FACTORS FOR DETECTION OF GUNSHOT RESIDUE ON SHOOTER'S HANDS

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FACTORS FOR DETECTION OF GUNSHOT RESIDUE ON SHOOTER'S HANDS

by

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LIST OF SYMBOLS

º	Degree
µm	Micrometer
%	Percentage
<	Less than
>	More than
kV	Kilovolt
m	Meter
mL	Milliliter
mm	Millimeter
nm	Nanometer

LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrometry
Al	Aluminium
ANOVA	Analysis of Varience
ASTM	American Society for Testing and Materials
Ba	Barium
BSE	Back Scattered Electron
Ca	Calcium
Cl	Chloride
Cu	Cuprum
EDX	Energy Dispersive X-ray
ENSFI	European Network of Forensic Science Institute
et al.	*et alia* – and others
Fe	Ferum
Fl	Fluorine
FTIR	Fourier Transform Infra-red Spectrometry
GC-MS	Gas Chromatography-Mass Spectrometry
GC-TEA	Gas Chromatography-Thermal Energy Analysis
GSR	Gunshot residue
HPLC-EC	High performance liquid chromatography-electrochemical
IBM	International Business Machine
i.e.	*id est* – that is
ICP-AES	Inductively Coupled Plasma-Atomic Emission Spectrometry
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry

IMS	Ion Mobility Spectrometry
IqR	Interquartile Range
K	Potassium
KeV	Kilo electron Volt
LB	Left Back
LIMS	Laboratory Information Management System
LP	Left Palm
NAA	Neutron Activation Analysis
NC	Nitrocellulose
NG	Nitroglycerine
Ni	Nickel
NQ	Nitroguanidine
P	Phosphorus
Pb	Plumbum
PULAPOL	Police Training Centre Kuala Lumpur
RB	Right Back
RP	Right Palm
S	Sulfur
Sb	Antimony
SEM-EDX	Scanning Electron Microscope-Energy Dispersive X-ray
Si	Silica
Sn	Stanum
SPL	Special
SPSS	Statistical Package for the Social Sciences

SWGGSR	Scientific Working Group for Gunshot Residue
TIFF	Tagged Image File Format
UV-vis	Ultraviolet–visible
XRF	X-ray Fluorescence Spectrometry
Zn	Zinc

FAKTOR UNTUK PENGESANAN SISA TEMBAKAN PADA TANGAN PENEMBAK

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) khususnya 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 persampelan, iaitu dengan kaedah tekapan dan kaedah kesatan, berdasarkan jenis senjata api dan peluru, serta pelbagai kawasan persampelan. Dengan mengambil kira plumbum, barium dan antimoni sebagai kriteria untuk mengesahkan kehadiran GSR, keputusan eksperimen telah menunjukkan bahawa bilangan zarah GSR yang lebih banyak telah ditunjukkan pada sampel-sampel yang diperolehi berikutan penggunaan revolver bersama dengan peluru .38 SPL berbanding pistol semi-automatik dengan peluru 9 mm (*p*= 0.034). Tiada perkaitan statistik bererti yang terbukti antara kawasan-kawasan persampelan dan bilangan zarah GSR yang dikesan (*p*= 0.545 bagi pistol semi-automatik; *p*= 0.218 bagi revolver). Kesemua sampel tekapan (n=12) 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 persampelan 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 tidak menunjukkan perbezaan (*p*= 0.561).

Walau bagaimanapun, keputusan eksperimen menunjukkan bahawa bilangan GSR tidak berkait dengan bilangan tembakan. Analisis GSR yang diperolehi daripada enam jenis peluru yang berbeza juga menunjukkan perbezaan dalam profil GSR. Kajian ini telah berjaya mengesan kehadiran zarah-zarah GSR yang boleh berfungsi sebagai bahan bukti sokongan dalam mengaitkan seseorang suspek kepada suatu kes penembakan. Namun begitu, kaedah kesatan mempunyai kekangan dalam memulihkan sampel GSR daripada tangan penembak yang melepaskan hanya satu tembakan. Kaedah ini adalah berguna apabila suatu alat tekapan tidak tersedia di tempat kejadian atau untuk memulihkan zarah GSR daripada sesuatu tempat tidak dapat dicapai oleh sesuatu alat tekapan demi mengelakkan kehilangan zarah-zarah surih. Tambahan pula, kaedah kesatan adalah sesuai untuk mengekstrak zarah-zarah GSR untuk dianalisis daripada ruang dalaman kelongsong peluru tertembak yang membenarkan pemprofilan forensik pelbagai jenis peluru.

FACTORS FOR DETECTION OF GUNSHOT RESIDUE ON SHOOTER'S HANDS

ABSTRACT

One important link in the chain of evidence 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 areas. 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 was shown in those samples collected upon firing using revolver with .38 SPL ammunition compared to semi-automatic pistol with 9 mm ammunition (*p*= 0.034). No statistical significant association was evident between the sampling areas and the number of GSR particles detected (*p*= 0.545 for semi-automatic pistol; *p*= 0.218 for revolver). All stub samples (n=12) 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 no significant association between the types of firearms and the number of GSR particles detected from respective cartridge cases (*p*= 0.568). The number of swabbing from spent cartridge case showed no significant difference (*p*= 0.561). However, the experimental results showed that the intensity of GSR did not associated with the number of shots.

