MJFAS
Malaysian Journal of Fundamental and Applied Sciences

Ramadass *et al.* | Malaysian Journal of Fundamental and Applied Sciences, Vol. 22 (2026) 1096–1107

RESEARCH ARTICLE

Gunshot Residue Distribution Pattern of 9 mm Calibre at Different Distances and Angles on Two Different Substrates Using Observational and Statistical Analysis

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Abstract In investigations involving firearms, crime scene reconstruction plays a crucial role in establishing the circumstances and details surrounding the incident. Typically, cardboard is used as a substitute substrate during such reconstructions to simulate the gunfire impact distribution pattern. However, this practice may raise questions in legal proceedings, particularly regarding the accuracy and reliability of using cardboard to represent human flesh. Such concerns could potentially undermine the evidentiary value of the reconstruction and its ability to meet the standard of proof beyond a reasonable doubt for any criminal investigation. Considering this, the objective of the present study is to evaluate whether significant differences exist in gunshot residue (GSR) distribution patterns and particle distribution between cardboard and meat substrates, thereby assessing the validity of using cardboard as a stand-in material in forensic reconstructions. Bovine meat was used as the meat substitute to test residue GSR patterns. A P99 automatic pistol with 9 mm ammunition was used, and the person who fired the gun was right-handed, between 165–175 cm tall and weighed between 80–90 kg. The experiment was conducted in two parts. In the first part, the gun was fired at 4 different distances and in the second part, the gun was fired at 4 different angles. Each distance and angle were tested five times on both cardboard and meat. Altogether, the experiment involved 70 samples. The results were evaluated by visually examining the GSR distribution patterns and statistically analysing the GSR particle distribution using statistical tests of significance. The visual analysis showed no major differences between cardboard and meat at most distances, except at 5 cm, where a noticeable difference in the GSR pattern was observed. However, the analysis showed that the p-values were above 0.05, which means there was no significant difference between the groups, so the null hypothesis was accepted. Overall, the study found no significant differences in GSR patterns or particle counts between cardboard and meat substrates, regardless of the distance or angle of the shots. This finding is important for crime scene reconstruction, as it addresses concerns about the reliability of using cardboard in gunshot reenactments. While concerns have been raised regarding the suitability of cardboard as a tissue simulant, the present findings indicate no significant difference in GSR distribution between cardboard and meat substrates under the tested conditions.

Keywords: Gunshot residue, GSR distribution pattern, GSR particle distribution, cardboard substrate, meat substrate, statistical analysis.

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Received: 9 December 2025
Accepted: 10 September 2026

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Introduction

Gunshot residue (GSR) is an important form of trace evidence generated during the discharge of a firearm and can be transferred to individuals, objects, and surrounding surfaces [1-3]. Its detection, distribution, and analysis can provide valuable information for the interpretation and reconstruction of firearm-related incidents [4-6]. GSR consists of particulate materials originating from the primer, propellant, projectile, and firearm components, and its deposition is influenced by various factors associated with the firing event and receiving surface [7-10]. Recent reviews have highlighted the importance of understanding GSR transfer, persistence, and distribution to improve the interpretation and evidential value of GSR in forensic investigations [3]. In particular, the spatial distribution of GSR on a target surface may provide useful information for estimating shooting conditions. Several factors have been reported to influence GSR distribution patterns, including wind velocity, firing distance, and firing angle [11-15]. In addition to these factors, the physical characteristics of the substrate on which GSR is deposited may also affect particle retention, penetration, and distribution. Previous studies have primarily examined GSR deposition on different surface materials, including cotton, denim, and nylon [16]. However, these studies have largely focused on the exposed surface material, while the influence of the underlying substrate material on GSR distribution remains insufficiently investigated.

Cardboard is commonly used as an underlying substrate in experimental GSR studies because it is inexpensive, readily available, and relatively easy to standardise. However, cardboard does not adequately represent biological tissue encountered in actual firearm-related incidents, where GSR may be deposited on surfaces supported by underlying soft tissue. Differences in physical structure, density, moisture content, and other material properties between cardboard and biological tissue may influence the deposition and spatial distribution of GSR particles [17-18]. This raises an important question regarding whether GSR distribution patterns obtained using cardboard as an underlying substrate are representative of those obtained using a biological substrate. Therefore, this study aims to compare GSR distribution patterns using meat and cardboard as underlying substrate materials. The effects of firing distance and firing angle on GSR distribution are also investigated. The findings of this study are expected to provide experimental evidence on the influence of underlying substrate materials on GSR distribution and contribute to a better understanding of the factors affecting GSR deposition in forensic firearm investigations.

