

**DETECTION OF DRUG TRACES IN POST-DEVELOPED FINGERMARKS
USING ATR-FTIR SPECTROSCOPY**

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LIST OF SYMBOLS AND ABBREVIATIONS

AFIS	Automated Fingerprint Identification System
ALS	Alternate Light Source
ATR-FTIR	Attenuated Total Reflectance-Fourier Transform Infrared
DFO	(1,8-diazafluoren-9-one)
IR	Infrared
LOD	Limit of Detection
NSAIDs	Nonsteroidal anti-inflammatory drugs
PCM	Paracetamol

PENGESANAN SISA DADAH DALAM CAP JARI SELEPAS PEMBANGUNAN MENGGUNAKAN SPEKTROSKOPI ATR-FTIR

ABSTRAK

Cap jari biasanya digunakan untuk pengecaman individu dalam penyiasatan forensik, ia juga berfungsi sebagai takungan kimia yang boleh menyimpan sisa bahan asing seperti dadah. Dalam amalan forensik sebenar, proses pembangunan biasanya digunakan untuk melihat cap jari sebelum analisis kimia, tetapi kesan pembangunan ini terhadap keupayaan untuk mengesan bahan kimia masih belum cukup dikaji. Tujuan kajian ini adalah untuk menilai potensi Spektroskopi Inframerah Transformasi Fourier Pantulan Penuh Dilemahkan (ATR-FTIR) sebagai teknik analisis tidak merosakkan yang boleh digunakan untuk mengesan sisa dadah dalam cap jari yang telah dibangunkan. Cap jari sebum yang tercemar dengan paracetamol dan kafein telah diletakkan pada permukaan yang dipilih yakni kaca, plastik, dan gulungan aluminium yang tidak berliang. Sebelum analisis ATR-FTIR dijalankan, serbuk cap jari magnetik dan bukan magnetik digunakan untuk membangun cap jari tersebut. Kajian had pengesanan (LOD) sedang dijalankan untuk menentukan kepekatan minimum dadah yang boleh dikesan. Pada masa yang sama, strategi pensampelan yang berbeza dinilai untuk menentukan cara terbaik untuk mengoptimumkan pemulihan sisa dadah dan cap jari tercemar. Kajian ketahanan juga dilakukan untuk mengetahui keupayaan untuk mengesan sisa dadah pada selang masa 7 hari selepas peninggalan. Keputusan kajian menunjukkan bahawa jalur penyerapan inframerah paracetamol dan kafein dapat dikesan dengan jelas dalam cap jari pasca pembangunan tanpa diganggu oleh serbuk cap jari, cap jari atau bahan pengangkat. Selain itu, sisa dadah dapat dikesan dalam tempoh 7 hari, menunjukkan bahawa dadah dapat bertahan dalam matriks cap jari. Kajian ini mencapai kesimpulan bahawa ATR-FTIR adalah kaedah yang berkesan untuk mendapatkan maklumat ciri-ciri dan kimia daripada cap jari yang telah

dibangunkan. Penemuan ini menyokong idea bahawa analisis cap jari forensik biasa boleh menggunakan ATR-FTIR untuk meningkatkan nilai pembuktian dengan menggabungkan pengecaman biometrik dan maklumat kimia.

DETECTION OF DRUG TRACES IN POST-DEVELOPED FINGERMARKS USING ATR-FTIR SPECTROSCOPY

ABSTRACT

Fingermarks are commonly employed for human identification in forensic investigations; however, they can also serve as chemical reservoirs, retaining residues of foreign chemicals such as narcotics. Fingermarks are frequently subjected to development techniques before to examination in genuine forensic cases, but the impact of these activities on later chemical detection has received scant attention. This work assesses the feasibility of Attenuated Total Reflectance-Fourier Transform Infrared (ATR-FTIR) spectroscopy as a non-destructive analytical method for detecting drug residues in post-developed fingermarks. Sebaceous fingermarks contaminated with paracetamol and caffeine were deposited on selected non-porous substrates namely glass, plastic, and aluminum foil surfaces. Fingermarks were developed using magnetic and non-magnetic fingerprint powders for visualisation and then analysed using ATR-FTIR spectroscopy. A limit of detection (LOD) investigation was carried out to establish the lowest detectable levels of both medications, and several sampling procedures were investigated to optimise drug recovery from contaminated fingermarks. A persistence study was also conducted to determine the detectability of drug residues in contaminated fingermarks after one week of deposition. The findings showed that typical ATR-FTIR absorption bands of paracetamol and caffeine could still be successfully detected and recognised in post-developed fingermarks with minimal interference from fingerprint powders or lifting materials. Furthermore, drug residues were detectable during 7 days of intervals, demonstrating reasonable persistence within the fingermark matrix. Overall, this study demonstrates the potential of ATR-FTIR spectroscopy to preserve ridge detail while also providing chemical information from

post-developed drug-contaminated fingerprints. The findings justify the incorporation of ATR-FTIR analysis into standard forensic fingerprint examination, which increases the evidential value of fingerprints by allowing for simultaneous biometric and chemical intelligence.

