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# LINKING OF SHOOTER AND SHOOTING: DETECTION OF GUNSHOT RESIDUE ON SHOOTER'S HANDS USING MICROSCOPY AND SCANNING ELECTRON MICROSCOPE-ENERGY DISPERSIVE X-RAY METHODS

(Perkaitan Antara Penembak dan Penembakan: Pengesanan Sisa Tembakan pada Tangan Penembak Menggunakan Kaedah Mikroskop dan Kaedah Mikroskop Pengimbas Elektron-Sebaran Sinaran-X Bertenaga)

Farah Ad-din Nordin[1, 2], Ahmad Fahmi Lim Abdullah[1], Kah Haw Chang[1]*

*[1]Forensic Science Programme, School of Health Sciences,*
*Universiti Sains Malaysia, 16150 Kubang Kerian, Kelantan, Malaysia*
*[2]Criminalistic Section, Forensic Division,*
*Department of Chemistry, Jalan Sultan, 46661 Petaling Jaya, Kuala Lumpur, Malaysia*

**Corresponding author: changkh@usm.my*

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**Abstract**

One important link in the chain of proof during investigation of shooting cases is the evidence to prove a person had fired a firearm, or somehow was connected with the firing activity. Gunshot residues (GSR), particularly on shooter's hand, could provide significant aid in such investigation. Therefore, this study was aimed to investigate the detection of GSR particles recovered from the hands of shooter using two sampling methods, namely stubbing and swabbing, on the basis of the types of firearms and ammunitions, as well as the varying sampling sites. By considering lead, barium and antimony as the criterion to definitely confirm the presence of GSR, the experimental results revealed that greater number of GSR particles were shown in those samples subjected to firing by using revolver with .38 SPL ammunition compared to semi-automatic pistol with 9 mm ammunition ($p = 0.034$). Based on Kruskal-Wallis test, there was no statistically significant association shown between the sampling sites and number of GSR particles detected ($p = 0.545$ for semi-automatic pistol; $p = 0.218$ for revolver). All stub samples demonstrated positive detection of GSR particles, but only one single characteristic GSR particle was detected on swab samples. Further examination on the collection efficiency of respective sampling methods demonstrated with no significant association between the types of firearms and number of GSR particles detected from the respective cartridge cases ($p = 0.568$). The number of swabbing from spent cartridge case gave almost similar testing result ($p = 0.561$). This study has successfully detected the presence of GSR particles, which could serve as a supporting evidence to relate a suspect to a shooting case. Although swabbing has limited ability in recovering GSR samples from the hands of shooter, it is useful whenever a stub is not available or to recover GSR particle from a place where could not be reached by a stub to avoid the loss of trace particles.

**Keywords:** forensic science, firearm, gunshot residue, stub, swab, shooter

**Abstrak**

Satu perkaitan penting dalam rantaian bukti ketika penyiasatan kes penembakan adalah bahan bukti yang dapat membuktikan seseorang individu telah melepaskan suatu tembakan atau dikaitkan dengan aktiviti penembakan tersebut. Sisa tembakan (GSR) yang lazimnya pada tangan penembak boleh memberikan bantuan bererti dalam penyiasatan kes-kes sedemikian. Justeru, kajian ini bertujuan menyiasat pengesanan zarah GSR yang dipulihkan daripada tangan penembak menggunakan dua kaedah pensampelan, iaitu dengan puntung dan kesatan, berdasarkan jenis senjata api dan amunisi serta pelbagai tapak pensampelan. Dengan mengambil kira plumbum, barium dan antimoni sebagai kriteria untuk mengesahkan kehadiran GSR secara jelas, keputusan eksperimen telah menunjukkan bahawa bilangan zarah GSR yang lebih banyak telah ditunjukkan pada sampel-sampel yang ditembak menggunakan revolver bersama dengan amunisi .38 SPL berbanding pistol semi-automatik dengan amunisi 9 mm ($p$ = 0.034). Berdasarkan ujian Kruskal-Wallis, tiada perkaitan statistik bererti yang terbukti antara tapak-tapak pensampelan dan bilangan zarah GSR yang dikesan ($p$ = 0.545 bagi pistol semi-automatik; $p$= 0.218 bagi revolver). Kesemua sampel puntung menunjukkan pengesanan positif bagi zarah GSR tetapi hanya satu zarah berciri GSR sahaja yang dikesan pada sampel kesatan. Pemeriksaan seterusnya pada keberkesanan pengumpulan bagi kedua-dua kaedah pensampelan tidak menunjukkan perkaitan yang bererti antara jenis senjata api dan bilangan zarah GSR yang dikesan daripada kelongsong peluru masing-masing ($p$ = 0.568). Bilangan kesatan daripada kelongsong peluru tertembak memberikan keputusan yang lebih kurang sama ($p$ = 0.561). Kajian ini telah berjaya mengesan kehadiran zarah-zarah GSR yang boleh berfungsi sebagai bahan bukti sokongan dalam mengaitkan seseorang suspek kepada suatu kes penembakan. Sungguhpun kaedah kesatan mempunyai kekangan dalam memulihkan sampel GSR daripada tangan penembak, kaedah ini adalah berguna apabila suatu puntung tidak tersedia atau untuk memulihkan zarah GSR daripada sesuatu tempat tidak dapat dicapai oleh sesuatu puntung demi mengelakkan kehilangan zarah-zarah surih.

