RECOVERY OF FINGERMARKS FROM SURFACES PREVIOUSLY CONSIDERED TO BE PROBLEMATIC WITHIN PRACTICE

by

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Thesis submitted

for the degree of MSc by Research

2022

Abstract

Fingerprints are an important type of evidence within the criminal justice system, and these have been used for multiple purposes since the 19th century. Within forensic investigation these are primarily used for identification and/or elimination purposes. Numerous methods and techniques, including physical and chemical procedures, are used to enhance and recover fingermarks from surfaces. However, there are continuing surface and exhibit types which are considered to be problematic to develop and recover within practice.

The purpose of this research was to overcome some of these issues focusing specifically on fingerprints in/on anti-climb paint, leaves, and feathers. The effectiveness of cyanoacrylate ester fuming (CEF) was implemented for all exhibit types, with the addition of physical developer (magnetic powder) on leaves and feathers (*chapter 4)*. The adhesion of the physical developer was consistent throughout feathers, and green leaves, but varying results were obtained from brown leaves. The overall recovery types chosen were lifting (J-lar tape lift and gel lift), and casting (Provil and resin), with varying results being obtained both in terms of ridge detail recovered, as well as damage caused to the exhibit.

CEF development on anti-climb paint produced robust fingermarks and was therefore suitable for casting, due to the presence of three-dimensional features (*chapter 3)*. Casting methods captured a good level of ridge detail, with a small number of limitations, primarily caused by the quality of the original fingerprint deposit. Recovery techniques proposed within this work allow for preservation of ridge detail on a surface previously considered difficult in practice.

Acknowledgements

I would like to express appreciation to a few people who helped me get to where I am today. I would not have been able to accomplish my thesis without them.

To my supervisor, Laura Vera-Stimpson, this year would not have been possible without you. I cannot express how truly grateful I am for your help, guidance and mentoring. You taught me throughout my undergrad, inspired me to pursue a masters, helped on my application, and have gone above and beyond for me on many occasions. I cannot even begin to thank you enough; you are truly an amazing supervisor and someone I will always and forever consider a friend.

To my best friend Niamh Richards, my fellow masters student, the rock I never knew I needed. This friendship was unexpected, but I am eternally grateful to you for the motivation you gave me every week to go to lab, the library, and to continue my studies. The conversations, giggles and memories we made on our projects, as well as outside of them, are forever.

To my mum and Damien, I want to thank you for always believing in me (even when I didn't), for loving me and for always being there when I needed a shoulder to cry on, laugh or lean on.

Last but certainly not least I would like to give special thanks to my dad, if it was not for you I would not have been able to come back to this university to continue my studies. I am so thankful for all your support, last minute pick-ups when I was struggling, and how proud you make me feel about this work.

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Chapter 1

Introduction and literature review

1.1 Forensic Science

Forensic science can be defined as the application of sciences to criminal investigations as well as court proceedings (Forensic science strategy, 2016). There are many specialisms such as forensic anthropology, toxicology, and biology (Roux, Willis and Weyermann, 2021), all of which are important in the reduction, detection, and investigation of crimes. Within forensic investigation and law enforcement, innovations ranging from deoxyribonucleic acid (DNA) to fingerprints and even digital evidence, are all continuing to provide new powerful pieces of evidence which can be used to identify suspects and perpetrators (Forensic science strategy, 2016).

1.2 Fingerprints

1.2.1 Introduction to fingerprints/fingermarks

Friction ridges are unique patterns on the fingertips, palms, and soles of the feet (Lee and Gaensslen, 2001). There are two terms that are used, fingermarks and fingerprints. Fingermarks are the presence of friction ridges from an unknown individual (e.g. those found at a crime scene), and fingerprints are the presence of friction ridges from a known source (e.g. those taken under controlled circumstances). They are unique to the individual and can be used for identification (Lee and Gaensslen, 2001)

The first recorded use of fingerprint for identification was by J.C.A Mayer in 1788, where he stated no two skin ridge pattern and arrangement have ever been found to be the same. In 1858 was then the first use of fingerprint identification was used by Sir William James Herschel. He noticed that upon closer examination of the similar fingerprints, there were small differences which can allow for individualisation. Throughout 1880-1892, Dr Henry Faulds developed a method to ink fingerprints, Sir Francis Galton 'defined the five ridge detail types'. Within 1901 Sir Edward Richard Henry devised the method known as the Henry System (Kasper, 2016). He introduced the use of fingerprints in a criminal investigation and created the fingerprint classification system that is still used today (Hawthorne, 2009).

Fingerprints were first used as personal identification in July 1901 in the United Kingdom (UK) and the first recorded use of these within the criminal justice system was in 1905 (Leadbetter, 2005). In this case, bloody fingermarks were found at the scene, which did not match those of the victim. Two suspects were identified, both brothers. It was shown that a bloody fingermark was a match to one of the brothers, and even though fingerprint identification was still very new, this was enough for the jury to convict them (Leadbetter, 2005).

Fingerprints are composed of ridges and furrows that are reflected on the epidermis, which cause the friction ridge skin (Wertheim, 2011). When a superficial injury occurs, there will only be a temporary change while the injury heals, going back to its original pattern. However, if injury reaches the original layer of ridges and furrows (generating layer), scar tissue will form instead of the ridges. This can be an accidental injury but can also be done on purpose to hide identification, such as by burning, cutting, or using acid (Feng, Jain and Ross, 2009). An example of fingerprint alteration using acid is a 1930s bank robber named John Dillinger. However, after his death, his fingerprints could still be used for identification due to there still being significant characteristics present (Imamverdiyev *et al*., 2008).

1.2.2 Fingerprint reside

Based on these placements of glands, in every latent fingermark deposition (to some degree) there will be a presence of eccrine secretion, as well as sebaceous secretion due to common activities such as touching the face and hair.

Individuals have been found to have differing amounts of these residues on their ridges. For example, children have been found to have a different chemical composition than adults, as well as less residue on surfaces (Champod et al., 2004). Contaminants such as dust, bacteria spores, and food can also be found in fingermark reside. Gas Chromatography - Mass spectroscopy (GC-MS) has been found to be useful for the identification of some contaminants in the fingermark residue (Girod, Ramotowski and Weyermann, 2012). However, some cosmetics can contain similar residues that are naturally occurring in fingermarks. There can be lipid compounds, this can make it hard to differentiate between intrinsic fingermarks residue and cosmetics. The chemical composition of the residue causes the fingermarks to be highly unstable, and vulnerable meaning they can be destroyed easily (Girod, Ramotowski and Weyermann, 2012).

1.3 Importance of fingerprints

1.3.1 Within forensics

Fingerprints and fingermarks became and are still a powerful piece of evidence as they are unique (Kaushal and Kaushal, 2011). They can be used for many purposes such as identification, reconstruction of a scene, and linking an individual to a specific location, scene, or object (Azman et al., 2019).

1.3.2 Other uses

Fingerprints are also used in biometrics. Some countries have opted to use biometric systems in order to strengthen the border and prevent attempts of identity fraud, by tracking and managing the flow of people. Within consumer biometrics, there are many devices which incorporate fingerprint sensors for security reasons, such as phones, door locks and surveillance systems, by providing secure authentications. Within finance, companies have adopted the use of cash machines with fingerprint scanners. Within recent years Mastercard, have been developing a card that includes a fingerprint scanner as added authentication for the payment (Yang et al., 2019).