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

A fingerprint is an impression produced by the friction ridges of the human finger, and it can be transmitted from the finger to other items as a latent or patent print. The imprinted patterns correspond to an individual's fingers, palms, and feet. As a result, fingerprints can be utilised as an ideal instrument for human identification or individualization. Fingerprint identification or handprint identification, also known as dactyloscopy, is an essential branch of forensic science since it is proof of contact (Szyrkowska-Jóźwik et al., 2021).

The chemical composition of fingerprint residue differs from that of sweat because it contains a diverse variety of components derived from several glands. Furthermore, fingerprint residues can hold several pollutants such as cosmetics, food residues, dead cells, and skin oils, which contain residues of medicines or various substances, and their metabolites present in the body (Jasuja et al., 2016).

To improve detection sensitivity and preserve ridge detail, fingerprint detection and recording techniques have evolved over the course of more than a century. Latent fingerprints are typically produced in situ at a crime scene using powders. Forensic technicians utilise a variety of latent fingerprint powders, based on factors such as substrate type and fingerprint quality. After being treated with powders, fingerprints must be photographed and are often lifted with specific sticky tapes to transfer and preserve the fingerprint's information (Richards et al., 2024).

The foundation of the criminal justice system is forensic science, which uses scientific techniques to find, examine, and analyze visible evidence to aid in

investigations and court decisions. Fingermarks continue to be a vital component for both event reconstruction and personal identification among the various types of physical and trace evidence gathered at crime scenes. This is because they are extremely individualised and permanent. Fingermarks, the ridge patterns created by folds, twists, and turns on the fingertip, are a trustworthy biometric for connecting a person to a thing or place (Daluz, 2018).

At the same time, fingerprint-based biometric technologies have multiplied throughout society and are utilised for access control, financial transactions, device authentication, and border control. Adversarial attacks to get around these systems have increased because of their broad deployment, such as obfuscation, reconstruction, and spoofing, which provide comparable issues for forensic practice and are a developing security problem for biometric systems. The fidelity and stability of the materials and techniques used to make spoofs, such as silicone, gelatine, playdough, and wood glue, vary. Some provide excellent ridge reproduction but may deform or have a short shelf life, which affects both their usefulness as spoofing tools and their suitability as preserved forensic samples (Amin et al., 2022).

Despite advancements, study examines how to identify drug traces in fingermarks following traditional development and examines the consequences of fingerprint reproducibility for forensic preservation and biometric security. Studies specifically explore non-destructive development and preservation techniques that preserve ridge detail for forensic comparison for ATR-FTIR analysis, and permit the production of high-fidelity casts that, when suitable, could serve as presentation-attack artifacts for capacitive and ultrasonic sensors without erasing the original evidence (Zapata et al., 2021).

1.2 Problem Statement

Fingermark evidence plays a vital role in forensic investigations by linking suspects to crime scenes through ridge patterns and chemical residues. In recent years, researchers have explored the potential of fingermarks as chemical reservoirs that can reveal traces of drugs, explosives, or other contaminants. However, most drug detection studies have focused on latent fingermarks, while post-developed fingermarks, those that have undergone visualisation processes such as powder dusting, cyanoacrylate fuming, or ninhydrin, are often neglected. These common development techniques can alter the chemical composition or degrade residues present in the fingermark, leading to possible interference with subsequent chemical analysis (Hazarika et al., 2010).

Spectroscopic techniques such as Raman spectroscopy have shown that exogenous chemicals, for example, cocaine and amphetamine, can still be detected after powder formation, albeit with greater complexity. Importantly, FTIR spectroscopy in ATR mode has shown promise, where researchers have successfully identified substances such as TNT, C-4, and aspirin in fingermark dusted with powder and then lifted with adhesive tape using Fourier-transform infrared (FTIR) techniques. This demonstrated that FTIR can do non-destructive chemical profiling while preserving fingermark morphology (Alkhuder, 2022).

Despite these developments, there is still a significant gap in the literature where nothing is known about the detection of common drugs in post-developed fingermarks using ATR-FTIR spectroscopy. While previous research has demonstrated that potent or unlawful substances can survive the development process, the behaviour of more innocuous but highly relevant drugs of abuse under these settings remains unknown.

From a forensic standpoint, knowing how long such drug residues remain in a formed fingermark is critical. Persistence influences not only whether a molecule is

detectable, but also how it is understood in each circumstance. While some research has looked into residue stability in untreated marks or other ways, few studies have looked into the persistence of drugs in fingerprints (Amin et al.,2022).