Analysis of the GSR recovered from six different ammunition types also demonstrated the variations in the GSR profiles. This study has successfully detected the presence of GSR particles, which could serve as supporting evidence to relate a suspect to a shooting case. However, swabbing has limited ability in recovering GSR samples from the hands of shooter firing a single shot. The method is useful whenever a stub is not available at the scene or to recover GSR particle from a place unreachable by a stub, to avoid the loss of trace particles. Additionally, the swab method was suitable to extract GSR particles to be analysed from the internal compartment of fired cartridges, which allow for the forensic profiling of various ammunition types.

CHAPTER 1

INTRODUCTION

> "Whereever he steps, whatever he touches, whatever he leaves, even unconsciously, will serve as a silent witness against him"
>
> Paul L. Kirk

1.1 Background of the Study

"Every contact leaves a trace." This is the Locard's Principle of Exchange which forms the underlying principle during crime scene investigation. This principal plays crucial role in order to link suspect to the victims, as well as to the physical evidence and the crime scene. In brief, whenever there is a contact between two surfaces, there will be an exchange.

In firearm related cases, the key challenge to the law enforcement authorities is to establish the answer for a question "who fired a firearm?" through scientifically determination, whether a person had fired a firearm, or somehow was connected to the firing activity. The answer for this question is crucial as firearm related crimes are frequently serious and need the greatest investigative effort. Therefore, important forensic evidence in the chain of proof during investigation of firearm related cases is gunshot residue (GSR). Analysis of GSR has proved useful in revealing vital trace evidence consequent to discharge of firearm, through the deposition onto various parts of body surfaces, including hands, face, hair as well as the wearing attires during a shooting activity (Zeichner, 2003; Dalby *et al.*, 2010; Chang *et al.*, 2013; Blakey *et al.*, 2018; Maitre *et al.*, 2017). In routine practice, the detection of GSR is particularly focused on the hands of a shooter (Schwoeble & Exline, 2000; SWGGSR, 2011; Chang *et al.*, 2013; Blakey *et al.*, 2018), as it possesses higher chance to deposit on such surfaces which had been used to hold a firearm during the act of firing (SWGGSR, 2011; Heard, 2008).

Based on Locard's exchange principle, positive detection of GSR with the possible use of firearms, on a suspect apprehended after a shooting could be used as an associative evidence to link him/her in cases of armed assaults, murders, poaching and other violations (Dalby *et al.*, 2010; Chang *et al.*, 2013; Costa *et al.*, 2016; Blakey *et al.*, 2018). Additionally, GSR could also serve as reconstructive evidence for forensic investigators. Better understanding would be gained on whether an individual was involved in the shooting, or merely being in the nearest vicinity of a firing weapon during that incident by chance, or just getting in contact with an object which has been contaminated with GSR (Chang *et al.*, 2013; Blakey *et al.*, 2018). In view of this, forensic investigators must be able to recover and subsequently determine the presence of GSR or exclude its presence, mainly by examining the morphology of the particles, and more importantly, its elemental composition. This study focused on the analysis of forensic evidence recovered from the hands of shooter upon shooting to establish the detection of GSR by analytical instrument upon the application of two different sampling methods.

1.2 Gunshot Residue

Projection of energetic force through a firearm after the combustion of explosives within ammunition expels discharge products, which are collectively referred as GSR (Schwoeble & Exline, 2000; Dalby *et al.*, 2010; Chang *et al.*, 2013). These gaseous products are rapidly cooled from extreme temperature upon the chemical reaction and deposited on the proximate surfaces (Chang *et al*., 2013; Blakey *et al*., 2018). In general, GSR is consisted of discrete and characteristic burned, partially burned and unburned products combined with constituents from the primer, bullet, cartridge case and/or firearm itself (Meng and Caddy, 1997; Chang *et al*., 2013; Romolo and Margot, 2001; Dalby *et al*., 2010; Maitre *et al*., 2017). These particles could also be varied in size, shape and colour (Burnett, 1989; Muller *et al*., 2007; Chang *et al*., 2013).

Classification scheme of metallic particles of inorganic GSR was firstly introduced by Wolten *et al.* (1979). Later, it was further modified by Wallace and McQuillan (1984). Since 2008, a standard guide coded as E-1588 was established by American Society for Testing and Materials (ASTM), and it remains widely used and accepted for current practice for GSR analysis (ASTM, 2016). The standard guide covers the detection of GSR particles with high atomic number elements through scanning electron microscope-energy dispersive x-ray (SEM-EDX) technique. The technique requires minimum sample preparation to search for GSR particles, and subsequently associates a sample recovered from a suspect with a shooting activity.

1.3 Frequency of Firearm Related Crimes

Firearm related crimes are major concern to public safety, including Malaysia. Such crimes frequently lead to injuries and death, and greatly affect the security of the country. One of such was the recent shooting case in the mosque in Christchurch, New Zealand. Therefore, the authorities shall recover and analyse the potential forensic evidence readily recovered from a scene especially in the absence of witness or CCTV footage. This would aid in the prosecution of firearm criminals to reduce crime rates and safeguard the societal well-being of our country.

In Malaysia, the Criminalistics Section of the Department of Chemistry Malaysia deals largely with the examination of physical evidence related to criminal cases, especially cases involving firearms examination. In addition to that, the Section also receives cases related to vehicle examination, trace evidence analysis, scene investigation of fire/arson, explosion and accident cases. Samples or evidence collected by the Royal Malaysia Police are sent to the laboratory for analysis and report. An average of 100 cases involving GSR examinations were received from 2016 to 2018, demonstrated in Figure 1.1. It was based from the statistics data obtained from Laboratory Information Management System (LIMS).

