APPLICATION OF EGGSHELLS AND SEASHELLS FOR LATENT FINGERMARK DEVELOPMENT

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APPLICATION OF EGGSHELLS AND SEASHELLS FOR LATENT FINGERMARK DEVELOPMENT

by

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TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF SYMBOLS

®	Registered
™	Trademark

LIST OF ABBREVIATIONS

AgLDI	Silver-Assisted Laser Desorption Ionization
ALS	Alternate Light Sources
ANOVA	Analysis of Variance
ATR	Attenuated Total Reflectance
C	Commercial
CD	Compact Disc
DFO	1,8-Diazafluoren-9-one
DNA	Deoxyribonucleic Acid
EDS	Energy Dispersive Spectrometer
EDX	Energy-Dispersive X-ray
e.g.	*exempli gratia*
ES	Eggshells
ESDA	Electrostatic Detection Apparatus
et al.	*et alia*
FESEM	Field Emission Scanning Electron Microscope
FTIR	Fourier Transform Infrared
HSD	Honest Significant Difference
HCl	Hydrochloric acid
IMS	Imaging Mass Spectrometry
M	Mean
MC	Magnetic Commercial
MPs	Magnetic Particles
MS	Mass Spectrometry
MSPE	Magnetic Solid-Phase Extraction
N/A	Not Applicable
NaOH	Sodium hydroxide

NP	Nanocarbon Powder
SD	Standard Deviation
SEM	Scanning Electron Microscope
SPR	Small Particle Reagent
SPSS	Statistical Package for the Social Sciences
SS	Seashells
ToF-SIMS	Time of Flight Secondary Ion Mass Spectroscopy
UV	Ultraviolet
W	Watt
3D	Three-Dimensional

LIST OF UNITS

%	percent
mol	mole
L	litre
g	gram
°C	degree Celsius
mA	milliampere
mm	millimetre
kV	kilovolt
cm^{-1}	reciprocal centimetre
nm	nanometre
mg	milligram
μM	micrometre
μg	microgram

LIST OF APPENDICES

PENGGUNAAN KULIT TELUR DAN KULIT KERANG UNTUK PEMBANGUNAN CAP JARI PENDAM

ABSTRAK

Pengenalan cap jari kekal sebagai aspek penting dalam bidang sains forensik, menjadi alat yang boleh dipercayai untuk mengenal pasti suspek dan membina semula peristiwa jenayah. Penyelidikan semasa meneroka kemungkinan penghasilan serbuk cap jari daripada kulit telur (ES) dan kulit kerang (SS), dua produk sisa bio yang mudah didapati dan kebanyakannya terdiri daripada kalsium karbonat. Pencirian serbuk ES dan SS menggunakan kaedah FTIR, SEM, dan EDX menunjukkan bahawa kedua-dua jenis magnetik dan bukan magnetik adalah alternatif hijau yang berkesan untuk pembangunan kesan cap jari pendam. Jenis magnetik amat sesuai untuk digunakan pada permukaan yang sensitif atau bernilai. Ujian Friedman mendedahkan perbezaan yang ketara dalam perkembangan cap jari pendam di kalangan pelbagai serbuk, dengan nilai *p* dicatatkan kurang daripada 0.001. Serbuk kulit telur magnetik (MES) terbukti menjadi alternatif semula jadi terbaik untuk digunakan pada permukaan tidak berliang, mempamerkan profil ketahanan yang membolehkan pelbagai percubaan pemulihan. Serbuk kulit kerang magnetik (MSS) menunjukkan butiran yang paling konsisten dalam corak rabung mikroskopik, menunjukkan potensi besar sebagai pengganti mesra alam untuk serbuk magnetik komersial dalam pembangunan cap jari pendam yang kaya dengan asid amino, kolesterol, dan skualena pada permukaan tidak berliang. Serbuk ES dan SS bukan magnetik menunjukkan prestasi yang baik dalam kes deposit berasaskan DL-serina. Serbuk magnet ES dan SS menunjukkan potensi besar sebagai alternatif mesra alam kepada cap jari berasaskan asid palmitik. Selain itu, kedua-dua varian magnetik dan bukan magnetik menunjukkan definisi rabung yang paling ketara untuk cap jari yang kaya dengan asid laktik, menunjukkan potensi besar mereka untuk

pembangunan sisa hidrofilik. Ujian Kruskal-Wallis menunjukkan bahawa jenis serbuk tidak memberi kesan signifikan terhadap skor cap jari untuk kedua-dua penuaan haba (p = 0.998) dan penuaan rendaman (p = 0.903). Ini bermakna pembangunan cap jari adalah serupa merentas semua jenis serbuk dalam kedua-dua keadaan. Sebaliknya, skor cap jari berbeza secara signifikan antara sepuluh jenis permukaan yang diperiksa (p < 0.001 untuk kedua-dua kajian penuaan). Serbuk semula jadi yang diperolehi daripada kulit telur dan kulit kerang, terutamanya dalam bentuk magnetiknya, telah menunjukkan prestasi yang kompetitif, dan selalunya lebih baik, berbanding serbuk komersial di bawah pendedahan air. Sebaliknya, serbuk bukan magnetik terbukti sangat tahan lasak dalam pelbagai keadaan, terutamanya apabila terdedah kepada haba tinggi. Ringkasnya, penyelidikan ini menawarkan maklumat berharga mengenai proses forensik yang berkaitan dengan serbuk sumber semula jadi, menggerakkan bidang ini ke arah kaedah yang lebih hijau dan selamat untuk penglihatan cap jari pendam.