The ability to detect drug traces from post-developed fingerprints would enhance the evidential value of recovered marks, especially in real casework scenarios where fingerprints are routinely developed before chemical testing. However, there is limited research examining how different development methods affect the detectability and stability of drug residues such as paracetamol and caffeine. Therefore, the problem addressed in this study was the lack of reliable information on whether drug traces can still be detected using ATR-FTIR spectroscopy after common fingerprint development procedures have been applied.

1.3 Objectives

1.3.1 General Objective

The objective of this study was to evaluate the potential of ATR-FTIR spectroscopy as a reliable tool for detecting drug traces in post-developed fingerprints.

1.3.2 Specific Objectives

1. To determine the effectiveness of magnetic and non-magnetic powdering methods in developing latent fingerprint contaminated with paracetamol and caffeine traces.
2. To determine the ATR-FTIR spectral profiles of paracetamol and caffeine residues in post-developed fingerprints.
3. To determine the persistence of paracetamol and caffeine using different sampling strategies in post-developed fingerprints after 7 days of deposition.

1.4 Scope of Study

This study investigates the ability of Attenuated Total Reflectance-Fourier Transform Infrared (ATR-FTIR) spectroscopy to detect paracetamol and caffeine residues in post-developed fingerprints. Both drugs were chosen as surrogates for legal drugs. The study was limited to sebaceous fingerprints on non-porous substrates such as glass slides, plastic surface, and aluminium surface to ensure uniformity in sample preparation and good ATR-FTIR contact during analysis. Following deposition, fingerprints were developed with two types of fingerprint powders, which were magnetic and non-magnetic powders. This was to determine how different powdering techniques affect chemical detectability and ridge clarity.

The study was limited to laboratory circumstances and excludes other drug types, porous surfaces, environmental variables, and alternative analytical techniques like Raman or mass spectrometry. The established scope assures that the inquiry was focused on the capabilities and limitations of ATR-FTIR as a non-destructive instrument for chemical identification of drugs from post-developed fingerprints.

1.5 Significance of the Study

The significance of this study lies in its potential to increase the forensic evidential value of fingerprint by combining chemical intelligence with standard ridge-based identification. Fingerprints are commonly used for personal identification, but they also carry chemical residues that might reveal vital information about the items an individual has encountered. However, in genuine forensic cases, fingerprints are almost always developed with powders before examination, and there has been little investigation into whether drug residues, particularly drugs such as paracetamol and caffeine, can be detected after development. This study addresses a significant

knowledge gap in forensic science by evaluating the detectability and persistence of these residues using ATR-FTIR.

Understanding if ATR-FTIR can successfully detect drugs in post-developed fingerprints may enable forensic laboratories to incorporate a quick, non-destructive chemical analysis into standard fingerprint procedures. This has the advantage of acquiring both identity and chemical information from the same trace without sacrificing ridge detail. Furthermore, comparing magnetic and non-magnetic fingerprint powders can help identify whether the development approach is better suited for subsequent chemical detection, thereby guiding forensic practitioners to more effective evidence recovery strategies. Collectively, these advancements would strengthen forensic workflows, promote cross-disciplinary collaboration between criminalistics and forensic chemistry.

CHAPTER 2

LITERATURE REVIEW

2.1 Fingerprint

Fingermarks from friction ridge skin are composed of elevated ridges and furrows arranged in distinct patterns. These ridge patterns form during foetal development when the basal layer of the epidermis grows at a different rate than the surrounding layers, leading to its folding into ridges. The position and arrangement of sweat pores along these ridges create the micropattern, which is later transferred as a fingerprint when the skin contacts a surface. Ridge structures are thus morphological representations of skin anatomy and developmental processes, governing how and where secretions, mostly eccrine sweat and transferred sebaceous oils, are deposited on contacting surfaces. Understanding the developmental and anatomical basis is critical to explaining the reproducibility and detail of fingerprint impressions (West & Went, 2009).

Fingerprint analysis has long been used as a key tool in forensic science to identify and associate persons with crime scenes. While fingerprint evidence has traditionally been utilised for ridge pattern analysis, current advances in analytical chemistry and spectroscopy have broadened its use to include chemical profiling. Fingermarks not only give distinct ridge detail, but they also include a complex blend of biological and exogenous elements such as sweat components, skin oils, and trace pollutants (Amin et al., 2022). Among these, the identification of illicit drugs and their metabolites have emerged as a major area of research, with both forensic and investigative applications.

Fingermarks are particularly essential in forensic research because they provide a long-lasting and unique method of human identification. The friction ridge patterns

on fingertips are complex enough to distinguish individuals, including identical twins, and they last for a lifetime unless severely injured. In practice, fingermarks retrieved at crime scenes are classified as latent, patent, and plastic. Latent fingermark form when the body's natural oils and sweat on the skin are deposited on another surface. Latent fingermark can be found on several surfaces; however, they are not easily visible, and discovery often necessitates the use of fingerprint powders, chemical reagents, or alternative light sources (Walker, 2020).

