RECOVERY AND DETECTION OF METHAMPHETAMINE-CONTAMINATED FINGERMARKS IN FORENSIC SETTINGS

SARAH ALIAH BINTI AMIR SARIFUDIN

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RECOVERY AND DETECTION OF METHAMPHETAMINE-CONTAMINATED FINGERMARKS IN FORENSIC SETTINGS

by

SARAH ALIAH BINTI AMIR SARIFUDIN

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In the name of Allah, The Entirely Merciful, the Especially Merciful. All praise is due to Allah, Lord of the worlds. It is universally acknowledged in the world of forensics that "every contact leaves a trace". However, this "contact" is not limited to fingermarks, but also to every interaction and experience. I am indeed very blessed to have met amazing people in my life and during my studies, and the ones that first come to mind are definitely my supervisors. A thank you could never outweigh all the help, advice and support I have received from them. Therefore, my special thanks go to Associate Professor Dr Ahmad Fahmi Lim Abdullah, Associate Professor Dr Khoo Bee Ee and Dr Chang Kah Haw for everything they have given me along the way and over the past decade. I would like to thank Universiti Sains Malaysia for their financial support through the RUI grant (1001/PPSK/8012236). A big thank you to Dr Vanitha Kunalan from the Department of Chemistry Malaysia for her logistical support for the study. Special thanks to the Fingerprint Section, D10 Division of the Bukit Aman Criminal Investigation Department (Forensic Laboratory) for their insights and participation in the crime scene processing. I would also like to thank everyone from the Forensic Science programme for their support throughout my study. From the bottom of my heart, I thank my family and friends, especially Aishah (and Darcy), Teh, Hui Pheng, Fatin, Wan, Koon, Sumayya, ASP Yam, Lee Khai, Teha, Ain, Uncle Daddy and the rest of you for your time and help. Last but not least and absolutely important, Mak and Abah; from the beginning to the end of time. They are my support when everything else fell apart. They are always there and never let me down, and I hope I am not a disappointment to you both either. Always and forever.

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LIST OF SYMBOLS

®	Registered
™	Trademark

LIST OF ABBREVIATIONS

6-MAM	6-Monoacetylmorphine
AFIS	Automated Fingerprint Identification System
Ag-LDI	Silver-Assisted Laser Desorption Ionisation
AMLA	Anti-Money Laundering and Anti-Terrorism Financing Act
ANFO	Ammonium Nitrate-Fuel Oil
ANOVA	Analysis of Variance
BY 40	Basic Yellow 40
C-4	Composition C-4
CA	Cyanoacrylate
CAST	Centre for Applied Science and Technology
CID	Criminal Investigation Department
DESI	Desorption Electrospray Ionisation
DFO	1,8-Diazafluoren-9-one
DNA	Deoxyribonucleic Acid
EDX	Energy-Dispersive X-ray
ESEM	Environmental Scanning Electron Microscope
et al.	*et alia*
FESEM	Field Emission Scanning Electron Microscope
FID	Flame Ionisation Detection
FTIR	Fourier Transform Infrared
GC	Gas Chromatography
HMX	High Melting Explosive
HRMS	High Resolution Mass Spectrometry
IBM®	International Business Machines Corporation
i.e.	*id est*
IMS	Imaging Mass Spectrometry
IR	Infrared
ISO	International Standard Organisation
LC	Liquid Chromatography
LDA	Laser Desorption Ionisation
MALDI	Matrix-Assisted Laser Desorption Ionisation

MBD	7-(p-methoxybenzylamino)-4-nitrobenzene-2-oxa-1,3-diazole
MDA	Methylenedioxyamphetamine
MDF	Medium-Density fibreboard
MDMA	Methylenedioxymethamphetamine
MS	Mass Spectrometry
NSAIDs	Nonsteroidal Anti-Inflammatory Drugs
O-PTIR	Opitcal-Photothermal Infrared
PETN	Pentaerythritol Tetranitrate
PVC	Polyvinyl Chloride
R6G	Rhodamine 6G
SECM	Scanning Electrochemical MIcroscope
SEM	Scanning Electron Microscope
SERS	Surface-Enhanced Raman Scattering
SLR	Single-Lens Reflect
SPME	Solid Phase Microextraction
SPSS®	Statistical Package for the Social Sciences
RCI	Raman Chemical Imaging
RDX	Royal Demolition Explosive
RMP	Royal Malaysia Police
THC	Methylenedioxymethamphetamine
ToF-SIMS	Time-of-Flight Secondary Ion Mass Spectrometry
TNT	Trinitrotoluene
UNODC	United Nations Office on Drugs and Crime
UV	Ultraviolet
UV-Vis	Ultraviolet-Visible
VMD	Vacuum Metal Deposition

LIST OF UNITS

%	percent
µg	microgram
°C	degree Celcius
µg	microgram
µL	microliter
cm	centimetre
cm^2	square centimetre
g	gram
mg	milligram
min	minute
mL	millilitre
mm	millimetre
mol	mole
ng	nanogram
pg	picogram
s	second

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PEMULIHAN SEMULA DAN PENGESANAN CAP JARI YANG TERCEMAR DENGAN METAMFETAMIN DALAM PENETAPAN FORENSIK