Continuing research has shown that fingermarks can also provide detail about the donor who left it such as determining age, gender, race, drug detection, and health.

When looking into the age, it is noted that adults' fingerprints can be developed long after deposition, whereas children's fingerprints are hard to locate and develop, especially 24 hours after deposition (Dam et al., 2016).

Research has shown that fingerprint ridges can determine the gender of the individual. This can be done by examining various features such as ridge density, minutiae and fingertip size. For example, it is found that ridge density is lower in males compared to females (Mishra and Jain, 2022).

Drug detection can be used in two ways, if the individual has come into contact with certain drugs, or if they have ingested them. Both can be investigated through the friction ridge detail. However, there is still a need to distinguish the two (Jang et al., 2020).

Researchers have investigated, the use of antibody-magnetic particle conjugates for the detection of drug metabolites and narcotic drugs within sweat reside from fingermark deposits. Antibody-magnetic particles is the use of magnetic microparticles that are functionalised with a specific antibody. Within the first study (Hazarika, Jickells and Russell, 2009), anti-cotinine antibody was used due to the chosen drug being nicotine and cotinine is its metabolite. These fingermarks were deposited on glass surfaces and the cotinine antigen was able to be detected using the magnetic particle with anti-cotinine antibodies. This also provided visibility for imaging of the fingerprints which were sufficient in clarity, enabling identification to be made.

Within the second study (Hazarika *et al.,* 2010), the chosen drugs were cocaine and heroin. The metabolites of these include benzoylecgonine and morphine these were both looked at simultaneously in one fingermark. It was shown that morphine and benzoylecgonine can be successfully detected within the fingermark residue. Additionally, both metabolites were able to be detected simultaneously within one fingermark with the use of fluorescence or white light sources.

High resolution images were able to be captured meaning that identification can be established (Hazarika *et al.,* 2010).

1.4 Methods for the recovery and preservation of fingermarks

1.4.1 Physical developers

Physical and chemical developers are typically used to develop or enhance fingermarks. Physical methods refer to powdering the fingermark to aid visibility on non-porous surfaces. It is one of the oldest (Sodhi and Kaur, 2001) and most commonly applied developer type within crime scenes, accounting for approximately 50% of all fingermark submissions (Bumbrah et al., 2022). The powder particles will adhere to the oils, aqueous components, or amino acids within the latent fingermark residue, depending on the physical developer used. Some examples of these accepted powders within the forensic field are aluminium powder, magnetic powders, and fluorescent powders. There are some factors that can promote the adherence of particles, such as particle shape, size, and electrostatic charge (Jakupi and Avziu, 2019). The suggestion for particle shape, is that flake-shaped powders are more sensitive compared to granular shaped powders, due to this having an increased surface area, which will cause a 'better contact' with the fingermark (Ramotowski, 2013). When the fingerprint powder contains small fine particles, it will adhere to the fingermark with ease compared to coarse ones. Therefore, most of the fingerprint powders will be composed of rounded fine particles or flake fine particles (Sodhi and Kaur, 2001). It is stated that electrostatic charge can have an effect by making large contributions to the adhesion. When the particles are highly charged, it will cause the value of the attraction, of the electrostatic charge to exceed other factors which can contribute to adhesion (Ramotowski, 2013).

The choice on which to use can depend on the surface colour as well as other factors, such as age, surface type, surface colour, texture, contaminants, etc. It is important to carefully consider the physical developer used as this can lead to the destruction of the fingermark due to the fragility to the type of fingermark (Jakupi and Avziu, 2019).

1.4.2 Chemical developers

There are various chemical methods used for the enhancement of latent fingerprints, such as iodine fuming, ninhydrin, and cyanoacrylate ester fuming (CEF). Each method will target various or specific components within the fingermark residue (Jakupi and Avziu, 2019). For example, iodine fuming will become absorbed by the latent fingerprint, having a reaction with the unsaturated fats and ninhydrin will target amino acids. There are advantages and disadvantages to each technique. Iodine fuming is non-destructive, a simple process to carry out upon small exhibits, and cannot overdevelop the fingermark. However, the fingermark will need to be fixed/taped or photographed immediately after development as it fades. It is also considered insensitive, especially to fingerprints that are aged (Home office, Scientific Development Branch, 2005).

Ninhydrin can develop aged fingermarks from minutes to years old, it is effective and easy to carry out and can be used on exhibits that have been soaked in substances such as paraffin or petrol (Home office, Scientific Development Branch, 2005). On the other hand, it will not develop any fingerprints if the exhibit has encountered water. Development time can be several weeks, and it can cause the development of fingerprints when handled after treatment.

CEF will produce a solid white substance that increases durability, and it is easy to carry out. Some disadvantages are its toxic fumes, so a ventilation system is needed. Overdevelopment can be easy which can potentially destroy evidence, and visualisation can be difficult without the use of fluorescent dyes (Home office, Scientific Development Branch, 2005).

These methods sometimes can also cause destruction or damage to the material or exhibit, that the fingermark is on (Jakupi and Avziu, 2019).

1.4.3 Surface type

The surface type in which a fingermark is deposited on is an important consideration for the development and recovery. There are three main categories that surface types will fit into, these are: porous, non-porous and semi-porous (National Institute of Justice (U.S.), 2011).

Porous surfaces allow for absorption, which causes the water-soluble (WS) components of latent fingermark deposits to be absorbed into the surface. Damage can still be caused to these fingermarks but are less susceptible due to the absorption of the fingermark. Some examples of these include paper, untreated wood and cork (Seerat et al., 2015).

Non-porous surfaces repel moisture and liquids. This means that the components of the latent fingermark deposits will sit on the top of the surface which will make them more susceptible to damage. Some examples of these include glass, rubber and metal (Seerat et al., 2015).

Semi-porous surfaces have both repelling and absorption qualities, the water-soluble (WS) components of the fingermark residue will absorb into the surface at different rates. The non-water-soluble (NWS) components will settle on the outer layer, these will persist on the surface for a period of time which is longer than porous surfaces but not longer than non-porous. Some examples of these surfaces are polymer banknotes, waxed paper, and some painted surfaces (Champod et al., 2004).

1.4.4 Other uses on non-traditional surface types

These physical and chemical developmental techniques can also be used on non-traditional exhibits. For example, researchers (Singh, Sodhi and Jasuja, 2006), have used charcoal, and light grey powders, and compared these with iodine fuming on the development of latent fingerprints on fruits and vegetables. These were also tested on the substrate over several days. Results showed that black powder provided the best contrast, as well as being able to develop consistent, very clear developments on apples, bananas, and onions over the several days (Singh, Sodhi and Jasuja, 2006).

Further research (Rae, Gentles and Farrugia, 2013) on types of fruits and vegetables have been carried out in relation to enhancement of fingermarks made in blood. Some examples of the enhancement techniques used within this study included protein stains (acid black 1, acid violet 17 and acid yellow 7), ninhydrin and DFO. On exhibits such as cumbers and bananas the protein stains provided the highest quality fingermarks. Whereas the use of ninhydrin and DFO produced little to no results of enhancement on these exhibits. It was theorised that this could be due to the intended use of them being for porous surfaces, and the exhibits used are non-porous, causing the amino acids present to be washes away during the treatment (Rae, Gentles and Farrugia, 2013).