Patent fingermark, on the other hand, can be created using blood, grease, ink, or dirt. This form of fingermark is clearly visible to the naked eye. Plastic fingermarks are three-dimensional impressions created by pressing your fingertips onto fresh paint, wax, soap, or tar. Plastic fingermarks, like patent fingermarks, may be seen with the naked eye and do not require any additional processing for visibility (Richards et al., 2024).

These classifications dictate the future processing and evidence handling stages. Modern forensic procedures also rely on automated technologies that translate ridge patterns into digital ridge feature sets for comparison against vast databases, allowing for faster candidate discovery and case linkage. Fingermarks are one of the most widely used biometric and forensic markers in the world due to their longevity, distinctiveness, and ease of collection without invasive procedures (Oblak et al., 2022).

Friction ridge patterns are distinct due to genetic and stochastic developmental effects. Although overall fingerprint patterns like loops, whorls, and arches are partly inherited, the exact placement of minutiae such as ridge endings, bifurcations, islands, and dots results from small random changes during embryonic skin development. These tiny developmental variations make every fingerprint uniquely different. Since these tiny ridge features are numerous and highly detailed, fingerprint matching focuses on

comparing minutiae and ridge characteristics rather than just the overall pattern. This microscopic detail is what makes fingerprint identification reliable. To verify identity, forensic examiners and automated algorithms search for and compare minutiae and other ridge characteristics (Templeton et al., 2017).

Fingerprint databases and automated comparison systems, such as the Automated Fingerprint Identification System (AFIS), are essential in modern forensic practice because they enable the rapid scanning of extensive libraries of digitised ridge data. These systems convert fingermark images into digital representations that can be efficiently compared using match algorithms. When a latent fingermark is recovered and processed, its digital features are compared to a database to find potential matches for human verification. The effectiveness of these databases is dependent on image quality, correct ridge capture during development, and accurate feature set encoding, which reduces the match probability and necessitates careful expert review. Integration of such databases with procedural best practices and legal standards enhances investigative speed while maintaining scientific rigor (Gibb et al., 2023).

Friction ridge skin varies from other skin sections in its layered structure and surface microrelief. The epidermis, including the basal layer, overlies the dermis and produces the ridge pattern, which is supported by the dermal papillae. During foetal development, the epidermal basal layer grows differently from neighbouring layers, resulting in the initial folds, while the dermis provides mechanical support and vascular supply to maintain ridge morphology throughout life. Importantly, the topical biochemical environment of ridge crests, which consists of eccrine secretions mostly water, salts, and amino acids, transfers sebaceous lipids and cellular debris, establishes the chemical fingerprint of the fingermark, and influences how residues attach to

various surfaces. Consequently, both the anatomical structure and the physiological composition of secretions govern the quality of ridge impressions and the chemical signal available for analytical techniques (Mizokami et al., 2015).

Several inherent and extrinsic factors influence friction ridge creation, deposition quality, and the resulting fingerprint. Intrinsic factors such as genetics, age, sex, health, and glandular activity affect ridge clarity and the composition of fingerprint secretions. Extrinsic factors, including recent activities such as hand washing or touching oily surfaces, the type and texture of the surface, environmental conditions, and the development method, also influence the quality of a deposited fingerprint. The choice and use of development methods, such as magnetic or non-magnetic powders and chemical reagents, directly affect both ridge visibility and the chemical residue. This is because different powders adhere to moisture and lipids in different ways and may introduce interference during later chemical analysis. Understanding these multifactorial factors is critical when interpreting fingerprint evidence, optimizing recovery techniques, and developing chemical detection algorithms for compounds found in fingerprints (De Alcaraz-Fossoul et al., 2019).

2.2 Composition and Chemistry of Fingermarks

Fingermarks are chemically complex deposits that occur when friction ridge skin comes into contact with a surface, leaving behind a mixture of fluids and environmental pollutants. Fingerprint residue, rather than being made entirely of sweat, is made up of material from the eccrine, sebaceous, and apocrine glands, as well as trace exterior compounds taken up during daily activities. Fingermarks' chemical complexity makes them not only useful for identification, but also a great source of

biochemical information that can reflect lifestyle, activity, or exposure to medications, cosmetics, or environmental toxins (Cadd et al., 2015).

Eccrine secretions are likely the most abundant component in newly formed fingermarks. These secretions are mostly composed of water, but they also contain organic and inorganic solutes like amino acids, urea, lactic acid, and salts like sodium and potassium. While it is often said that eccrine sweat contains more than 98% water, more extensive investigations show that once a fingerprint is deposited, the water content decreases dramatically due to evaporation. It was proposed that a fresh fingermark may contain no more than 20% water, which is much less than previous expectations (Keisar et al., 2018).