ABSTRAK

Cap jari pada kebiasaan tidak kelihatan, boleh wujud atas sebarang permukaan dalam sesuatu tempat kejadian jenayah dan juga boleh dicemari oleh sebatian asing seperti dadah. Apabila terdapat jenayah berkaitan dadah, sama ada pemprosesan dadah haram atau pengedaran dan penyalahgunaan dadah haram, cap jari dan sebatian dadah merupakan dua bukti forensik yang penting dan nilai bukti tersebut patut dimaksimumkan. Justeru, kajian ini bertujuan untuk menyiasat pengesanan cap jari yang dicemari oleh metamfetamin dalam penetapan forensik. Dalam kajian ini, cap jari pada sebelas jenis permukaan telah dikesan dengan menggunakan serbuk cap jari hitam dan serbuk cap jari putih. Kesan kehadiran metamfetamin ke atas penimbulan dan pentafsiran cap jari, serta kedekatan pemendapan sama ada sebagai cap jari yang diletakkan atas suatu permukaan yang telah dicemari oleh metamfetamin atau cap jari yang diletakkan pada suatu permukaan bersih dan seterusnya dicemari oleh metamfetamin juga telah disiasat. Akhir sekali, sampel metamfetamin di atas permukaan yang telah ditimbulkan dengan serbuk cap jari telah ditentukan melalui ujian kimia Simon, teknik spektrofotometri ultraungu tampak dan teknik gas kromatografi. Penggunaan serbuk cap jari adalah baik dalam penimbulan cap jari atas sebarang permukaan tetapi kesesuaiannya bergantung kepada sifat bahan permukaan tersebut. Terdapat kesan yang signifikan atas serbuk cap jari dan skor cap jari dengan F (1, 122.22) = 301.834, $p < 0.001$. Penimbulan cap jari di atas kesemua sebelas permukaan menggunakan serbuk cap jari hitam adalah lebih baik berbanding dengan serbuk cap jari putih. Namun, cap jari yang wujud pada permukaan bahan kaunter dapur kuarza dan papan zarah melamina perang sukar untuk ditimbulkan. Cap jari yang dicemari oleh metamfetamin masih boleh ditimbulkan dengan menggunakan serbuk cap jari tetapi skor cap jari berkemungkinan berkurang disebabkan kehadiran sebatian asing. Dalam penentuan kedekatan pemendapan cap jari, kehadiran sebatian metamfetamin di kawasan luar sisa cap jari serta pemisahan yang jelas antara kawasan rabung dan lekuk cap jari boleh mencadangkan cap jari tersebut telah diendapkan pada permukaan yang tercemar. Ujian kimia Simon, teknik spektrofotometri ultraungu tampak dan teknik gas kromatografi adalah berguna dalam pengesanan kehadiran metafetamin dalam sampel yang disampelkan dari permukaan. Serbuk cap jari juga didapati kurang cenderung dalam mengganggu pengesanan positif. Tiada kesan yang signifikan antara serbuk cap jari dan ujian positif Simon (p = 0.709). Kesimpulannya, kaedah-kaedah pengesanan cap jari yang dicemari dengan metamfetamin haram telah berjaya dibangunkan.

RECOVERY AND DETECTION OF METHAMPHETAMINE-CONTAMINATED FINGERMARKS IN FORENSIC SETTINGS

ABSTRACT

Fingermarks are usually invisible and could be contaminated by exogenous substances such as drugs. Whenever there are drug-related crimes, either clandestine drug manufacturing or distribution and abuse of illicit drugs, fingermark, and the drug substances are the two important pieces of forensic evidence where their evidential values shall be maximised. This study aimed to investigate the detection of methamphetamine-contaminated fingermarks in forensic settings. In this study, fingermarks were developed on eleven types of surface materials using black and white fingerprint powders. The effect of the presence of methamphetamine towards the recovery and interpretation of the fingermark, as well as the immediacy of deposition either as a fingermark deposited on a priorly methamphetamine-contaminated surface or a fingermark deposited on a clean surface but subsequently contaminated by the methamphetamine, were also investigated. The application of fingerprint powder was good in developing fingermarks from any surface; however, its suitability depends on the nature of the surface materials. The choice of fingerprint powders significantly affected the fingermark scoring with F (1, 122.22) = 301.834, $p < 0.001$. Black fingerprint powder produced better visualisation where the fingermarks on all the eleven surface materials tested in this study were successfully recovered compared to white fingerprint powders; however, fingermarks appeared on quartz countertops and brown melamine particle board surfaces were found more difficult to be recovered. Methamphetamine-contaminated fingermarks could still be recovered using the fingerprint powdering method, but the scoring of fingermarks could be reduced due to an exogenous substance. In determining the immediacy of deposition, methamphetamine crystals at the exterior of the fingermark residue and the distinct separations between the ridge and non-ridge areas of the fingermark could suggest the prior-deposition contaminated fingermark under a scanning electron microscope. Simon’s chemical test, UV-Vis spectrophotometry, and gas chromatography methods were useful in detecting the presence of methamphetamine from the surface-sampled samples. The fingerprint powder particles were less likely to interfere with the positive detection. No association was found between the application of fingerprint powder and the positive detection of methamphetamine by Simon’s test ($p = 0.709$). To conclude, techniques for detecting illicit methamphetamine-contaminated fingermarks were successfully established.

CHAPTER 1

INTRODUCTION

1.1 Research background

Fingermarks found at a crime scene can aid in identifying the individual involved in criminal activity. Due to the complexity of a crime scene, fingermarks might exist in various conditions, i.e., perfectly shaped fingermarks, partial marks, patent or even latent fingermarks. The former is less likely to be encountered by forensic investigators. These various fingermarks could be affected by the contributor or donor of the marks, the surface materials where the fingermark are deposited, and the environmental factors (Chen et al., 2021; Khare and Singla, 2022).

A fingermark comprises endogenous organic and inorganic substances transferred onto a surface from the finger. Depending on the nature of the surface materials, usually porous or non-porous, the fingermark can be developed using suitable fingermark recovery methods, such as ninhydrin for the former and the conventional powdering procedure for the latter (Saferstein, 2015). However, there are possibilities where contamination could occur in the fingermark by exogenous substances that do not belong to the fingermark residues, such as drug substances, cosmetic products, explosive and gunshot residue, and others. Such exogenous substances might interfere with the fingermark recovery methods, where the fingermark recovered from a surface is of lower quality (Khare and Singla, 2022).

