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# Image analysis of gunshot residue on entry wounds II – A statistical estimation of firing range

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**Abstract**

A statistical investigation of the relationship between firing range and the amount and distribution of gunshot residue (GSR), used automated image analysis (IA) to quantify GSR deposit resulting from firings into pig skin, from distances ranging between contact and 45 cm. Overall, for a Ruger .22 semi-automatic rifle using CCI solid point, high velocity ammunition, the total area of GSR deposit on the skin sections decreased in a non-linear fashion with firing range. More specifically there were significant differences in the amount of GSR deposited from shots fired at contact compared with shots fired from distances between 2.5 and 45 cm; and between shots fired from a distance of 20 cm or less, with shots fired at a distance of 30 cm or more. In addition, GSR particles were heavily concentrated in the wound tract only for contact and close range shots at 2.5 cm, while the particle distribution was more uniform between the wound tract and the skin surfaces for shots fired from distances greater than 2.5 cm. Consequently, for future scientific investigations of gunshot fatalities, once standards have been established for the weapon and ammunition type in question, image analysis quantification of GSR deposited in and around the gunshot wound may be capable of providing a reliable, statistical basis for estimating firing range. © 1999 Elsevier Science Ireland Ltd. All rights reserved.

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## 1. Introduction

In the past, ballistics experts and forensic pathologists have classified gunshot wounds with respect to range by a variety of methods. These methods include inspection and

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comparison with test firings of the of distribution or pattern of GSR at a wound site. Other methods which have been used to measure and characterise GSR include Atomic Absorption Spectroscopy [1], Neutron Activation Analysis [2], Autoradiography [2] and Scanning Electron Microscopy [3]. These methods have been applied to GSR residues from wound sites in range determination studies and to samples collected from skin to identify the firing hand. Dermal sampling with testing methods such as the dermal nitrate test has been largely discredited due to problems of possible contamination from other sources [4].

Electron microscopy and energy dispersive X-ray analysis of the type and quantity of firearm discharge residue has also been used to support expert evidence on the estimation of firing range [3]. These investigations are highly specialised, and therefore labour intensive and costly. In addition, preparation of skin samples for electron microscope analysis renders the sections unsuitable for further histological analysis. An alternative technique of estimating range has been developed and standardised by Brown et al. [5], which overcomes these difficulties associated with electron microscopy. This new technique combines light microscopy (LM) and automated image analysis (IA) methods to provide a measure of the amount and distribution of gunshot residue (GSR) particles deposited in and around a gunshot wound. Brown et al. [5] have shown that Alizarin Red S labelled GSR particles composed of barium and lead, and also dark sooting debris consisting of carbon and metallic fragments, can be successfully detected and measured on histology sections of skin prepared from a gunshot wound [5–7]. Preliminary LM/IA results indicate that measuring the amount of residue on histology sections of the gunshot wound can provide a scientific basis for making conclusions in relation to range [5].

As expected, preliminary studies have shown that the amount of GSR present at a wound site decreased with increasing firing range [5]. More importantly, it was found that the relationship between the quantity of GSR and the distance from which a shot is fired is non-linear [5]. In addition, for shots fired from the same distance the variability in the amount of residue deposited decreases as the firing range increases [5]. However, for this earlier study the number of shooting trials conducted at each distance (five) was not sufficient to conclusively confirm the existence of these trends. In addition, the use of hair bearing skin introduced uncontrollable factors such as the variations in the orientation and density of hair, the removal of hair and cleaning of the skin surface during sample preparation [5]. Consequently this statistical investigation of the relationship between the firing range and the quantity of GSR particles deposited, uses the combined LM and IA techniques to obtain a measure of the amount of GSR deposited on the hairless surface of a shaved pig skin, for 30 trials at each distance.