1.4.5 Ethical considerations

Within forensic science, some research is conducted on non-human participants due to ethical reasons restricting the use of human issue, meaning substitute material is required (Fenton, Horsfall and Carr, 2018). Porcine materials are considered to be a suitable alternative due to a number of anatomical and physiological similarities to humans. Some examples include the epidermis thickness, blood vessels and body hair. Epidermal thickness in human skin ranges from 50 – 120 µm, and pigs ranges from 30 - 140 µm and is therefore considered similar. The blood vessels present in the dermis layer of pig skin has a similar shape, distribution, and orientation to that of human blood vessel. Both skin types (pig and human) have sparse body hair in which follicles go through the hair cycle independently from each other. However, there can be some differences between pig and human skin, such as eccrine glands are not present in pig skin, and instead distributed throughout apocrine glands. Structures between pig and human are similar but not enough to be considered the same, such as subepidermal plexus, which is considered to be underdeveloped in pigs (Sullivan, Eaglstein, Davis and Mertz, 2001). Other substitutes can include natural products (example animal skin or leather) or synthetic products (example rubber or silicone) (Fenton, Horsfall and Carr, 2018).

1.5 Expanding knowledge in development and recovery of Fingermarks

1.5.1 Difficult surfaces

There are still some surfaces encountered within practice that can be difficult and problematic to develop and recover fingermarks. Some examples of these surface are human skin (Lennard, 2007), metals and alloys (Thandauthapani et al., 2018), fabrics, (Fraser et al., 2011), bricks (Davis and Fisher, 2015), and painted walls (Dawkins et al., 2020). However, as research continues methods and techniques are proposed and used to develop on these difficult surfaces.

Researchers (Dawkins et al., 2020) have focused on painted walls on the development of latent fingermarks. They used a variety of paints (matte, silk, bathroom, and eggshell) and development techniques such as ninhydrin, magneta flake and black magnetic granular powders. It was found that difference in matte and non-matte paints shows particle size variations, which could cause an effect on the development of fingermarks, however the greatest influence was determined to be the texture of the wall. Black magnetic flake powder was found to the most effective and ninhydrin and magnta flake were found to be the least effective (Dawkins et al., 2020). Wet paint was not looked at here.

Recovery on human skin has been of interest since 1960s, where the earliest recovery attempt was made, with little success. A first conviction using fingermarks from a cadaver was made in 1978 (Singh, 2020). Progression from there in 1991, had researchers looking into reliable and consistent ways to develop and recover these marks but results failed to be consistent (Futrell, 1996). Within the 21st century, various methods such as black powder, magnetic powder, cyanoacrylate fuming, Kromekote technique, laser detection by inherent luminescence and RTX have all been investigated. Reviews suggest that Swedish black and black magnetic powders gave positive results for deceased and living skin. However, RTX provided the overall best results on deceased skin, and is suggested as the appropriate method (Singh, 2020).

Vertical surfaces are another surface type in which fingermarks are considered difficult to recover from. Specifically, when powdering the powder can 'drop off'. Magnetic powders are widely used for the development of latent fingermarks on vertical surfaces, however literature regarding these surfaces is limited ((Lee and Gaensslen, 200 and Ramotowski, 2013)

Metal and alloys are another type of surface classed as difficult to develop fingermarks from. CEF alone does not provide detail to develop the fingermarks on this surface type. This creates the need for enhancement techniques such as powdering, vacuum metal deposition and fluorescent dyes. However, there are a number of factors which can influence the success of visualising the fingermarks such as environmental conditions, age of fingermark and how the reagents can react to the metal surface. BY40 staining provided results on both brass and aluminium discs produced clear quality fingerprints after three days of deposition, but this quality steadily decreases after eight days on these surfaces. Other staining enhancements such as Sudan black and Crystal Violet on brass and aluminium shows a significant decrease on quality of the fingermarks compared to BY40 (Thandauthapani et al., 2018).

On stainless steel surfaces, BY40 did not provide recognisable fingermarks after three days. The use of an imaging technique called 'time of flight secondary ion mass spectroscopy (ToF-SIMS) was implemented. This is a highly sensitive, non-destructive technique which has been previously used on exhibits such as carrier bags, newspapers, and silicon wafers. On the use of stainless-steel metals, it was able to produce high quality fingermarks, even up to twenty-six days of aged fingermarks (Thandauthapani et al., 2018).

Various types of metal surfaces are frequently found in ballistic evidence, such as in bullets. The technique that is needed to recover these fingerprints, need to be highly sensitive, able to detect degraded fingerprints on surfaces which have been potentially corroded, and should not be react with contaminants. Other factors which can affect the recovery on bullets, involve the reactivity of the metal, the small size and curvature of the bullet, additionally the loading process can mean partial or overlapping fingermarks which will mean less residue present. There have been other methods (as previously mentioned above) in recovering on metal surfaces. Another method which is widely used is known as vacuum metal deposition (VMD). This process uses the evaporation and deposition of metals such as gold or silver, which is followed by zinc to develop the fingermark, using a high vacuum chamber. Research by Christofidis (2019) showed that it was possible to develop fingerprint ridges on 'ballistic brass tiles even after firing, allowing for second level detail of fingerprint ridges to be identified. A study by Pollitt (2020), further supports the use of VMD on brass ballistic evidence, showing that using sliver/zinc or gold/zinc was effective at developing fingermarks. (Pollitt, *et al.,* 2020).

Another use of VMD has been investigated on fabric surfaces which are also considered difficult. It is considered problematic due to the open weaves, type of fabric (natural or synthetic) and absorbency of the fabric having an effect on the adherence of fingermark residues. Within this study the use of VMD showed that nylon consistently produced good ridge detail, compared to material such as cotton, where only the outline of fingerprint or palms could be observed (Fraser et al., 2011).

Types of crime scenes such as arson scenes, are also considered to be difficult to recover fingermarks from. This is due to the degradation of the chemical components within the latent fingermarks, so attempts to develop them will give poor reactions, additionally creating difficulties to recover and use for identification purposes (Birnbaum, 2011).

It is possible to develop fingerprints from arson scenes but due to the unpredictability of fire and variety of factors that can impact it, there is no sole technique that can be appropriate for every scene in removal of soot, and development of fingermarks (O'Hagan and Calder, 2020).

Soot can adhere to fingermarks at the scene creating a protective layer. However, due to the colour and thickness of the soot, the latent or patent fingermarks may not be visible even with the use of light sources. Therefore, techniques were developed to remove the soot, while limiting the damage to the fingerprints. There is a need to select areas where it is believed the perpetrator touched, as some of the techniques can be time consuming and costly. Within this area, the type of surface will also have an impact on the technique chosen. For example, bushing can be used on both porous and non-porous, which is used as a quick effective method. For porous surfaces, Mikrosil can be used, and non-porous surfaces lifting tape can be used followed by other enhancing techniques such as sodium hydroxide (O'Hagan and Calder, 2020).