Drug-related issues remain critical in Malaysia despite strict policies and penalties imposed on drug users, drug smugglers, or distributors. Specifically, methamphetamine was found as the top substance abused among Malaysians at the rate of 64.7% (National Anti-Drug Agency, 2021). In 2021, the United Nations Office on Drugs and Crime (UNODC) confirmed that the manufacturing of methamphetamine remains to dominate the black market, where illegal activity has spread across the globe as more countries were found involved (UNODC, 2021). In Malaysia, up to 22 clandestine laboratories were reported in 2019, and seven of them were involved in the manufacturing of methamphetamine. Figure 1.1 shows the number of dismantled clandestine laboratories in Malaysia from 2011 to 2019.

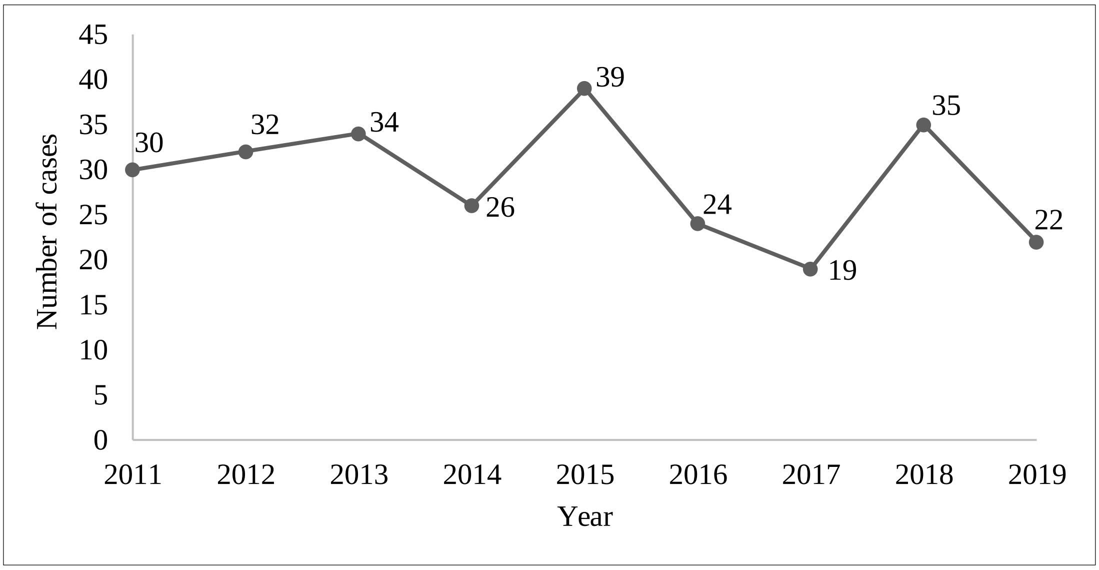

Figure 1.1 Number of dismantled clandestine laboratories in Malaysia (National Anti-Drug Agency, 2020).

The clandestine laboratory is a serious security threat as they continue supplying illicit drugs to the market. Traditionally, they existed as industrial-scale laboratories set up so that many desired illicit drugs could be produced quickly. In recent years, the structure of drug manufacturing has turned into a smaller scale, also known as kitchen laboratories. This type of clandestine laboratory uses only basic equipment and simple procedures (Government of Western Australia, 2021). The efforts of tracking the clandestine laboratories are always undertaken by our law enforcement agencies. For instance, the Royal Malaysia Police (RMP) seized a drug laboratory and RM1.27 million in drugs in 2018 (Kumar, 2018). In 2020, illegal drug laboratories were raided; however, only one person was caught (Zack, 2020a; Zack, 2020b). While in 2021, another two drug laboratories were seized, and more individuals were arrested (Zolkepli, 2021).

It was believed that the clandestine laboratory activities should involve more individuals than those who were caught, frequently spotted at the scene during the tracking and dismantling actions. Given this, the recovery of fingermarks from such crime scenes carries important evidential values. In most instances, the surfaces within the clandestine drug laboratories are frequently contaminated by the drug substance, and the effect of such exogenous substance toward the recovery and interpretation of the fingermark-related evidence is crucial to track the personnel who are not present at the scene during the police's spot checks.

Furthermore, both fingermark and illicit methamphetamine can appear together on any surface which had been touched by any individual who is involved in abusing, distributing, or sales of illicit drugs. This shows that the presence of both fingermarks and drug do not only limit within clandestine laboratory settings. In whichever scenario, determining the forensic evidence can aid in predicting the modus operandi and individuals related to drug-related activity.

1.2 Problem statement

Fingermarks, usually invisible, can appear on any crime scene surface. Given that fingermark is fragile, and the forensic investigator has only one opportunity to recover it, the most appropriate fingermark recovery technique shall be used to maximise the evidential values. Although many techniques were established worldwide, frequently aiming for improved sensitivity and more advanced approaches, the conventional application of fingerprint powders is the choice of law enforcement teams, including in Malaysia. In certain scenarios whereby the fingermarks are contaminated with exogenous substances, using fingerprint powder might not provide the expected results even when such a technique is the most suitable to apply on the surfaces. At the same time, forensic personnel might not be aware of the capabilities of fingerprint powders to be applied to such a state of the evidence.

Drug-related activities might lead to the contamination of a fingermark by illicit drugs, and it is unclear if the presence of exogenous substances would affect the recovery and interpretation of the fingermark. At the same time, the drug evidence needs to be preserved for forensic investigation. Both fingermarks and drug substances are important for prosecution. Under the Dangerous Drugs Act 1952, Section 39B, offenders can face the death penalty and life imprisonment for possession of certain weights of drugs (Dangerous Drugs Act 1952). However, this could only be conducted with fingermarks to relate individuals with the drugs beyond a reasonable doubt.