**Kata kunci:** sains forensik, senjata api, sisa tembakan, puntung, kesatan, penembak

## Introduction

Locard's Principle of Exchange is the underlying principle during crime scene investigation, which could be summarised as "every contact leaves a trace". In firearm related cases, therefore, one important link in the chain of proof during its investigation is gunshot residue (GSR) evidence to prove that a person had fired a firearm, or somehow was connected to the firing activity. Traces of GSR particles, following the discharge of firearm are deposited onto various parts of body surfaces, particularly on the hands of a shooter [1-3]. Hence, based on the principle, the detection of GSR on a suspect apprehended after a shooting can be used as an associative evidence to link the suspect in cases of armed assaults, murders, poaching and other violations involving the possible use of firearms [2-5]. Additionally, GSR can also serve as reconstructive evidence for the investigator to gain better understanding whether an individual is definitely involved in the shooting, merely being in the nearest vicinity of a firing weapon, or just getting in contact with an object contaminated with GSR [2, 3]. As a result, forensic investigator must be able to recover and determine the presence of GSR or exclude its presence, mainly looking at the morphology of the particles, and more importantly, its elemental composition.

GSR analysis by scanning electron microscope-energy dispersive X-ray (SEM-EDX) detector on the basis of their morphology and characteristic elemental composition has become the preferred method until today [1, 6]. The standard for GSR analysis used in the forensic community was set forth by the American Society for Testing and Materials (ASTM), with acceptable criteria for morphological features and respective elemental profiles to definitely confirm GSR identities, to allow the questioned samples to be said as "characteristic of" or "consistent with" GSR [6]. ASTM E1588 states that particles which are the characteristic of GSR must contain lead, antimony and barium. The presence of only one or two of these three elements could only be considered as indicative or merely consistent with GSR [6-8].

A suspect in shooting related case shall be sampled as soon as possible, particularly from the hands, since the time elapsed between an incident and sampling [4, 9-13], washing of hand by a suspect [4, 9, 10, 13] and concealment of body surfaces by the suspect [14] could contribute to potential sample loss. Under controlled condition, GSR particle count drops rapidly in the first two to four hours after firing [12]. Unnecessary delayed sampling should not be tolerated due to foreseeable sample loss or introduction of contaminants [3]. Several GSR collecting techniques for GSR have been developed, including swabbing, glue-lifting, vacuuming, tape-lifting and direct stubbing [3, 13]. For SEM-EDX analysis, direct stub collection method involves the dabbing of an adhesive coated aluminium stub over the sampling area [1, 4, 6, 15, 16]. Swabbing using cotton swab as collection media has been used for inorganic GSR analyses by atomic absorption spectroscopy and SEM-EDX analysis [16, 17]. As a non-adhesive surface, GSR could be lost during handling, packaging and transporting, and this explains why swabbing gave much poorer recovery [16]. Nonetheless, when stub kits are not available, swabbing should be attempted.

Common small firearms found in forensic cases are revolver and semi-automatic pistols. Ammunition could be loaded in a revolver and upon firing; the cartridge has to be extracted out manually. In semi-automatic pistol, the cartridge is ejected from the firearm after each round of firing. The two mechanisms also led to the deposition of GSR onto the different parts of hands of a shooter [3, 18-20]. In this study, samples were collected from the hands of shooter using two different firearms to establish if there was significant difference on the total GSR count. Samples were collected using stubs and swabs on different parts of hands to compare sampling efficiency using both the methods, as well as to establish the distribution of GSR on different parts of the hands of shooter. The determination of suitable sampling method is crucial for investigative team in maximising the chance for the detection of GSR particles, and subsequently aid in linking a suspect to a shooting incident.

## Materials and Methods

### Shooting and sampling

A semi-automatic pistol P-99 Walther® and a Smith & Wesson® .38 Special police revolver were used in firing the ammunitions, namely SME 9 mm and SME .38 SPL, SME Ordnance, Selangor, Malaysia supplied by Royal Malaysia Police, in an open shooting range in Police Training Centre, Kuala Lumpur. Shooting was performed by a trained police officer. Prior to shooting, both hands of the shooter were washed thoroughly. Two-hand shooting was performed and GSR was generated from single shot with the respective firearm in three replicates. Immediately after each shot, samples were collected from the hand surface of the shooter at four different sites, namely right palm, right back, left palm and left back, using four different stubs (Electron Microscopy Sciences, Hatfield, PA). Stubs with samples were packed into their respective containers and labelled accordingly. The same procedure was also carried out using cotton buds (Puritan Medical Products, Guilford, ME) and packed into separate paper bags after each sampling. Between each shooting, the shooter was asked to wash both hands with tap water thoroughly and dry on disposal paper towels. The washing procedure was aimed to remove any residual GSR particles from hand surface to avoid carrying over. Positive control was collected by the inner compartment of spent cartridges while negative control was sampled from shooter's hand surface before shooting and after each washing procedure.

