ORİJİNAL ARAŞTIRMA ORIGINAL RESEARCH

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# Infrared Imaging as a Complementary Aid in Estimating Muzzle-to-Target Shooting Distance: An Application on Dark, Patterned and Bloody Sample

## Namlu-Hedef Arası Atış Mesafesi Tahmininde Tamamlayıcı Yardımcı Yöntem Olarak Kızılötesi Görüntüleme: Koyu, Desenli ve Kanlı Örnekler Üzerinde Bir Uygulama

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**ABSTRACT Objective:** The aim of this work was to assess the utility of the infrared camera as an effective tool for observing physical features like soot and gunshoot residues around the entrance hole, to aid estimation of the shooting distances on bloody, dark and patterned samples. **Material and Methods:** In this study, white control samples, as well as colored and patterned fabrics were fired from several distances (contact, 6 inches, 12 inches, 24 inches, and 36 inches). All shootings were performed with three replicates. Post-shooting infrared images were taken by use of Crime-lite 82S infrared, before and after application of blood on the samples. Human whole blood was sprayed onto the clothing by means of an aerosol spray bottle in two stages, and was partially dried before capturing the image with the infrared camera. **Results:** Using visual examination, it was not possible to detect any soot distribution on patterned fabrics, and the intensity of soot decreased and began to fade at 10 inches for other colored fabrics. The addition of blood to clothing masked the observation of inner soot and decreased the accuracy of the measurements. However, the soot was still visible when using an infrared camera on bloody samples, navy and black unknowns (10 inches) and patterned samples (contact and 6 inches), indicating the utility of an infrared camera on dirty and darker fabrics. **Conclusion:** The results of this study indicate that, similar to Modified Griess Test and Sodium Rhodizonate Test, soot alone is not the most accurate or reliable parameter for predicting true muzzle-to-target distance. However, an infrared camera enhanced the observation of presence of gunshoot residues not easily visible to the naked eye on dark, patterned and bloody samples. Thus, the proposed application of infrared imaging can easily be utilized as a complementary approach in the prediction of muzzle-to-target firing distance on dark, patterned and bloody fabrics.

**Keywords:** Gunshot residues; infrared imaging; shooting distance determination

**ÖZET Amaç:** Bu çalışmanın amacı, kızılötesi kameranın, giriş deliği etrafındaki is ve ateşli silah kalıntıları gibi fiziksel özellikleri gözlemlemek için etkili bir araç olarak kullanımını değerlendirerek; kanlı, koyu renkli ve desenli örnekler üzerinde atış mesafelerinin tahmin edilmesini sağlamaktır. **Gereç ve Yöntemler:** Bu çalışmada, beyaz kontrol örneklerinin yanı sıra renkli ve desenli kumaşlara da farklı mesafelerden (bitişik, 6 inç, 12 inç, 24 inç ve 36 inç) ateş edilmiştir. Her atış üç tekrarla yapılmıştır. Atış sonrası kızılötesi görüntüleri, numunelere kan uygulanmasından önce ve sonra Crime-lite 82S kızılötesi kullanılarak alınmıştır. İnsan tam kanı, giysilere iki aşamada bir aerosol sprey şişesi vasıtasıyla püskürtülmüştür. Görüntü kızılötesi kamerası ile çekilmeden önce kıyafetler kısmen kurutulmuştur. **Bulgular:** Görsel inceleme ile desenli kumaşlarda is dağılımı tespit edilememiştir. Diğer renkli kumaşlarda ise is yoğunluğu azalarak 10 inç'ten sonra solmaya başlamıştır. Bununla birlikte, lacivert ve siyah bilinmeyenler (10 inç) ve desenli numuneler (bitişik ve 6 inç) üzerinde kızılötesi kamera kullanıldığında is gözlenebilmektedir. Bu sonuç kızılötesi kameranın koyu renkli kumaşlar üzerindeki kullanışlılığına işaret etmektedir. **Sonuç:** Bu çalışmanın sonuçları, is dağılımının Modifiye Griess Testi ve Sodium Rodizonat Testine benzer şekilde tek başına gerçek namlu-hedef mesafesini tahmin etmek için en doğru veya güvenilir parametre olmadığını göstermektedir. Bununla birlikte, kızılötesi kamera, koyu, desenli ve kanlı numunelerdeki çıplak gözle kolayca görülemeyen ateşli silah kalıntıları varlığının gözlemini kolaylaştırmıştır. Bu nedenle, önerilen kızıl ötesi görüntüleme uygulaması; koyu renkli, desenli ve kanlı kumaşlarda namludan hedefe atış mesafesinin tahmininde tamamlayıcı bir yaklaşım olarak kullanılabilir.