Sebaceous contributions to fingermark residue are made up of lipids, which are primarily transmitted from other areas of the body. These lipids include fatty acids, wax esters, squalene, cholesterol esters, and other substances. Since the friction ridge skin of the palms and fingers lacks sebaceous glands, much of the lipid content is thought to derive from contact with other sebum-rich parts of the body, such as the face or scalp (Khoo et al., 2016).

Apocrine secretions also play a role, albeit to a lesser extent, in fingermark residue. These glands, which exude a more protein-rich, oily fluid, are typically located in the underarms and groin. Their contribution to fingermark residue is influenced by the donor's physiology and the areas of their body they have touched. Fingermarks are more than just physical prints; they also contain chemical information that can be used in forensics (Chen et al., 2020).

Fingermarks can contain both endogenous fluids and foreign chemicals, such as pollutants or xenobiotics. These could comprise cosmetics, food remnants, or even drug

traces that the person has handled or digested. Fingerprint residue composition varies greatly, depending on a variety of conditions. These include the donor's age, food, medicine, and lifestyle, as well as any post-deposition environmental exposure. For example, volatile components like water and tiny organics might evaporate or deteriorate with time, altering the fingerprint's chemical makeup (Robson et al., 2022).

2.3 Fingerprint Identification and Classification

Fingerprint identification is one of the most well-established and reliable means of connecting people to objects, locations, and crime scenes. This is because of the uniqueness and persistence of friction ridge skin. These ridge structures appear on the fingers, palms, and soles during the third month of foetal development and persist throughout life, save in cases of severe injury or decomposition. The raised ridges and recessed furrows generate complicated patterns unique to each individual, even identical twins, while the pores along the ridges release residues that leave latent impressions on touched surfaces. As a result, fingerprints are used as both a biometric identification and a potent forensic tool (Sudha et al., 2021).

Fingerprint classification is a popular strategy in biometric and forensic systems since it lowers the penetration rate while exploring huge fingerprint databases. Fingerprint images, which feature different ridge-based structural patterns, can be classed based on the morphology of their ridge flow. The most widely recognised classifications are arch, tented arch, left loop, right loop, and whorl, each having a distinct ridge pattern. These classes appear at varying frequencies in the population, resulting in a naturally unbalanced dataset in which arch and tented arch patterns are disproportionately underrepresented compared to loops and whorls. Misclassification

is more common in minority groups, which presents a difficulty for automated classification systems (Zabala-Blanco et al., 2020).

The pores in the skin release a substance that leaves behind latent fingerprint impressions. Patent prints become visible once a person touches a nonporous surface such as glass. Plastic, or indentation, prints can be found on soft surfaces like putty. Invisible latent prints must be developed using laser, powder, and chemical processes.

Fingermark pattern interpretation aids in the classification, search, and suspect elimination procedures. Fingermark minutiae, such as ridge ends, dots, islands, bifurcations, and other traits, can be analysed to uniquely identify a person (Momani et al., 2024). The comparison of fingermark minutiae to an individual fingermark provides a method of personal identification. Elimination prints are used to identify family members and others who have legitimate access to the murder scene. Elimination prints aid in the isolation of the suspects.

Unbalanced datasets can also result in uneven misclassification costs, with errors in smaller classes having more serious implications. To solve this issue, machine learning employs a variety of methodologies, including under-sampling, over-sampling, and algorithmic cost-sensitive methods. Under-sampling reduces the size of the dominant class while potentially losing vital information, and over-sampling enhances the representation of minority classes but may distort the dataset. Algorithmic approaches, which alter misclassification penalties for each category, are a realistic and successful answer in fingerprint classification jobs (Win et al., 2020).

The fingerprint classification method typically consists of three stages, which are pre-processing, feature extraction, and classification. Pre-processing removes noise and background interference, which improves image quality. The fingermark image is

then converted to a numerical representation using feature extraction, which identifies significant ridge features and structural characteristics. Finally, classification algorithms use the retrieved features to classify the fingerprint into one of the established pattern groups. This systematic technique allows for the creation of extremely accurate classifiers while keeping reasonable processing efficiency (Saad Hammed et al., 2023).

2.4 Factors Affecting Latent Fingerprints

Latent fingerprints are extremely sensitive to a variety of external and internal conditions that affect their quality, visibility, and longevity. The condition of the finger at the time of deposition, the environment in which the fingerprint was left, and the physical and chemical properties of the substrate all influence how well the fingerprint may be recovered and analysed. These circumstances can cause fingerprints to fade, blur, or lose ridge definition over time, making them difficult to spot. Understanding these factors is critical for forensic practitioners to optimise fingerprint recovery and accurately interpret results.