As mentioned in the above section, methamphetamine was found to be the topped substance abused among Malaysians; and under Section 39B of the Dangerous Drugs Act 1952, possession of 50 g of methamphetamine would lead to life imprisonment and the death penalty (Dangerous Drugs Act 1952). In recent years, proposed amendments of the act in reducing the weight of drugs that can be charged under Section 39B of the law and charging those involved in drug trafficking under the Anti-Money Laundering and Anti-Terrorism Financing Act (AMLA) 2001 were presented. According to the Narcotics Crime Investigation Department of RMP, the weight of methamphetamine must be reduced to 15 g or lower as the drug is the most seized in the country compared to other drugs (Bernama, 2021).

Hence, methamphetamine was chosen as the target substance to investigate its influence on fingermark recovery in this study. Fingermarks contaminated with methamphetamine were applied with the conventional fingerprint powders, observed, and interpreted. This study compared the uncontaminated and contaminated fingermarks developed using conventional fingerprint powders existing in black and white powder forms on eleven types of surface materials commonly encountered in a household setting and suggested the appropriate choice for each surface material.

At the same time, the forensic investigator must answer the immediacy of the deposition of a fingermark at a crime scene. A fingermark can be deposited on a priorly methamphetamine-contaminated surface, which means that the methamphetamine substance was existed on a surface followed by the deposition of the fingermark. On the other hand, the fingermark can also be deposited on a clean surface but subsequently contaminated by the methamphetamine substance, appearing on top of the fingermarks. To the author’s knowledge, there was no similar study carried out to differentiate these fingermarks either with or without the application of fingerprint powder; and therefore, this study explored the possibility of discrimination.

Whenever there are drug-related crimes, either clandestine drug manufacturing or distribution and abuse of illicit drugs, fingermark, and the drug substances are the two important pieces of forensic evidence to be investigated. To the best level, both pieces of evidence shall be recovered; however, any surface that is expected to have a fingermark will be dusted with fingerprint powders. Here raises the question of whether the powdered surface can be sampled and tested for the presence of methamphetamine to prove the drug-related activity. Previous studies reported on the possibilities to detect such exogenous substances. Still, the instrumentations are less likely in most drug testing laboratories, including Malaysia. Therefore, an analytical protocol to detect methamphetamine, even from samples contaminated with fingerprint powder particles, shall confirm the existence of the drug substance for forensic investigation.

1.3 Aim and objectives

The aim of this study was to investigate the detection of methamphetamine-contaminated fingermarks. To achieve this goal, the objectives were pursued:

i. To justify the suitability of fingerprint powdering technique for detecting fingermarks on various surface materials.

ii. To evaluate the influence of methamphetamine contamination on the recovery of fingermarks by fingerprint powder procedure and validate the sequence of fingermark deposition and methamphetamine contamination on glass surfaces.

iii. To characterise the colour test, spectrometric and chromatographic techniques for detecting methamphetamine from surfaces dusted with fingerprint powder.

1.4 Significance of the study

This study investigated the chances of recovering the fingermarks from various surface materials using conventional fingerprint powders, especially when the fingermarks were contaminated by illicit methamphetamine. The immediacy of fingermark deposition, whether the contaminant appeared on the surface before its deposition or a fingermark was subsequently contaminated by the contaminated, was also explored. Since the fingerprint powdering procedure tends to further contaminate a surface suspected to have contained fingermarks, such a procedure might also contaminate the exogenous substance, such as the methamphetamine that appeared on that surface. The possibility of detecting the presence of illicit methamphetamine from the wiped samples from the powdered surfaces was also examined through the routinely used instrumentation by the country's law enforcement authorities. Failure to assess suitable fingermarks detection techniques for drug-contaminated fingermarks and the fear of destroying fingermarks and drug evidence might be possible and become a stigma among the practitioners.

This study would benefit law enforcement agencies, especially those involved in the forensic investigation of drug-related activities. The study would suggest the most appropriate method for the best recovery of fingermarks. This study would also propose the appropriate sample processing protocol to collect and analyse the samples from a surface suspected to contain drug substances, even had been powdered using fingerprint powder. In most instances, surfaces applied with fingermark powder might not be collected and analysed; however, it remains useful to provide information even if fingermark fails to develop. Therefore, such evidence shall not be overlooked as a source for detecting suspected drug substances.

The availability of analytical methods to detect the presence of methamphetamine from samples from which the fingerprint powder had further contaminated could aid in proving the drug activity and predicting the modus operandi of that activity. The ability to identify the substance from a surface, although it might or might not be able to recover the fingermark, provides the law enforcement team with the information and direction of the forensic cases. It would allow the team to take immediate action and proper investigative procedures to track the drug syndicate and its activities.

1.5 Scope of the study

The RMP utilises fingerprint powdering as the primary technique for detecting fingerprints on non-porous surfaces, especially at crime scenes. Based on the current and routine protocol implemented by the RMP, white and black fingerprint powders were explored in this study to develop the fingermarks on selected non-porous surface materials. Groomed fingermarks were prepared according to the standard universal protocol available worldwide.

Methamphetamine was selected as the target substance as it is the most common drug found to be manufactured and seized in Malaysia. In this study, it served as the representative exogenous substance frequently appearing in clandestine laboratories and drug trafficking, distribution, and sales. With its detection, it would assist the forensic investigation.

The design of this study shall be reflected in the routine forensic analysis in Malaysian settings. Colour tests and gas chromatography techniques are the two detection strategies commonly used by the Department of Chemistry, Malaysia, and UNODC in drug testing procedures. Furthermore, Ultraviolet-visible (UV-Vis) spectrophotometry was also explored for its possibility to detect the presence of methamphetamine from fingermarks, both unpowdered and powdered. Given this, three detection strategies were established.