### Physical examination

Samples on stubs and swabs were examined visually and under microscope (digital microscope KH-7700, Hirox Co. Ltd., Japan) equipped with a digital camera and supported by the operating system integrated into one unit. Magnification factors for image display were ranged from 50× to 200×. Any foreign particles on the stubs and swabs were carefully observed and photographed.

### Sample preparation prior to SEM/EDX analysis

No preparation procedure was performed on stub samples since they were directly placed on the stage of the microscope for analysis. Swab samples were placed into a small test tube and added with 1 mL of GC grade hexane of purity ≥ 96.0% (Merck, Kenilworth, NJ). The solution was then sonicated for 30 minutes and transferred onto individual evaporating dish, allowing for evaporation until it dried. Then, the surface was tape-lifted using individual SEM collection kit. Positive controls were also prepared using the same procedure after swabbing of the inner compartment of cartridge cases. A clean unused cotton bud was used as negative control.

**SEM-EDX analysis**

All samples were analysed using a Zeiss Evo 50 SEM (Zeiss, Germany) with Oxford EDS system (Oxford Instrument Analytical Limited, United Kingdom). The system was supported by INCA GSR-analysis Software (Oxford Instrument Analytical Limited, United Kingdom), allowing detection, analysing and classifying of particles into a pre-determined classification scheme. The analysis was performed by means of an automated INCA Feature/GSR programme, searching for particles of defined characteristics through analysis of specimen surface divided into small rectangular fields. Size of the field depends on the applied magnification and scanning resolution. In this study, two magnification settings, namely 100× and 200×, were used according to the standard of procedure in Department of Chemistry Malaysia. An accelerating voltage of 20 kV and working distance of 8.5 mm were used throughout the scanning process. On completion of each run, any particles that classified under unique and characteristic category was relocated and reanalysed for reconfirmation.

**Statistical analysis**

Statistical analyses were carried out using IBM Statistical Package for the Social Sciences (SPSS) Statistics Version 24.0 (IBM Corporation, NY). Data cleaning and descriptive analysis were performed to ensure there were no errors. Independent t-test or Mann Whitney statistical tests were carried out when there were two categorical groups. One-way ANOVA or Kruskal Wallis test was used for more than two groups of independent variables for parametric and non-parametric tests, respectively. These statistical tests determined an association between the tested variable (*i.e.* types of firearm, sampling sites, sampling methods, and efficiency of extraction techniques) and the number of GSR particle detected. Two-way ANOVA compared the mean differences between groups of two independent variables (*i.e.* types of firearm and number of swabbing procedure) to establish if there are an interaction between the two variables on the number of GSR detected from the SEM-EDX analysis. In this study, a $p$-value of $<0.05$ was considered as statistically significant.

## Results and Discussion

**Physical examination**

Using microscope, foreign particles were observed on the surface of cotton swab stick, appearing as irregular shape of varying sizes (Figure 1a). Smaller particles appeared in dust form were also shown (Figure 1b). Besides being black in colours, they are also brown coloured particles on the surface (Figure 1c). On the contrary, negative control samples showed no evidence of such particles, suggesting that these particles could be deposited upon the combustion of ammunition after a firing activity [2]. The observations were similar to those observed on gloves in a previous study [14]. Note that these particles were only observed on cotton swab stick with white background. On carbon adhesive tape attached on stubs, such particles were not readily visible due to poor background contrast. Besides particles originating from the combustion process, foreign materials such as fibre were also observed on the surface of carbon tape and cotton swab stick, shown in Figure 1d and Figure 1e.

**SEM-EDX analysis**

The presence of GSR was confirmed through the detection of particles by SEM-EDX on the examined surfaces, specifically stubs in this study. Negative control samples gave negative result with no detection of GSR particle. In other word, samples taken from the shooter prior to contact with firearm did not contain particle to be identified as GSR. Under view using SEM, GSR appeared as spheroidal or irregular shaped particles, as illustrated in Figure 2.

Overall, the sizes of GSR particles detected, focusing on stub samples, were ranged from 1.8 to 53 µm. Spheroidal particles were also found to be smaller in size as compared to those irregular ones, as stated by ASTM that the former particles usually found with a diameter between 0.5 and 5.0 µm while the latter could be varied from 1 µm up to more than 100 µm [6]. Therefore, the size of a GSR particle was not definite, especially after the combustion of the primer and smokeless powders contained in ammunition. In term of the percentage of spheroidal and irregular particles detected on stubs, the latter was reported with high percentage as tabulated in Table 1, regardless of the types of ammunition.