Materials and Methods

Introduction

To investigate the GSR distribution pattern influenced by different underlying substrate materials (meat and cardboard), firing distance and shooting angle, a collaboration with Polis Diraja Malaysia (PDRM) was made and the data collection was conducted at Lapang Sasar PDRM Bukit Bakri, where two distinct phases were carried out. The first phase involved assessing GSR dispersion at four specified distances on two substrate types: meat and cardboard. The second phase focused on evaluating the effects of four firing angles using the same substrates. Residue patterns were subsequently collected, measured, and analysed to determine the extent to which these variables impact GSR distribution.

Shooter Selection Criteria

A Walther P99 semi-automatic pistol, loaded with 9 mm ammunition was selected as the gun and ammunition model. The model was selected due to it being the model of handgun available to the public. Figures 1 (a) and (b) show the gun used in this study as well as the ammunition.

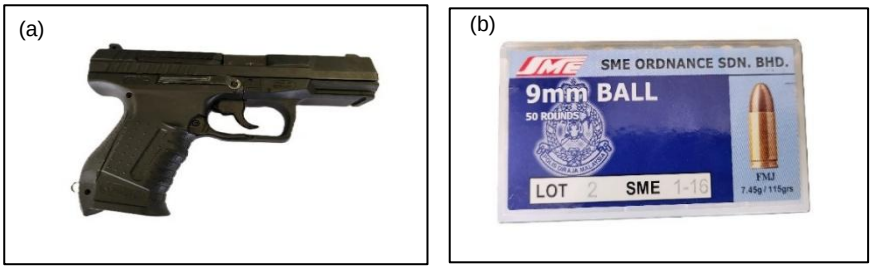


Figure 1. The gun (a) and ammunition (b) used for the sample collection.

An experienced shooter with at least 5 years of experience in shooting was selected. The criteria for the selected police officer were height range between 160 cm and 180 cm, weight range between 70 kg and 100 kg, male police officer and was right-handed. The range was provided as to make it easier for reproducibility. These criteria were chosen because of the standard of the Malaysian male population averaged within these measurements [19].

Frame Construction Protocol

A custom-designed wooden frame, measuring 35 cm by 45 cm, was utilized to support the test materials throughout the study. Two types of cardboard were prepared: thick cardboard of thickness of 2 cm and thin cardboard of thickness 0.5 cm, with 35 pieces of each cut to match the dimensions of the frame. The thick cardboard was employed in trials investigating differences between substrates, including cardboard itself, while a cotton cloth was affixed to the surface using metal clamps. For tests involving the meat substrate, a sheet of thin cardboard was positioned behind the meat to provide structural support. The meat sample was centrally placed on the cardboard and secured using plastic wrap, which was wrapped around both the meat and the frame to ensure stability. All components were held firmly in place with metal clamps. Figure 2 illustrates the front and side views of the frame setup for both substrate types.

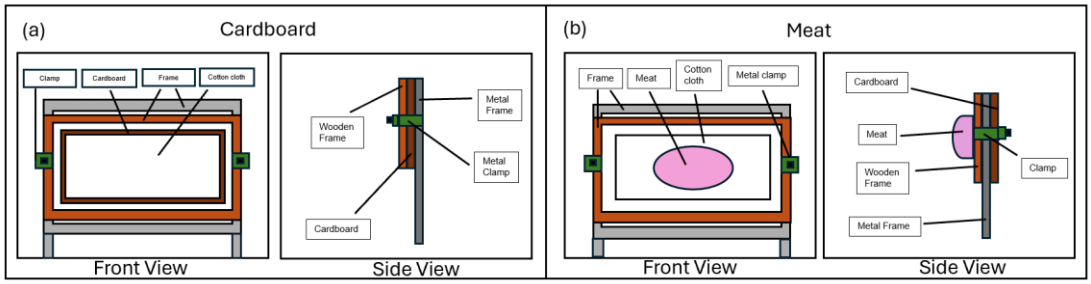


Figure 2. Frame design for front and side view for (a) cardboard and (b) meat substrates

Sampling Area

The semi-indoor 25-meter firing range located at Maktab Teknik PDRM Bukit Bakri, Muar, Johor required monitoring of environmental conditions to ensure the reliability of the collected data. Wind speed was measured using an anemometer, and firing was conducted only under stable wind conditions. Weather factors, such as rainfall and strong winds, were also considered; testing was postponed during adverse conditions and resumed on clear days to reduce environmental interference. Temperature data, including daily minimum and maximum values, were obtained from the Malaysian Meteorological Department (Jabatan Meteorologi Malaysia), and relative humidity was also recorded to support the environmental context and consistency throughout the data collection process.