**Anahtar Kelimeler:** Ateşli silah kalıntıları; kızılötesi görüntüleme; atış mesafesi belirlemesi

The estimation of firing distance is an important part of forensic analysis in firearm-related cases. The term gunshot residues (GSR) may be defined as a combination of unburned and burned particles originating from the primer components, propellant, and materials from the projectile like cartridge case, bullet jacket and bullet.[1-5] A cone-shaped cloud of particles is released from the muzzle by the time a gun is discharged.[6] Distribution of GSR is influenced by various circumstances like distance, caliber, type of propellant or weapon, muzzle-to-target angle, target material, and atmospheric conditions. Therefore, distribution of residues that reach the target varies, resulting in diverse patterns.[1,7-9] Presumptive tests for GSR are beneficial to predict muzzle-to-target ranges.[10] These estimations were first predicted on unknown distance samples by direct examination of the apparent GSR patterns or else GSR patterns formed by the Walker test, and comparing with trial firings at known distances. The Walker test was then replaced by the modified Griess test (MGT), which became the approved method for investigating nitrite compounds in GSR patterns since 1990.[11,12] Following to the MGT, the sodium rhodizonate test can be applied to test for the presence of lead.[13]

The MGT is a chemical color test to screen for the presence of nitrite compounds which are formed by the burning of smokeless powder. Moreover, MGT focuses on the examination of the distribution, size and density of nitrite residues transferred from a victim's clothing or other objects. In order to evaluate this color test precisely, reproduction of test fires at known distances are performed by using the same brand of suspect's firearm along with the same type of ammunition and target substrates.[11] The chemical reaction for MGT is shown in Figure 1. The Sodium Rhodizonate Test (SRT) is a color test, which reacts with lead produced by materials such as primer residues (lead styphnate or lead azide), lead bullets, or shot pellet wipe. Therefore, lead residues in firearm-related cases may be identified via the SRT as described by Dillon's paper in 1990.[13] The chemical reaction describing the SRT is shown in Figure 2.

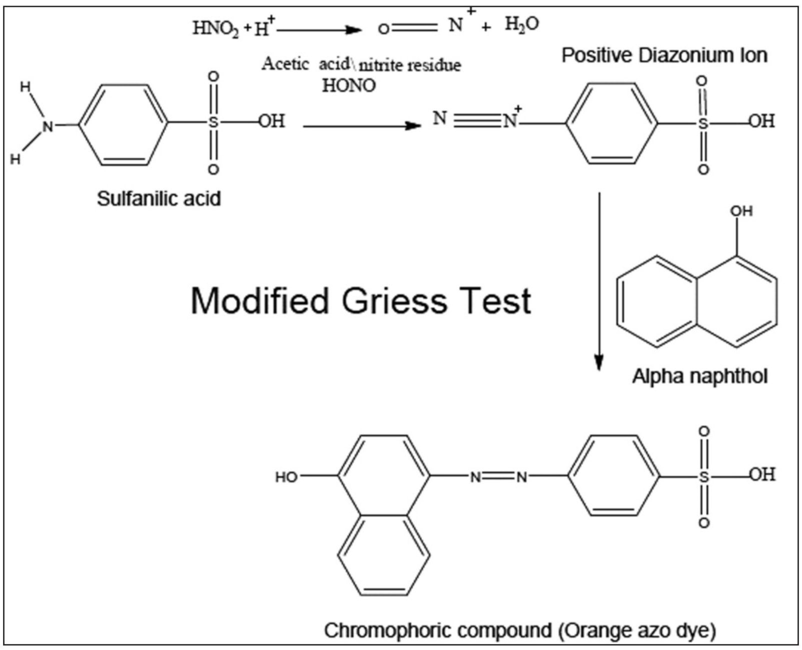


**FIGURE 1:** The chemical reaction for the Modified Griess Test (The orange color is caused when the nitrites are introduced to acetic acid and heated to form nitrous acid. The nitrous acid then forms a diazonium compound with sulfanilic acid, and this compound then couples with the alpha-naphthol to produce the orange azo dye).