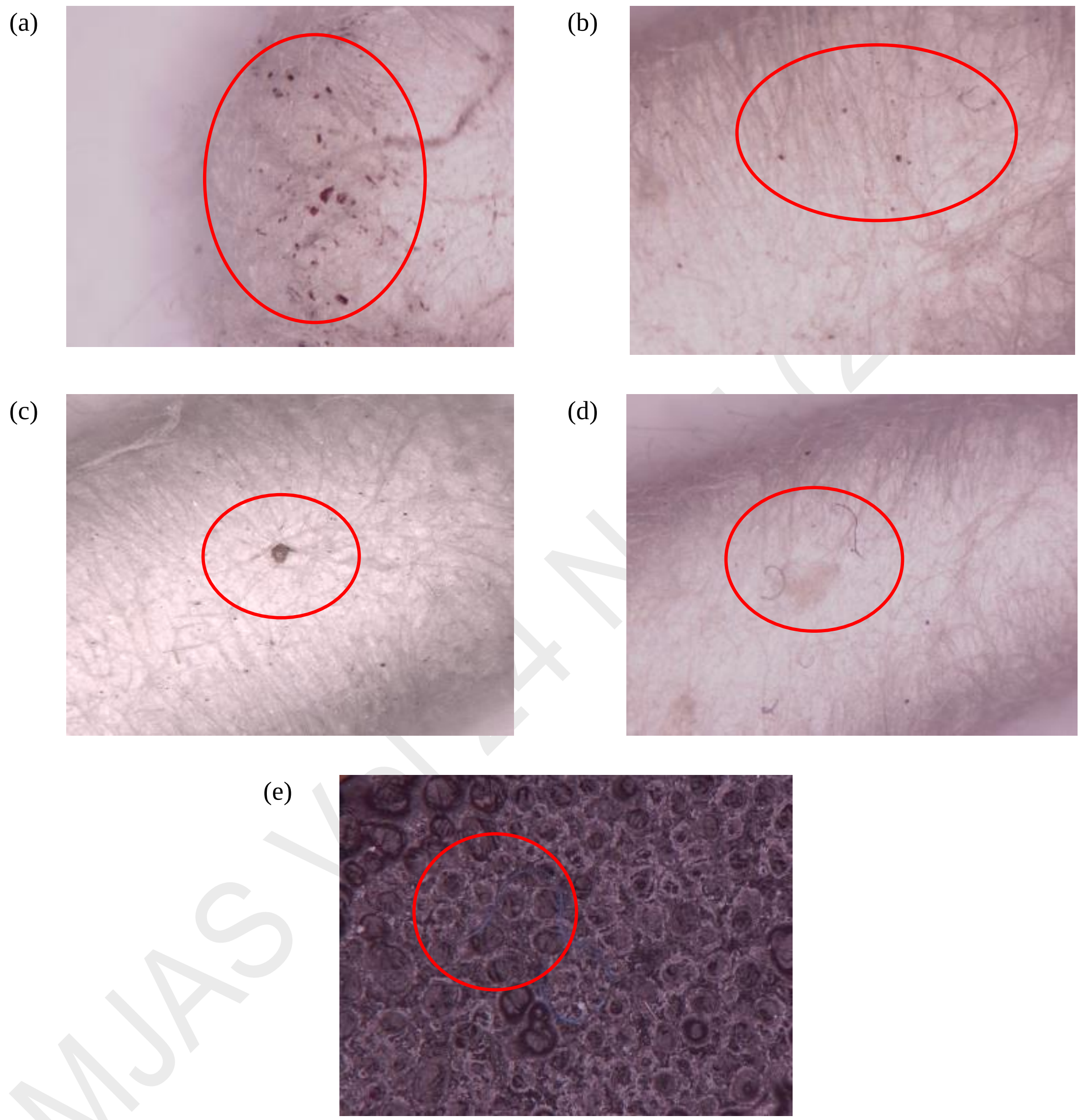
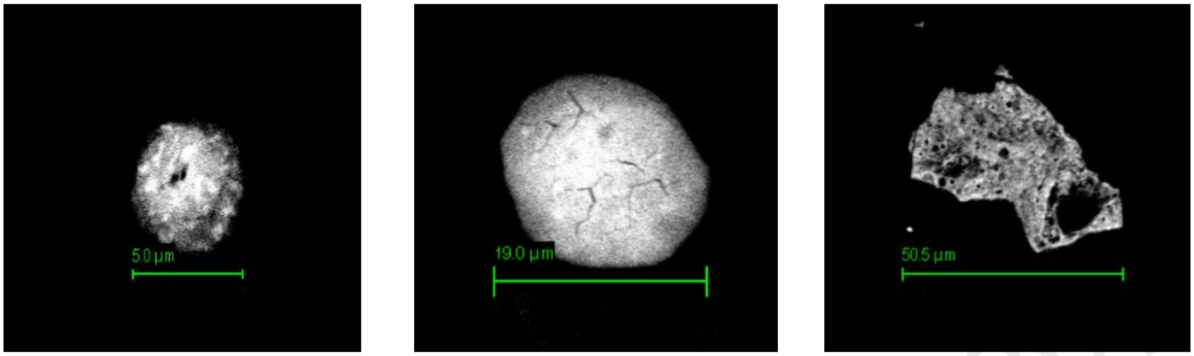