APPLICATION OF EGGSHELLS AND SEASHELLS FOR LATENT FINGERMARK DEVELOPMENT

ABSTRACT

Fingerprint identification remains an essential aspect in the field of forensic science, being a reliable tool for identifying suspects and reconstructing criminal events. The current research explores the possibility of producing fingerprint powders from eggshells (ES) and seashells (SS), two widely available biowaste products that are mainly made up of calcium carbonate. The characterisation of ES and SS powders using FTIR, SEM, and EDX methods demonstrated that both the magnetic and non-magnetic types are efficient green alternatives for the development of latent fingermarks. The magnetic type is especially suitable for application on sensitive or valuable surfaces. A Friedman test revealed considerable differences in the development of latent fingermarks among the various powders, with a *p*-value noted at less than 0.001. Magnetic eggshell powder (MES) proves to be the best natural alternative for use on non-porous surfaces, exhibiting a durability profile that allows for multiple recovery attempts. Magnetic seashell powder (MSS) exhibited the most consistent detail in microscopic ridge patterns, showing great potential as an eco-friendly substitute for commercially magnetic powders in the development of latent fingermarks rich in amino acids, cholesterol, and squalene on non-porous surfaces. Non-magnetic ES and SS powders performed well in the case of DL-serine-based deposits. MES and MSS powders showed great promise as environmentally friendly alternatives to palmitic acid-based fingerprints. In addition, both magnetic and non-magnetic variants exhibited the most pronounced ridge definition for lactic acid-rich fingerprints, indicating their great potential for the development of hydrophilic residues. The Kruskal-Wallis test showed that the type of powder did not significantly

affect fingermark scores for either heat ageing ($p = 0.998$) or submersion ageing ($p = 0.903$). This means that fingermark development was similar across all powder types in both conditions. In contrast, fingermark scores varied significantly among the ten surface types examined ($p < 0.001$ for both ageing studies). Natural powders derived from ES and SS, especially their magnetic forms, had shown competitive, and often better, performance than commercial powder under water exposure. On the other hand, their non-magnetic powder had proven to be remarkably resilient under different conditions, especially when subjected to high heat. In summary, this research offers valuable information on the forensic process relating to natural resource powders, moving the field towards a green and safe method for latent fingermark visualisation.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

According to Locard's exchange principle, every contact leaves a trace; material exchange occurs whenever two objects or surfaces encounter each other (Mistek et al., 2019). Recent studies suggest that fingerprints are important for identifying people at the scene of a crime, as they are unique and remain consistent for each individual. Liu et al. maintain that fingerprints and latent fingermarks are among the most frequently used types of forensic evidence internationally (Liu et al., 2023). Zhu et al. emphasise that latent fingermarks necessitate visualisation techniques for practical application in forensic settings (Zhu et al., 2025). Fingerprints constitute a direct source of individual identity, owing to the intricate and distinctive characteristics of friction ridge skin patterns. Salmeron and Alcaraz-Fossoul examine the inconsistency in the clarity of friction ridge impressions and their implications for forensic analysis, especially concerning the age and environmental factors of fingermarks (Salmeron & Alcaraz-Fossoul, 2022). Fingerprints were first proposed in the late 19^{th} century as a means of personal identification and have been incorporated into criminal investigations and personal identification ever since (Wang et al., 2017)

At the crime scene, fingermark evidence can be classified into patent, plastic, or latent impressions. Patent fingermark occur when the friction ridges on the fingertips contact a surface, leaving a smear or imprint of those unique ridge patterns that are readily visible to the naked eye. It is visible due to contaminants, such as blood, oil, ink, soot, or dust on the skin (Chelladurai et al., 2024; Fraser, 2020). In the case of plastic marks, a specific type of fingermark is left as three-dimensional impressions in a soft material. These impressions occur when the ridges of a person's fingertip press into a pliable substance, such as clay, wax, putty, melted plastic, heavy grease, or tacky paint. The impressions formed preserve the individuality of the friction ridge patterns and thus their validity for forensic identification (Jelly et al., 2009; Para, 2010; Richards et al., 2024). Latent fingermarks are an essential part of forensic science, which are marks deposited by fingertips on surfaces and cannot be viewed unless enhancement methods are used. These marks are primarily composed of residues from skin secretions, including sweat, oils, amino acids, proteins, and fatty acids (Olszowska-Łoś et al., 2020; Robson et al., 2022). The development of latent fingermarks is one of the most challenging aspects of forensic investigation due to the many factors influencing its efficiency. Therefore, it will affect the quality of latent fingermarks. It is also essential to consider the distortion and degradation of a fingermark when determining its quality (Pulsifer et al., 2013).

In forensic investigations, latent fingermarks are remarkably useful in creating evidence of contact between a criminal, the victim, and the crime scene (Errington et al., 2016). The problem with latent fingermarks is that they do not exhibit visibility on most surfaces because of the minimal residue deposited. Some of the most common surfaces on which latent fingermarks are analysed include glass, plastics, and metals, but their composition usually requires specialised techniques to make them visible (Croxton & Joyce, 2023; Jevtić et al., 2024). For the latent fingermarks to be seen, optical, physical, and chemical methods must be applied (Hazarika & Russell, 2012). Several reagents and methods have been explored over the last century to develop latent fingermarks, including powder dusting, multi-metal deposition (MMD), superglue fuming, fluorescent dyes (He et al., 2014), the application of 1,2-Indanedione and zinc for amino acid detection (Bouzin et al., 2020; Kumar et al., 2021), and the use of advanced nanomaterials that exhibit luminescent properties (Assis et al., 2022; Shahbazi et al., 2021). As a result, the choice of the processing method is determined by the nature of the substrate (porous, semi-porous or non-porous), the texture (smooth or rough), the condition (dry or wet), the colour of the surface on which the latent fingermark is deposited, as well as the age of the deposit (Bleay et al., 2020; Croxton & Joyce, 2023; Said et al., 2021).