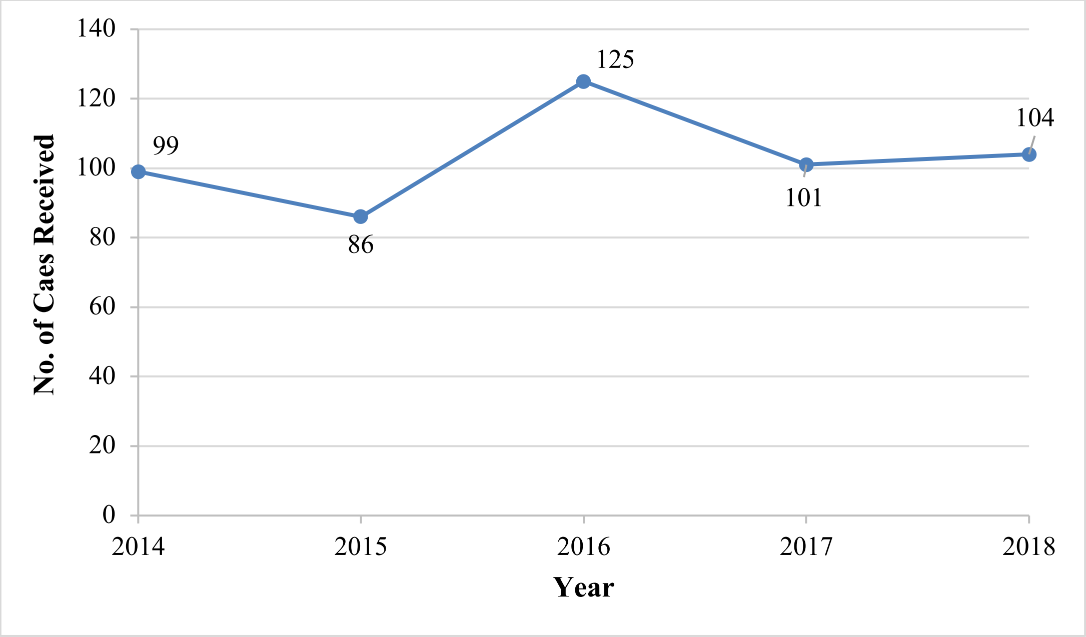


Figure 1.1 The number of cases received involving GSR examination at Criminalistics Section, Petaling Jaya

Commonly, samples with suspected presence of GSR sent to the laboratory were collected using stub. However, in some instances, such forensic evidence was also received in the form of swab stick samples. All these samples could either be from the hands of suspect, gunshot wounds of victims, clothing items of suspects or victims, or from a target where a projectile passed through or stopped at. Both the stubbed and swabbed samples, are then analysed using SEM-EDX. Analysis of GSR on stub is routinely practiced by the Department of Chemistry Malaysia. However, it is unclear whether a swabbing technique on hand surface is adequately effective, given that the forensic investigating team has recovered the potential GSR from hands of a suspect using swab sticks. Therefore, the efficiency of the sampling procedure as well as the effectiveness of the extraction step was intended to be explored in this study. Both samples (stubs and swab sticks) collected in this study were viewed under SEM-EDX to search for the presence of GSR particles.

1.4 Problem Statement

A forensic analyst is always required to accurately determine the presence of GSR. Absence of GSR particles might indicate that a suspect was not involved in an alleged shooting incident. The time elapsed between an incident and sampling (Kilty, 1975; Krishnan, 1977; Meng & Caddy, 1997; Jalanti *et al.,* 1999; Mastruko, 2003; Dalby et al., 2010), washing of hand by a suspect (Kilty, 1975; Meng & Caddy, 1997; Dalby *et al.*, 2010), concealment of body surfaces by the suspect (Mohd Rafee *et al.*, 2019) and the efficiency of sampling technique might also lead to the depletion of such traces, and subsequently give negative results.

A suspect involved in a shooting related case should be approached as soon as possible to collect the GSR particles from his/her body surfaces, particularly from the hands. More commonly, stubs with adhesive tape are used. However, swabbing technique could also be carried out when a stub is unavailable at the shooting scene or when a suspect was apprehended. Additionally, swabbing could also be carried out on any surface not reachable by stubbing, such as the circumstances of bullet hole, deserving a suitable swabbing and extraction procedure to maxmise the detection of GSR particles.

In this study, samples were collected from the hands of shooter using two sampling methods, namely stubs and swabs, to assess the efficiency of respective methods in recovering GSR particles. The association of the number of GSR particles to the types of ammunitions as well as the sampling areas were also determined. 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 forensic investigation linking a suspect to a shooting incident.

1.5 Scopes of Study

This study focused on the analysis of forensic evidence recovered from the hands of shooter upon shooting to establish the detection of GSR by SEM-EDX. The number of unique GSR particles detected were compared between:

i. Two different types of firearms which were the semi-automatic pistol and revolver.
ii. Different sampling areas which were the Left Palm, Left Back, Right Palm and Right Back.

iii. Two different sampling methods which were the tape-lifting using stub and swabbing using swab stick.
iv. Samples retrieved from expanded cartridge cases and hands of shooter.
v. Effect of number of shots where single-shot and multiple shots (10 shots) were carried out.
vi. Elemental profiles of six different ammunition types.

All the comparison was carried out using ammunition from SME Ordnance (9 mm and .38 SPL), except on the investigation of six other ammunition types.