Figure 1. Illustration of (a) irregular-shaped flakes, (b) dust form particles and (c) brown coloured particle, (d)-(e) foreign materials found on the surfaces of cotton swab sticks after sampling from the hands of surface




(a) (b) (c)

Figure 2. Illustration of spherical and irregular shaped GSR particles (100× magnification)

Table 1. The percentage of frequencies for spheroidal and irregular particles on stubs

| Ammunition | Shape | Frequency (Percentage) |
|---|---|---|
| 9 mm | Spheroidal | 27 (48.2%) |
| | Irregular | 29 (51.8%) |
| 0.38 SPL | Spheroidal | 41 (33.1%) |
| | Irregular | 83 (66.9%) |

Previous study found that GSR particles were mostly in spheroidal shape [21]. In this study, irregular shaped particles were slightly greater in their percentages. Since both spheroidal and irregular particles could indicate the presence of GSR particles, morphological feature alone should never be considered as the only criterion for GSR identification [6]. As such, elemental analysis is used in the forensic investigation for the presence of GSR particles. In this study, only characteristic GSR particles were taken into consideration according to the classification scheme by ASTM [6], as in Table 2. A representative EDX spectrum of a particle recovered from shooter's hand is shown in Figure 3.

During a firing, striking of firing pin of a firearm hits the primer cup, causing the ignition of shock-sensitive chemicals, and subsequently channels a tiny flame through a flash hole into the powder charge, which is the smokeless powder. The ignition of smokeless powder gives off heat and creates gases to develop very high pressure inside the cartridge case to force the projectile out of it and accelerate at high speed towards a target. Due to the firing mechanism, the gunshot residues could consist of burnt, partially burnt or unburned products originated from the smokeless powder, primer, bullet, cartridge case and/or traces from the firearm itself [2, 3]. Table 3 summarised the elements detected from the EDX analysis on the GSR samples collected from the hands of the shooter in this study, as well as their possible sources.

The elements detection from the GSR particles could be derived from the constitution of the bullet, a jacket over the bullet, as well as the ingredients of the primer and smokeless powders. The results suggest that the ammunition used in this study were typical type of primer, containing initiating explosive (*i.e.* lead styphnate), an oxidiser (*i.e.* barium nitrate) and a fuel (*i.e.* antimony sulphide) as the main composition [4, 22-25]. The presence of these materials or so-called "tricomponents unique particles" making up the primer also enabled the definite confirmation of GSR particles whenever Pb, Ba and Sb exist in one single particle analysed by SEM-EDX [6, 25]. This rarely occurring set of trio-elements in other settings is the foundation criterion for the identification of GSR particle when the molten metals in the expanding plume rapidly cooled upon firing.

In addition to above trio-elements, the primer composition among ammunition manufacturers could be varied as a result of product formulation of other compounds to achieve the desired ballistic performance [26]. Aluminium in the powder form and silicon as powdered glass, were also commonly found in primer mixture, acting as a friction material in ammunition [13, 22]. The presence of both sulphur and antimony indicate the usage of antimony sulphide as fuel, reacts together with oxidiser through rapid burning upon ignition has contributed to the profiles of both ammunitions [24]. Calcium silicide in the primer mixture also aids the passage of incendiary sparks to the smokeless powder to ignite the charge, as indicated by calcium and silicon seen in the GSR profiles [24, 27].

Table 2. Classification scheme for GSR particles by ASTM

| | |
|---|---|
| **Characteristic GSR particle** | • Pb, Sb and Ba |
| **Consistent with GSR particle**[a] | • Ba, Ca and Si (with or without trace of S) |
| | • Ba and Sb (with no more than a trace of either Fe/S) |
| | • Pb and Sb |
| | • Ba and Al (with or without trace of S) |
| | • Pb and Ba |
| | • Pb[b] |
| | • Sb[b] |
| | • Ba (with or without trace of S) |

[a] May contain one or more of the elements: Al, Si, P, S (trace), Cl, K, Ca, Fe (trace), Ni, Cu, Zn, Zr and Sn
[b] Only in the presence of particles with compositions mentioned in characteristic and consistent of GSR