2.4.1 Deposition and Aging

How a fingerprint is deposited has a significant impact on its final quality, clarity, and long-term persistence on a surface. Several deposition-related parameters influence the amount and distribution of residues transferred, including the pressure used, the duration of contact, finger movement during deposition, and the natural composition of fingerprint secretions such as eccrine, sebaceous, or a combination of the two. When a finger meets a surface, the ridge patterns operate as conduits, depositing perspiration, oils, amino acids, fatty acids, and other biological elements on

the substrate. The quantity and consistency of these secretions differ between individuals and can fluctuate depending on recent activities such as hand washing, touching the face, environmental exposure, or the presence of pollutants such as lotions or medicines (Ferreira et al., 2021).

Pressure is one of the most important variables. A controlled investigation employing a variable-force fingerprint sampler found that the clarity of ridge patterns, the surface area of the contact, and the overall amount of residue transmitted all changed significantly when prints were deposited with forces ranging from 1 to 10 N. Fingermarks with smaller forces tended to have faint ridge outlines and minimal residue deposition, resulting in prints with incomplete or uneven ridge flow. Higher pressures, on the other hand, increased the quantity of residue transmitted while also increasing the risk of ridge distortion, which occurs when ridges become smeared, broadened, or partially flattened as a result of excessive stress. This can weaken the distinctiveness of ridge features, jeopardizing identification (Hefetz et al., 2019).

Contact duration is also important. Longer contact enables more time for secretions to transfer and distribute across the surface, which can improve ridge clarity while potentially producing diffusion at the edge. Additionally, small lateral movement or rotation of the finger during deposition can disrupt the ridge pattern, resulting in smudged or jumbled ridge imprints. The physiological content of the deposit also adds to variability. Eccrine-rich prints, which are more watery, evaporate faster and may leave weaker ridge imprints, but sebaceous or mixed prints with oils and lipids attach more strongly and last longer, typically developing better with fingerprint powders. Aging studies have revealed measurable changes in fingerprint morphology; for example, ridge breadth and height can change with time, potentially impairing print

clarity. One study discovered that fingermarks on plastic dissolved faster than those on glass over six months when stored under controlled indoor circumstances (Zou et al., 2021).

2.4.2 Environmental Conditions

After a fingermark is deposited, the environmental conditions surrounding it have a profound impact on its persistence, visibility, and overall quality over time. Several environmental parameters, including temperature, relative humidity, light exposure such as visible and ultraviolet, air movement, and contact with water or other substances, can accelerate degradation or alter the chemical and physical characteristics of the fingermark residue (De Alcaraz-Fossoul et al., 2012).

Temperature and humidity fluctuations have a substantial impact on the stability of latent fingermarks. For example, a study that subjected fingermarks to extended heat discovered that higher temperatures reduce fingermark quality; prints formed on light bulbs with high surface temperatures had significantly less ridge detail than those on cooler areas of the bulb (Colella, et al., 2019).

Humidity has a comparable effect on fingermark preservation. In print development procedures such as cyanoacrylate fuming, humidity levels are crucial. According to research, a relative humidity of 80% is often ideal for proper polymerisation during fuming, revealing ridge detail. On the other hand, excessive or insufficient humidity might impede the process or cause residues to deteriorate more quickly, either by hastened drying or by encouraging diffusion and chemical decomposition of fingerprint components (Stewart et al., 2016; Paine et al., 2011). Furthermore, in contexts with varying humidity and temperature levels, such as outdoor

crime scenes or poorly climate-controlled indoor rooms, the quality of latent prints may decline unexpectedly. Fingermarks on non-porous surfaces may last for months, but those on more sensitive surfaces, such as some plastics, might disintegrate more quickly under changing environmental conditions.

Light exposure, particularly sunshine or UV light, can hasten the chemical breakdown of fingerprint remnants. Fingerprint residue components, such as lipids, fatty acids, and amino acids, are vulnerable to photo-oxidation or other photochemical reactions when exposed to light, which can impair adhesive capabilities, degrade ridge contrast, and change chemical structure. Several studies have found that latent prints exposed to light and heat decay faster than those stored in darkness or in stable indoor conditions (Soták et al., 2025). However, the effect of light may vary depending on the makeup of the fingermark. In trials examining the aging of fingermarks created with powders, samples supplemented with sebum showed varying but sometimes stronger resistance than pure eccrine prints under various light settings (De Alcaraz-Fossoul et al., 2020).

Water, moisture, or submersion represents one of the most serious threats to latent fingermark preservation, particularly on non-porous surfaces like glass, metal, and plastic. Research on fingerprints submerged in fresh or seawater discovered that, while prints can still be recovered, their quality decreases with extended submersion duration. In a recent investigation, latent fingerprints on non-porous surfaces submerged in tap or sewage water were detected using a customized formulation known as Phloxine B-based SPR. The study discovered that glass, a smooth and non-porous surface, could retain high-quality ridge detail classified as "Grade 5" for up to 15 days under water before gradually deteriorating, whereas plastic and metal surfaces lost ridge

detail much faster. Plastic lost Grade 5 quality by day 10 and metal by day 8 under comparable conditions (Kushwaha et al., 2025).