Meat Selection Criteria

Fresh meat was procured on the same day that testing was conducted to ensure sample consistency and integrity. A total of ten meat samples were utilized, with each sample subjected to a minimum of five gunshots. Bovine meat was selected as a tissue analogue because its high-water content, soft structure, and organic composition provide a more representative biological substrate than rigid materials such as cardboard. Although it does not fully replicate human tissue, bovine meat offers practical and consistent material for investigating the effect of biological substrates on GSR deposition and distribution [17-18]. The bovine round meat was selected because it consists predominantly of relatively dense and uniform muscle tissue, providing a consistent biological substrate for experimental comparison and reducing variations in tissue composition between samples. The bovine meat was obtained from a licensed and regulated abattoir (meat market) for food purposes. The individual samples had an average weight of approximately 1.0 kg, with a permissible variation of ±0.2 kg.

Sample Collection

The firing rig was configured to evaluate the effect of distance on GSR distribution using two substrates: bovine muscle tissue (meat) and cardboard. Testing was conducted at four distances (5 cm, 10 cm, 20 cm, and 30 cm). Each substrate was covered with a clean cotton cloth to facilitate GSR collection and mounted onto a metal frame, with the cloth positioned at the front. Firing commenced at a fixed angle of 90 degrees, starting at 30 cm. A total of five replicates were performed at each distance, with the cotton

cloth replaced after each shot to ensure independent collection of GSR for every replicate. The distances were then sequentially reduced to 20 cm, 10 cm, and finally 5 cm, repeating the same procedure for both substrates. This protocol resulted in a total of 40 samples. Figure 3 shows the frame design at different distances and angles.

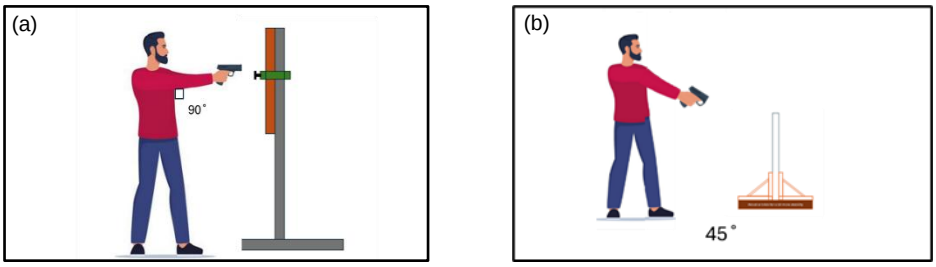


Figure 3. Sketch of experiment protocol (a) at 4 different distances (n = 5 cm, 10 cm, 20 cm & 30 cm) and (b) at 3 different angles (n = 30˚, 45 ˚ & 60 ˚).

Safety equipment, including gloves, earmuffs, and safety goggles, was used throughout the experiment to ensure the safety of the shooter. The procedure was subsequently repeated to investigate the effect of varying firing angles on GSR distribution, with the firing distance fixed at 30 cm. Firing angles of 30°, 45°, 60°, and 90° were evaluated for both substrate types. The experiment was conducted on the floor to simulate a shooting scenario involving a seated subject. A protractor and measuring tape were used to accurately measure and maintain the firing angle and distance. For each combination of firing angle and substrate, five replicates were performed, with the cotton cloth replaced after each shot to ensure independent GSR collection. In total, 70 samples were collected across all firing distance and angle conditions. Following each shot, the cotton cloth was placed on the surface of the bovine muscle tissue, while the cardboard substrates were photographed for documentation. The cotton cloth was subsequently secured onto a cardboard backing using metal clamps to prevent crumpling and stored individually in zip-lock bags for subsequent analysis. Experimental consistency was maintained by measuring and verifying the firing angle and distance before each shot. A five-minute rest period was provided between consecutive shots to minimise shooter fatigue and maintain consistency throughout the experiment.