From the early 1900s until today, the powdering method has been used to treat latent fingermarks, although many new techniques have been developed to detect latent fingermarks (Garg et al., 2011). The mid-20th century marked a milestone with the existence of specialised powder for fingerprinting, such as metallic and fluorescent powder, which significantly improved detection efficiency. Liu et al., for example, showed the use of polydopamine nanoparticles as a novel powder for fingerprint detection and proposed their usage in the comparison of different backgrounds (Liu et al., 2024). The transition was critical in expanding the types of surfaces on which the powder dusting technique could be effectively utilised. The powder dusting method is the conventional and most widely used method for developing latent fingermarks because it requires only low cost, simplicity, minimal instrument dependence, and extensive applicability (Liu et al., 2024; Peng et al., 2017). Upon applying fingermark powder over a suspected area, the powder adheres to any constituents (oil, sweat, or other materials) left in the fingermark (Garg et al., 2011).

In contemporary practice, the dusting powder is further divided, distinguishing between metal powders, magnetic powders, and fluorescent powders (Gao et al., 2024). Multiple researchers have worked to develop various techniques for revealing latent fingermarks, utilising commonly available chemicals, powders, pigments, and dyes. (Thakur & Garg, 2016). Among the key issues is the incorporation of most of the conventional fingerprint powders, which may include dangerous chemicals such as lead and mercury. These substances have been criticised as being health risky due to exposure during use as well as handling, precipitating the need to design safer options (Sari & Nasution, 2023; Hameed et al., 2022). Various new formulations of fingermark powder derived from natural resources have been introduced over the years to overcome this limitation. Genipin is one of these formulations, as well as Banana peel activated carbon, Turmeric powder, and Imperata cylinderca (Thakur & Garg, 2016).

This study aims to determine the feasibility of developing a new fingermark powder that is naturally derived. ES and SS waste are abundant natural waste materials that are non-toxic, readily available, cheap and do not pose health risks to human beings. There has been much interest in ES waste in recent years because it is inexpensive, abundant in nature and has an intrinsic pore structure. ES is also commonly applied as fine powders to treat industrial wastes in the adsorption process (Arshad et al, 2021; M. Hossain et al, 2024). The major component of the ES is the calcite $CaCO_3$ (94%), $MgCO_3$ (1%), $Ca_3(PO_4)_2$(1%) and organic matter (4%) (Baláž et al., 2016). At the same time, SS commonly found along seashores were investigated for various purposes, including removing heavy metals and incorporating them into polymer composites. In addition, they were also used to replace conventional materials, such as cement, sand, and coarse aggregate (Mo et al., 2018). SS waste, consisting of the exoskeletons of marine organisms, has a high $CaCO_3$ content, with calcite as the mineral phase (Egerić et al., 2018; Mo et al., 2018). The empty SS piled up on beaches by waves and tides are typically the remains of marine molluscs (Egerić et al., 2018).

Nevertheless, applying conventional fingerprint powders with a fingerprint brush to porous surfaces, plastics, and textured surfaces presents incredible difficulty compared to non-porous surfaces. A magnetic flake powder develops latent fingermarks more effectively on complex surfaces than conventional powders because it has an optimum diameter larger than conventional powders. As the excess powder particles can be removed with a magnetic applicator, the fingermark ridges would only be touched by the powders, resulting in less "background staining" (Gürbüz et al., 2015; Thonglon & Chaikum, 2010). In 1961, MacDonell et al. were the first to report using magnetic powders for developing latent fingermarks. These powders typically consist of magnetic particles that serve as carriers, along with non-magnetic colourants such as carbon black, bronze flakes, aluminium flakes, and fluorescent powders, which act as developers (Wang et al., 2017).

Fluorescent magnetic powder is typically recommended for multicoloured, textured, and non-porous surfaces. To view the results for fluorescent powders, UV light or an alternative light source is required (Frisby et al., 2016). Several surfaces, including vinyl imitation leather, lightly textured dashboards, and door panels of automobiles, as well as living and dead human skin, have been successfully fingerprinted using magnetic fingerprint powders (Gürbüz et al., 2015; Trapecar & Balazic, 2007). Accordingly, this study aims to develop a magnetic and non-magnetic powder for fingerprint analysis using ES and SS waste materials to enhance the development of latent fingermarks, particularly for those deposited on non-porous substrates.

1.2 Problem statement

Latent fingermarks are a key type of physical evidence in forensic investigations because they can reliably identify individuals involved in criminal activities. The most common way to visualise latent fingermarks on non-porous surfaces is by using fingerprint powders. While commercial powders can be effective, they often contain synthetic chemicals that may be costly, possibly harmful to users, and detrimental to the environment. One thing to consider is that their effectiveness may not hold up in certain situations, such as when fingermarks are old, damaged, or exposed to different environmental factors like humidity, temperature, and light.

Recently, more people have shown interest in finding environmentally friendly and affordable alternatives. This has led researchers to look into natural biomaterials. ES and SS contain a lot of calcium carbonate and are often considered waste products, which makes them a promising choice for developing fingerprint powders. Their unique microstructure and surface chemistry could provide good adhesion properties for developing latent fingermarks. However, there is still a lack of comprehensive studies that synthesise both magnetic and non-magnetic powders from these materials, along with thorough spectroscopic characterisation to understand their properties.

Previous research has focused on natural and sustainable powders, such as food-derived materials and biologically based shell powders. However, few studies have rigorously compared these powders to commercial formulations, especially after ageing or exposure to different environmental conditions. The chemical complexity and variability of fingermark residues, which include water, amino acids, squalene and other lipids, salts, and external contaminants, result in diverse interaction dynamics. The mechanisms underlying these interactions in the context of natural powders are not yet well characterised. These gaps currently hinder the broader use of natural, sustainable powders in forensic practice. Addressing these challenges by creating, characterising, and evaluating ES and SS powders could transform the fingermark study field. This will also highlight the need for ongoing development in forensic research.

1.3 Aim and objectives

This research aimed to synthesise fingerprint powders from natural resources for visualisation of latent fingermarks. To achieve this goal, specific aims were identified and subsequently pursued:

i. To synthesise both non-magnetic and magnetic fingerprint powders using ES and SS as natural sources.

ii. To characterise the synthesised powders using various spectroscopic techniques.

iii. To evaluate the interaction between the synthesised powders and fingermarks of different chemical compositions, using an artificial finger to ensure standardised deposition and avoid the mixing of natural secretions.

iv. To assess the effectiveness of the synthesised powders in developing aged latent fingermarks on a range of non-porous surfaces under different conditions, in comparison with commercially available powders.