## 2. Materials and methods

Pig skin comprising the epidermis, dermis and subcutaneous fat, was obtained from an abattoir. The skin surface was first shaved to remove any bristles, and then prepared for the shooting trials as described by Brown et al. [5]. These trials were conducted using a Ruger .22 semi-automatic rifle and CCI solid point, high velocity ammunition. Target-to-

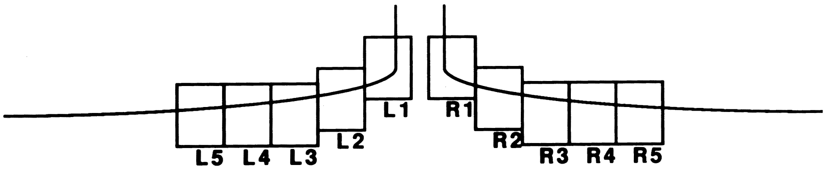


Fig. 1. Diagram showing consecutive fields of view from which measurements of GSR were made, to the left (L1, L2 . . . ) and to the right (R1, R2 . . . ) of the central bullet wound.

gun firing distances tested were contact, 2.5, 5, 10, 20, 30, and 45 cm, with 30 trials being conducted at each distance.

The resulting 210 skin samples were sectioned and stained with Alizarin Red S (ARS) to highlight the metallic GSR particles. A measure of the amount of GSR present on the histology sections was obtained using the LM/IA method previously reported [5]. The relationship between the firing distance and the amount of GSR deposited was determined as follows. The area of GSR deposit was first measured for each field of view across a skin section, where the width of one field of view, represented in Fig. 1 by a rectangular tile, covered a distance of ~2000 μm. The total area of GSR deposit for each skin section, was calculated by summing the measured areas of all the fields of view across the sample, i.e. L1+L2+ . . . +R1+R2+ . . . . For each distance investigated, the mean total area of GSR deposit and the 99 and 95% confidence intervals across all 30 sections were computed. To determine the distribution of GSR particles at each distance, the mean area of GSR deposit and the corresponding 99% confidence intervals were calculated for each equivalent field of view across all the 30 skin sections, i.e. L1 in all 30 sections, L2 in all 30 sections etc.

Overall, this study aimed to determine the relationship between firing distance and the amount and distribution of GSR, the amount being the total area of GSR deposit on a histology section. In addition the variability in the amount of GSR deposited from consecutive firings from the same distance was assessed.

## 3. Results

The relationship between the total amount of GSR deposited within and around a gunshot wound, and the distance from which the gun was fired, was initially assessed by plotting the mean GSR deposit area against the firing range (Fig. 2). A clearly decreasing trend in the mean GSR area was observed with increasing firing distances (Fig. 2). In particular, the amount of residue was noticeably much reduced when the gun was fired from distances greater than 30 cm, compared with ranges less than 20 cm (Fig. 2). The 99% confidence intervals confirmed that the variability in the total amount of GSR deposit across the 30 samples from each shooting trial, decreased with increasing firing range (Fig. 2).

The hypothesis that the amount of firearm discharge would vary significantly with range was tested statistically using a one-way analysis of variance (ANOVA) with $\alpha$ set at 0.001. This very conservative level of $\alpha$ was chosen because of the need for rigorous