When developing fingerprints from arson scenes, many factors such as surface type, circumstances of the scene/fire, and extinguish type need to be assessed before deciding the appropriate technique. For example, porous surfaces, ninhydrin, and physical developer will only work, whereas non-porous will only work with vacuum metal deposition or cyanoacrylate fuming. When considering extinguishing methods, for example when water is used, small particle reagent will provide results, whereas Ninhydrin will not (O'Hagan and Calder, 2020).

1.5.2 New approaches

Within Forensic investigation, at crime scenes as well as within laboratories, there are standard procedures used to locate and recover fingermarks.

In order to locate fingermarks, the use of alternative light sources is implemented. Alternative light sources allow the use of filters with specific wavelengths such as infrared (IR) and ultraviolet (UV). Accessories can be used alongside, such as coloured screens which will allow visualisation of the light's fluorescence, as well as providing protection to the user. This technique will work on porous surfaces, as well as textured, fragile, contaminated, and fluorescent surfaces. After the use of chemical or physical developers, alternative light sources can be used to enhance visualisation (Miller, 2018).

To recover fingermarks, tape-lifts, gel-lifts, and electrostatic lifters can be used, or the use photography to capture the fingerprints. These are a standard method used to within the forensic field to lift and recover powdered fingermarks (Harush-Brosh et al., 2020).

Routinely used powders pose a health hazards. Previous powders contained lead or mercury but have been discontinued. However, to this day there are metal components with magnetic and carbon black powder which can cause respiratory diseases (Kim et al., 2019). The size of the powder particle plays a role in the impact it can have on the body, such as finer particles can potentially enter the blood stream as well as the respiratory tract. Even though some precautions are in place, such as personal protective equipment (PPE) and ventilation, this issue is still a factor (Kim et al., 2019 and Chen, Shi, Ma and Zhang, 2020).

Within recent years, investigation into novel techniques have been developed to produce cheaper and safer techniques for the development of latent fingermarks (Chen, Shi, Ma and Zhang, 2020). Some examples of these reagents include nanoparticles (Bumbrah et al., 2022) and food (Vadivel, Nirmala and Anbukumaran, 2021).

Nanoparticles are increasingly being used to develop latent fingermarks due to their high resolution, strong adherence and low background interference. They have been used on a wide variety of surfaces and in some cases can be further enhanced with a dye (Bumbrah et al., 2022). For example, aluminium oxide nanoparticles that have been coated in Eosin Y dye can develop on paper, plastic and wood (Sodhi and Kaur, 2006). When the aluminium oxide nanoparticles were coated in Lucifer Y, they were able to develop on laminated sheets and postal stamps (Sodhi and Kaur, 2008). Gold and silver nanoparticles have been used to develop on aluminium foil (Choi *et al*., 2006), and copper oxide nanoparticles have been able to develop on butter and steel (Bhagat *et al.,* 2021). Zinc oxide and tin oxide nanoparticles have also been used to develop latent fingerprints on glass and glossy cardboard Luthra and Kumar, 2018). Arshad study (2015) were able to reach third level detail on metallic cans and plastic (Arshad *et al.,* 2015).

Uses of foods and food additives have been investigated on development of latent fingermarks, due them being easily available, cheap, and non-toxic properties. Turmeric powder is an example, which is a yellow-brownish colour that adds flavour to food. Curcumin is the main component with turmeric that is responsible for the aroma and colour observed. It is thought that the make-up of curcumin containing carbonyl and hydroxyl groups, as well as the hydrogen bonds between the fatty acids and glycerides present in the sebum of fingermark residue, causes the adherence of the powder. This has been tested on a variety of surfaces, where both porous (such as ceramic tiles), and non-porous surfaces (such as granite), performed well. Surfaces which did not work well included human skin due to contrast, and cardboard and rubber due to lack of sebum adherence from latent residues on these types of surfaces (Vadivel, Nirmala and Anbukumaran, 2021).

1.5.3 Physical and chemical on feathers and leaves

The need to protect wildlife is important, and the main reason there is a 60% decrease over the last 40 years in the population of birds, amphibians, mammals, and fish is due to human beings (WWF - Endangered Species Conservation, 2022). Reasons for this include poaching, the loss of habitats and climate change. In different areas of the world, the world wildlife organisation categorised certain species as extinct, extinct in the wild, critically endangered, endangered, vulnerable, near threat or least concern. For example, pandas are mostly found in the southwest of China and they are considered vulnerable, whereas Sunda tigers which can be found in Indonesia are considered to be critically endangered (WWF - Endangered Species Conservation, 2022).

Wildlife forensics helps to enforce the regulation and laws in regard to wildlife (Underkoffler and Adams, 2021). Within UK law, wild birds, their eggs, and nests are all protected. However, despite this the Royal Society for the Protection of Birds (RSPB) can receive up to 500 cases of 'wild bird crimes' every year (REF). RSPB work with other organisations to investigate these crimes. In 2018 there was only 87 confirmed prosecution cases of bird prey crime but only one conviction within 2017 (Birdcrime, 2022). The reasons for the lack of convictions are due to lack of evidence. There is test such as toxicological test which can be carried out, but these will only provide evidence of poisoning, not of any human involvement. There was an incident where a court did not allow video evidence to prove these 'raptor persecution' (crime against wildlife) as it was deemed non-admissible. This poses the need to for DNA analysis or fingerprint development techniques to be carried out for these cases (McMorris et al., 2019).

Research has previously been conducted to determine the use of physical developers for the recovery of latent fingermarks from bird of prey feathers (sparrowhawk, red kite, buzzard, white-tailed eagle, and buzzard) (McMorris, Farrugia and Gentles, 2015). Enhancement techniques included magneta flake, red and green magnetic fluorescent, black magnetic and cyanoacrylate ester fuming which was followed by basic yellow powder. The red magnetic gave the best results, followed by green magnetic. Other developers showed good results; however, a low sample number was used, and this technique could not be investigated further. Fingermarks in this study were not recovered, only developed (McMorris, Farrugia and Gentles, 2015)

The time between fingermark deposition and recovery has also been investigated (McMorris, Farrugia and Gentles, 2015 and McMorris et al., 2019) where a particular focus was placed upon environmental conditions. Researchers McMorris, Farrugia and Gentles (2015) have shown that as time increases, the number of positive enhancements decrease which is to be expected. This is due to components of the fingermark residue being lost over time, as well as being lost because of exposure to the environmental conditions. Red and green fluorescent developers provided consistent results up until 21 days period, whereas magnets flake developers provided consistent results up to 7 days (McMorris, Farrugia and Gentles, 2015).

Further work by McMorris (2019), specifically used red and green fluorescent powder and results showed that fingermarks were successful in development of up to sixty days with indoor feathers. Also, up to twenty-one days with outdoor feather which were exposed to the natural condition of the environment. It was noted however, that the optimum period for best results for outdoor feathers were fourteen days. The fingermarks in this study were also developed and not recovered (McMorris et al., 2019).