1.6 Aim and Objectives

This research study was aimed to compare GSR sample collection techniques by stub and swab for determination of inorganic GSR. In order to achieve the aim, the objectives of the study were as follows:

i. To describe GSR recovered from the hands of shooter upon firing using different types of firearms, and from different sampling areas.
ii. To compare the collection efficiency of GSR by the two different sampling techniques, namely from stubs and swabs in detecting the presence of GSR particles.
iii. To identify factors that affect the successfully recovery of GSR particles from a hand surface.
iv. To describe the inorganic components of GSR from various types of ammunitions by using SEM-EDX.

1.6 Significance of the Study

Whenever there is any firearm related case, SEM/EDX is the choice of technique routinely carried out to detect the presence of GSR after a shooting activity. Unique GSR particles could have resulted from the discharge of a firearm, being in a close proximity to a discharging firearm or due to handling of contaminated firearm and/or ammunition components. The successful detection of GSR particles from samples collected would aid in confirming a shooting activity, as well as in determining the possible shooter who had fired a firearm.

This study also focuses on the influential parameters which could affect the successful detection of GSR particles, namely the sampling methods, types of firearm used from shooting, as well as the sampling areas to recover GSR particles. Such experiments would help in providing the clue on the residue transfer mechanism on the basis of firearm types, and also the efficiency of different sampling techniques utilised in the study besides giving the information on the elemental profile of GSR by using the SEM-EDX.

This study would contribute in establishing factors that might affect the amount of GSR particles successfully recovered from a hand surface, which is important for the forensic investigating team to carry out the proper sampling method to maximise the percentage of successful recovery of such trace evidence. Information retrievable from SEM-EDX analysis would allow for the enhancement of practice in firearm related investigation, especially on the planning of correct sampling strategies and evidence preservation for indicative determination in Royal Malaysia Police and Department of Chemistry Malaysia whenever GSR sample is encountered. The elemental results generated from this study will also allow for comparison with GSR particles detected from daily cases and gives better information in making interpretation or provide expert opinions.

CHAPTER 2

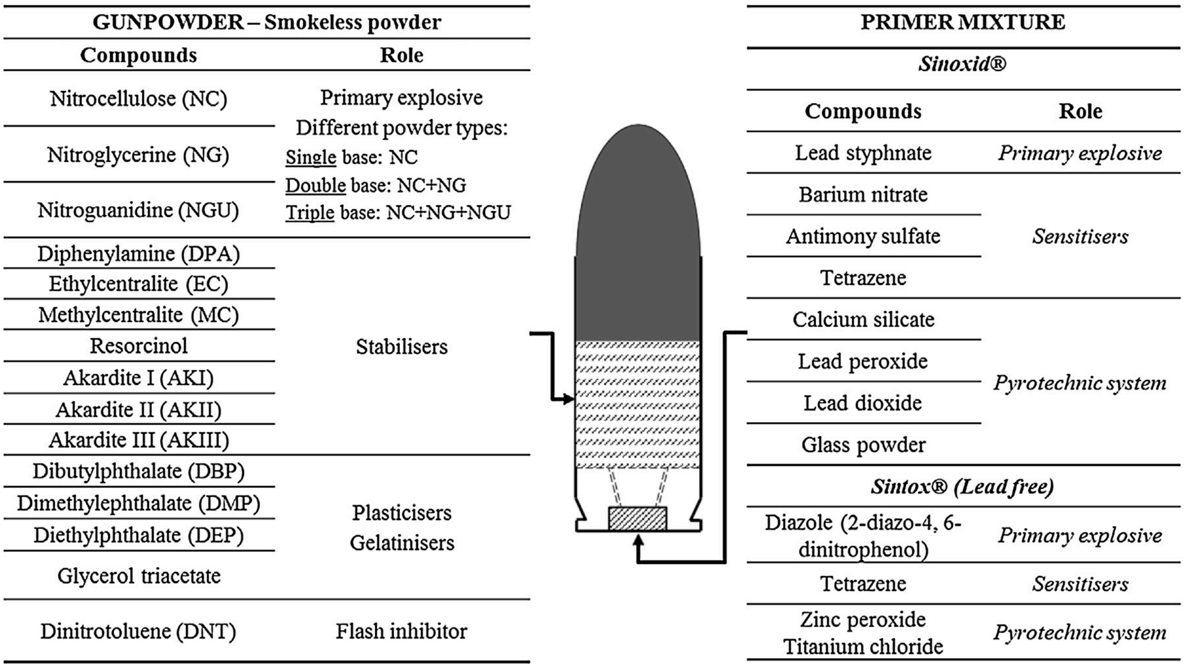
LITERATURE REVIEW

2.1 Forensic Ballistics

Forensic ballistic represents a sub-area of criminalistics, covering the study of firearms and ammunition that aims is to relate a suspect to a weapon used in a shooting incident, usually through the analysis of ammunition (Costa *et al.*, 2016). Firearm is a weapon that aims and discharges lethal projectile from a barrel towards the target at high velocity after the building up of great amount of gases within the ammunition due to the rapid and confined burning of smokeless powders (Meng and Caddy, 1997; Warlow, 2005; Wallace, 2008; Heard, 2008; Dalby *et al.*, 2010; Chang *et al.*, 2013). On the other hand, ammunition is a combination of projectile, smokeless powder and primer packed in a cartridge case which precisely made fitting into firing chamber of firearm (Wallace, 2008; Chang *et al.*, 2013).