1.6 General approach of the study

Appendix A illustrates the general approach of this study. In general, this study was divided into three major studies. The first study involved the comparison of fingermarks recovered upon application of fingerprint powders on eleven types of surface materials. The effect of methamphetamine on the scoring of recovered fingermarks was also examined. For the second study, the immediacy of fingermark deposited on a methamphetamine-contaminated surface or subsequently contaminated by the methamphetamine after deposition was investigated using a scanning electron microscope. For the third study, the detection of the presence of methamphetamine from a surface that had undergone a powdering procedure was carried out. Three analytical procedures were considered in the forensic drug laboratories, including colour tests, spectrometric and chromatographic techniques.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

At present, identifications of individuals are based on fingermarks (Sears et al., 2012) due to the nature of the fingermarks, which are unique and permanent, the availability of universal methods for classification, and the ability to deposit marks on surfaces (Lennard, 2007; Saferstein, 2015). As fingermarks are commonly used for identification purposes, fingermarks identification is preferable for connecting individual(s) with the scene of a crime(s) and/or evidence (Lennard, 2014). Fingermarks recovered at the crime scene could be examined and compared with known fingermarks for identification purposes (Warren, 2013). Fingermarks are the primary identification in criminal investigations compared to identification based on deoxyribonucleic acid (DNA) (Lennard, 2001).

2.2 Fingermark and its examination

A fingermark, or fingerprint, is an elevated area of minutiae ridges on the skin surface found on every finger. These friction ridges appear like lines of mountains varying in width, height, and contour under visualisation, forming rough and textured surfaces to resist fingers and between fingers and a surface touched by an individual. Each fingermark consists of a specific ridge pattern of minutiae characteristics (Yamashita and French, 2010; Daluz, 2018).

Contact involving interaction between a finger and a surface tends to leave a fingermark on that surface. With each contact, materials are transferred between the finger and the surface until the finger is removed. The transfer of materials between the two entities has been found to depend on the substances present and their relative affinity for transfer. The friction ridges of the fingers are interspersed with sweat pores of various sizes and contours (Girod et al., 2012; Daluz, 2018). As a result, a fingermark with a specific pattern can be found on the surface upon contact.

2.2.1 Types of fingermarks

The patterns of fingermarks can be generally divided into three large groups, namely an arch, a loop, or a whorl, where each group bears an equivalent family similarity. Figure 2.1 illustrates the three fingermark patterns. Arch appears like an undulating pattern, accounting for about 5% of all pattern types. A loop pattern recurves on itself to form a loop shape. This pattern is the most common pattern, making up about 60% of the three pattern types. The remaining 35% consists of the circular or spiral pattern known as whorl (Daluz, 2018). It was also noted that the patterns might be further divided into sub-groups due to the smaller differences between the patterns within the same group (Table 2.1). The friction ridge patterns, regardless of their groups, possess unique variations in terms of the shape and relationship of the ridges. The characteristics allow for the match of a fingermark with a known fingerprint (Daluz, 2018).

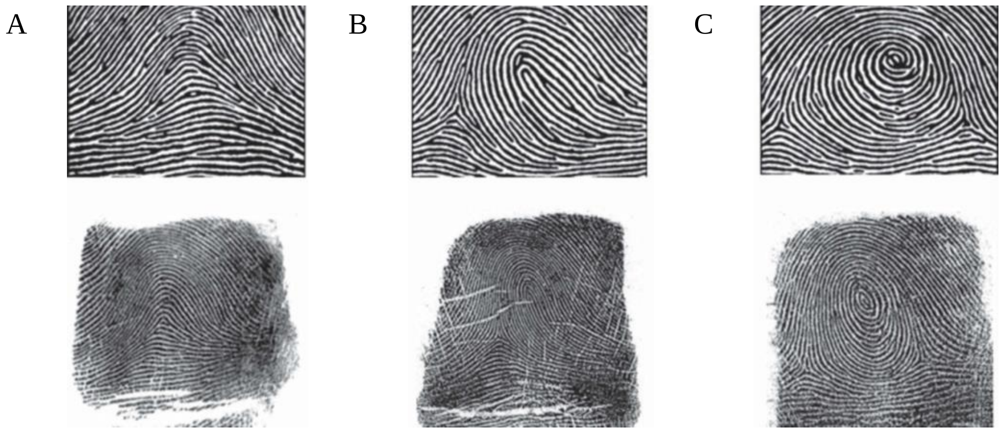

Figure 2.1 The three general fingermark pattern types; (A) arches, (B) loops, and (C) whorls (Daluz, 2018).

Table 2.1 Fingerprint pattern groups.

General Group	**Arches**	**Loops**	**Whorls**
Sub-Groups	Plain Arch Tented Arch	Radial Loop Ulnar Loop Nutant Loop	Spiral Concentric Lateral Pocket Central Pocket Twin Loop Composite Almond

Fingermarks can be found on various surfaces in the form of either patent or latent prints. Patent fingermarks are formed when blood, dirt, ink, paint, etc., is successfully transferred from a finger to a surface. These fingermarks could be present on a wide kind of smooth, rough, porous, and/or non-porous surfaces (Yamashita and French, 2010; Girod et al., 2012; Khare and Singla, 2021; Chen et al., 2021).

On the other hand, latent fingermarks are formed due to the deposition of natural oils and sweat from the skin onto a surface. The latter, the more commonly encountered forensic evidence in real case scenarios, are frequently found on various surfaces but are not readily visible (Yamashita and French, 2010). Hence, optical, physical, and/or chemical treatments must be implemented on such evidence for visualisation (Lennard, 2007). It was also noted that the types of surfaces with deposited fingermarks, as well as the manufacturing processes, raw material used during the manufacturing, and the end use of materials, could have displayed varying physical and chemical properties, influencing the chance to recover and enhance fingermarks for visualisation (International Fingerprint Research Group, 2014). Given this, selecting the most appropriate treatment techniques to maximise the detection and determination of fingermarks becomes a key issue during a forensic investigation.