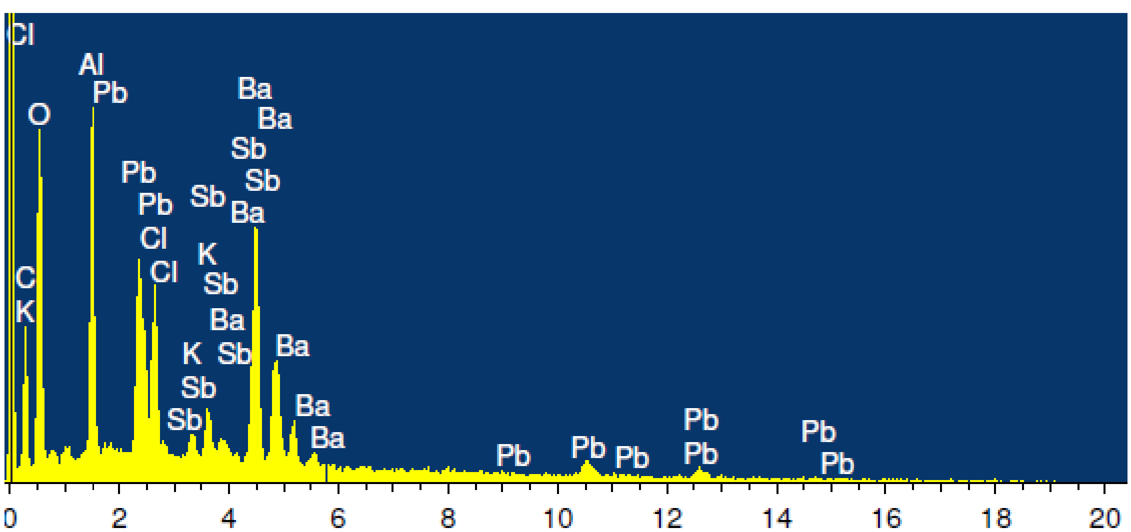



Figure 3. EDX spectrum of a unique GSR particle, showing the detection Pb, Ba and S

Table 3. Elements detected in this study and their respective sources

| **Element** | **Ammunition** | | **Possible Sources** |
|---|---|---|---|
| | **9 mm** | **.38 SPL** | |
| Aluminium (Al) | + | + | Primer mix |
| Antimony (Sb)* | + | + | Primer mix/Bullet |
| Arsenic (As) | + | + | Case |
| Barium (Ba)* | + | + | Primer mix |
| Calcium (Ca) | + | + | Primer mix/Propellant powder |
| Chloride (Cl) | + | + | Propellant powder |
| Copper (Cu) | + | + | Primer cup/Bullet jacket/Case |
| Iron (Fe) | - | + | Rust inside barrel/Erosion of internal bore/Case |
| Molybdenum (Mb) | + | + | Barrel |
| Lead (Pb)* | + | + | Primer mix/Bullet/Case |
| Potassium (K) | + | + | Propellant powder |
| Silicon (Si) | + | + | Primer mix |
| Sulphur (S) | + | + | Primer mix |
| Tin (Sn) | + | + | Primer cup/Bullet jacket |
| Zinc (Zn) | + | + | Primer cup/Bullet jacket/Case |

* Elements of characteristic GSR particle; + Detected; - Not detected

Noteworthy to mention that lead could also be contributed by the lead core that made up of the projectile, and usually with a small amount of antimony [4, 13, 22]. Jacketed bullets, where softer lead core is encased by a thin layer of harder metals, provide substantially lead-copper-zinc particles [13, 21, 22]. In addition, a small amount of Sn could also be added to the composition of bullet jacket [13, 22].

Cartridge case is usually made up of brass, a combination of copper and zinc, and may contain traces of lead and iron [22-26]. Copper and zinc are also two main ingredients in manufacturing primer cup with very small amount of other elemental impurities [25]. These two elements could vaporise from the primer cup upon discharging of a projectile down the barrel [24]. In certain instances, a small amount of arsenic was added into the composition of brass in the manufacturing process of cartridge case and primer cup [25]. Tin detected in this study might be originated from the sealing of the primer cup in the bottom of the cartridge case [1].

The presence of iron, only observed in the profile of .38 SPL ammunition, could probably arise due to the erosion of the internal bore of the weapon [22, 24]. Molybdenum alloy steels were reported in barrels of modern firearm and could contribute to the composition of gunshot residue [1, 25]. It was observed that potassium and chlorine were also found in the GSR samples. They were possibly not contributed by the primer mixtures, but from the propellant powders [22, 24, 25]. Besides being an ingredient in primer mixture in the form of calcium silicate, the presence of calcium in the GSR profile could also be contributed by the modern smokeless powders, appearing as calcium carbonate [22, 25]. Literature has reported that titanium and zinc could be seen in lead-free ammunition [28]. However, titanium was not observed in our analysis, and this observation is in-line with the traditional ammunition used in our experiment.

Based on the elemental profiles, Al, Ca, Cl, Cu, Fe, K, Si, S, Sn and Zn were detected alongside with characteristic GSR with Pb, Sb and Ba, in agreement with the definition by ASTM [6]. In general, the elemental compositions of the two GSR produced from two locally manufactured ammunitions by two types of firearms were very similar, with exceptions on iron, probably due to the makeup of the firearm. Though it is not the aim of this study to investigate the elemental profiles of various ammunitions by different firings, it is possible to compare the profiles of the two firing incidents; nonetheless, further collation of analytical information with different combination of ammunition and firearm are necessary for forensic intelligence.