1.4 Significance of the study

The powder dusting technique is an efficient means of developing latent fingermarks and can be used in a wide range of cases, including murder investigations, sexual assaults, property crime and more. This method is currently used in crime scene investigation and criminal identification worldwide and remains one of the most reliable methods of uncovering vital evidence for criminal investigations. It can be considered the simplest and the easiest method. Nevertheless, the chemical composition of the commercial powder itself has its drawbacks; it is often toxic, poses a health risk and is generally not cost-effective. The purpose of developing ES and SS powders incorporated with magnetic particles in this study was to develop powder formulations that are effective for developing fingermarks. Due to its magnetic properties, it is easy to clean. Latent fingermarks are not likely to be damaged or scratched since only the powder encounters them. The fact that they are made from natural components also means that they are environmentally friendly and user-friendly. Materials derived from natural and waste materials are not toxic and can be safely used by humans. When properly prepared, natural waste products can transform into highly sought-after products, highlighting their importance for environmental sustainability.

1.5 Scope of the study

The powder dusting method is a popular technique for detecting latent fingermarks. The present objective is to identify a powder that is inexpensive, non-toxic, and widely available as an alternative to the expensive, toxic, and complex powders currently in use. This study explored two types of natural powders (ES and SS), to develop the latent fingermarks on selected non-porous surface materials using powder dusting methods. The non-porous substrates used in this research were glass panels, banknotes, acrylic sheets, plastic containers, aluminium foil, compact discs, tiles, matte screen protectors, metal plates, and cellulose tape. The groomed fingermarks were prepared following the recognised universal protocol that included eccrine, sebaceous and natural secretions. The present study examined various variables, including different types of secretions, the chemical composition of latent fingermarks, and various environmental conditions, such as extreme heat exposure and submersion in water. The quality of the developed prints was evaluated to determine their sensitivity and suitability for use at the crime scene.

1.6 Thesis outline

The structure of this thesis comprises five chapters. The first chapter introduces the study's background and context on latent fingermark detection including limitations of conventional fingerprint powders, outlines the research problem, objectives, significance and scope. The second chapter reviews the literature on latent fingermarks, fingerprint powder principles, and the recent use of natural, sustainable materials in forensic science. Chapter three details the study's methodology, describing materials, synthesis and preparation, characterisation techniques, and experimental procedures. It also highlights the use of an artificial finger to ensure standardised and reproducible fingermark deposition. Chapter four presents and discusses the experimental results. Analyses cover the characterisation of developed powders and their use in latent fingermarks development. Comparative evaluation with commercial fingerprint powders is included. The final chapter concludes the thesis by summarising the main findings, outlining the research contributions, and suggesting future research directions for sustainable forensic fingerprint powders.

CHAPTER 2

LITERATURE REVIEW

2.1 Fingerprint and fingermark

The fingerprint is created by bringing the papillary ridges found on fingertips, palms, and soles into contact with surfaces. The process involves using ink deposition or an optical device that uses a known sample under controlled circumstances. Since they were acquired in pristine conditions, prints of friction ridge skin are near-exact representations of the original friction ridge skin (Becue & Cantu, 2012; González et al., 2020). As opposed to a fingerprint, which is a print left by a known finger in a controlled environment, a fingermark is a chance impression left by a finger on an object (sometimes called an "unknown" or "questionable" print) such as those found at crime scenes. In many cases, marks imply a poor-quality impression that may be latent, partial, distorted, reversed (tonal or lateral), or superimposed (Lennard et al., 2011; Popov et al., 2017). Touching a surface with one's finger leaves a deposit of the secretions from the fingertips on the surface. As a result of the secretions, the finger ridge is formed.

Forensic science's fundamental principle of fingerprinting is that no identical fingerprint has ever been found in two individuals. The significant variability of friction ridges causes this (Kaushal & Kaushal, 2011; Lennard et al., 2011). According to Galton's (1982) calculations, the probability of finding identical fingerprint was one in 64 million. Essentially, the second principle states that the configurations and characteristics of an individual's fingerprints remain the same until death (Kaushal & Kaushal, 2011; Lennard et al., 2011). Finally, there are some limitations to how different shapes can be regarding the types of shapes.

However, despite these differences, there is enough similarity between the patterns of ridges to enable a systematic classification (Global Forensic and Justice Center (GFJC), 2013). There are three primary types of fingerprint patterns: arches, loops, and whorls (Dey et al., 2019). Some studies also include a fourth type called composite or compound (Singh & Kadu, 2020). Research has shown that loops are the most common pattern (60% to 65%), followed by whorls (30% to 35%), composite (10.04%), and arches (5%) (Saferstein, 2015; Singh & Kadu, 2020). Figure 2.1 shows the types of fingerprint patterns: loops (radial and ulnar), whorls (central pocket, lateral pocket, twins, and accidentals), and arches (plain or tented).

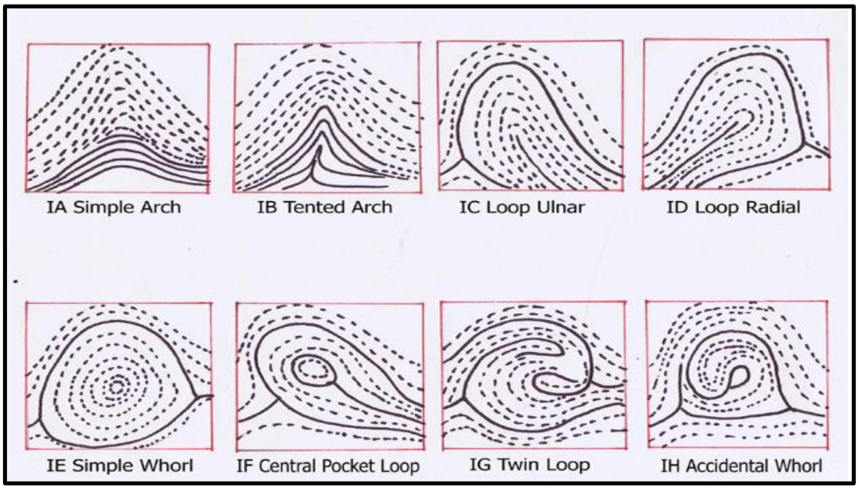

Figure 2. 1: Types of Fingerprint Patterns: loops (radial and ulnar), whorls (central pocket, lateral pocket, twins, and accidentals), and arches (plain or tented) (Kaushal & Kaushal, 2011).