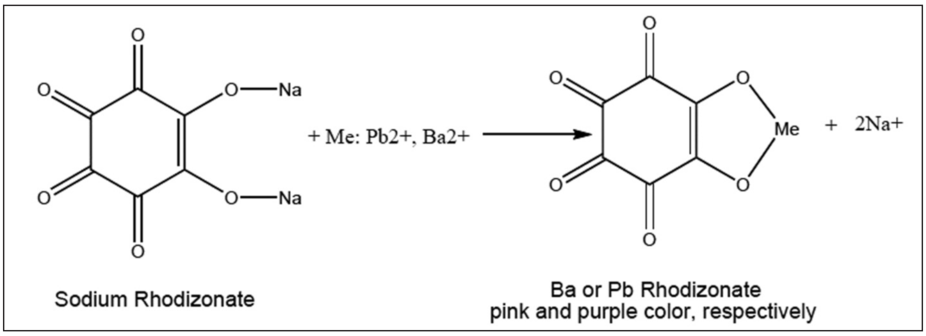


**FIGURE 2:** The chemical reaction describing the Sodium Rhodizonate Test.

Although colorimetric tests are practical and widely used in forensic laboratories, they have known selectivity and sensitivity limitations. For instance, the color and cleanliness of the substrate can mask the color reaction and important characteristics such as soot, gunpowder particle distribution, and gunpowder particle density around a suspected bullet hole. Thus, the purpose of this study was to assess whether or not an infrared (IR) camera can be used as an auxiliary tool for observing physical features like soot and gunpowder particles around the entrance hole to assist with estimation of the shooting distances on bloody, dark and patterned samples.

## MATERIAL AND METHODS

### STUDY ITEMS

Sample collection for shooting range determination took place at WVU Ballistic Laboratory under controlled environmental conditions. Test firings were performed with a Springfield Armory® firearm (USA) loaded with Starline Brass 9 mm Luger ammunition. White (control), grey and patterned fabrics were shot at known distances (contact, 6 inches, 12 inches, 24 inches and 36 inches) while another set of colored fabrics (orange, maroon, navy and black samples), and patterned textiles were shot at distances unknown to the examiner (blind test). All shootings were performed with three replicates. Totally, 63 fabrics were shot during this research.

### APPLICATION OF BLOOD

Application of the blood on white control samples was conducted in a properly ventilated biohazard hood. The blood was prepared with 55% plasma and 45% red blood. IR images taken by a Crime-lite 82S IR Figure 3 with a 5MP IR sensitive camera with IR filters (Foster and Freeman), were collected before and after the application of blood. Photographs using a Nikon D7200 camera were also taken before and after fabrics were covered with blood.

### CHEMICALS AND EQUIPMENT

For the Modified Griess test, acetic acid (Lot# 171289; Fischer Scientific, NH), alpha-naphthol (Lot#10190898; Alfa Aesar, MA), sodium nitrite (Lot#A0267857, Acros Organics-Thermo Fisher Scientific, MA), sulfanilic acid (Lot#BCBQ1007V; Sigma Aldrich, MO), methanol (Lot#170983; Fisher Chemical, PA), cheesecloth, desensitized photo paper, cotton swabs, and an iron were utilized as

**FIGURE 3:** Crime-lite 82S with 5MP IR sensitive camera.

proposed in literature.[11] Additionally, sodium bitartrate (Lot#BCBR3492V; Sigma Aldrich, MO), sodium rhodizonate (Lot#BCBR0492V; Sigma Aldrich, MO), hydrochloric acid (Lot#167045; Fisher Scientific, NH), tartaric acid (Lot#Y04A021; Alfa Aesar, MA), Search Power Spray Units (Sirchie Acquisition Company LLC, NC), and Whatman paper #42 (Fisher Scientific, NH) were used as suggested in sodium rhodizonate test procedure.[13] The Search Power Spray Units (Sirchie Acquisition Company LLC, NC) were used to spray reagents during the sodium rhodizonate test. ImageJ® (product version: 2006.02.01) software was used to measure color area and soot area in the images taken by both the IR and Nikon D7200 cameras. Microsoft® Excel® (2016 MSO 16.0.4266.1001) was used for data analysis.