Sample Processing for GSR Visual Examination and Particle Density Analysis

To enhance the visibility of GSR particles, each image of the cotton cloth was digitally inverted using Adobe Photoshop. In the inverted images, GSR particles were visualized as white dots and subsequently circled in red to facilitate particle counting and quantitative analysis. An automated particle analysis software was not used as the method used for this research was adopted from previous research by Zain et al. [13]. GSR distribution was quantified using the particle density formula, $D = n/cm^2$, where D represents particle density, n is the number of GSR particles, and cm^2 denotes the area of the region analysed. The area was calculated using the formula for the area of a circle, $A= \pi r^2$ where $\pi=3.142$ and r represents the radius in centimetres. For this study, an 8 cm radius was used to define the region of interest. Particle density was determined for three zones: the inner 4 cm radius, the outer ring between 4 cm and 8 cm, and the entire 8 cm circular area. The total number of GSR particles within each zone was counted manually. To facilitate accurate counting, a grid overlay was applied to the inverted images, and each visible GSR particle, identified as a distinct glowing dot, was tallied before being used in the particle density calculation. Figure 4(a) shows the area used to calculate the particle density, and Figure 4(b) shows the visual appearance of soot adherence and dotted marks originating from GSR particles. Only the dotted marks were included in the particle density calculation.

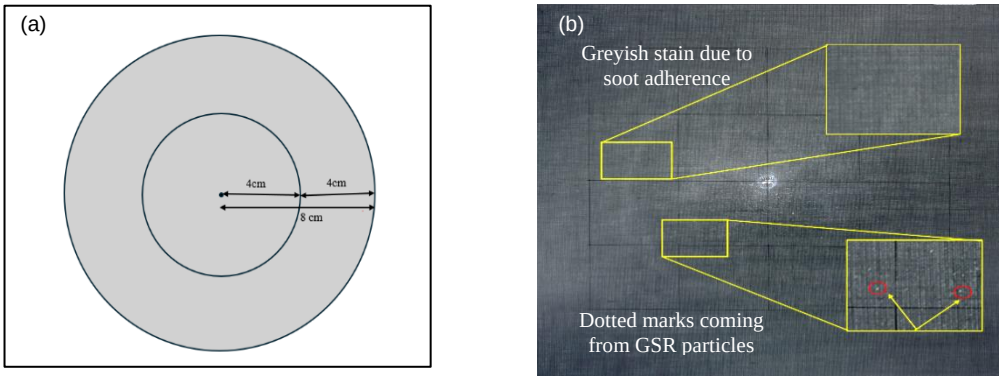


Figure 4. The diagram for (a) the area of divisions of particle density calculations and (b) visual appearance of soot adherence and dotted marks originating from GSR particles.

Statistical Analysis

To explore potential differences in GSR particle distribution between bovine meat and cardboard substrates, statistical analyses were carried out using IBM SPSS Statistics version 30 [20]. The distribution of the particle density data was first evaluated for normality using the Shapiro-Wilk test [21], given the sample size did not exceed 50 observations. Depending on the distribution characteristics, descriptive statistics were reported either as mean ± standard deviation for data approximating normality, or as median with range for data not meeting this assumption. The choice of significance tests was guided by the outcome of the normality assessment, with ANOVA considered for normally distributed datasets and the Mann-Whitney U test applied in cases where the data were not normally distributed [22]. These decisions were based on standard criteria involving sample size, distribution patterns, and the assumption of independent observations.

The variables which are the different distances and different angles in this study were independent of each other and there were fewer than 3 samples, therefore, the selection of independent T-test and Mann Whitney U test was the most suitable to analyze the dataset of this study. The results of the significance test were used to determine whether the null hypotheses could be rejected or not. Furthermore, the analysis was also conducted to see if there was significant difference between the GSR distribution pattern at different distances and angles. Figure 5 is a flowchart of the selection methodology for statistical analysis.

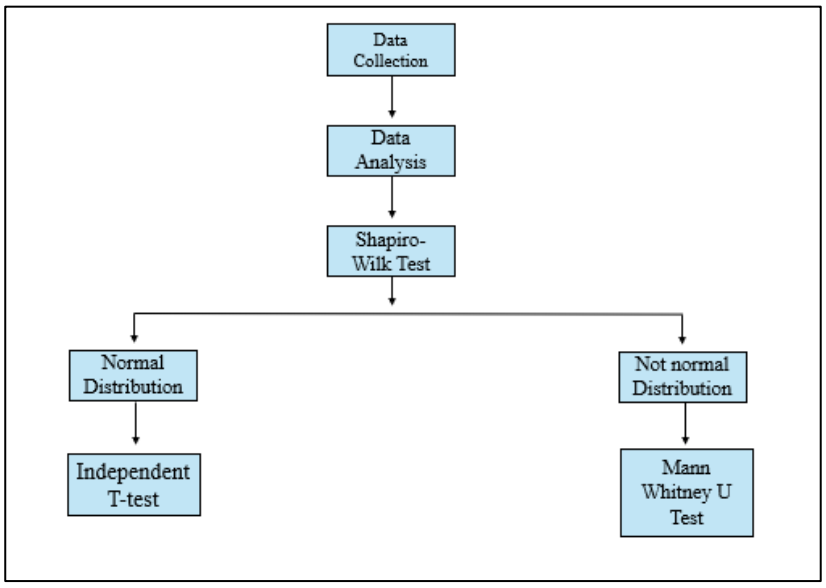


Figure 5. Flowchart for statistical analysis selection.