**Comparison of GSR particles recovered from firing a pistol and a revolver**

When comparing two different firearms, the Mann-Whitney statistical test shows that the median number of characteristic GSR particles detected when firing with a revolver is not equal to those detected when firing with a semi-automatic pistol ($p = 0.034$) (Table 4). Revolver produced greater number of GSR particles (7.50, IqR 12) as compared to a semi-automatic pistol (2.50, IqR 7).

GSR could be detected from various surfaces in the proximity of shooters, specifically on hands, face and the clothes they worn [2, 29]. Upon firing, the gaseous GSR exits all openings of a firearm [18]. Literature reported that the design of a weapon and its firing mechanism affect the escape of GSR away from that particular firearm [3, 13, 20]. The presence of gap between the revolving drum and barrel allow a substantial amount of GSR to be escaped and subsequently deposited on any surface in close proximity areas, especially hands [13, 20]. The formation of plume could be observed from the gap for revolvers on which intense condensation, particle formation and deposition process take place [3, 20]. On the contrary, a semi-automatic pistol ejects the spent cartridge from one side of the pistol and reloads a new round from within the magazine. The smoke and particles are mainly emitted through the opening of ejection port in a more compact flume, restricting the spread of GSR resulting in the detection of lesser GSR particles upon firing by using semi-automatic pistol [18, 20]. Additionally, larger calibre ammunition used in revolver could also give rise to possibility of larger amount of GSR that to be deposited onto the hands of shooter, as opposed to semi-automatic pistol [3, 13].

**Comparison of GSR particles recovered from different sampling sites**

Upon firing, GSR particles escape from a firearm, move outward and away from a firearm, and finally deposit onto nearby surfaces. Due to the non-normal distributed data by Shapiro-Wilk test ($p < 0.05$), a Kruskal Wallis test was used in our study to determine association between the sampling sites and the detection of GSR particles for pistol, as showed in Table 5. On the other hand, with the normal distributed data (Shapiro-Wilk test with $p > 0.05$) in relation to firing using revolver, one-way ANOVA was used to compare the mean of the four sampling sites on the number of GSR particles detected, and the statistical output was demonstrated in Table 6.

Our experimental results supported the finding by Jalanti et al. [12] and Ditrich [20], in which GSR particles could be detected in both hands if the other hand was used as support during a shooting event. In our study, the shooter was a right handed person. His left hand that was below the grip overlapped the right hand which was positioned above the grip while holding the grip. For GSR samples recovered from pistol, the Kruskal Wallis test showed that there was no statistically significant association between the sampling sites with the detection of GSR on hands ($p = 0.545$) (Table 5). The medians on the number of GSR particles detected for the four sampling sites were not significantly different. There was also no significant different among the sampling sites where GSR particle were recovered after firing using revolver ($p = 0.218$) (Table 6). All the sampling sites showed the detection of GSR.

Deposition of GSR was random and varied with each firearm discharge. The GSR particles were found on both the firing hands, and both "back" and "palm" sites [12, 14, 29]. Generally, dorsum of the hand holding the weapon would be exposed to deposition of GSR particles, thus giving more chances for the detection of GSR particles as compared to the palm surface that used to grab the pistol. GSR found on the "palm" surface could be due to the transfer of previously deposited GSR from the grip of the pistol or revolver, which was termed as "memory effect" [12, 20, 30]. Since there is possibility to find GSR particles on all the four different sites allowable for sampling, it is advisable to collect GSR samples from more sampling sites whenever a suspect is apprehended for forensic examination to maximise the chance for positive identification.

Table 4. Comparison of GSR particles recovered from firing a pistol and a revolver

| **Variable** | **Median (IqR)** | | **Z stat**[a] | ***p*-value** |
|---|---|---|---|---|
| | **Pistol** | **Revolver** | | |
| Number of unique GSR particle | 2.50 (7) | 7.50 (12) | -2.120 | 0.034 |

*Mann-Whitney test was used

Table 5. Association between the sampling sites and the detection of GSR particles from firing using pistol.

| **Sampling Site** | **Median** | **χ2 stat* (df)** | ***p*-value** |
|---|---|---|---|
| Right back | 4 | 2.133 (3) | 0.545 |
| Right palm | 1 | | |
| Left back | 1 | | |
| Left palm | 2 | | |

*Kruskal Wallis test was used

Table 6. Means and standard deviations in the number of GSR particles detected on different sampling sites.

| **Sampling Site** | **Mean** | **SD** | **F-statistics (df)** | ***p*-value** |
|---|---|---|---|---|
| Right back | 4.67 | 3.512 | 1.843 (3, 8) | 0.218 |
| Right palm | 16.00 | 8.544 | | |
| Left back | 13.67 | 8.083 | | |
| Left palm | 7.00 | 6.083 | | |