## RESULTS AND DISCUSSION

The distribution and quantity of GSR that reach a target vary depending on the firing distance and other conditions such as ammunition, firearm, firing angle and atmospheric conditions.[1,7,8] Forensic experts predict the firing distance ranges using a visual analysis of the characteristics of GSR patterns.[5] Color tests have been the primary assay to help analysts in assessment of GSR patterns for decades.[1,5,11,13] Bailey and co-workers presented a method to increase the visualization of GSR patterns on dark and patterned fabrics compared with the MGT, which consisted of treating the textile with an application of a 5.25% solution of sodium hypochlorite.[8] However, the authors reported that some coloring agents were not impressed by sodium hypochlorite, and concluded that bleaching may not improve the visualization of firearm discharge residues (FDR) patterns in some textiles.[8] In our previous work, restrictions of conventional color tests (MGT and SRT) were discussed in detail.[14] These examples stress the lack of selectivity associated with chemical color tests on substrates commonly encountered in casework items at crime scenes, such as dark colored, patterned, or bloody clothing.

Plattner et al. stated that FDR on substrates may be characterized by measuring inner and outer gunpowder soot area, emphasizing inner gunpowder soot area is much more visible than outer gunpowder soot area.[15] The authors also reported that the area of inner and outer gunpowder soot increases while density of soot decreases, with ascending muzzle-to-target shooting distance. However, their results were based on very limited shooting distances from contact up to 0.2 cm (~0.08 inch). A recent study by Barrera et at., conducted test firings at 20 cm (~7.87 inch) and concluded that outer gunpowder soot area can be visualized by the combination of an orange-colored filter and 440-nm illumination while the inner gunpowder soot area can be visualized by infrared photography.[16]

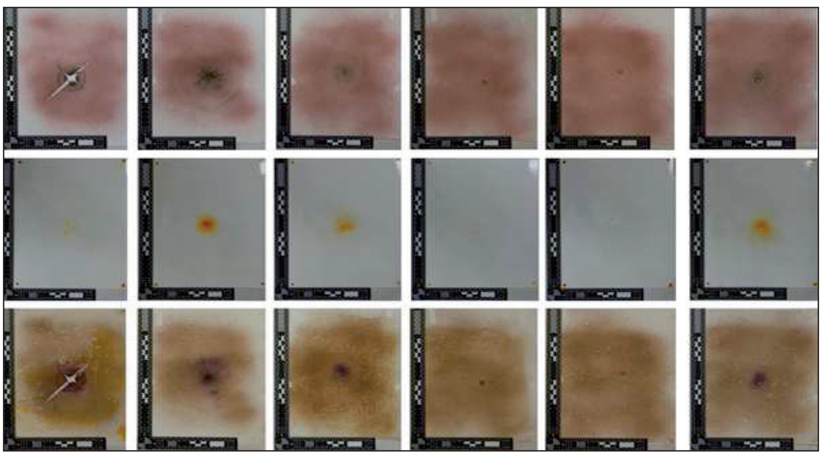

**FIGURE 4:** Photographs of fired white fabrics after blood application (top), the respective results after the indirect Modified Griess test (middle), and the results after direct application of Sodium Rhodizonate Test (bottom). Firing distances are in order from left to right: contact, 6 inches, 12 inches, 24 inches, 36 inches, and unknown (10 inches).

We conducted an application on dark, patterned and bloody samples from different shooting distances ranging from contact to 36 inches, and our measurements were based on inner gunpowder soot area. MGT and SRT were respectively applied to the control white fabrics on which blood was sprayed. Visual results of colorimetric tests are shown in Figure 4, and corresponding measurements are given in Table 1. The measurements show that blood masked the accurate visualization of soot and FDR particles on samples, and affected the accuracy of the respected measurements (Table 2). However, the use of an IR camera filtered interference from blood, allowing for enhanced observation of both soot and particles surrounding the entry hole (Figure 5).