Results and Discussion

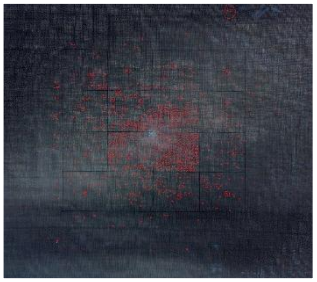
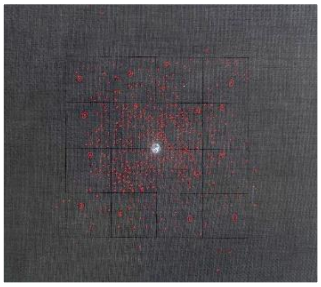
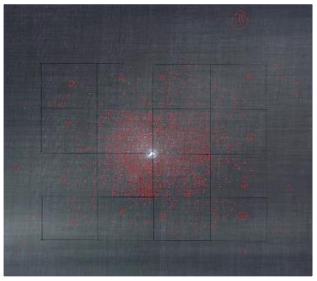
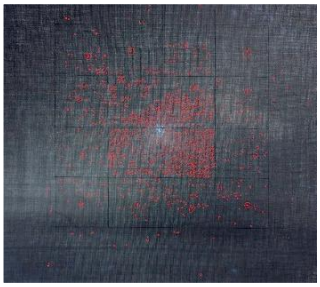
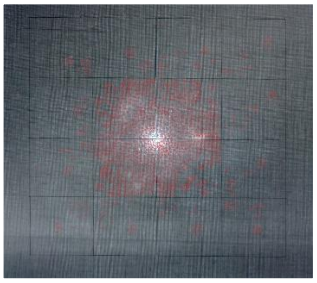
Environmental Data

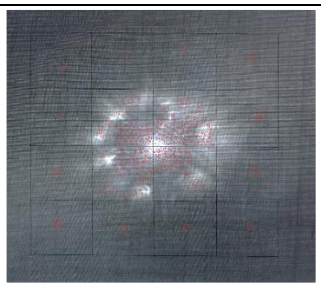
Minimum, maximum, and average values of wind speed at 3.2 km/h, 4.3 km/h, and 4.0 km/h, were recorded respectively. Weather conditions were documented as clear, bright, and sunny on the day of data collection. Temperature and humidity data were obtained from the nearest station of the Malaysian Meteorological Department (Jabatan Meteorologi Malaysia), with temperatures ranging from a minimum of 23°C to a maximum of 33°C, and an average of 28°C. The recorded relative humidity was 70% [23].

Visual Comparison of Different Distances on Cardboard and Meat Substrates.

The GSR distribution pattern was compared at different distances on both cardboard and meat substrates to identify any differences in the distribution. Table 1 showed the images that were compared on their GSR distribution pattern for each distance.

Table 1. Comparison of GSR distribution pattern at each distance between meat and cardboard substrates.

Distance	Underlying Substrates	
	Cardboard	Meat
30 cm		
20 cm		
10 cm		

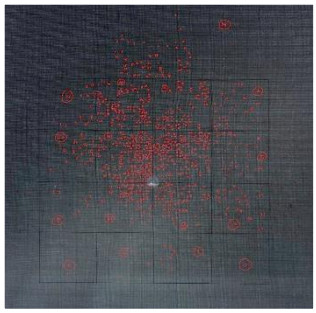
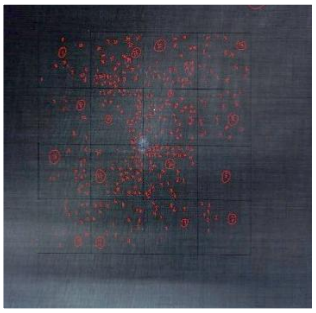
5 cm		