Primer functions to initiate explosive combustion of smokeless powder after a shock sensitive reaction due to the impact of firing pin against the primer cup. A great volume of gaseous materials is then produced upon burning of smokeless powder, and finally, the projectile leaves the muzzle and gaseous material escaped are collectively called GSR (Wallace, 2008).

In general, GSR contains discrete and characteristic burned, partially burned and unburned combustion products along with the constituents from primer, bullet, cartridge case and/or firearm itself (Wolten *et al.*, 1979; Schwoeble & Exline, 2000; Chang *et al.*, 2013). In other words, although priming mixture is the principal constituent in which GSR is identified in forensic practices, there are also other components within an ammunition which could also contribute to the residue, including smokeless powder, cartridge case, projectiles such as bullets, slugs or pellets (SWGGSR, 2011). The firearm itself might also add into the elemental compositions of GSR in certain combustion instances, originated more commonly from the barrel and cylinder particularly in revolvers (Wolten *et al.*, 1977; Warlow, 1996). Figure 2.1 illustrates the composition of ammunition, as well as the common ingredients used in manufacturing ammunition.



GUNPOWDER – Smokeless powder	
Compounds	**Role**
Nitrocellulose (NC)	Primary explosive Different powder types: Single base: NC Double base: NC+NG Triple base: NC+NG+NGU
Nitroglycerine (NG)	
Nitroguanidine (NGU)	
Diphenylamine (DPA)	Stabilisers
Ethylcentralite (EC)	
Methylcentralite (MC)	
Resorcinol	
Akardite I (AKI)	
Akardite II (AKII)	
Akardite III (AKIII)	
Dibutylphthalate (DBP)	Plasticisers Gelatinisers
Dimethylephthalate (DMP)	
Diethylphthalate (DEP)	
Glycerol triacetate	
Dinitrotoluene (DNT)	Flash inhibitor

PRIMER MIXTURE	
Sinoxid®	
Compounds	**Role**
Lead styphnate	*Primary explosive*
Barium nitrate	*Sensitisers*
Antimony sulfate	
Tetrazene	
Calcium silicate	*Pyrotechnic system*
Lead peroxide	
Lead dioxide	
Glass powder	
Sintox® (Lead free)	
Diazole (2-diazo-4, 6-dinitrophenol)	*Primary explosive*
Tetrazene	*Sensitisers*
Zinc peroxide Titanium chloride	*Pyrotechnic system*

Figure 2.1 Composition of firearm ammunition where smokeless powder residues are known as organic GSR (OGSR) and the primer mixture residues are categorised as inorganic GSR (IGSR) (Maitre *et al.*, 2018)

2.2 Composition of GSR

Various components from ammunition and firearm could contribute to GSR composition. Inorganic components of GSR are commonly derived from primer mixtures while the organic components are derived from propellant powder, more specifically smokeless powders. Nowadays, smokeless powders are more commonly used as the main ingredients in manufacturing of ammunition, replacing black powders.

The single based powders commonly use nitrocellulose (NC) as explosive, while the double based powders contain both NC and nitroglycerine (NG). The triple base powders contain NC, NG together with nitroguanidine (NQ) salts where NQ provides various advantages including low flame temperature, flashlessness, low barrel erosion and long shelf life (Chang *et al.*, 2013). All smokeless powders contain a number of additives, which include stabilizers, plasticizers, flash inhibitors, coolants, moderants, surface lubricants and anti-wear additives, depending on their respective intended uses (Dalby *et al.*, 2010; Chang *et al.*, 2013).

In the context of firearm, primer is a mixture of highly sensitive explosives, oxidising agents, fuel and a small amount of sensitisers, friction material and/or binder (Dalby *et al.*, 2010; Meng & Caddy, 1997; Zeichner, 2009; Chang *et al.*, 2013). All these ingredients are housed in small metal cups that precisely fit into a primer pocket at the center of the base of cartridge case for center fire ammunition type (Zeichner, 2009).

The availability of different types of primer used in ammunition could generate varying materials of interest due to their respective variations in formulations among different manufacturers. Amongst, lead styphnate is the common explosive initiator in primers, which has replaced lead azide and mercury fulminate due to their insufficient intensity of flame produced upon combustion, and the corrosive effect, respectively (Meng & Caddy, 1997; Heard, 2008; SWGGSR, 2011). Oxidising agents are used in primers to support the burning process. Barium nitrate is commonly used in small-arms ammunition, but barium peroxide, lead nitrate or lead peroxide may also be encountered in the composition of certain ammunition types (Meng & Caddy, 1997; Heard, 2008; SWGGSR, 2011). Antimony sulfide acts as the fuel in primers, where calcium silicide, lead thiocyanate, powdered aluminum and powdered zirconium, magnesium, as well as titanium have also been used to react with the explosive and oxidising agent in producing energy and heat (Meng & Caddy, 1997; Heard, 2008; Zeichner, 2009).

Existence of initiator, oxidising agent and fuel provide the important elements for combustion reaction to occur within ammunition whenever a friction is exerted on the primer cup. Additionally, tetracene is a common sensitising material used in small-arm primers apart from trinitrotoluene to increase and provide stability in ignition's sensitivity (Dalby *et al.*, 2010; SWGGSR, 2011; Chang *et al.*, 2013).