Literature regarding fingermark recovery on leaves is limited, where a primary research focus has been placed upon the recovery of DNA (Craft, Owens and Ashley, 2007). In regard to fingerprints on leaves, two studies have been found. The first study (Hiroi, 2018) focused on development of latent fingermarks on leaves, but also fruits and vegetables. The development techniques used were fingerprint powder (white fingerprint powder or black onyx), magnetic powder (Bi-chromatic) and fluorescent superglue fuming (Lumicyano). Jasmine leaves, Rhododendron leaves and Philodendron leaves were chosen due to the non-porous waxy surface and being household (jasmine and rhododendron) and outdoor plants (philodendron). Fingerprint powder gave the best results, followed by magnetic however it was observed that magnetic would occasionally coat the ridges and furrows (Hiroi, 2018).

The second study (Usmani and Albanese, 2021), looked specifically at different time intervals of depositing fingermarks and how long a fingermarks would last. It used ‘indoor plants’ where they were kept attached to the plant, however investigated dead leaves too which were broken off from the plant. The first plant was smaller but had a smoother surface (less veins) compared to the second plant. To develop the fingermarks ‘black lifting powder’ was used, and to recover them ‘clear tape’ was used. The results showed lifting was easier on plant one, and the visibility of the fingermarks were clearer compared to plant two. It was determined that this was due to the presence of ‘veins’ causing the oil particles deposited by the fingermark to settle into them. It was also noted that the vein print of the leave was picked up by the clear tape which caused difficulties to analyse the fingermarks. It was concluded that fingermarks could be recovered from fresh and dead leaves weeks after the deposit of the fingermark was made (Usmani and Albanese, 2021).

1.5.4 Ageing fingermarks

Fingermarks age over time, which will change the composition of the residue compared to initial deposition. They undergo alteration processes which can be evaporation, degradation, polymerisation or oxidation (Girod, Ramotowski and Weyermann, 2012).

The key component that evaporates is water, where a study (Mong, Petersen, and Clauss, 1999) showed that over a two-week time frame, 85% of the fingermark weight was lost. It was suggested that this was due to the water evaporation. The amino acids in the fingermark stay present for a long time, allowing for fingermarks to still be recovered. A study showed that after 236 days, amino acid specific agents such as ninhydrin, was able to still reveal the fingermark (Girod, Ramotowski and Weyermann, 2012).

Degradation process beings after deposition, and over time it causes changes to the fingerprint composition. Within lipids, the unsaturated compounds will undergo an oxidizing degradation process, which will remove the unsaturated molecules. Research specifically looking at lipids shows they degrade significantly in concentration over thirty days (Girod, Ramotowski and Weyermann, 2012).

Research has shown that cholesterol found in fingerprints is susceptible to oxidation, which causes multiple products to be created. The identification of these can give an estimate of the age of the fingerprint (Girod, Ramotowski and Weyermann, 2012).

Being able to determine the age of a fingermark increases the value of the evidence by creating a timeline. In order to establish this timeline, many different methods and treatments have been proposed over the last 40 years such as Gas Chromatography Mass Spectroscopy (GC-MS), Raman spectroscopy (reference) and Fourier transform infrared microscopy (reference). The chemical composition degradation and visual physical characteristics changes have now been used to generate a more precise age of fingermarks. Although there have been various attempts at determining the age, it is still considered within the early stages due to fingerprint resides varying between individuals as well as these being unstable and fragile (Chen, Shi, Ma and Zhang, 2020).

It is generally assumed that aged fingermarks are of poor quality compared to fresh ones (REF). However, this is not always the correct assumption and was shown through a case within Australia. Where a police officer had not been to the premises within two years, but a high-quality fingerprint of theirs was found on an external window. Due to the quality and the placement (outside where environmental factors can influence the fingerprint), it was assumed to be fresh. It was only determined to be of over two years of age, due to further analysis on the window showing a presence of a similar quality fingermark of another police officer who had also been on the premises two years prior. Due to this further analysis has been carried out, to determine how long a fingermark can persist on glass under enduring environmental conditions. From this, it was determined that oily fingermarks (deposited from sausages and chips as well as 'linseed oil putty'), were able to produce high-quality fingermarks that persisted after 2 ½ years. This supports the hypothesis that fingerprint age cannot be determined through quality alone, however, this was only tested with one individual, meaning it is not sufficient enough as of yet to be conclusive (O Hagan and Green, 2018).

A common component that is looked for within aging fingermarks are lipids due to them being more durable compared to other components. GC-MS is a highly sensitive technique that is commonly used for the detection for these lipids. (Chen, Shi, Ma and Zhang, 2020).

Researchers have also investigated non-chemical methods for the determination of age, including optical methods. Fingermarks can be two or three dimensional, therefore photos and scans have been used to investigate the loss of height in ridges and if this correlates to aging. De Alcaraz-Fossoul (2018), investigated the use of optical profilometers (OP) for the detection of micro-abrasions within surfaces. It is non-destructive, contactless, pre-treatment is not needed for the latent fingermarks to be visualised, and reobservations can be made overtime until the fingermark will naturally disappear. It works by recording images when the microscope moves vertically. Quantitative and qualitative data was collected within this study. Quantitative data was regarding the height measurements of the latent fingermark over a year. It was observed that the loss in height was considerably more noticeable within sixty days (from deposition), after which it plateaus. However, qualitative data is the analysis of these height variations from visual examination, and the OP is capable of producing images on both fresh and ages latent fingermarks. The quality of the image would highly depend on the height of the ridges, as higher contrast was found in fresh fingermarks. Within aged fingermarks, ridge quality was much lower and, in some cases, could not be visible (De Alcaraz-Fossoul *et al.,* 2018).

Overall, it was noted that as the fingermark ages, residues reduce in size, and it is assumed that the sweat residues either evaporate or diffuse over the furrows which hide the height of the ridges causing a plateau in height. This is where OP is limited, as it cannot pick up on the distinctions, as it can only work above 0.02 µm thickness (De Alcaraz-Fossoul *et al.,* 2018).

1.6 Fingerprint comparison and Fingerprint analysis

ACE-V is the standard procedure in which fingerprint experts examine friction ridges. It stands for analysis, comparison, evaluation, and verification. Analysis is looking at the detail within the fingerprint/fingermark, such as level one, two and three features. The quantity of these details needs to be noted as well as the quality of the 'print' to ensure it is suitable for comparison purposes. The unknown fingermark or poorest quality is always examined before the known fingerprint or best quality ‘print’ (Kaushal and Kaushal, 2011).

Comparison is using the information analysed from the unknown fingerprint (or poor quality) to the known fingerprint (or better quality) and comparing them side-by-side. The fingerprint examiner will first look at the level one features from the unknown fingermark and will then compare this to the known fingerprint. If this matches, then the level two details will follow the same principle, assessing the unknown fingermark information, then comparing to the known fingerprint. Level three details are also noted in analysis and will also be compared if level two details match (Kaushal and Kaushal, 2011).

Evaluation is concluding, based on all the information from analysis and comparison stages, if there is an identification, an exclusion, or an inconclusive answer. Identification means that there is enough matching information from the fingermark and the fingerprint to determine that they came from the same individual. Exclusions means that there is enough information that does not match from the fingermark and fingerprint to determine that they are not from the same individual. Inconclusive means that a decision cannot be made between the fingermark and the fingerprint due which could be due to quality or absence of an area (Kaushal and Kaushal, 2011).