The classification of these patterns is based on the number and location of deltas or triradii (Figure 2.2), which are areas where three ridge systems converge (Rivaldería & Gutiérrez-Redomero, 2021; Zhou et al., 2007). Typically, whorl patterns have two deltas, while loops have one (Singh et al., 2018).

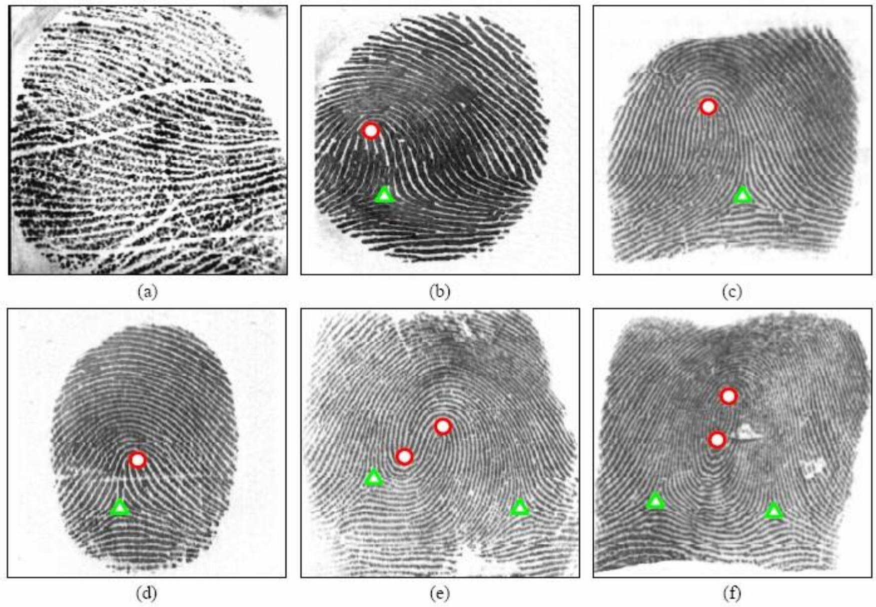

Figure 2. 2: Various types of fingerprints with the cores (circle) and the deltas (triangle) marked: (a) Plain Arch, (b) Tented Arch, (c) Left Loop, (d) Right Loop, (e) Twin Loop, and (f) Whorl (Zhou et al., 2007).

However, rare cases of three deltas in a whorl pattern have been reported (Figure 2.3), highlighting the need for consideration in fingerprint evaluation (Singh et al., 2018). Recent studies have revealed interpopulation differences in the frequency distribution of delta types, with sunk open total deltas, sunk open total with point, and tripod long being the most common across populations (Rivaldería & Gutiérrez-Redomero, 2021). This research contributes to the field of dactyloscopy and can aid in forensic investigations.

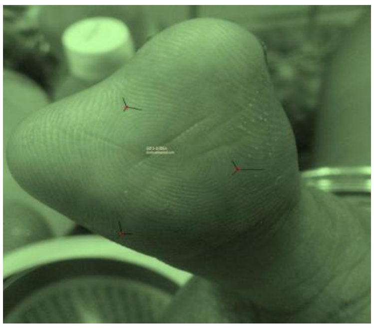

Figure 2. 3: Whorl pattern showing three deltas (Singh et al., 2018).

When comparing fingerprints, three levels of information are recognised. As illustrated in Figure 2.4, the first level considers the general pattern, the general flow of the fingerprint ridges; the second level examines the minutiae, the points at which ridges stop or split; and the third level examines the structure of the fingerprint ridges and details such as sweat pores (Mattijssen et al., 2020).

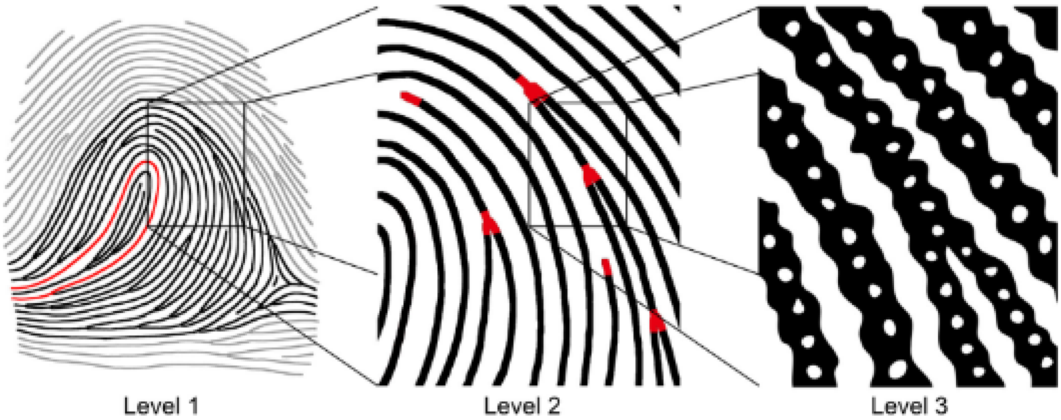

Figure 2. 4: Representation of the three levels of information. Level 1: the general pattern, highlighted in red, Level 2: the minutiae, highlighted in red, and Level 3: the structure of ridges and details such as sweat pores (Mattijssen et al., 2020).