2.2.2 Composition of fingermarks

The formation of fingermarks, particularly the latent fingermark, is due to the transfer of biological fluid from a human onto a surface. Fingermark is principally made up of a complex mixture originating from the natural secretions of glands within the skin. Its essential constituents include 95-99% water and organic and inorganic substances (Cadd et al., 2015; Khare and Singla, 2022). Three primary glands contribute to sweat production: the sudoriferous glands (eccrine and apocrine) and sebaceous glands, where each gland produces a unique mixture of chemical substances. These substances are regularly secreted from pores onto the friction ridges or are transferred to the friction ridges through a surface touch (Girod et al., 2012; De Alcaraz-Fossoul et al., 2013).

Generally, with no exception, eccrine glands are found all over a body. This type of gland appears as a tubular-shaped structure with a duct portion that coils deep into the dermis layer in a spiral fashion. It re-absorbs sodium, chloride, bicarbonate, glucose, and several other small solutes into a human's body system (Girod et al., 2012). Eccrine glands typically contain excessive water up to 98%, allowing for water evaporation from the skin surface without losing essential solutes under normal conditions (Lee and Gaensslen, 2001). Besides, such glands were found to have contributed to the major component of amino acids, acting as the primary compounds of a latent fingermark. Serine, glycine, and alanine are the foremost abundant amino acids, while threonine, leucine, tyrosine, isoleucine, lysine, phenylalanine, methionine, and cystine are present in lower amounts (Cadd et al., 2015).

Sebaceous glands are small sac-like organs, usually found within the dermis layer of skin. They appear throughout the human body and are related to body hair; however, they are absent on the hands and feet (Girod et al., 2012). These glands secrete sebum, a complex composition containing fatty acids, wax esters, triacylglycerol, cholesterol, and squalene. It was also noted that sebum could also be present on the palm and hands after contact with other parts of the body before the deposition of fingermark on a surface (Cadd et al., 2015). Apocrine glands are scent glands with odour in their secretion, usually found in axillary regions such as the armpits, groin, and the area around the nipples of the breast. However, their compositions are less likely to be encountered in fingermarks (Girod et al., 2012).

Concerning latent fingermarks, eccrine and sebaceous glands are the most deposition contributors, where the deposits are originated from the various combination of excretion from these two types of glands. In certain instances, one form of secretion may prevail as a purely eccrine or sebaceous deposit. As a latent fingermark occurs due to the contact between a finger and a surface material without exogenous substances on the finger during the deposition, the fingermark residue originating from these glands is transferred onto the substrate. An appropriate fingermark recover technique shall be implemented for forensic investigation to retrieve the fingermark and interpret the fingermark to determine the depositor (Lennard, 2007).

2.2.3 Factors affecting deposition of fingermarks

During fingermarks deposition, the residues originating from the finger will interact with the substrate and the surrounding. In most scenarios, especially during a forensic investigation, the fingermark recovery procedure is nearly impossible to carry out immediately after its deposition, where it could be exposed to ageing and environmental insults. A recent review paper by Chen et al. (2021) critically highlighted the advances in fingermark age determination techniques. The authors highlighted donor features, deposition conditions, the properties of surface materials, environmental conditions, and the revealing methods as the factors that could potentially contribute to determining fingermarks and the reliability of the age estimation. A review paper on the advancements in the chemical examination of the composition of latent fingermark residues, where lifestyle, occupation, and contaminants might also influence factors (Khare and Singla, 2022).

Fingermark features

The quality of fingermarks highly depends on when a fingermark was deposited on a surface. Age, gender, races, physical conditions, and diet are among the variables among the donors of fingermarks which could contribute to variations in the fingermark residues (Chen et al., 2021). Fingermark deposited on a surface by a child was found to degrade more rapidly than an adult, especially in the chlorine composition that originated in the residues (Cuthbertson, 1969; Antoine et al., 2010). Penn et al. (2007) and Croxton et al. (2010) also suggested the compositional difference in fingermarks contributed by male and female donors. Amino acid contents within the fingermarks of vegetarian and omnivorous donors were also varied, where alanine, glycine and serine contents were said to be relatively higher in the individual with a former diet (Croxton et al., 2010).

Apart from the donor features, the pressure exerted during a deposition, the time of contact between a finger and a surface, the dimension of the fingertip area in contact with a substrate, as well as the angles in contact with the surface might also contribute to variations in the fingermark residues (Girod, 2012; Chen et al., 2021). Generally, a greater pressure would transfer more residues onto a surface (Jasuja et al., 2009). Merkel et al. (2011) also investigated how contact, pressure, contact time, smearing and oil/skin lotion towards the determination of fingermarks, and found that contaminants containing water could facilitate the ageing of fingermarks.

Due to the possible variations that could arise from donors, this study utilised only a single donor to investigate fingermark characteristics upon application of the recovery technique. A standardised fingermark production procedure was also implemented, adapted from Fieldhouse (2011), which will be further described in Chapter 3. To ease the deposition of fingermarks under controlled conditions, Fieldhouse (2011) suggested the implementation of a fingerprint sampler to ensure the consistency and reproducibility of the deposition procedure, which also produced significantly higher-quality fingermarks.

Surface materials

The surface materials on which a fingermark is deposited determine the retention time of fingermark residue, the amount of residue to be retained, and the method to recover and develop the latent fingermark. Two key properties that might influence the deposition of fingermarks are substrate porosity and substrate chemistry. The influence of a surface on the composition of fingermark differs with the porosity of the surface and its capability to retain compounds (Girod, 2012). Higher surface porosity could have contributed to a greater adhesion effect between the fingermark and the surface.