Verification is a peer reviewing stage to ensure the results are accurate and reliable. If a conclusion is deemed to be an identification, then a second qualified fingerprint examiner is needed to verify this. When there is a conclusion of exclusion or inconclusive, it can also be verified but it not deemed necessary by the ‘Scientific Working Group on Friction Ridge Analysis Study and Technology’ (Kaushal and Kaushal, 2011).

When there is a fingermark but no fingerprint to compare to, it can be placed into fingerprint databases such as Ident-1, to be compared to fingerprints on the system (Sutton, Glazzard, Riley and Buckley, 2013).

Chapter 2

Methodology

2.1 – Introduction

As mentioned in chapter 1, fingerprints are unique which make them an important piece of evidence. There are various techniques in which fingermarks can be developed and enhanced. The aim of this study is to develop and recovery fingerprints on problematic surfaces, anti-climb paint, feathers, and leaves. This chapter focuses on the methods (fingerprint specific as well as non-fingerprint specific), and techniques developed in order to achieve this aim.

2.2 – Fingerprints/fingermarks

The term fingermark refers to unknown ridge detail that can be found at a crime scene and or on exhibits. The term fingerprint refers to the known (origin) ridge detail that is taken in a controlled environment. The fingerprint can be compared to the fingermark to include or eliminate a suspect (Neumann et al., 2015).

When a surface is touched, it causes a fingermark to be left. This fingermark is made up of sweat, sebaceous deposits, and other contaminants (Champod et al., 2004). This is a key piece of evidence as it proves contact with that particular item or scene, as they cannot be transferred indirectly (de Ronde, Kokshoorn, de Poot, and de Puit, 2019).

Fingerprints (as mentioned previously) are taken within a controlled environment. This is normally carried out within two ways, inking or a line-scan fingerprint. Inking is when the finger is rolled onto an even layer of ink, ensuring the roll is from one side of the nail to the other capturing all of the friction ridge skin. This inked finger will then produce the same rolling motion onto white paper, to give the inked version. These can then be scanned via optical scanners or camera (Lee and Gaensslen, 2001).

Live scanning is the process of capturing the fingerprints without the need to the enhancement via the inking procedure. Instead of a roll technique, a dab technique is implemented upon a device, where the finger is simply placed upon it (Lee and Gaensslen, 2001).

Fingermarks are usually encountered at a crime scene or on an exbibit. Within Forensic Investigation, there are three distinguishing types of fingermarks, these are plastic, patent and latent (see figure 2.1).

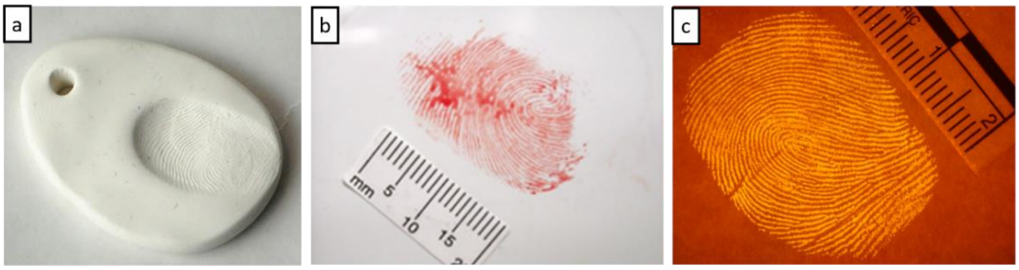


Figure 2.1: Example of plastic fingermark (a), patent fingermark (b) and latent fingermark aided by lighting (c)
(The Body Farm, n.d.;Sutori, n.d ; National Forensic Science Technology Center (NFSTC), 2013)

Plastic fingermarks are impressions of fingerprint ridges in soft material such as wax or putty, creating a three-dimensional fingermark due to the malleable properties of the substrates (see figure 2.1 (b)). A patent fingermarks are ridge impressions made in a non-solid residue such as blood, paint, dirt or grease, which causes contrast from the exhibit surface colour (see figure 2.1 (a)). Both of these types of fingerprints are visible to the naked eye; therefore, no further enhancement is needed. However latent fingermarks, due to their composition are not visible to the naked eye and therefore need further enhancement (see figure 2.1 (c)) (Kaushal and Kaushal, 2011).

Latent fingermarks are made up of mixtures of secretions from glands, and impurities from the environment. These secretions from the skin originate from three glands: sudoriferous apocrine, eccrine, and sebaceous glands (Champod et al., 2004).

The sudoriferous glands are long coiled tubes that produce sweat which is more than 98% water, and they are distributed throughout the body. They are situated in the hypodermis layer and traverse the epidermal layers.

There are three principal layers of skin: hypodermis, dermis and epidermis. The hypodermis is the inner layer that insulates and cushions. The dermis is the middle layer that allows flexibility of the skin and is the supportive layer for connective tissue. The epidermis is the outer layer that is made up of stacked cells and is a rapidly regenerative layer (Kaushal and Kaushal, 2011).

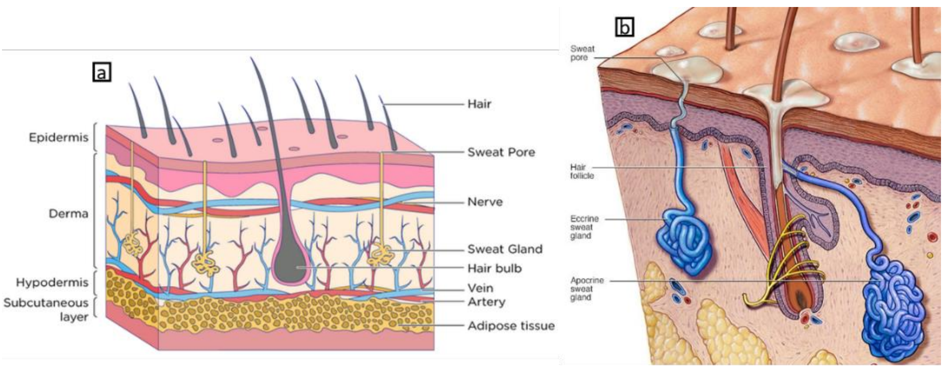


Figure 2.2: Skin layers (a) and (b) highlights the glands contributing to the latent fingermark production (Jack Wesin, n.d. and Mayo Clinic, 2022)

There are two different sudoriferous glands; apocrine and eccrine (see figure 2.2 (b)). Apocrine are located in the armpits, groins and areas of female and male external sex organs (e.g. perianal regions, lips of the vagina, mammary areolae and glands of the penis). The eccrine gland can be found in the palms of the hands as well as the soles of the feet. These will only produce the secretion of eccrine glands. Both of these glands produce secretions of sweat and are made up 'water-soluble organic components' such as (amino acids, proteins and lactic acid) and 'inorganic salts' (such as ammonia, phosphate and water). This mixture causes the deposit water-soluble (Champod et al., 2004) and is given the term water soluble (WS) deposit.

