescence were minimized while providing a great distinction between the GSR and the shirt material (e.g., GSR appears a bright neon green on a black, nonexistent background). Gunshot residue at 455 nm and 475 nm also provided strong contrast. The CSS filter appeared to fluoresce GSR in a yellow/gold color on top of a dark orange background. Particles were still easy to see and could be measured, if needed, at this wavelength. The 495 nm wavelength provided similar results to CSS but with a dark orange to brown background. Wavelengths within the 500's caused GSR to fluoresce red on black, purple, or orange backgrounds. Visually, it was increasingly laborious to study the GSR, no matter the eye protection. Most specifically when using the SP575 filter, although it photographed well. Beyond 575 nm, photographs became more difficult to take, as the results were not representative to what the eye was visualizing. At 600 nm and 630 nm, results were poor with little to no contrast between the GSR and background fluorescence. It was difficult to discern the GSR from the shirt material. The white light setting was also tested to remain consistent and found to produce results similar to that of examining GSR with no eye protection under ambient light; only large particles could be visualized. Once all wavelengths had been documented and scored, it was concluded that the range of 445 nm to 495 nm, including CSS, would be most efficient at detecting and photographing GSR on dark clothing and therefore used for the rest of the analysis (Fig. 1).

The first set of targets examined were those using different shirt materials. Using the established range of wavelengths, the black polo shirt and the blue polo shirt of slightly different material were found to have similar results. Gunshot residue appeared successfully under all five filters and could be photographed for later data acquisition. The police issue uniform shirt possessed far fewer GSR particles than the other two shirts; the material was also very thin and allowed the white paper underneath the shirt to fluoresce, creating a high incidence of background interference. The decrease in quantity of GSR, in combination with high background fluorescence, made it extremely difficult to detect the GSR present. The smaller, tighter weave of this appeared to be the cause of decreased GSR, and because of this, the fabric retained only a small amount of GSR as it propels from the firearm at a high velocity. Both of the polo shirt fabrics possess a waffle-like weave, and the loose knit seems to catch and preserve more of the incoming GSR, which allowed for better study.

In a side-by-side comparison of the various firearm/ammunition calibers used (i.e., .38 Spl, .357 Magnum, 9 mm, and .40 S&W), the Remington .38 was noted to have the least amount of GSR particles. The .357 Winchester had the largest GSR spread (*c.* 22 × 22 cm) as well as the densest coverage, allowing it to fluoresce brightly. The .357 particles also appeared to be finer or smaller in diameter compared with the three other calibers within this set. Despite the physical and spatial characteristics seen for each caliber, all fluoresced the same color and had the same contrast against the background, in respect to the wavelengths used.

The next set of targets was analyzed for differences in performance between the 9 mm manufacturers. The S&B, Hornady, PPU, PMC, and Wolf ammunition yielded little to no GSR visible to the naked eye in ambient lighting. Once illuminated by the ALS, all GSR patterns fluoresced brilliantly. The Speer Lawman and the PMC have the largest amount of spread, at *c.* 15 × 15 cm. Speer also had the largest diameter size of all GSR particles, while Wolf had the smallest or finest particle size. PPU, PMC, and Wolf had the greatest amount of particles per square centimeter, while the Federal and S&B ammunition had the least amount of GSR particles present.

When separating the bullets from their case for the primer portion of this study, geometric characteristics in gunpowder were observed. S&B and Wolf had much finer gunpowder, and Remington, Federal, Speer, and PMC had some version of disk-shaped gunpowder. Hornady also had disk shapes but each with a single perforation. PPU had gunpowder best described as fine pebbles. They were smaller in size compared with the disks but were not evenly spheroid. These observations in gunpowder characteristics may be important in explaining why we see certain residue characteristics (e.g., difference in size of particles).