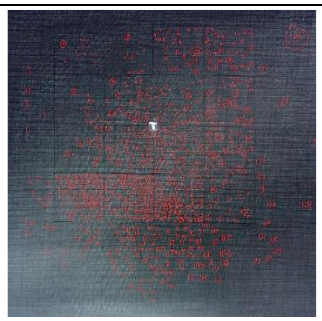
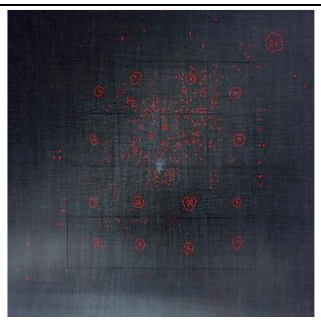
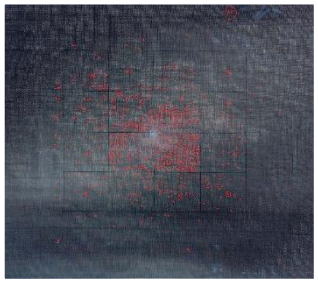
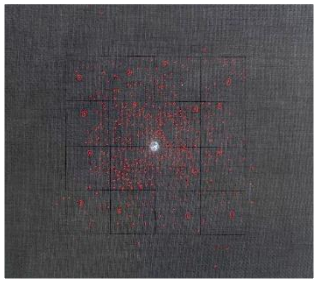
The GSR distribution patterns observed on both meat and cardboard substrates at 30 cm, as depicted in Table 1, demonstrated only subtle visual differences. Although no statistically significant differences were identified in the overall GSR distribution between the two substrates, minor visual variations were noted, potentially attributable to the absorptive nature of the meat. The meat, possessing elastic and rubber-like properties, may have attenuated the bullet's impact [17], thereby localizing the GSR more closely to the point of entry rather than dispersing it outward. Furthermore, the GSR distribution patterns at 20 cm and 10 cm distances exhibited considerable similarity across both substrates. In both instances, the GSR deposition remained concentrated near the entry point, with no discernible differences between the images, suggesting a consistent pattern of residue accumulation at closer firing ranges. At a firing distance of 5 cm, no significant differences were observed in the distribution of GSR particles between the tested surfaces. However, a distinct circular pattern of soot deposition was evident, radiating outward from the point of impact. This phenomenon may be attributed to the differing textures and physical properties of the underlying substrate materials. Specifically, the cardboard, being firmer and more rigid than the meat surface, likely results in greater reactive force upon impact, thereby influencing the dispersion pattern of the soot [12, 17].

Visual Comparison at Different Angles on Meat and Cardboard Substrates.

The distance for this part of the experiment was maintained at 30 cm. Four different angles were used, which were 30˚, 45˚, 60˚ and 90˚.The GSR distribution pattern was compared between the meat and the cardboard for each angle and each replication. Table 2 shows the images that were compared on their GSR distribution pattern for each angle.

Table 2. Comparison of GSR distribution at each angle between the meat and cardboard substrates.

Angle	Underlying Substrates	
	Cardboard	Meat
30˚		

45˚		
60˚		
90˚		

The GSR distribution patterns on both the cardboard and meat substrates, as presented in Table 2, were generally consistent across all tested angles. At 30°, the GSR pattern appeared skewed in the direction of the firearm's angle, with the bullet entry point aligning with the trajectory of the shot. Residue dispersion extended downward up to approximately 6 cm from the point of entry. A similar trend was observed at 45°, where the GSR pattern followed the direction of the angled shot, with residue extending up to 8 cm below the entry point. At 60°, the skew in the GSR distribution was more pronounced, again following the angle of the firearm, with residue dispersed as far as 16 cm from the entry point. At a perpendicular firing angle (90°), the GSR exhibited a concentric dispersion pattern, characterized by a circular distribution radiating outward from the point of impact. These observations suggest that increasing the firing angle leads to a more elongated and directional GSR pattern, consistent across both substrate types [11, 24].

Analysis of GSR Particle Distribution at Different Distances and Different Angles on Different Underlying Substrates.

The GSR particle density data across varying distances was assessed for normality using the Shapiro-Wilk test. To reduce variability and enhance comparability, the analysis was conducted using the ratio of particle density. The results indicated that the data did not follow a normal distribution, as the significance value obtained from the Shapiro-Wilk test was below the 0.05 threshold [21]. A significance level below 0.05 suggests a deviation from normality, thereby justifying the use of non-parametric statistical methods. Consequently, the Mann-Whitney U test was employed for further analysis, as it is appropriate for data that do not meet the assumptions of normal distribution [22]. The outcomes of this analysis are presented in Table 3.

Table 3. Mann-Whitney U test comparison of GSR particle distribution between Cardboard and Meat substrates (n = 5 per group).