Sebaceous glands produce oil and are found throughout the body with the exception of hands and soles of the feet. These are found in areas which have hair roots, such as chest and back, with a large number found in the forehead. This secretion is made up of waxes, 'semisolid mixture of fats' and long-chain alcohols (such as fatty acids, glycerides and wax esters) that cause the deposition to be non-water-soluble deposit (Champod et al., 2004). These components are termed non-water soluble (NWS) deposits.

The epidermis contains ridges and furrows that alternate, these are known as friction ridges (Kaushal and Kaushal, 2011). These are rooted in the dermis, which are known as primary and secondary ridges. Primary ridges are the ridges present in this underlayer, and secondary ridges are the valleys/furrows. These are reflected in the epidermis layer, giving it the friction ridge skin (Wertheim, 2011).

Friction ridge is described as the flow of ridges on the hands and feet that form friction ridge detail. Friction ridge detail is described the combination of friction ridge characteristics, friction ridge structure and friction ridge flow. Friction ridge flow is the path and the arrangement of these friction ridges on those areas. These are known as level one characteristics. (Forensic science providers: codes of practice and conduct, 2020).

2.2.1 Fingerprint classification

The first level detail characteristics of a fingerprint is the overall friction ridge pattern. These are classified either loops, whorls or arches (figure 2.2). These first level details have several features which are present and common on all fingerprints, such as a core and deltas (Azman et al., 2019). A core is the central innermost area of the pattern (see figure 2.3), and it is a fixed point. For each pattern, the core is different, for example within a whorl, the core will appear as a dot or can be at the start of a spiral. Deltas within patterns are the outermost point of the loops (figure 2.3). It is comprised of three ridges, which are at an angle of 120^{o} to one another (Sudha, Singh and, Sodhi, 2021).

Figure 2.3: Showing the cores (highlighted in the red circles) and deltas (highlighted in the red triangles) in loops, whorls and arches (Bayometric, 2022).

A loop pattern (see figure 2.4) is when ridges enter from one side of the finger, curve and terminate on the same side in which it started, and these tend to have only one delta. These can be further classified into radial and ulnar loops depending upon the direction of flow.

Radial loops occur when the overall ridge flow is moving towards the thumb or radius bone (figure 2.4 (a)), and ulnar loops are when the overall ridge flow is towards the little finger ulnar bone (Rao, and Balck, 1980).

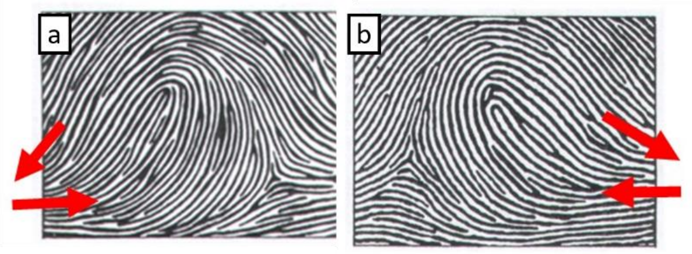


Figure 2.4: Radial loop shown on the left, and ulnar loop shown in the right image (Bayometric, 2022)

An arch is made up of ridges that enter on one side, raise a small amount towards the middle and flow out on the other side, and tend not to have any deltas (see figure 2.5). A tented arch has the same ridge flow as the plain arch, but the rise in the middle is a higher peak compared to the plain arch (Rao, and Balck, 1980).

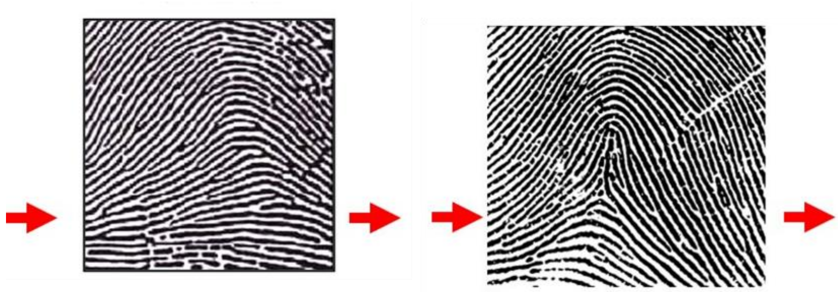


Figure 2.5: Plain arch shown on the left, and a tented arch shown on the right (Bayometric, 2022)

A whorl in general is composed of two deltas and will have a recurving ridge that flows into a spiral or circle pattern. (Rao, and Balck, 1980). There are four different types under this category, there are:

- Plain whorl
- Central pocket loop
- Double loop
- Accidental whorl

In a plain whorl when an imaginary line is drawn between the two deltas, at least one of the inner ridges that recurve will be touched or 'cut' (figure 2.6 (a)). Within a central pocket loop whorl, the imaginary line between the two deltas will not touch or 'cut' any of the inner recurving ridges (figure 2.6 (b)). A double loop (also known as twin loop pattern) is made up of two loop formations that are distinctively separate from each other (figure 2.6 (c)). An accidental whorl pattern will focus on the pattern made by the two deltas (figure 2.6 (d)). The first delta is related to the re-curve in the ridges, and the other is related to the upthrust of the ridges. This impacts the pattern of the accidental pattern (Bhargava *et al.,* 2012).

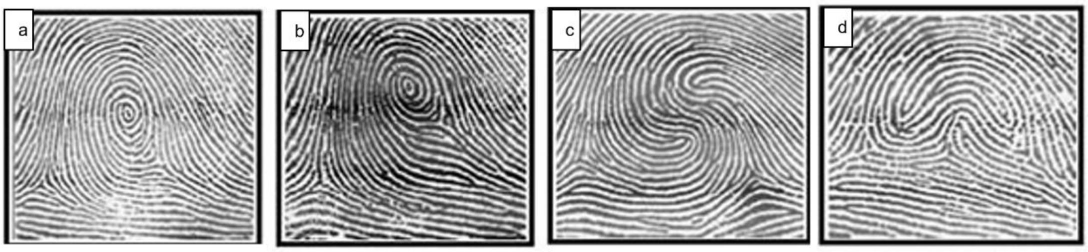


Figure 2.6: Showing a plain whorl (a), Central pocket whorl (b), Double loop whorl (c) and Accidental whorl (d) (Bayometric, 2022).

On average, loop patterns make up 60-70% of the population with ulnar loop patterns being the most common (Win et al., 2020) whereas 30% of the population have whorl patterns and 5% make up arches (Bhargava *et al,* 2012).

The unique features which individualise the patterns are called minutiae, and this is the second level detail of a fingerprint. Some examples of these are bifurcations, ridge endings, lakes, and ridge crossing (see figure 2.7).(Krishna Prasad and Aithal, 2017).