The next sets of targets were those subjected to primer residue test fires. Prior to analysis with the CrimeScope, no residue patterns were observed on any of the targets under ambient lighting conditions. With the ALS, only S&B and PPU ammunition cases provided results (Figs 2 and 3, respectively). A small GSR pattern, *c.* 2 × 2 cm, fluoresced red on the S&B target. A larger, denser spread of, *c.* 5 × 5 cm, appeared on the PPU target; also fluorescing red. When referencing the previous photographs of GSR created by the full round, no particles fluoresced red in any wavelength. All particles appeared homogenous in a color dependent upon the wavelength being used.

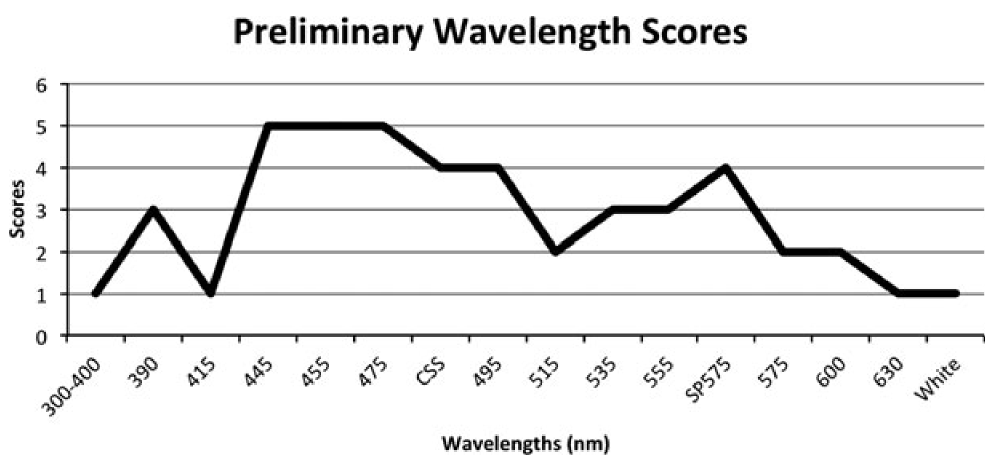

FIG. 1—*Values ranging from one to five given for the performance of the 16 wavelengths tested on the Mini-CrimeScope. The lowest score of one meant no particles could be seen, or there was poor contrast between particles and the background. The highest score of five was assigned to those with great contrast and little to no loss in visualization of particles.*

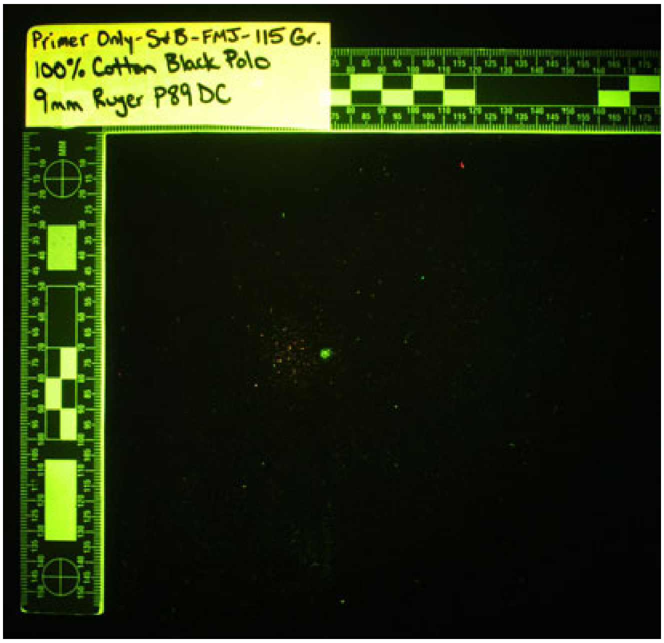

FIG. 2—*Photograph of S&B primer residue under 445-nm filter. Scale given in mm.*