Substrate	Parameters	Test Statistics			
		Mann-Whitney U	Z	Asymp. Sig (2-tailed)	Exact Sig. [2*(1-tailed Sig.)]
Cardboard	5 cm	9.500	-0.647	0.518	0.548[b]
	10 cm	5.000	-1.567	0.117	0.151[b]
	20 cm	12.000	-0.104	0.917	1.000[b]
	30 cm	9.000	-0.731	0.465	0.548[b]
	30˚	4.000	-1.776	0.076	0.095[b]
	45˚	6.000	-1.358	0.175	0.222[b]
	60˚	11.000	-0.313	0.754	0.841[b]
	90˚	9.000	-0.731	0.465	0.548[b]
Meat	5 cm	9.500	-0.647	0.518	0.548[b]
	10 cm	5.000	-1.567	0.117	0.151[b]
	20 cm	12.000	-0.104	0.917	1.000[b]
	30 cm	9.000	-0.731	0.465	0.548[b]
	30˚	4.000	-1.776	0.076	0.095[b]
	45˚	6.000	-1.358	0.175	0.222[b]
	60˚	11.000	-0.313	0.754	0.841[b]
	90˚	9.000	-0.731	0.465	0.548[b]

a. Grouping Variable
b. Not corrected for ties

The Mann-Whitney U test was conducted to evaluate differences in GSR particle distribution between the cardboard and meat substrates across various distances (5 cm, 10 cm, 20 cm, and 30 cm) and firing angles (30˚, 45˚, 60˚, and 90˚), as presented in Table 3. This non-parametric test was selected due to the non-normal distribution of the data, as previously determined by the Shapiro-Wilk test. Statistical significance was assessed using a threshold of $p < 0.05$. In all comparisons, the resulting p-values exceeded this threshold, indicating that there were no statistically significant differences in GSR particle distribution between the two substrates at any of the tested distances or angles. Therefore, the null hypothesis could not be rejected, suggesting that the types of underlying substrate (i.e. cardboard or meat) did not significantly influence the distribution of GSR particles under the conditions examined.

The GSR particle distribution was quantified using the particle density formula ($D = n/cm^2$), where n represents the number of particles per unit area. Consistent with the approach adopted by a previous study [13], the analysis was based on the ratio of particle density to account for potential variability in GSR distribution. The cited study noted that GSR patterns can vary between individual shots, even when the same firearm, distance, and angle were used. Such variation may arise due to multiple influencing factors, including environmental conditions, ammunition inconsistencies, or firearm handling [20, 25]. To minimize the impact of these uncontrolled variables, the ratio of particle density was used in the statistical analysis of this study. This method enhances the comparability and reliability of the data. Table 4 presents the average GSR particle distribution across different firing distances and angles for both cardboard and meat substrates.

Table 4. GSR particle distribution for different distances and angles on the cardboard and meat substrates.

Substrate	Distances (cm)			
	5	10	20	30
Cardboard	18.788 cm^{-2} (0 – 61.667 cm^{-2})	8.351 cm^{-2} (8.099 – 8.961 cm^{-2})	2.665 cm^{-2} (2.448 – 3.858 cm^{-2})	0.645 cm^{-2} (0.621 – 0.671 cm^{-2})
Meat	25.819 cm^{-2} (0 – 81.143 cm^{-2})	8.27 cm^{-2} (8.000 – 8.939 cm^{-2})	2.78 cm^{-2} (2.313 – 3.132 cm^{-2})	0.661 cm^{-2} (0.607 – 0.696 cm^{-2})
	Angles (°)			
	30	45	60	90
Cardboard	0.645 cm^{-2} (0.621 – 0.671 cm^{-2})	0.450 cm^{-2} (0.230 – 0.777 cm^{-2})	0.402 cm^{-2} (0.332 – 0.513 cm^{-2})	0.859 cm^{-2} (0.823 – 0.902 cm^{-2})
Meat	0.661 cm^{-2} (0.607 – 0.696 cm^{-2})	0.414 cm^{-2} (0.351 – 0.517 cm^{-2})	0.472 cm^{-2} (0.442 – 0.541 cm^{-2})	0.818 cm^{-2} (0.781 – 0.854 cm^{-2})

The GSR particle distribution for distance could be seen in Table 4. Based on the table showing different distances, the GSR distribution within a 4 cm radius was very dense near the bullet entry point. For all distances and replications, the total GSR particle distribution within an 8 cm area was 0.276 cm^{-2} on the cardboard substrate and 0.217 cm^{-2} on the meat substrate, with a difference of 0.059 cm^{-2}, which is relatively small. Regarding the different angles, the GSR distribution within an 8 cm radius was denser in the direction the gun was angled. Since the gun was fired downward at an angle, the GSR particles tended to accumulate more near the outer edge of the 8 cm area and became less dense closer to the 4 cm mark. The total GSR distribution across all distances and replications for the angled shots was 0.143 cm^{-2} on the cardboard and 0.137 cm^{-2} on the meat, with a negligible difference of 0.006 cm^{-2}. The trend of the GSR particle density was analysed and plotted in Figure 6 (a) and (b).