More recently, there are a large number of manufacturers produced ammunition with lead-free primers due to increase concerns over health problems relating to air-borne pollution and exposure to high levels of heavy metals, especially lead (Zeichner, 2009; Chang *et al.*, 2013). Some examples of lead-free ammunition brands included CCI Blazer Lead Free, Remington/UMC Leadless, as well as Fiocchi (SWGGSR, 2011). Compounds used in lead-free primers were found differed among these manufacturers, and also varied from the conventional primer manufacturers. For example, lead styphnate has been replaced by diazodinitrophenol, and barium nitrate and antimony sulphide were substituted by a mixture of zinc peroxide and titanium metal powder, respectively (Wallace, 1990; Zeichner, 2009). These lead-free ammunitions might include antimony/barium, aluminium/barium/silica, aluminium/strontium, zinc/titanium as their elemental compositions (SWGGSR, 2011).

2.3 Laws Related to Firearm and Ammunition in Malaysia

An alarming trend of shooting cases, particularly street killings, has becoming a great concern among the public throughout the world. Risk of injuries and fatalities related to firearm cases not only affect the targeted individual, but the innocent people as well, especially by misfire or stray bullets. In Malaysia, a total of 204 cases of death due to shooting have been reported in Klang Valley alone from 2006 to 2016. 2009 recorded the most cases with 43 cases (21.1%) and only 4 fatalities cases (2%) was recorded in 2007. (Adawiyah *et al.*, 2018).

In Malaysia, firearms are governed under the Arms Act 1960, covering arms, imitation arms, as well as ammunition (Arms Act 1960). On the other hand, Internal Security Act 1960 describes general provisions which related to internal security in the country pertaining to the power of preventive detention, prevention of subversion, as well as suppression of organised violence against persons and properties in specified areas of Malaysia (Internal Security Act 1960).

These two Acts refer firearm as “any lethal barrelled weapon of any description from which any shot, bullet or other missile can be discharged or which can be adapted for the discharge of any such shot, bullet or other missile and any weapon of whatever description designed or adapted for the discharge of any noxious liquid, gas or other thing, and includes any component part of any such weapon as aforesaid" (Arms Act 1960; Internal Security Act 1960).

Another act known as Firearms (Increased Penalties) Act 1971 provides increased penalties for the use of firearms in the commission of certain offences and for offences relating to firearms, and to make special provision relating to the jurisdiction of courts in respect of offences thereunder and their trial. It also defines firearm in the same way; the act also includes bomb or grenade containing explosive charge as firearm (Firearms Act 1971).

Ammunition refers to "ammunition for any firearm as hereafter defined and includes grenades, bombs and other like missiles whether capable of use with such a firearm or not and any ammunition containing or designed or adapted to contain any noxious liquid, gas or other thing" (Arms Act 1960; Internal Security Act 1960). Blank ammunition, where a cartridge contains only propellant powder but no bullet, is also classified as ammunition (Arms Act 1960). Referring to discharge, Firearm (Increased Penalties) Act 1971 defines it as a mean that "causes discharge of a shot, bullet or other missile from a firearm by means of an explosive charge, and includes the causing of a bomb or grenade to explode" (Firearms Act 1971).

No person shall have in his possession, custody or controlled any arms or ammunition unless he possesses an arm's license. In Malaysia, this is governed under the Section 3 of Arms Act 1960. Section 4 of the act states that for the person to apply for the arm’s license, he shall make an application to the Chief Police Officer of the state in which the applicant resides. Generally, a person who has in his possession, carries or uses any arm or ammunition without an arms license or permit, if convicted, can be imprisonment for a term not exceeding seven years, or to a fine not exceeding ten thousand ringgit, or to both (Arms Act 1960).

In any situation where firearm or ammunition is recovered from a crime scene, forensic practitioners shall help to retrieve information such as the serial number of the firearm, which firearm has been used to fire the ammunition, whether shot has been fired from the firearm and so forth. Furthermore, the detection of GSR also plays its role to determine whether a person had fired a firearm.

2.4 Evidential Values of GSR Analysis

A firing activity is a complex process, from the loading of ammunition to the stoppage of projectile on a target. Today, firearms and ammunition designs are greatly diversified according to the various manufacturers. Further, the ingredients that have been used to make up primer and smokeless powder varies among ammunition produced by different manufacturers, or even from a single manufacturer (Dalby & Birkett, 2010). The variations arisen from manufacturers, in addition to other factors such as the personal hygiene and environmental factors during the firing activities, have contributed to the variation in GSR, and potentially impede its determination (Chang *et al.*, 2013). GSR analysis therefore, helps revealing vital trace evidence for solving a wide range of issues consequent to be determined by court.

2.4.1 Determination of the person who fired a weapon

One important link during forensic investigation of shooting cases is to determine whether a person had fired a firearm, or was connected with a firing activity. Traces of GSR particles due to the discharge of firearm may be found on any part of body surface such as hand, hair and face, as well as the front upper side of the clothing of the person who fired it (Jalanti *et al.*, 1999; Stahling & Karlsson, 2000). Detection of GSR on the suspect apprehended following a shooting provides significant evidence aiding forensic investigation, covering alleged suicides, armed assaults, murders, and other violated use of firearms (Brazeau & Wong, 1997).

Since the development of colour spot test in 1959 to detect the presence of GSR using hydrochloric acid in coupled with triphenylmethylarsonium iodide, various analytical techniques have been found useful for such context (Chang *et al.*, 2013). Recently, instrumental techniques have rapidly superseded colour spot tests, in which they are commonly utilised on either detection of inorganic or organic GSR particles.