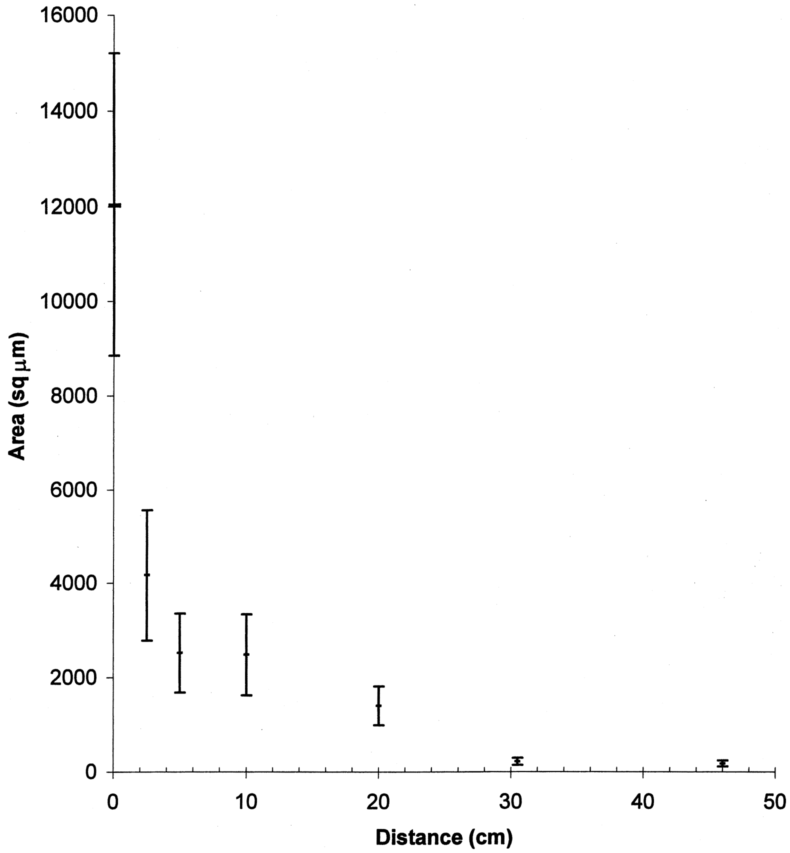


Fig. 2. Graph showing the relationship between the mean area of GSR deposit and firing range. (Error bars represent the 99% confidence intervals).

testing of this hypothesis. The results of the ANOVA test indicated that for shots fired from the selected distances, there was an overall, statistically significant difference in the amount of GSR deposited at the wound site. Once this significant $F$ value was obtained, the patterns of significant differences between the means of the GSR deposit area were explored using two approaches: Scheffé's test of paired comparisons [8], and the confidence intervals. The mean amount of GSR deposit, and the associated 95 and 99% confidence intervals at each distance, are given in Table 1. It was confirmed for those firing ranges where the corresponding confidence intervals did not overlap, that significant differences in the amount of GSR deposited did exist. At the 99% confidence level, the intervals for both the 30 and 45 cm trials do not overlap with the intervals for trials conducted at 20 cm or less. Furthermore, at this level the interval for the contact trial does not overlap with those of any other trial.

The significance of the difference in mean area of GSR deposit between all possible pairs of distances was tested using a Scheffé test, with $\alpha$ initially set at 0.01 (Table 2).

Table 1
The mean area of GSR deposit on skin samples, and the corresponding 95 and 99% confidence intervals, for shots fired at each range

| Range (cm) | Mean | 95% confidence interval | 99% confidence interval |
|---|---|---|---|
| Contact | 12024 | 10793–13256 | 8851–15198 |
| 2.5 | 4326 | 3267–5385 | 2933–5719 |
| 5 | 2454 | 823–3122 | 1624–3284 |
| 10 | 2473 | 1825–3122 | 1620–3326 |
| 20 | 1400 | 1088–1712 | 990–1810 |
| 30 | 219 | 161 –278 | 143–296 |
| 45 | 169 | 120–219 | 195–234 |

The results indicated that the amount of GSR deposited from shots fired from 45 cm was significantly different from shots fired at contact and from 2.5 cm (Table 2). Similarly, the amount of GSR deposited from shots fired from 30 cm was significantly different from shots fired at contact and from 2.5 cm, and the amount of GSR deposited from shots fired at contact was significantly different from shots fired from 2.5, 5, 10 and 20 cm (Table 2). The amount of variance ($\eta^2$) explained by the variables entered into the analysis was 63.7%, indicating that almost two thirds of the variance in the total GSR deposit area was explained by the distance from which the shot was fired.

The average radial distribution of GSR deposit around the centre of the wound, was determined for each firing range by plotting the mean GSR deposit area for each field of view, against the field of view label i.e. L1, L2 etc. (Fig. 3). The first one to two fields in each graph corresponded to GSR particles within the wound tract. From approximately the third field the data corresponded to GSR particles impregnated into the skin surface (Fig. 3). For the contact and 2.5 cm shooting trials, GSR particles were heavily concentrated within and adjacent to the wound tract, with the concentration decreasing at increasing radial distances from the centre of the wound (Fig. 3). For greater firing distances ($>$2.5 cm) the radial GSR distribution curve was flatter, indicating that the concentration of GSR particles within and adjacent to the wound tract was not significantly greater than the GSR particle concentration at greater radial distances from the centre of the wound site. Furthermore, the fields of view extended over a wider range

Table 2
Results of Scheffé test with $\alpha$ set at 0.01

| Distance (cm) | Distance (cm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 45 | 30 | 20 | 10 | 5 | 2.5 | Contact |
| 45 | | | | | | | |
| 30 | | | | | | | |
| 20 | | | | | | | |
| 10 | | | | | | | |
| 5 | | | | | | | |
| 2.5 | * | * | | | | | |
| Contact | * | * | * | * | * | * | |

* Denotes significant differences in the GSR deposit area between corresponding firing ranges.