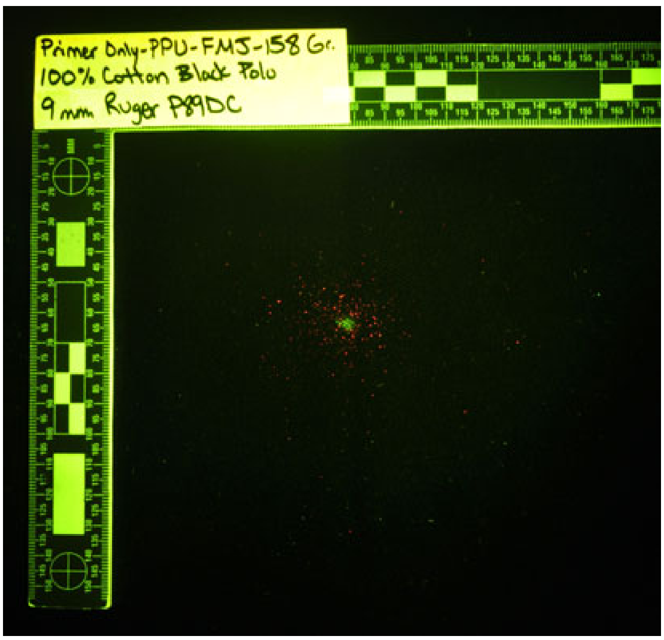

FIG. 3—*Photograph of PPU primer residue under 445-nm filter. Scale given in mm.*

After reviewing all of the data, it was determined across all variables and wavelengths that a 445-nm filter performed the best, as it was given the highest rating most often (Figs 4 and 5). This filter provided clearer contrast with particles, showing up neon green on a black background, making it the easiest to observe and photograph. The majority of particles could also be seen at this wavelength with none fading into a background that was too fluorescent or noisy. Performance of the other wavelengths between 445 nm and 495 nm generally decreased as 500 nm was approached.

Discussion

In the experiment discussed above, the best wavelength for viewing GSR on dark-colored clothing was 445 nm. In contrast, the operating manual, which accompanied the SPEX Forensics Mini-CrimeScope, included a reference table, which suggests a wavelength from 455 nm to the CSS filter. It also suggested paying attention to the light source intensity because "fluorescence is weak" (12). Results from this study not only found a wavelength below the SPEX prescribed wavelength, but it also found GSR fluoresced brightly at this wavelength. It was not necessary to maximize the light source intensity. In comparison with the study by Atwater et al. (2), results from this study and theirs vaguely agree. They reported that with the use of the video spectral comparator, a waveband filter range of 440 nm to 580 nm and a long-pass filter of 610 nm was part of the optimum settings for viewing GSR. Regardless, for the purpose of this study, which was to quickly detect GSR on dark-colored clothing without the use of chemicals, the wavelength filter of 445 nm worked well for detecting close range GSR. All targets tested during this study were known to possess GSR and it was possible to see the deposition of large particles using only the naked eye in ambient lighting on some targets; however, other targets showed no signs of deposited GSR particles under the same conditions. For instance, the target possessing PMC 9 mm Luger residue had no visible signs of GSR prior to analysis with ALS, but when illuminated, it was revealed to have one of the largest spreads of GSR. Once the 445-nm filter was used to illuminate all the targets, the GSR fluoresced substantially, regardless of the visualization of GSR in ambient lighting. The particles fluoresced so markedly that it would be possible to use the Mini-CrimeScope at a crime scene and document the results. Once the original pattern has been discovered and documented, it could then be returned to the laboratory for further testing and verification.

The data obtained after examining the different shirt materials provided additional unexpected results. The original hypothesis for testing of the above variables indicated there may be certain fabric blends that fluoresce more brightly than others, thus causing more background noise and difficulty in identifying a complete GSR pattern. In contrast, it was not a difference in fluorescence that was the source of difficulty, but rather the weave or knit of the fabric material. The polo shirt fabric appeared to capture and preserve the GSR particles much more effectively than the uniform shirt (Figs 6 and 7). In a study by Brozek-Mucha (18), the parameters characterizing GSR were found to differ, depending on the type of target substrate, that is, white cotton fabric versus black bovine leather. From a shooting distance of one to 100 cm, the number of particles collected from the cotton target was consistently greater than from the leather target, especially at a distance of 20 cm. These unusual results were found to be a product of the particle velocities and target material. Brozek-Mucha (18) concluded that at distances greater than 10 cm, (*c.* 4 inches), particles move at slower velocities (compared with distances below 10 cm) and the cotton target appears to possess a greater adhesive property due to its complex weave of threads, which is nonexistent in a leather substrate. This principle seems to apply to an experiment carried out by Berk et al. (19) in which randomly selected Chicago Police Department transportation vehicles were tested for the presence of GSR. The vehicles possessing cloth seats had a much higher rate of GSR occurrence as opposed to those with vinyl seats. These studies support the results obtained from the comparison