For the detection of inorganic GSR, bulk analytical technique, namely the neutron activation analysis (NAA) was initially used to detect antinomy and barium in GSR (Price, 1968; McFarland *et al.*, 1973; Krishnan, 1974; Krishnan, 1977; Rudzitis, 1980). Atomic absorption spectrometry (AAS), based on detection on the content of lead, barium and antimony, was also utilised to differentiate person who fired a weapon from those who did not (Krishnan, 1977; Rudzitis, 1980; Newton, 1981; Dahl *et al.*, 1985; Koons *et al.*, 1987; Koons *et al.*, 1989; Reed *et al.*, 1990).

Inductively coupled plasma-atomic emission spectrometry (ICP-AES) was compared with AAS for the determination of barium (Koons *et al.*, 1988), as well as lead and antimony (Koons *et al.*, 1989) from swab samples with suspected GSR particles. In 1998, the concentration levels of lead, barium and antimony in GSR collection swabs were determined using inductively coupled plasma-mass spectrometry (ICP-MS), and subsequently allowed for association with the shooters (Koons, 1998; Reis *et al.*, 2003; Sarkis *et al.*, 2007).

Recently, SEM-EDX, a particle analysis technique, became the most preferred technique for determination of the presence of GSR, especially for the association of the person who did a recent firing (Wolten *et al.*, 1979; Gunaratnam & Himberg, 1994; Lebiedzik & Johnson, 2000; Fojtasek & Kmjec, 2005; Brozek-Mucha, 2009; ASTM 2016).

Many researchers also focused on the detection of organic GSR, particularly those originating from the smokeless powders for the purpose of identification and to aid in the forensic investigation of criminal cases. The presence of GSR on gloves could be detected using modified Griess reagent (Mohd Rafae *et al.*, 2019). Smokeless powders were also analysed using gas chromatography-mass spectrometry (GC-MS), revealing a combination of NG, 2,4-dinitrotoluene, dibutyl phthalate, ethyl centralite and diphenylamine as the common ingredients, and subsequently demonstrated the presence of GSR on hands (Mach *et al.*, 1978).

GSR collected from the clothing of shooter by a vacuum sampler was also analysed by gas chromatography-thermal energy analysis (GC-TEA), IMS and GC-MS by

Zeichner *et al.* (2003). Petraco *et al.* (1981) used ultraviolet–visible (UV-vis) spectrometry to identify smokeless powder and their residues on swabs. High performance liquid chromatography-electrochemical (HPLC-EC) technique detected stabilisers on collection swabs, serving as screening procedure as a potential mean to identify GSR (Dahl *et al.*, 1985; Dahl *et al.*, 1987). Fourier Transform Infra-red Spectrometry (FTIR) technique was also reported its use in determining NC in GSR swabs (Leggett & Lott, 1989).

The detection of inorganic and organic GSR, both play important role to determine a shooter through different analytical techniques. In this study, inorganic GSR is the main concern, in order to establish variations in term of the different firearms and different sampling methods, for successfully determining the shooter who had fired a firearm, utilising SEM-EDX.

2.4.2 Estimation of firing distance

Estimation of firing distance, which is the distance between a firearm and a target, is important for the reconstruction of firearm related cases through detailed examination of residual pattern around a bullet entry side. Commonly, a distant gunshot impact occurs where only the bullet reaches the target, without the presence of powder residue that successfully reaches a target. On the other hand, a close-range gunshot impact could be described by adequate short range, where powder residue discharged from a firearm could reach a target with certain characteristic features such as the deposition of stippling and soot (Messler & Armstrong, 1978; Stone *et al.*, 1978; Chang *et al.*, 2013). Such estimation is frequently assisted by chemical means, particularly the use of modified Griess reagent (Zeichner & Glattstein, 1986; Stahling, 1999; Muller *et al.*, 2007; Vinokurov *et al.*, 2010), as well as other colour test (Bailey *et al.*, 2006; Andreola *et al.*, 2011).

Instrumental techniques were also utilised to estimate firing distance, including GC-MS and GC-TEA to confirm the chemical identification (Muller *et al.*, 2007). NAA was reported to be used in estimating firing range through the detection of barium and antimony on surfaces subjected to different firing range (Krishnan 1967). EDX and AAS were carried out on the body tissue (Stone *et al.*, 1978) and cloth targets around bullet hole (Ravreby, 1982) to compare contact and distant wounds. Detection of possible changes in the characteristics of GSR in term of their sizes and the respective proportions, as well as the dispersion of GSR was also studied using SEM-EDX (Brozek-Mucha, 2009; Brozek-Mucha, 2011).

Depositing pattern and quantity of GSR were found to be varied with regard to the distance between the target and the muzzle of a firearm, and its quantity reduced greatly with increasing range of firing (Chang *et al.*, 2013; Maitre *et al.*, 2017; Zapata *et al.*, 2018). However, it is important to note that the estimation on firing distance based on the detection of GSR might only limit to close range shooting (Messler & Armstrong, 1978; Chang *et al.*, 2013; Zapata *et al.*, 2018). In fact, estimation of firing distance could aid in the reconstruction of shooting event, especially for the determination of the manner of firing, either homicide or suicide.

2.4.3 Confirmation of bullet hole

Identification of bullet marks and holes through detection of metal traces transferred from a projectile or the deposition of GSR could confirm a firing, or more specifically indicating a mark or a hole was caused by a projectile. Previously, bullet hole was identified through the utilisation of NAA and autoradiography for the presence of barium and antimony (Krishnan & Nichol, 1968), photoluminescence for lead (Jones & Nesbitt, 1975), as well as EDX and AAS for lead, barium and antimony detections (Stone *et al.*, 1978). Ravreby (1982) investigated bullet hole on cloth through the detection of primer particles and their chemical constituents by SEM-EDX.