**Comparison of collection efficiency of swabs and stubs from shooter's hands**

SEM-EDX analysis utilised automated search for GSR particles at a magnification of 100×. All the stub samples demonstrated positive detection of GSR particles. On the contrary, only one characteristic GSR particle was detected on swabs through SEM-EDX analysis, even though a higher magnification of 200× was used. It showed that stub shall be the preferred collection method to recover GSR particles from the hands of shooter, especially in cases where only one shot was being released by the suspect as seen in our experimental conditions. The adhesive strength of the tape attached on the aluminium stub allows the collection of GSR particles from a large surface area, although the stickiness tends to loss with repeated dabs [4, 16, 31]. Besides, the packaging step where the placements of cotton swab stick into the paper bag could also potentially remove some of the collected particulates from the hand surface of the shooter [16].

Our experimental continued to test the efficiency of GSR particle recovery from swab stick samples. The internal part of spent cartridge was swabbed using cotton stick and proceeded with extraction procedure as described in swab stick samples from shooter's hand. Both types of spent cartridges were swabbed by circling the inner compartment of cartridge case once, thrice and five times, separately. After the extraction procedure, all the swab samples from the cartridge cases revealed the presence of GSR particles. A two-way ANOVA statistical test (Table 7) shows that there was no significant difference on the number of GSR particles recovered from the spent cartridges of 9 mm and .38 SPL after firing ($p$ = 0.568). Apart from that, the detection of GSR particles on the swabs has also no significant association with the number swabbing carried on a single cartridge case ($p$ = 0.561).

The successful detection of GSR particles from swab stick samples suggested the possibility of recovering the particles from the surface of the swab stick through the extraction procedure. It also proved that the residues for a surface could be transferred onto the cotton bud during swabbing. The failure in recovering GSR particles from the hand surfaces, in our case, could be due to the limited number of GSR particles that successfully deposited onto the sampling surfaces upon firing of only a single shot as demonstrated in our experimental condition. This was also explained by a previous study where three shots were used in the experimental design [21]. Still, approximately half of the total samples were tested negative using an alcohol-moistened swab of much larger collecting surface area as compared to cotton bud used in our experiment. In fact, the deposition of GSR particles onto proximate surfaces was influenced by a number of factors, including retention mechanism or collection issue, the type and condition of the weapons, the number of shots, the direction and force of air currents, and the amount of oil, moisture or perspiration on a skin surface [4, 13, 32].

In general, stubbing technique is preferable to collect GSR particles from the hands of a shooter, providing higher probability to successfully determine a shooting activity. In some scenarios, the use of cotton sticks was also important and could not be ruled out, especially for surfaces which could not be reached by a stub such as nose [1] or bullet hole [17, 33] when sampling of suspected GSR samples become necessary.

Table 7. Adjusted mean and 95% confidence interval of the main effects of ammunition types and number of swabbing on the detection of GSR particles

| **Factors** | | **Adjusted Mean (95% CI)** | **F Statistic (df)** | ***p*-value** |
|---|---|---|---|---|
| Ammunition type | 9 mm | 11.33 (8.41, 14.26) | 0.341 | 0.568 |
| | .38 SPL | 9.22 (1.64, 16.80) | | |
| Number of Swabbing | 1 | 8.00 (2.90, 13.10) | 0.602 | 0.561 |
| | 2 | 10.00 (3.33, 16.67) | | |
| | 3 | 12.83 (2.10, 23.56) | | |

## Conclusion

This study shows that the detection of GSR particles from the hands of a shooter is important to offer an investigative clue on shooting related cases. Using stubs, GSR particles were detected with the presence of Pb, Ba and Sb as the criteria for positive determination. The experimental results revealed that the types of firearms and ammunitions show significant association with the number of GSR particles detected from the stub samples, where greater number was seen in revolver with .38 SPL as compared to semi-automatic pistol with 9 mm ammunition. When two-hand shooting was performed, the four sampling sites equally allow for the detection of GSR. In this study, all stub samples demonstrated positive detection of GSR particles, but only one swab sample showed the presence of such particles under the experimental conditions, indicating the limitation of letter in a single shot case scenario.

Further testing on the collection efficiency suggested that neither revolver nor semi-automatic pistol showed significant association with the number of GSR particles detected from respective cartridge cases. Additionally, no statistically significant association was also shown among the three different swabbing procedures from cartridge cases. Since GSR particles could be varied unpredictably between each firing, it is advisable to collect suspected GSR samples from various surfaces of a suspect. Whenever a stub is not available or a place could not be reached by a stub, swabbing procedure should still be carried out to avoid the loss of trace particles at a larger skin surface area. To conclude, this study has successfully detected the presence of GSR particles, which could serve as a supporting evidence to relate a suspect to a shooting case. For future study, the factors such as the influence of the number shots, single-handed shooting as well as the time elapsed between the firing activity and the sampling, which could affect the detection of GSR, should be investigated.

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