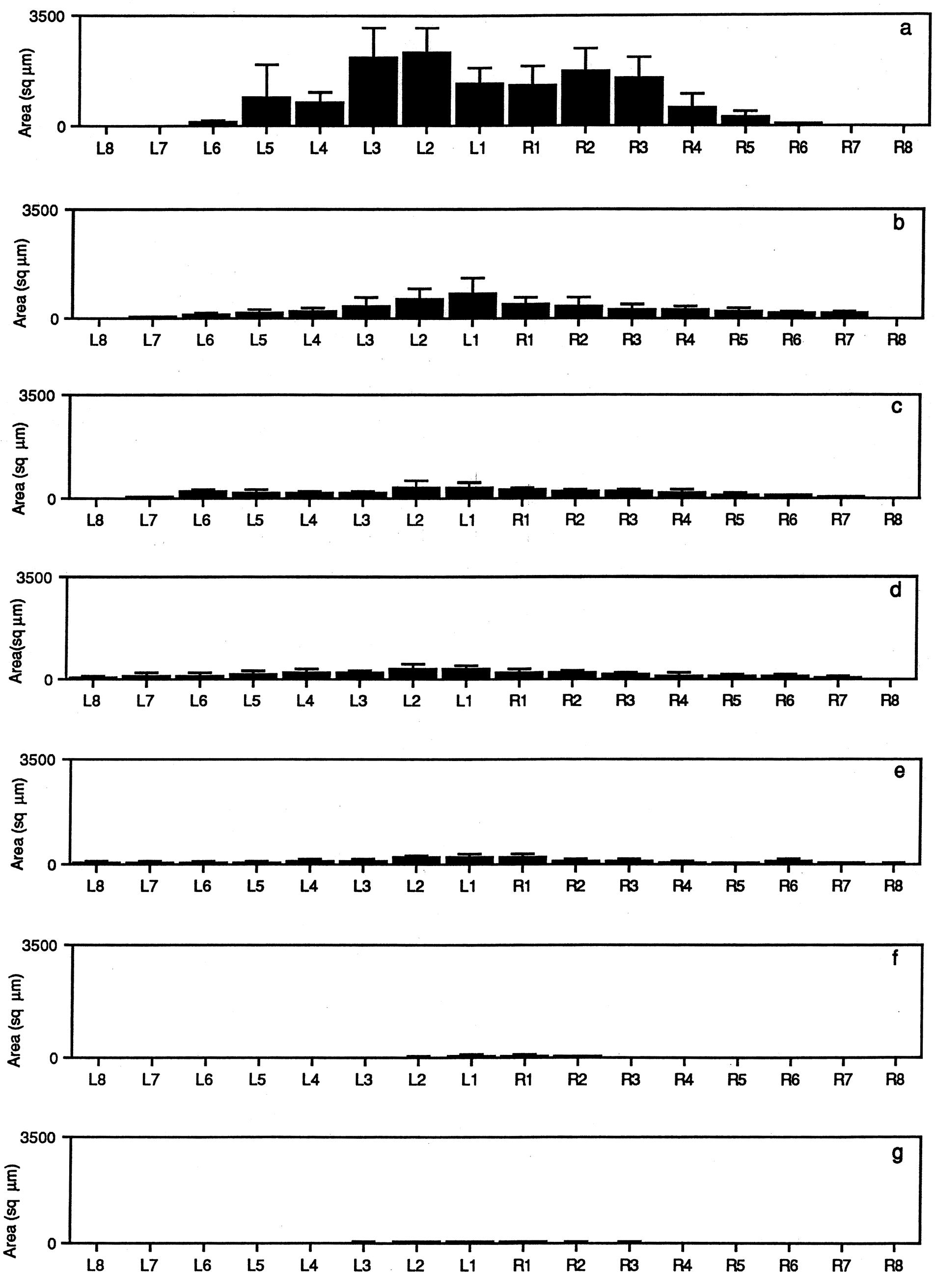


Fig. 3. Graphs showing the mean distribution of GSR deposit, for shots fired from contact (a), and from distances of 2.5 (b), 5 (c), 10 (d), 20 (e), 30 (f) and 45 cm (g). (Error bars represent the 99% confidence intervals).