Furthermore, water salinity is important. Prints submerged in seawater degraded faster than those in fresh water, due to salt's corrosive effects and greater chemical stress on the residue. Once the water has receded and the item has dried, residue can be washed away, spread, or chemically changed, posing substantial challenges to effective development even with modern processes. In addition to water exposure, other environmental conditions, such as dust, air movement, frequent handling, or contact with chemicals or toxins, can degrade or taint latent fingerprints, lowering their chances of successful development (Madkour et al., 2017).

These environmental impacts show why the context in which a fingermark is discovered is just as essential as how it was formed. This emphasises the need for timely and effective evidence retrieval for forensic practitioners, particularly in harsh environmental conditions. It also underlines the importance of testing and validating fingerprint development and detection technologies in various environmental settings to understand their limitations and improve protocols accordingly.

2.5 Fingermark Development and Enhancement Method

Latent fingermark development is based on three basic groups of techniques: physical, chemical, and optical, with each chosen dependent on the substrate type and chemical composition of fingermark residue. Physical methods, particularly powder dusting, are still one of the most commonly utilised methods for seeing prints on non-porous and semi-porous surfaces. Powder dusting works by adhering fine particle matter to the sebaceous and oily components of fingerprint residue. Conventional non-

magnetic powders such as carbon black, aluminium, and fluorescent powders are applied with camel-hair brushes that make direct contact with the surface. These powders produce high contrast and rapid development on smooth surfaces such as glass, plastic, and painted metal; nevertheless, the mechanical action of brushing might upset fragile or old fingerprints if applied with too much force (Qiu et al., 2018).

Magnetic powders, on the other hand, are made up of magnetisable particles, usually iron oxides, that are handled with a magnetic applicator, allowing powder to be deposited without direct physical brush contact. This approach greatly lowers abrasion and is especially useful on textured, fragile, or uneven non-porous surfaces where typical brushing might smear ridge detail. Magnetic powders can cause background staining on some substrates, although their gentle application and minimal mechanical disturbance generally increase ridge clarity compared to non-magnetic powders. Recent advancements in magnetic nanoparticle compositions combine magnetic characteristics with fluorescence to enhance contrast under various light sources, further boosting sensitivity on problematic surfaces (De Oliveira et al., 2024).

Chemical development methods use reactions between specific fingerprint constituents, mostly amino acids, salts, and proteins, and chemical reagents to produce a visible or luminous result. Ninhydrin is the gold standard for porous materials like paper, interacting with amino acids to produce Ruhemann's purple and allowing the viewing of old or weak impressions. DFO (1,8-diazafluoren-9-one) is another amino-acid-reactive reagent extensively employed on porous substrates, creating bright fluorescence when lit with green or blue-green light, and is often more sensitive than ninhydrin for faint markings (Zampa et al., 2020).

Silver nitrate, which was traditionally used on porous materials, interacts with chloride ions to generate silver chloride, which darkens when exposed to light; however, it is less commonly employed today due to substrate staining and damaging effects. Cyanoacrylate fuming, which is typically classified as both physical and chemical, is most commonly employed on non-porous surfaces such as plastic, glass, and metal. During this technique, cyanoacrylate monomers polymerize on fingerprint residues, resulting in a white, durable polymer that can then be dyed with fluorescent dyes or powders to improve contrast. Chemical procedures necessitate rigorous adherence to proven sequences, as the order of application influences the quality and viability of later development processes (Wang et al., 2017).

Optical technologies improve fingerprints through light interactions rather than chemical deposition. These include oblique lighting, polarized light, and alternate light source (ALS) illumination, which take use of reflectance, absorption, and fluorescence differences between ridges and the surrounding surface. Some fingerprints illuminate naturally due to endogenous chemicals, whereas others require fluorescent powders or chemical reagents like DFO or rhodamine dyes for good visibility. Optical procedures are largely non-destructive and are frequently employed as a first-line treatment prior to more intrusive physical or chemical techniques. Advances in nanotechnology have also generated luminous nanoparticles such as quantum dots and rare-earth doped particles that provide strong fluorescence and great affinity for fingerprint residues, enabling enhanced sensitivity on complicated or multicoloured substrates (Lennard, 2018; Luo et al., 2013).

2.6 Analytical Studies of Fingermarks

Raman spectroscopy, Matrix-Assisted Laser Desorption/Ionization (MALDI), and Attenuated Total Reflectance Fourier Transform Infrared (ATR-FTIR) spectroscopy have all proven to be useful instruments for non-destructive investigation of drug-contaminated fingermarks (Chadwick et al., 2020).