At the same time, if a surface can exert certain chemical interaction with fingermark residues, the fingermark might change, particularly destruction. The interactions include the electrostatic forces and surface free energy related to the surface tension (Girod, 2012). Occasionally called substrates, surfaces are usually classified into three categories: non-porous, semi-porous, and porous (Girod, 2012; Chen et al., 2021). Table 2.2 illustrates the characteristic absorption features of fingermarks on these surfaces (Girod, 2012; Chen et al., 2021).

Table 2.2 Characteristic absorption features of fingermarks in porous, semi-porous, and non-porous surfaces.

Surface nature	Characteristics	Examples
Porous	Eccrine compounds are rapidly absorbed.	Paper, cotton, wood
Semi-porous	Eccrine compounds can be absorbed but need much more time than on porous surface. Sebaceous compounds are absorbed slowly and need more time than eccrine compounds.	Varnished wood, waxy surfaces, plastics, glossy papers
Non-porous	All fingermarks compounds (i.e., eccrine and sebaceous) remain on the surface of the surface.	Glass, metal, paint, plastics

According to Table 2.2, a fingermark stays on top of non-porous surfaces without penetrating the substrate. In detail, the fingermarks spread across the non-porous surface, depending on the wettability and the application pressure. After the deposition, the fingermark's physical profile could gradually shrink due to the loss of water content from the residues. The composition might change with time (Champod et al., 2004).

On the other hand, the fingermark residues can migrate into the porous substrate concerning the makeup of the substrate. The surface is wetted by the fingermark residues, and its constituents can be further absorbed into the substrate. A small portion of insoluble constituents might also retain on the surface while the water carries the water-soluble compositions into the interior (Champod et al., 2004). Intermediates between the above surfaces are called semi-porous surfaces, exhibiting combined properties.

The properties of surface materials are an important consideration when choosing a recovery technique, or a sequence of techniques, for detecting and determining fingermarks. Therefore, the properties of an unknown surface suspected to have contained fingermarks shall be examined before attempting to develop and visualise. In this study, eleven surfaces were assessed for the tendency towards detecting fingermarks when the fingerprint powdering procedure was applied, where these surfaces are the commonly found household items.

Environmental conditions

After a fingermark is deposited onto a surface, both are exposed to environmental conditions, including temperature, humidity, light exposure, rain, dust, air circulation, and/or any interference by the friction and contaminants in the atmosphere. These environmental insults or variations might significantly affect the degradation of fingermark composition over time. Studies have focused on determining latent fingermark residue's initial and aged composition (Girod et al., 2012; Cadd et al., 2015; Chen et al., 2021). With time elapsed, the lipid composition on the latent fingerprint residue could change upon deposition onto a surface (Archer et al., 2005; Cadd et al., 2015).

Girod et al. (2015) also utilised a Fourier transform infrared microscopy technique to investigate initial fingermark composition and ageing, where the fingermarks could be grouped based on their ageing regardless of the substrates in an open, well-ventilated, and air-conditioned space. However, the substrate played a crucial role when those fingermarks were contained in a dark environment where the samples deposited on the same substrate could only be grouped by age. It was also reported that temperature plays a crucial role in the degradation process of fingermark residues, where a higher temperature would facilitate the ageing of the fingermarks (Chen et al., 2021).

2.2.4 Fingermark recovery techniques

Investigation of fingermarks have been explored for the past four decades, including their individualisation and recoveries, and they remained the primary source of identification. Although fingermarks appear versatile, numerous studies continue to be established to enhance recovery methods and maximise their utilisation in the forensic context. Different conditions of fingermarks might require different techniques for their detection and preservation (Ramos and Vieira, 2012). Latent friction ridge fingermarks from objects of evidence or surfaces at crime scenes must be recovered for forensic interpretation. Based on the fingermark recovered from a surface can be compared with the record prints to determine if they could have originated from a common source. If the suspect is unknown, the unknown fingermarks can also be subjected to the search in the Automated Fingerprint Identification System (AFIS) to determine the identity of the owner of the fingermark.

As described in previous sections, the water content could be evaporated from the fingermark residues with time. A latent fingermark might contain only 20% water immediately after deposition (Hagan and Green, 2018). These latent fingermarks can be processed and recovered via optical, physical, and/or chemical treatment procedures. The selection of treatment procedures depends on the porous, semi-porous, and non-porous surfaces. Besides, chemical reagents are available to enhance patent prints, which may consist of a bloody or oily matrix (Bleay et al., 2018). Table 2.3 shows the common and available fingermark recovery techniques, their respective surfaces to implement, and the reactions involved.

Table 2.3 Fingermark recovery techniques and their respective surfaces to be applied and reaction involved (Bleay et al., 2018).

Technique	Surface material	Types	Reaction and Outcome
Forensic light source	Porous Non-porous	• Ultraviolet (UV) light • Visible light • Infrared light	• Initial procedure before any enhancement method. • Oblique lighting involves light shining at a shallow angle to contrast light and shadow. • Non-destructive process.
Fingerprint powder	Non-porous	• Granular powder (black, white, and bi-chromatic) • Magnetic powder (black, bi-chromatic, and/or fluorescent) • Fluorescent powder (many colours available) • Metallic flake powder (aluminium, copper) • Nanopowders • Infrared (IR) powders	• Adherence of powder particles onto the oil and water constituents of latent print residue. • Fast and low-cost. • Used on dry, non-porous surfaces. • More effective on fresh fingerprints.
Chemical treatment	Porous	• Ninhydrin	• Ninhydrin reacts with amino acids and other amine-containing compounds in the fingermark residues. • It can be applied by dipping, painting, or spraying the aqueous solution. • Reaction with proteins and amino acids forms a purple colour (Ruhemann’s purple).
		• Indanedione (1,2-indanedione) (indanedione–zinc)	• It reacts with the amino acids in fingermark residues but with different amino acids from ninhydrin. • Visible fingerprints are pink in colour and lighter than Ruhemann’s purple.