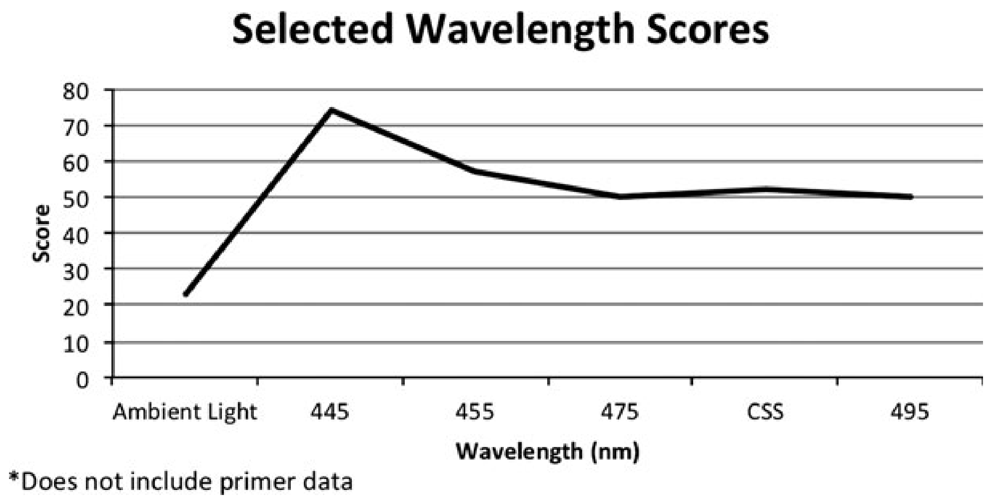

FIG. 4—*The total scores for all targets analyzed using the 445-nm to 495-nm filters, as compared to ambient light. The same criterion as described in Fig. 1 was used to assign scores.*

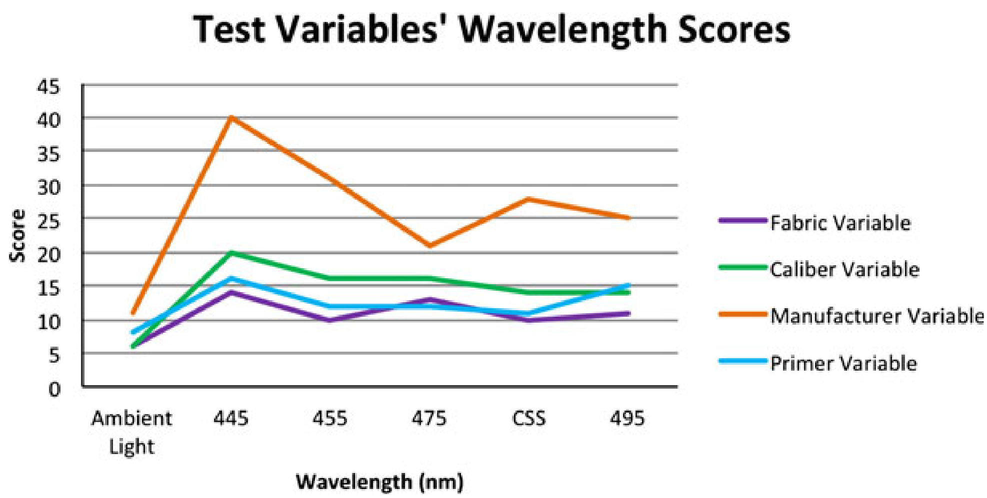

FIG. 5—*Shows the average scores of the different variables tested overall (i.e., fabric types and various calibers and manufacturers of ammunition) the wavelength range of main interest. The figure also provides the average scores given to the targets shot with only primed cartridges.*

of polo shirts and uniform shirt used in this study. At a shooting distance of six inches, the small tight weave of the lightweight uniform shirt effectively reflects more of the GSR than does the cotton and cotton mix weave of the two polo shirts.