A graphical comparison of soot area versus firing distance for grey, orange, maroon, navy, black and patterned fabrics is shown in Figure 6. IR imaging was useful to reveal GSR distribution in dark

**TABLE 1:** List of color area measured after blood application
(Results are given as mean of three replicate measurements ± standard deviation).

| White Control Fabrics | SRT Color Area (cm$^2$) | MGT Color Area (cm$^2$) |
|---|---|---|
| Contact | 26.9±0.9 | 6.6±0.5 |
| 6 Inches | 55.0±3.8 | 18.2±1.2 |
| 12 Inches | 9.9±0.4 | 11.5±0.5 |
| 24 Inches | N/A | N/A |
| 36 Inches | N/A | N/A |
| Unknown (10 Inches) | 11.1± 1.6 | 13.3±1.8 |

SRT: Sodium rhosiconate test; MGT: Modifed Griess test.

**TABLE 2:** List of soot area measured before and after blood application
(Results are given as mean of three replicate measurements ± standard deviation).

| White Control Fabrics | Before Blood IR Imaging Soot Area (cm$^2$) | After Blood Regular Imaging Soot Area (cm$^2$) | After Blood IR Imaging Soot Area (cm$^2$) |
|---|---|---|---|
| Contact | 24.5±0.5 | 21.2±1.1 | 22.4±0.8 |
| 6 Inches | 53.2±1.1 | 24.3±0.9 | 49.3±1.3 |
| 12 Inches | 20.3±0.9 | 14.3±0.7 | 18.2±0.5 |
| 24 Inches | N/A | N/A | N/A |
| 36 Inches | N/A | N/A | N/A |
| Unknown (10 Inches) | 20.4± 0.7 | 16.3±0.6 | 19.7±0.9 |

IF: Infrared.

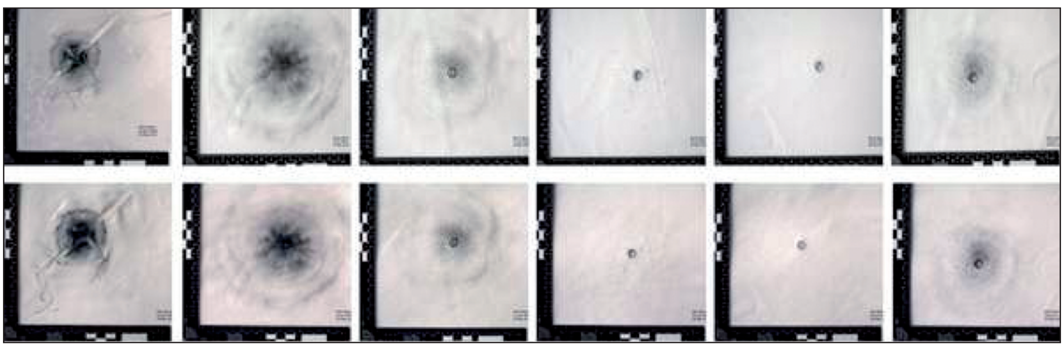

**FIGURE 5:** IR camera photographs of white control fabrics before blood application (top), IR camera photographs of white control fabrics after blood application (bottom). Firing distances are in order from left to right: contact, 6 inches, 12 inches, 24 inches, 36 inches, and unknown (10 inches).