Table 2.3 Continued

	• 1,8-diazafluoren-9-one (DFO)	• DFO reacts with amino acids in fingermark residues. • Highly fluorescent fingerprint reagent and superior to ninhydrin. • It can be applied to the substrate by dipping, spraying, or painting. • The reaction produces a strong fluorescent reaction that the naked eye does not see readily.
	• Physical developer	• An oxidation–reduction reaction where iron salt reduces aqueous silver nitrate to finely divided metallic silver. • Relatively fast, easy, and sensitive processes to develop fingermarks on porous items. • It can be used sequentially with the amino acid reagents but always after treatment.
Non-porous	• Cyanoacrylate (CA) Ester: Superglue Fuming	• CA fuming, a monomer of CA, is attracted to the latent print residue, resulting in white, 3-dimensional friction ridge impressions. • It can be applied through the fuming or vacuum chamber method.
	• One-Step Fluorescent CA	• CA dye complexes are mixtures of dye and CA, where the resulting compound is a one-step fuming process combining fumes and dye stain print. • Saves time as the item must not be applied with a separate dye stain.

Table 2.3 Continued

	• CA Dye Stains	• After CA fuming, a dye stain is applied to the item. • Luminescent dye stains selectively adhere to the CA polymer deposited along the friction ridges. • Common dye stains used in forensic laboratories are: ▪ Rhodamine 6G (R6G) ▪ Ardrox® ▪ 7-(p-methoxybenzylamino)-4-nitrobenzene-2-oxa-1,3-diazole (MBD) ▪ Basic yellow 40 (BY 40).
	• Vacuum Metal Deposition (VMD)	• VMD utilises vapourised metals in a vacuum chamber. • More effective at processing latent fingermarks on fabrics.

Accurately determining the surface suspected of having a fingermark is crucial for successfully recovering the forensic evidence. It is always followed by the selection of an appropriate technique or a sequence of techniques, depending on the nature of the surface (porous, semi-porous, or non-porous), the circumstances of the forensic case under investigation (indoors or outdoors, dry or wet surface, clean or dirty substrate, hot or cold surroundings, etc.), possibility to transport the suspected item to the laboratory (whether a fingermark can be recovered on-site or requires aid from specific instrument or apparatus), as well as the resources available to the police officers (Marriott et al., 2014). In brief, it involves a sequence initiated with a systematic search for latent fingermark, visual inspection using an appropriate forensic light source, sequential latent fingermark processing and treatment, and lastly, the documentation of the developed fingermark (Fraser and Williams, 2009; National Institute of Justice, 2011).

To maximise the evidential values of forensic evidence containing fingermarks, the most appropriate technique to consider during a forensic investigation must be prioritised, where most of the physical and chemical means of recovery techniques are destructive. In this study, the fingerprint powdering technique was a concern as this is the most common resource available to police officers.

Fingerprint powdering technique

Powdering is the common technique used in developing fingermarks from non-porous and semi-porous surfaces (Saferstein, 2015). Fingerprint powdering is a traditional fingermark recovery technique and remains the most common technique law enforcement agencies use worldwide. Its application is fast, low-cost, and effective, where the fingerprint powders can be freely dispersed on dry, non-porous surfaces such as glass and metal. Particles from these fingerprint powders tend to adhere to the oil and water components of the latent fingermark residue (Bleay et al., 2018). They can be applied on small and heavy items suspected to have contained fingermarks, including those immovable objects like furniture, windows, and railings to be processed on-scene.

Dusting fingermarks using fingerprint powders might be less sensitive than most chemical processing methods; however, it is the most effective technique for fresh fingermarks. However, whenever a fingermark is exposed for a longer time elapsed, it gets drier due to the evaporation of water-related substances, providing fewer substances for the fingerprint powder to adhere to (Cadd et al., 2015). Due to the simplicity of its application, various fingerprint powders have been developed throughout the years (Chadwick et al., 2012; Saferstein, 2015; Becue et al., 2020). Users can now decide which fingerprint powders to use depending on their suitability and practically under different conditions.

There are various types, colours, and formulations of fingerprint powders available in the market, and the selection could be based on the nature of the surface materials suspected to have fingermarks. In general, the fingerprint powder should be contrasted with the colour of the surface in question to enhance the visualisation. Granular powder, fluorescent powder, metallic flake powder (aluminium, copper), nanopowders, and infrared powders are examples of fingerprint powders available in the market, where the first three are more common (Girod et al., 2012; Daluz, 2018).

The granular powder is also commonly known as conventional fingerprint powders. Such powders can be applied on almost all non-porous and semi-porous surfaces. During a forensic investigation, granular fingerprint powders are frequently used. Granular powders consist of large asymmetrical particles, and the black fingerprint powder, a carbon-based granular powder, is most used at crime scenes. It contains iron oxide, quartz, kaolin, and carbon soot, and these particles adhere to fingermark residues, making a fingermark visible (Sodhi and Kaur, 2001). In addition to black colour, granular powders are also marketed in other colours, including grey, white, and pink (Sirchie, 2022; Tri-Tech Forensics, 2022). White and grey powders were said to potentially contribute to the evidence of background noise, making the visualisation more difficult.

Magnetic fingerprint powders can be applied on difficult non-ferrous surfaces, such as paper, polished or unpolished wood, glass, leather, and vinyl. They are commonly in black, white, and grey. Apart from these two types of fingerprint powders, metallic and fluorescent powders are available in the markets, although not as widely used as compared to the former. This is because metallic powders are more suitable for developing fingermarks on metal surfaces such as safes, file cabinets,