Advanced techniques like hyperspectral imaging and morphological operations can enhance the detection and matching these fine details (Carneiro et al., 2023; Delican et al., 2023). The use of multi-level classification methods based on fractal analysis and continuous classification has shown great potential in speeding up, improving fidelity, and making the systems robust in the recognition of large-scale fingerprints (Zhong et al., 2016). As part of the process of fingerprint certification for later comparative examination, measures that must be considered include degradation and distortion. It is preferable to analyse the latent or lowest quality fingermarks and then the known or highest quality fingermarks as much as possible.

2.2 Fingermarks impressions

Three categories of fingermark evidence may be found at a crime scene: patent, plastic, and latent impressions. The most frequently encountered type of fingermark at crime scenes is latent fingermarks, which are not visible to the naked eye (Nugroho et al., 2022).

2.2.1 Patent fingermarks

Patent impressions (Figure 2.5) are also known as visible fingerprints, which can be easily seen with the naked eye without needing to process fingermarks. Because patent fingermarks are already observable, they can often be more straightforward to process than latent fingermarks, which typically require enhancement techniques to be visible (Bonnaz et al., 2021; Bose & Kabir, 2017). A person forms it intentionally to prove their identity. During the identification stage, it is still used to record a person's presence (Tech et al., 2015). A visible mark is caused by a coloured contaminant on the body (such as blood, oil, or ink), leaving a positive visible impression. In contrast, a negative visible impression is left when a coloured substance is removed from the substrate (such as soot or dust) (Chelladurai et al., 2024; Jelly et al., 2009).

Figure 2. 5: Patent fingermark impression (blood) (Cadd et al., 2016).

2.2.2 Plastic fingermarks

In plastic impressions, the shape of these impressions can be three-dimensional (3D) (Bose & Kabir, 2017; Para, 2010). The impressions are created when fingerprint ridges are pushed into a soft material such as fresh paint, soap, tar, clay, putty, soft wax, melted plastic, heavy grease, or tacky paint (Figure 2.6) (Jelly et al., 2009; Tech et al., 2015; Yamashita et al., 2010). Photographs of plastic impressions are usually taken using oblique lighting, and silicone-type casting materials can also be used to preserve them (Yamashita et al., 2010). Recent research has explored innovative techniques for documenting and analysing plastic fingerprint impressions. Structured-light 3D scanning has shown promise in capturing detailed 3D features of plastic prints, outperforming traditional photography in some cases (Zhang et al., 2020). Novel methods for creating high-fidelity 3D fingerprint replicas have been developed, including solvent-assisted moulding of polycarbonate and microcontact replication using polydimethylsiloxane (Schultz et al., 2018). These methods generate rich phantoms that may standardize fingerprint sensors and biometric systems. These developments provide better ways to record and characterising fingerprint impressions of plastic "fingerprints" in forensic applications.

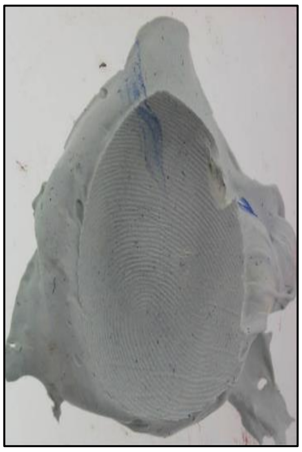

Figure 2. 6: Plastic fingermark impression (Zhang et al., 2020).

2.2.3 Latent fingermarks

Latent fingermarks (imprints made unintentionally at crime scenes) play a vital role in forensic and criminal investigations (Dhaneshwar et al., 2021). Nevertheless, the accidental nature of prints leads to the creation of low-image prints and, consequently, better methods are required by employing developing reagents to expose latent fingermarks that are either buried or invisible (Barros et al., 2013; Oblak et al., 2023). When the hands contact a surface, the compounds of sweat and sebaceous glands are transferred onto a substrate. By forming these deposits, ridge patterns are imprinted onto the surface, resulting in latent fingermarks (Aggarwal & Chitkara, 2022; Bleay et al., 2020). A physical or chemical treatment must be conducted to be able to examine the latent fingermark (Figure 2.7) (Nugroho et al., 2022).

Figure 2. 7: Latent fingermark impression after been developed using iodine fuming (Jasuja & Singh, 2009).

In forensic investigations, detecting latent fingermarks is the most challenging part because many factors can affect the efficiency of developing these marks. Consequently, it will affect the quality of latent fingermarks. It is also important to consider a fingermark's degree of distortion and degradation when evaluating its quality (Frisch et al., 2024; Alcaraz-Fossoul & Javer, 2022). Recent research has explored unconventional powder methods as alternatives to traditional, expensive, and potentially toxic powders for developing latent fingermarks (Harshita et al., 2022). One novel approach involves using brick powder on various porous and non-porous surfaces (Mia et al., 2023). These unconventional methods have shown promise in developing latent fingermark impressions on different surface types (Harshita et al., 2022). Researchers have systematically reviewed existing techniques to advance the field and highlighted challenges and research gaps (Dhaneshwar et al., 2021). The factors impacting the quality of latent fingermarks can be summarised using the acronym **CARPET** (Lennard et al., 2011).

C – the *composition* of the deposit: A high sebaceous content and the presence of contaminants, such as ink or paint, will enhance the durability of fingermarks and enable them to last longer.

A – the *amount* of material deposited: In either case, excessive deposit (e.g., heavy perspiration) may obliterate detail, while insufficient deposit leads to fingermarks that are not detectable.

R – the nature of the *receiving* surface: Surface texture can influence the degree of fine detail captured (i.e., a smooth surface will capture more detail than a rough surface); substrate porosity will affect the degree of deposit diffusion.

P – The amount of *pressure* applied between the fingertip and the surface during the contact (as well as how long this contact lasts).