For the purpose of this study, the only inferences made from the examination of different calibers and manufacturers supported the use of a 445-nm filter. All calibers and manufacturer ammunition showed up equally well at this wavelength, despite different physical characteristics or amount of GSR present. Prior to determining the best wavelength for detecting GSR, the research endeavored to determine what residue portion of the ammunition was fluorescing: primer residue or gunpowder residue. When the targets shot with empty cartridges containing only the primer were examined with ALS, it was interesting to see only two of eight fluoresce (i.e., the S&B and PPU primer cartridges). This could be due to one of two possible reasons: (1) as the only primers to fluoresce were European, it may be a different elemental composition than that used in the United States or (2) a chemical reaction occurring between the gunpowder and the primer that causes one to dominate the other when examining the full-load shot. What appear to be fluorescing from a full-load shot are the unburnt gunpowder particles. There are multiple pieces of evidence to support this conclusion. First, there is the fact that when examining the primer-only targets with ALS, only two fluoresce and all eight of the 9-mm full-load ammunition targets fluoresced. This indicates there is something other than the primer residue that is illuminating. Second, in a side-by-side comparison of primer residue and suspected gunpowder residue, there is a notable difference in particle size. The primer residue is much finer than the size of the fluorescing gunpowder particles, which are also more consistent with unfired gunpowder particle sizes. Finally, the Hornady ammunition shows that the majority of particles fluorescing are composed of unburnt gunpowder particles. As previously noted, after examining the loose unfired gunpowder of the Hornady Custom 9 mm Luger, the disk-shaped powder contains single perforations (Fig. 8). Closer examination of the picture, obtained while looking at the Hornady full-load target under 445 nm wavelengths, reveals nicely deposited gunpowder particles with single perforations in the center (Fig. 9). This unique physical characteristic of the Hornady gunpowder, which survived the firing

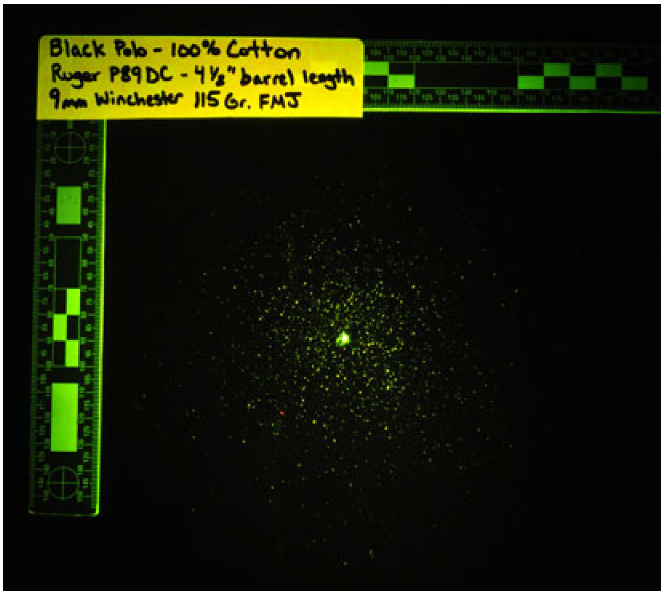

FIG. 6—*Photograph of black cotton polo shirt under 445-nm filter. Scale given in mm.*