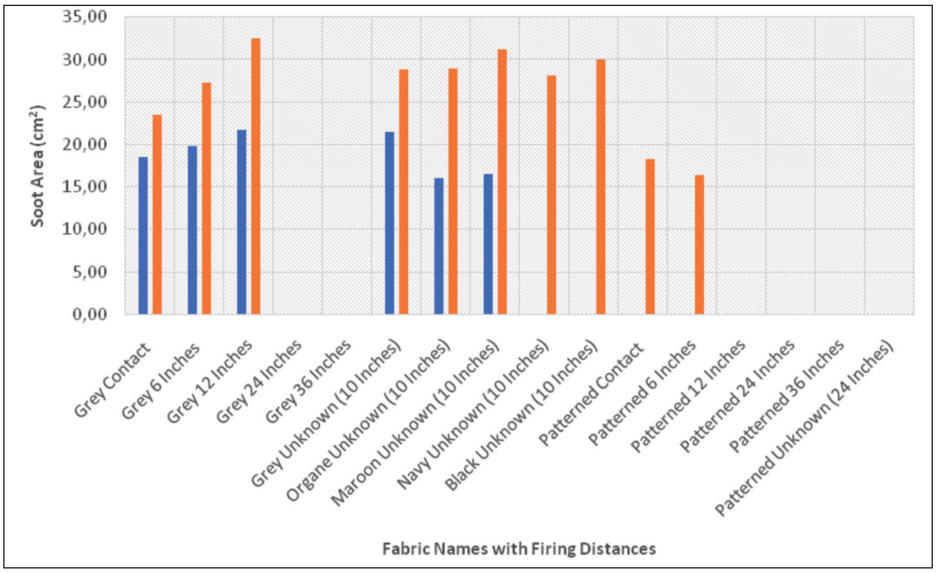


**FIGURE 6:** Soot area comparison with regular camera versus IR camera in listed fabrics with firing distances. Not applicable (N/A) measurements were represented as zero in the graph.

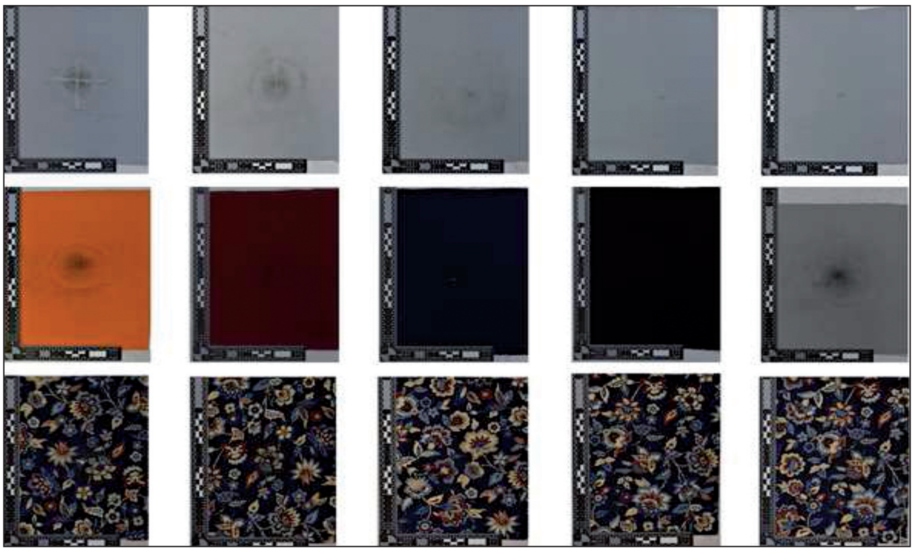

**FIGURE 7:** Regular camera photographs of original fired grey fabrics (top), colored fabrics (middle), and the patterned samples (bottom). Examples of unknowns (middle, from left to right: orange, maroon, navy, black, grey) while known distances of top and bottom images are in order from left to right: contact, 6 inches, 12 inches, 24 inches, 36 inches for grey and patterned fabrics.

backgrounds and bloody fabrics, which is not easily visible to the naked eye. Visual examination was not possible to detect any soot distribution on patterned fabrics, and the intensity of soot decreased and began to fade at 10 inches for other colored fabrics (Figure 7). However, soot was still visible when using an IR camera on navy and black unknowns (10 inches) and patterned samples (contact and 6 inches), indicating the utility of an IR camera on darker fabrics (Figure 8). As can be seen in Table 3 and Figure 6, an IR camera aided in the visualization and detection of soot compared to initial visual examination of the clothing.

## CONCLUSION

Muzzle-to-target shooting distance offers critical evidence in cases involving firearms. Even though