E – the *environmental* conditions: High temperatures, low humidity, and exposure to sun and wind will increase the rate of dehydration of a fingermark, as well as moisture loss from certain components (e.g., loss of eccrine material from rain).

T – The *time* interval between deposition and application of a development method: Fresh fingermarks are more easily detected than aged ones, which can dehydrate, lose stickiness, or be affected by bacteria.

2.3 Chemical composition of latent fingermarks

Regarding the composition of fingermark residue, there are two states where it can be described: the initial composition and the aged composition (Table 2.1 and Figure 2.8) (Frick et al., 2020; Girod et al., 2012).

Table 2. 1: The two states of the chemical composition of fingermarks (1) the initial composition and (2) the aged composition (Girod et al., 2012).

(1) The initial composition	(2) The aged composition
Upon contact with the substrate, fingermark residue was immediately transferred.	The chemical, biological and physical processes occurring over time on the initial composition of fingermarks.

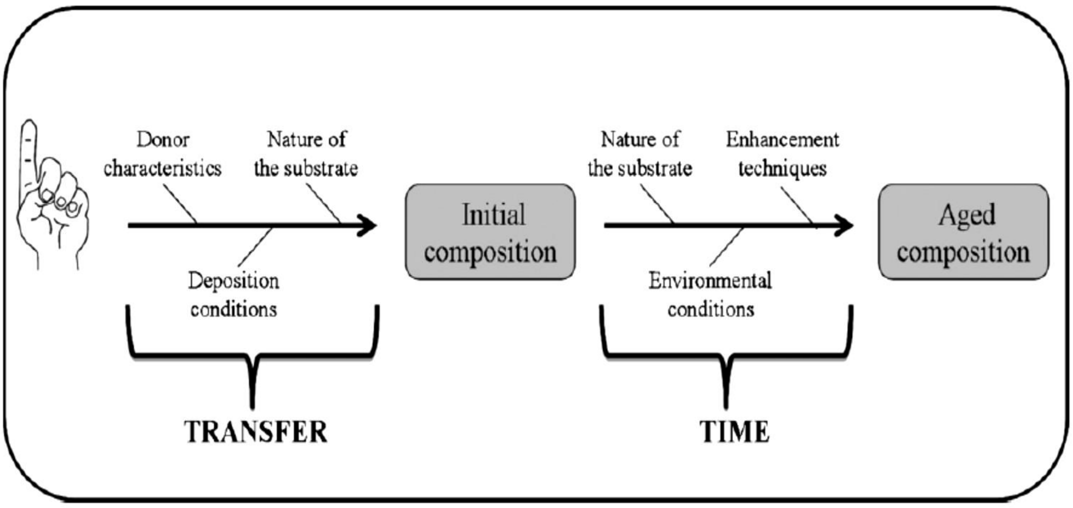

Figure 2. 8: The composition of fingermarks residue being affected by numerous influence factors and containing two different states: (1) the initial composition and (2) the aged composition (Girod et al., 2012).

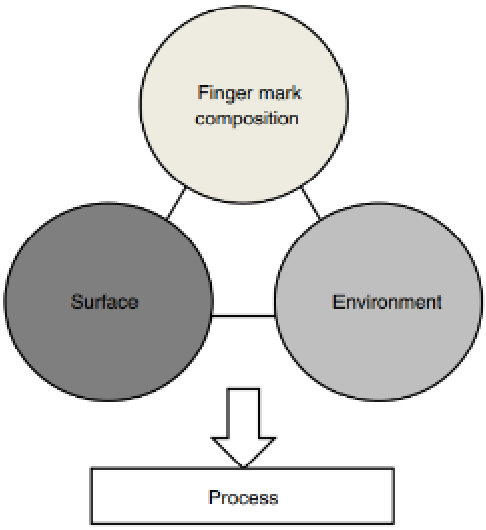

Figure 2. 9: The concept of the Triangle of Interaction (Sears et al., 2012).

Several factors influence the composition of fingermarks during the deposition process, including the characteristics of the donor, their age, race, and diet; the conditions of deposition, such as contact time, angle, and pressure; and the nature of the substrate, such as the surface texture and porosity (Cadd et al., 2015; Ferreira et al., 2021). These variations can result in variations in the initial composition. At the aging stage, fingerprint composition is affected by several factors, including the substrate, environmental conditions, enhancement techniques, and the time elapsed since deposition (Cadd et al., 2015). In general, the longer the aging period, the greater the degradation of latent fingermarks.

The chemical composition of the latent fingermarks residue itself can influence the success of the development of latent fingermarks. Most enhancement techniques have been developed to detect fingermarks using knowledge of the secretions of the human skin (Bramble & Brennan, 2000). Three primary glands, sudoriferous glands (eccrine and apocrine) as well as sebaceous glands, contribute to the production of sweat (Hu et al., 2018). Table 2.2 tabulates the three types of glands with their respective secretion types, the distribution, and the role of each gland (Jelly et al., 2009).

Table 2. 2: Human skin secretory glands (Jelly et al., 2009).

Types of glands	**Secretion types**	**Body distribution**	**Role of gland**
Sebaceous	Sebum (lipids)	Typically localized to regions containing hair follicles	Inhibits the growth of bacteria, lubricates and protects the keratin of the hair shaft and conditions the surrounding skin
Sweat (sudiferous) glands Eccrine (merocrine)	Sweat (aqueous)	Entire body, highly concentrated on the palms of the hands and soles of the feet	Cooling the surface of the skin to reduce body temperature, excretion of water, electrolytes and metabolites, protection from environmental hazards
Apocrine	Sweat (aqueous)	Associated with hair follicles around the axillary regions. In particular, the armpits, groin and chest	Scent glands (pheromones)

Two glands play a significant role in detecting latent fingermarks: the eccrine gland and the sebaceous gland. These two types of glands exude a combination of secretions that contribute to the development of latent deposits (Fritz et al., 2013; Jelly et al., 2009). Due to the absence of hair follicles on the palms and soles of the hands and feet, these glands are absent. However, their secretion is very much found in fingerprints due to the contact of the hands with other parts of the body, most commonly with the face, where they are abundant (Ferreira et al., 2021). Table 2.3 shows the composition of these two secretions that have made up the detection of latent fingermarks.