In very rare cases, characteristic GSR could be found around the bullet wipes on impact mark, probably carried by the projectile and finally deposited on the target surface (Vermeij *et al.*, 2012). In general, GSR particles detected from the bullet wipe could aid to confirm that an impact was caused by a projectile, and usually it had been fired from a relatively short distance. Elemental profiles to be considered during forensic analysis were varied for GSR and bullet wipe circulating the bullet hole. The former focuses on the detection of lead, barium and antimony, while the latter detects the presence of lead, especially for those unjacketed bullets, as well as copper and zinc for those jacketed bullets.

2.4.4 Estimation of time since discharge

In certain instances, the determination of the range of time when a firearm had been fired or a specific time when a spent cartridge was shot, is an interest aspect by the forensic investigator to reconstruct a shooting event. Such examination highly depends on the detection of volatile discharge products after discharge of a firearm, in relation to their relative abundance due to their varying escape rates (Sinha, 1976; Andrasko *et al.*, 1998; Andrasko & Stahling, 1999; Chang *et al.*, 2015). However, a number of factors might also influence the accuracy in estimating the time since discharge, including the type of weapon used, the amount and composition of smokeless powder, as well as the nature of ammunition (Andrasko *et al.*, 1998). Additionally, the number of shots fired, cleaning effect, as well as the effect of temperature and storage protocol might impact the interpretation process too (Sinha, 1976; Andrasko *et al.*, 1998; Andrasko and Stahling, 1999; Weyermann *et al.*, 2009). Therefore, time interval between GSR deposition and the last use of a firearm shall be interpreted with care, so that it could aid in clarifying specific crime scene situations to allow for more accurate estimation (Andersson and Andrasko, 1999; Fojtasek and Kmjec, 2005). In fact, the estimation of time since discharge was only concerned on the detection of organic GSR due to the volatile nature of organic compounds.

2.4.5 Determination of ammunition type

Primer and smokeless powder compositions vary on the basis of manufacturers, due to the intended use as well as the required performance of the ammunition (Burleson *et al.*, 2009). Therefore, the profiles of GSR, particularly their organic composition would be different, allowing possibility to determine the ammunition type which had been to fire a target. Additionally, metallic composition used to fabricate or cover the projectile and cartridge cases, as well as metallurgy that made up a firearm also differ among firearm and ammunition manufacturers of different brands (Brozek-Mucha & Jankowicz, 2001; Lebiedzik & Johnson, 2002). By comparison, the primer composition might not greatly differ among the types of ammunitions, unless more recent non-toxic primer was used but they are not commonly utilised to date.

Detection and determination of organic GSR profiles were mainly reported through the utilisation of GC (Andrasko, 1992; Burleson *et al.*, 2009; Weyermann *et al.*, 2009;

Dalby & Birkett, 2010; Joshi *et al.*, 2011; Chang *et al.*, 2015). Liquid chromatography, as a less common choice, was also used for comparison of GSR profiles (Andrasko, 1992; Mathis & McCord, 2003; MacCrehan & Bedner, 2006). Besides organic composition, inorganic ions present in the smokeless powder was analysed by Hopper and McCord (2005) using capillary zone electrophoresis. Lead isotopic composition was also analysed to investigate ammunition types which have been differed in term of their isotopic compositions (Zeichner *et al.*, 2006).

In fact, the capability of SEM-EDX shall not be overlooked for characterisation of ammunition types. Brozek-Mucha and Jankowicz (2001) successfully established the morphology and elemental content on six types of ammunition, suggesting variations in the frequencies of occurrence on the basis of the chemical classes of primer residues. Lebiedzik and Johnson (2002) also developed a database of GSR samples covering nine different types of firearms and more than 60 ammunition types according to their respective morphological information and elemental profiles.

Therefore, the detection of GSR particles, both organic and inorganic, and subsequently the establishment of the profiles of the GSR would allow for determination of the specific ammunition types, or at least narrowing down of possible types of ammunitions which could have produced an impact mark or for those recovered from the body surfaces of a shooter (Brozek-Mucha & Jankowicz, 2001; Lebiedzik and Johnson, 2002).

2.5 SEM-EDX Analysis

SEM-EDX technique is a powerful tool for particle analysis. Current forensic analysis focuses on inorganic GSR and utilises SEM-EDX to characterise particulates that originated from primer components within ammunition. Backscatter SEM images are obtained and particles are targeted based on their respective shape and morphology. On the other hand, EDX analysis is used to determine the elemental composition of observed particle.

Previously, inorganic GSR was also reported to be analysed using various techniques, including NAA, AAS, as well as ICP (Dalby *et al.*, 2010). Particle analysis by SEM-EDX is in contrast with bulk sample methods, such as NAA, AAS, and ICP, where the sample materials are dissolved or extracted to determine the total element concentrations (ASTM, 2016). X-ray Fluorescence Spectrometry (XRF), on the other hand, is a non-destructive technique like SEM-EDX but it does not provide morphological information and incapable for individual GSR particle identification (ASTM, 2016).

Due to non-destructive nature of SEM-EDX, it is always preferable in determining physical appearance and elemental profile of trace evidence deposited on a substrate (Hu *et al.*, 2009), and in this case, the GSR particles. It classifies and discriminates forensic evidence with its ability to perform simultaneous examination to determine the elemental composition and detailed morphology of object. The technique does not destroy the sample, and allows for repeated analysis on such important evidence.