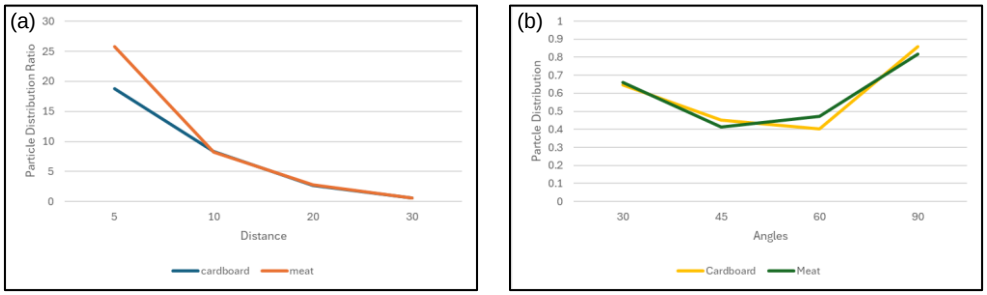


Figure 6. Graph of trend of GSR particle density on cardboard vs meat (a) at different distances and (b) at different angles.

The trends in Figure 6 (a) and (b) were analysed based on previous studies by Ditrich [26], Hofer et al. [27], and Abedi et al. [14]. In Figure 6 (a), the highest GSR particle density on the meat substrate was observed at a 5 cm distance. This is likely because the gun was very close to the substrate, allowing GSR particles to deposit directly onto the cloth before dispersing. However, the cardboard substrate did not show the same pattern at 5 cm. This is likely due to the rigid nature of cardboard, which cannot absorb impact and instead shatters when struck by the bullet, reducing GSR particle retention. At 10 cm, the cardboard still did not follow the trend seen in the meat substrate. This can be explained by the meat's soft, rubber-like texture, which cushions the bullet's impact and allows more GSR particles to settle [17]. In contrast, the hard substrate of the cardboard caused the force to rebound, limiting particle deposition. Beyond 10 cm, the data followed the expected trend, with GSR particle density decreasing as the distance increased. In Figure 6 (b), the trend for different firing angles showed a consistent decrease in GSR particle density within the 8 cm radius as the angle increased. This is because the GSR particles became more spread out and were skewed in the direction the gun was aimed, resulting in fewer particles near the bullet entry point. Both substrates (cardboard and meat) followed this same trend, showing no significant difference in GSR particle density patterns as the firing angle increased.

Conclusions

This study aimed to compare GSR particle distribution on meat and cardboard substrates at four distances (5 cm, 10 cm, 20 cm, and 30 cm) and four firing angles (30°, 45°, 60° and 90°) to determine if substrate type significantly affects GSR patterns. In terms of visual observations, no significant differences were noted in the overall GSR distribution patterns across the tested substrates. However, subtle variations were apparent between the distribution observed on the cardboard and the meat surfaces. These differences may be attributed to the inherent textural and mechanical properties of the substrates. Cardboard, being relatively rigid, resists deformation and thus results in a more concentrated impact upon firing. In contrast, the meat surface, due to its elastic and pliable nature, can absorb a portion of the kinetic energy, potentially leading to a slightly altered dispersion of GSR particles. The findings showed no significant differences in GSR distribution between the two substrates at any tested distance or angle, as confirmed by statistical analysis. The overall GSR patterns were consistent across both materials, with particles spreading in the direction of the shot angle. Minor variations were observed, but none were statistically significant. The only notable difference occurred at the 5 cm distance, where the meat substrate absorbed the bullet's impact more effectively than the rigid cardboard, preventing damage to the cloth. In conclusion, GSR distribution did not significantly differ between meat and cardboard substrates across various distances and angles, with only minimal pattern differences and one exception related to impact absorption at close range.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

Acknowledgment

This work was funded by the Ministry of Higher Education under the Fundamental Research Grant Scheme (FRGS/1/2022/STG04/UTM/02/6). The author would also like to thank Universiti Teknologi Malaysia for their efforts in supporting this research. The Royal Malaysian Police are also sincerely thanked for their readiness to collaborate in this research.

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