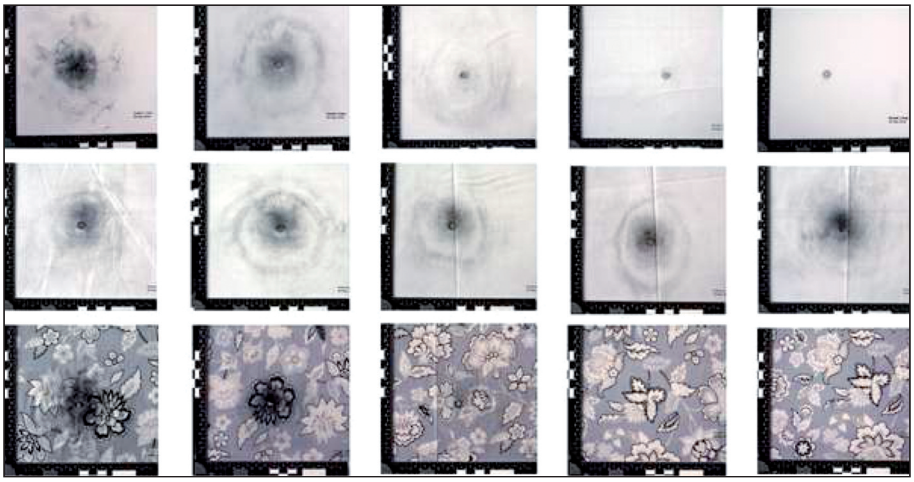

**FIGURE 8:** IR camera photographs of original fired grey fabrics (top), colored fabrics (middle), and the patterned samples (bottom). Examples of unknowns (middle, from left to right: orange, maroon, navy, black, grey all fired at 10 inches) while known distances of top and bottom images are in order from left to right: contact, 6 inches, 12 inches, 24 inches, 36 inches for grey and patterned fabrics.

**TABLE 3:** Comparison of soot area measured under IR imaging and regular camera imaging (Results are given as mean of three replicate measurements ± standard deviation).

| Sample Name | Regular Camera Imaging Soot Area ($cm^2$) | IR Camera Imaging Soot Area ($cm^2$) |
|---|---|---|
| Grey Contact | 18.5±0.6 | 23.4±3.4 |
| Grey 6 Inches | 19.8±0.5 | 27.3±1.1 |
| Grey 12 Inches | 21.7±0.9 | 32.5±2.1 |
| Grey 24 Inches | N/A | N/A |
| Grey 36 Inches | N/A | N/A |
| Grey Unknown | 21.5± 0.8 | 28.8±1.3 |
| Orange Unknown | 16.0±0.6 | 30.0±3.5 |
| Maroon Unknown | 16.5±0.7 | 31.3±1.0 |
| Navy Unknown | N/A | 28.1±1.3 |
| Black Unknown | N/A | 30.0±2.4 |
| Patterned Contact | N/A | 18.3±0.2 |
| Patterned 6 Inches | N/A | 16.4±0.6 |
| Patterned 12 Inches | N/A | N/A |
| Patterned 24 Inches | N/A | N/A |
| Patterned 36 Inches | N/A | N/A |
| Patterned Unknown | N/A | N/A |

Real distances of colored unknowns are 10 inches while patterned unknown is 24 inches.
IF: Infrared.

conventional colorimetric tests can reveal the GSR distribution around an entry hole, there are still restrictions in terms of the selectivity of the analyses. In particular, dark or bloody backgrounds can interfere with visualizing the change in color of the reaction and mask features such as soot, particle distribution, and particle density.

The results of this study indicate that, similar to MGT and SRT, soot alone is not the most accurate or reliable parameter for predicting true muzzle-to-target distance. However, an IR camera enhanced the observation of presence of GSR not easily visible to the naked eye on dark, patterned and bloody samples. In addition, blood did not interfere with the visualization of GSR when using the IR camera. It was shown that an IR camera successfully helped to interpret the important characteristics such as soot, particle distribution, and particle density on dark, patterned and bloody backgrounds. Furthermore, the proposed application of infrared imaging can be easily utilized as a complementary approach in prediction of muzzle-to-target firing distance on types of fabrics commonly encountered in crime scenes. Further instrumental research in shooting distance determination is needed to provide a more objective approach.

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### *Conflict of Interest*

*No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.*

### *Authorship Contributions*

***Idea/Concept:** Tatiana Trejos, Bayram Yuksel; **Design:** Tatiana Trejos, Bayram Yuksel; **Control/Supervision:** Tatiana Trejos, **Data Collection and/or Processing:** Courtney Vander Pyl, Mandy Ho, Oriana Ovide, Bayram Yuksel; **Analysis and/or Interpretation:** Tatiana Trejos, Courtney Vander Pyl, Mandy Ho, Oriana Ovide, Bayram Yuksel; **Literature Review:** Courtney Vander Pyl, Bayram Yuksel; **Writing the Article:** Bayram Yuksel, Tatiana Trejos; **Critical Review:** Bayram Yuksel, Mandy Ho, Oriana Ovide, Courtney Vander Pyl, Tatiana Trejos; **References and Fundings:** Tatiana Trejos.*

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