across the skin samples for the 10 and 20 cm shooting trials, compared with the 30 and 45 cm trials. This result indicates that the distribution or spread of measurable GSR deposit around a gunshot wound is reduced at firing distances greater than 30 cm.

## 4. Discussion

The relationship between the amount of GSR deposited within and around a gunshot wound has been assessed, using the new LM/IA technique described by Brown et al. [5]. The firing distances investigated (i.e. contact through to 45 cm), covered a range which may be of crucial importance in determining the circumstances of a particular firearm fatality case. This study has confirmed that for shots fired from a Ruger .22 semi-automatic rifle using CCI solid point, high velocity ammunition, the amount of GSR resulting from the discharge of the firearm is dependant in a non-linear fashion on the distance from which the gun was fired. Indeed distance was an extremely powerful predictor, accounting for almost two-thirds of the variance in the mean particle area. Moreover, using the more stringent Scheffé test, statistically significant differences exist in the amount of discharge residue deposited on the skin from shots fired at contact compared with those fired from distances ranging from 2.5 to 45 cm, and for shots fired from 2.5 cm compared with shots fired from distances greater than 30 cm. However, no significant differences were detected in the amount of GSR deposited from shots fired from 5 cm compared with shots fired from 10 cm, and similarly for shots fired from 30 cm compared with shots fired from 45 cm. Using the method of 99% confidence intervals to assess the results, the firings at 30 and 45 cm were significantly different from shootings at 20 cm or less.

In this statistical investigation of firing range, the question of setting an appropriate level of significance is a good illustration of the issues involved in making this decision. The need to prove the case of, say murder versus suicide, to a sufficient level in a court of law demands a stringent level of probability. However, because the collection of GSR deposit area data for 210 specimens was a labour intensive exercise, only the minimum number of skin sections (i.e. 30 per firing distance) required to establish statistical significance were used in this experiment. Furthermore a high level of variability was exhibited across the 30 specimens corresponding to each firing distance. These factors all argue in favour of a less stringent level of probability. However, when the Scheffé test was rerun at a lower $\alpha$ level, only one additional significant relationship emerged.

The distribution of GSR particles within the wound and across the skin section, showed some correlation with the distance from which the shot was fired. In particular, for the rifle and ammunition type used in these shooting trials, GSR particles were highly concentrated within the wound tract and immediately adjacent to the wound opening, for shots fired at contact and from 2.5 cm only, while for greater firing ranges, the distribution of GSR appears to be more uniform across the skin sample.

It is expected that the relationship between the distribution and amount of firearm discharge residue associated with a gunshot wound is dependent on the type of firearm and ammunition used. In firearm fatalities which are the result of a suicide, a murder disguised as a suicide, or an accident, the gun is generally found near the deceased. In the forensic investigation that ensues, it is therefore of utmost importance that the gun and ammunition found at the scene is used in any subsequent experiments conducted to assess range. The relationship between the type of firearm and ammunition, and the resulting amount and distribution of GSR particles when fired into skin, is therefore the subject of continuing studies. In order for the results of these studies to be of practical use in forensic investigations of gunshot fatalities, further work is also in progress which explores the probability of matching the amount of GSR from a single shot, to a known reference range.

## 5. Conclusion

The combined light microscopy and automated image analysis method of GSR quantification was used to determine the relationship between the amount and distribution of firearm discharge residue on histology sections taken from gunshot wounds. In the case of a firearm fatality involving a Ruger .22 semi-automatic rifle and CCI solid point high velocity ammunition, statistical testing of this relationship showed that it is possible to distinguish a contact shot from all other more distant shots, and shots from distances up to 20 cm from shots at distances greater than 20 cm. This finding would obviously have important implications in particular cases where distinguishing between a closer or a more distant range is the main issue.

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