Spectroscopic technologies have transformed the chemical investigation of fingermarks, providing quick, non-destructive, and extremely specific detection capabilities. It was proven that the ability to detect drugs of abuse in fingermarks, even after development with powders and adhesive lifters by utilising infrared spectroscopy to identify chemical residues without interfering with ridge patterns (West et al., 2009). Raman spectroscopy has been extensively studied due to its chemical specificity and ability to identify drug residues directly on fingermark surfaces. Raman spectroscopy was used to track the persistence of Nonsteroidal anti-inflammatory drugs (NSAIDs) in fingermarks, while the same approach was used to detect methamphetamine residues, proving its sensitivity to minor molecular changes (Amin et al., 2022).

Meanwhile, Matrix-Assisted Laser Desorption Ionization (MALDI-TOF-MS) was also used to detect both pharmaceuticals and explosives in fingermarks, providing a complementary method for complex mixtures. The study found that MALDI-TOF-MS could not only detect these compounds but also map their spatial distribution across fingermark ridge patterns, providing both chemical and morphological information. This dual analytical capability improves the evidential value of fingermarks by allowing the linkage of specific chemical residues to individual ridge features. Furthermore, MALDI-TOF-MS was shown to work well even on aged or environmentally exposed fingermarks, demonstrating its suitability for real-world forensic applications (Kaplan-Sandquist et al., 2014).

However, of all spectroscopic approaches, ATR-FTIR spectroscopy has shown the most promise due to its ability to identify a wide variety of functional groups and its low sample preparation needs. ATR-FTIR generates a chemical "fingerprint" of the material by analyzing absorbance patterns that correspond to molecular vibrations. It is especially useful for post-developed fingerprints because it enables simultaneous investigation of ridge detail and chemical composition while preserving the evidence. Recent research has focused on refining ATR-FTIR parameters for drug residue detection, demonstrating its ability to detect methamphetamine, cocaine, and different medicinal chemicals even after being exposed to standard development processes (Amin et al., 2022).

Aside from conventional chemical and spectroscopic approaches, various investigations have concentrated on increasing visibility and multi-target detection. Research has created a multi-target immunolabeling approach that improves fingerprint visibility while also detecting biological and chemical leftovers. This technique combines fluorescent tagging and selective binding agents to produce high-contrast pictures that preserve ridge detail. The dual functionality of such approaches bridges the gap between identification and chemical analysis, which is consistent with the objectives of this study (Van Dam et al., 2021).

The multi-target immunolabeling approach's strength is its dual-function capability, which allows for both biochemical detection and ridge pattern augmentation while maintaining sample integrity. Unlike traditional enhancement methods, which frequently focus solely on improving ridge visibility, this technique enables the localization of specific biomolecules within the fingerprint residue. This makes it especially valuable in complex forensic scenarios like drug handling or contact-based

transfer investigations, when both identification validation and chemical association are required (van Dam et al., 2014).

While multiple studies have shown that spectroscopic approaches may detect drugs in fingerprints, there are still several research gaps. Many previous investigations concentrated on Raman and mass spectrometry techniques, with little investigation into the use of ATR-FTIR spectroscopy for post-developed fingerprints. Furthermore, there is inadequate information on how fingerprint production processes affect subsequent chemical analysis. Most research concentrates on newly deposited samples, leaving a gap in knowing the long-term stability and detectability of drug residues following fingerprint visualization.

This study helped to close these gaps by evaluating the efficacy of ATR-FTIR spectroscopy in detecting drug traces in post-developed fingerprints. It investigated how diverse development processes and environmental circumstances affect spectral profiles, leading to improved protocols for non-destructive forensic drug detection.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the experimental methodologies and analytical techniques used in this research project.

3.2 Study location

All experimental procedures were conducted in the Forensic Science Laboratory, Faculty of Health Sciences, Universiti Sains Malaysia (USM). The ATR-FTIR spectroscopic analysis was carried out in the Analytical Laboratory.

3.3 Chemicals and Materials

The chemicals used in this study included “HI-FI” volcano silver/black latent print powder (SIRCHIE[®], USA), silver/black magnetic latent print powder (SIRCHIE[®], USA), caffeine (BDH Laboratory Supplies Poole, England), Paracetamol (SM Paracil, Kedah), and ethanol (HmbG[®] Chemicals, Selangor).

The materials used in this study were a reagent bottle, weighing boat, spatula, mortar and pestle, weighing balance, digital electronic weighing scale, labelling stickers, gloves, cotton swab, glass slides, plastic container, aluminium foil, fingerprint brush, magnetic powder wand (SIRCHIE[®], USA), and fingerprint hinge lifter (SIRCHIE[®], USA). The instrument used in this study was a Bruker Alpha II ATR-FTIR Spectrometer.