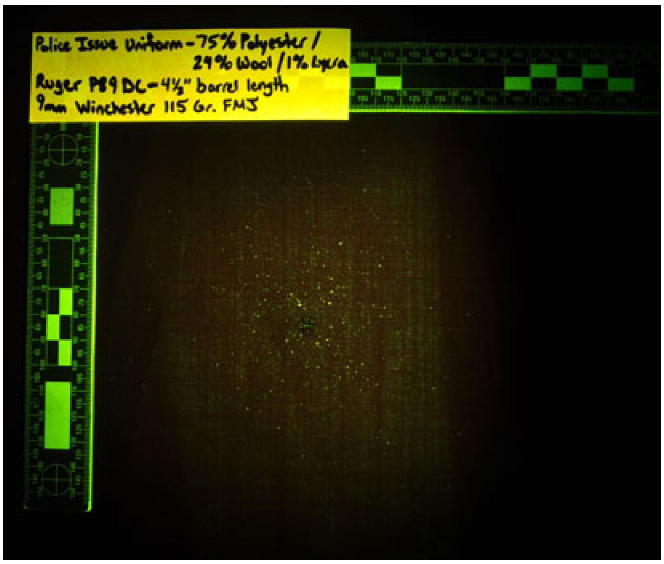

FIG. 7—*Photograph of police issue uniform shirt under 445-nm filter. Scale given in mm.*

process, aided in the identification of what is being illuminated with an ALS.

For future studies, it may prove beneficial to test additional variables such as shooting distance and angle, different firearms (i.e., rifles and shotguns), and various types of ammunition (e.g., hollow point, lead less, etc.). It would also have been ideal to collect samples from all targets once ALS had been used and perform analysis using an SEM-EDX. Although it was determined that the majority of residue fluorescing was unburnt gunpowder, it would have been advantageous to determine the elemental composition of those particles. Finally, a wide array of camera settings can be employed to better document what the examiner is seeing with ALS and it may improve results to develop a deeper knowledge of the camera and which settings would be optimal to aid in the interpretation of GSR evidence.

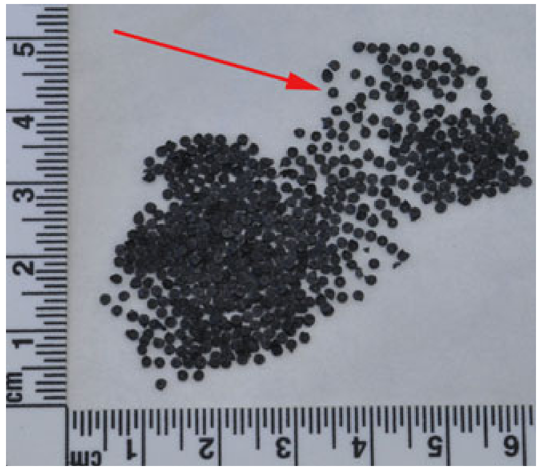

FIG. 8—*Photograph of Hornady Custom 9 mm Luger 115 gr. FMJ powder. Zoomed in 50% from original photograph. Arrow indicates disk-shaped powder particle with center perforation. Scale given in cm.*

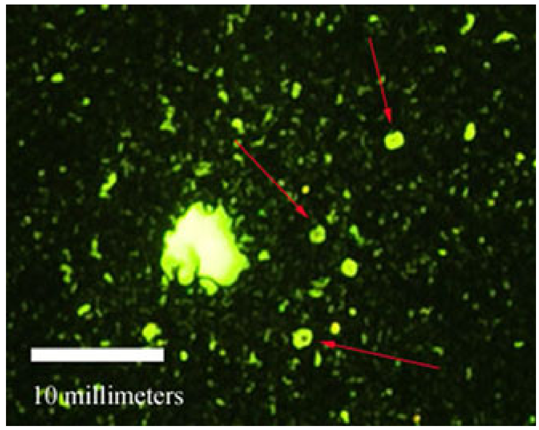

FIG. 9—*Photograph of Hornady residue under 445-nm filter. Zoomed in 200% from original photograph. Arrows indicate intact, unburnt gunpowder residue displaying center perforation characteristic, as shown in Fig. 8. Scale bar indicates 10 mm.*

Acknowledgments

Special thanks to the Austin Police Department of Austin, Texas, for the provision of materials and location in which to perform this research. I would also like to thank Dr. Kathy Sperry, Sr. Director of the Texas Tech University Institute for Forensic Science who served on my internship committee.

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