Table 2. 3: Summary of main constituents of eccrine and sebaceous skin secretions (Fritz et al., 2013; Jelly et al., 2009).

Secretion	Constituent	
	Organic	**Inorganic**
Eccrine	Amino acid Proteins Urea Uric acid Lactic acid Sugars Creatinine Choline	Water (>98%) Chloride Metal ions (Na^+, K^+, Ca^{2+}) Sulfate Phosphate Hydrogen carbonate Ammonia
Sebaceous	Glycerides Fatty acids Wax esters Squalene Sterol esters Sterol	N/A

Fingermarks can undergo additional alterations after they have been deposited as chemicals in the complex mixture interact and react with each other and with the surface where they have been placed. Consequently, each fingermark is a complex mixture of secretions from the body and contaminants from the local environment, each with its own physical and chemical characteristics. Many other factors can influence the chemical composition of a fingermark (Czech et al., 2020). Table 2.4 presents an overview of some of the most significant factors (Sears et al., 2012).

Table 2. 4: Some of the factors influencing the nature of a deposited fingermark (Sears et al., 2012)

Variable	Examples that affect fingermark
Glandular	Eccrine (fingers and palm only have eccrine glands); sebaceous; apocrine
Contaminants	Anything touched (as touching is a two-way process); pollution
Ambient conditions	Temperature; humidity; air flow; light
Donor factors	Time of day/year; diet; medication and recreational drugs; gender; age; mental and physical states; racial origin; cleaning regime
Deposition	Pressure; angle; movement at the moment of touch
Surface	Porosity (porous to non-porous ratio); condition; surface chemistry/physics, contamination; temperature
Biological	Bacteria; viruses

2.4 Types of surfaces

Latent fingermark analysis on various surfaces is crucial for forensic investigations. Research has explored different techniques for enhancing and analysing fingermarks on diverse materials. Among the factors that greatly influence the effectiveness of latent fingermarks are the nature of the surface (substrate), the pressure applied, and the time in which the fingermark is transferred to the substrate (Assis et al., 2022; Boseley et al., 2022; Nagachar et al., 2020). According to previous studies, several factors, including the type of surface, whether it is porous or non-porous, the time before fingermarks are lifted, and the exposure to the elements, all affect the quality of fingermarks (Gray, 2012). A multi-surface latent fingermarks database was created to study the impact of surface properties on print quality and matching performance (Sankaran et al., 2015).

In addition, the types of surfaces on which the fingermark is deposited influence the enhancement process used to visualise latent fingermarks (Wallace-Kunkel et al., 2007). Different enhancement methods were tested on surfaces like glass, paper, aluminium, duct tape, and cardboard, with varying effectiveness (Akers & Flood, 2016). Silver-assisted laser desorption ionisation imaging mass spectrometry (AgLDI IMS) has shown promise in detecting endogenous and exogenous compounds on nonconductive surfaces commonly encountered in investigations (Lauzon et al., 2017). For challenging metal surfaces, time of flight secondary ion mass spectroscopy (ToF-SIMS) has demonstrated superior results to conventional techniques, revealing detailed fingermark images that persist for extended periods (Thandauthapani et al., 2018).

In general, latent fingermarks deposited on different substrate types will behave differently. When a fingermark is deposited on porous surfaces, its compounds migrate beneath them since these surfaces are mostly absorbent (Ferreira et al., 2021). Iodine fuming and 1,2-indanedione in ethyl acetate were preferred methods for enhancing fingermarks on porous surfaces without compromising Deoxyribonucleic acid (DNA) quality (Tsai et al., 2016). Reagents that interact with amino acids are recommended for this type of surface because they remain stationary when absorbed. The interplay between porous surface, fingermarks deposits, and chemical modifiers is intricate, depending on the porosity, hydrophilicity, ambient humidity, and storage time (Vasil'ev et al., 2020). One that has a strong influence on the quality of fingermarks detected on porous surfaces is these.

Non-porous surfaces, both smooth and rough, are common to crime scenes. Because of the absence of pores, the fingermarks are deposited on the surface, have a brittle nature, and are easily broken (Ferreira et al., 2021). Different directions in the formation of latent fingermarks on non-porous surfaces have been investigated in recent studies. Biocompatible mesoporous silica nanoparticles have also been successfully applied to non-porous surfaces to showcase their use in sensitive fingerprint identification (Bhati et al., 2023). A novel fluorescent dye-based small particle reagent has been developed for wet, non-porous surfaces, demonstrating effectiveness on aluminium foil (Verma et al., 2021). Heavy-metal-free quantum dots offer a green alternative for latent fingermarks detection on various non-porous surfaces, including polymer banknotes and adhesive tape (Shahbazi et al., 2020).

Conventional fingerprint powder methods remain effective for recovering methamphetamine-contaminated fingermarks on non-porous surfaces, with black powder generally outperforming white powder (Sarifudin et al., 2023). However, the presence of contaminants can reduce the quality of recovered fingermarks. Thus, some enhancement methods are effective on some surfaces but not on others. As a result, when selecting fingermark enhancement techniques, consideration of the surface type in which latent fingermarks are to be developed is important (Croxton & Joyce, 2023; Lennard, 2001; Shahbazi et al., 2020).

2.5 Techniques for latent fingermarks detection and enhancement

Latent fingermarks can be visualised in several ways, including optical, physical, and chemical techniques. These methods have been routinely used to perform this task (Bumbrah et al., 2016). Depending on the substrate (porous, semi-porous, or non-porous), texture (smooth or rough), condition (dry or wet), colour of the surface where the latent fingermarks is deposited, and age of the deposits, a specific processing method is chosen (Bleay et al., 2020; Croxton & Joyce, 2023; Said et al., 2021).