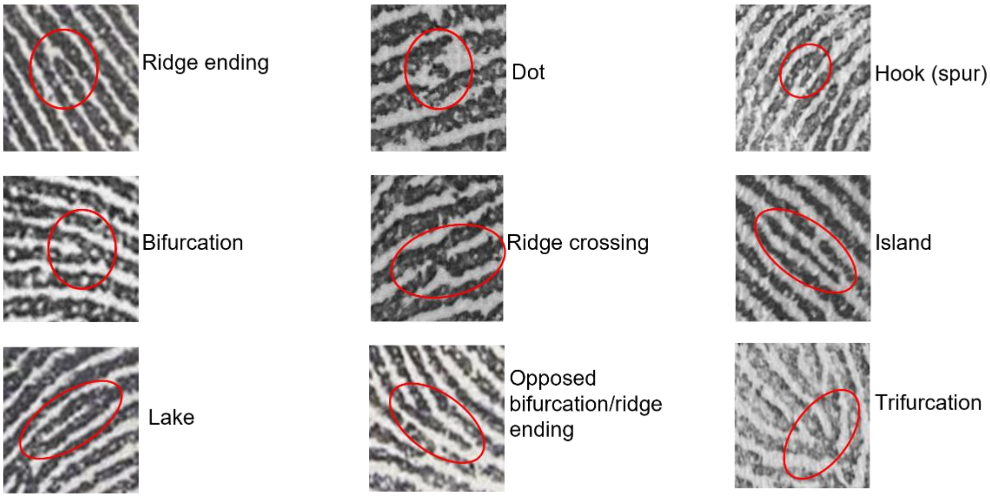


Figure 2.7: Examples of minutiae highlighted in red circles; ridge ending, bifurcation, lake, dot, ridge crossing, opposed bifurcation/ridge ending, hook (spur), island and trifurcation

Figure 2.7 highlights some examples of minutiae which are used within level 2 classification. A ridge ending is when there is a termination of a ridge, leaving an end. A bifurcation is when a ridge splits into two, and a Lake is when ridges form an enclosure, giving the appearance of a lake. A dot is a ridge that is in the shape of a full stop, it is not connected to any other ridges. Ridge crossing is when two ridges are connected together making it look like an X or a chromosome (Paul, Oladipo and Oghenemavwe, 2019). A hook or spur is described as a ridge that splits into two, where one ridge is short branching off from the other one which is long (Singh et al., 2018). The island is a short ridge which is not connected to others, standing alone. And a trifurcation is where one ridge splits into three separate ridges (Paul, Oladipo and Oghenemavwe, 2019).

Level 3 detail is described as dimensional features and are only used for comparison when the fingermark and fingerprint are of sufficient quality (Zhao, Feng, and Jain, 2010). These include creases (see figure 2.7(a)), dimension of ridges, pores (see figure 2.7, (b)), scars and warts. Distributed along the ridges are sweat pores, which range in size, location, frequency, and shape from person to person. Pore shape can be round, oval, square or triangular and normally range from 2 – 50 µm in diameter.

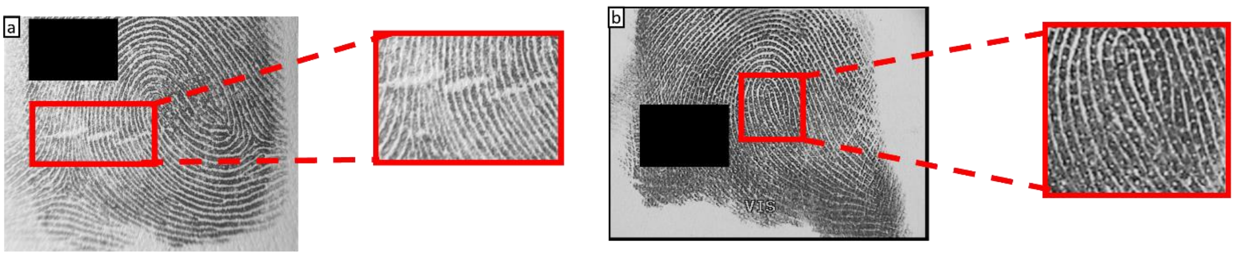


Figure 2.8: Showing fingerprint creasing (a) magnification in red box, and fingerprint pores (b) magnification in red box. Black boxes are void areas.

2.2.2 Formation

As discussed previously, fingerprints are unique to an individual. There are different theories and hypotheses summarising the formation of the fingerprint ridges and why these are unique. However, the most commonly accepted hypothesis for uniqueness relates to the formation of friction ridges during the embryological development (National Institute of Justice (U.S.), 2011). This theory is supported within the field particularly as identical twins do not have the same ridge characteristics.

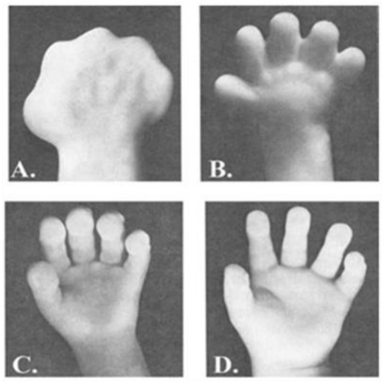


Figure 2.9: Showing the hand morphology, (a) 0-6 weeks EGA, (b) 6-7 weeks EGA, (c) showing 7-8 weeks EGA and (d) showing 8-9 weeks EGA

This theory suggests that the flow of amniotic fluid, as well as the fetus position (within the uterus) will change the growth cell patterns on the fingertips, which will determine fingerprint structure. It also states that there are microenvironments between each finger, which are all slightly and subtly different. However, this difference is amplified due to the variation of the cells. This creates a macroscopic difference, that shows not even identical twins have the same fingerprints (Han et al., 2004).

The biological processes involved are complex however it is generally thought that the developmental timeline has an overall effect on the ridge patterns created. These processes begin during the early stages (4 weeks) of gestation when limbs and finger development begins (5-6 weeks) (figure 2.9 (a)) as small protrusions as the hand shape is small and paddle-like (figure 2.9 (b)). Around this time a series of volar pads appear sequentially on fingertips with muscle and cartilage beginning to form. This leads to the separation of fingers (7 – 8 weeks) and further development of volar pads occurs (figure 2.9 (c)). At approximately 8 – 9 weeks, the joints and thenar crease begin to form the morphology of the hand which can be recognised as an infant's hand. During this period (approx. 9 weeks) flexion occurs where creases develop within the fingers (figure 2.9 (d)) (Champod et al, 2004). Further developmental processes occur during the second and third trimesters (detailed in appendix A.1).

2.2.3 Fingerprint classification

Between 1953-2001, fingerprint experts in the United Kingdom (UK) used a sixteen-point standard when comparing fingerprints and fingermarks. Meaning a minimum of sixteen characteristics were required to match from the unknown to the known fingerprint for a positive match to be concluded. However, this was not a legal requirement, and there were numerous cases where there were less than sixteen characteristics matched for fingerprint evidence (Leadbetter, 2005). Since 2001, this requirement has been superseded by the use of ACE-V (as mentioned in section 1.6). A fingerprint expert will use their training and expertise to carry out this method, with verification by a second expert. (Fingerprint Specialist, 2022). This process relies on the competency of the fingerprint experts, and their findings as evidence are considered opinion, not a fact. (Friction Ridge Detail (Fingerprint) Comparison, n.d.)

However, within forensic science research, fingerprint grading systems are still generally accepted as a form of comparison (Ferguson et al., 2013; Hiroi, 2021; Pulsifer et al., 2013; Rajan *et al.,* 2018; Yadav, 2019)

2.2.3.1. Experimental details of fingerprint classification

Fingermark analysis is qualitative data, and in order to turn it into quantitative, a grading system was created (table 2.1), similarly to previous research (Ferguson et al., 2013; Hiroi, 2021; Pulsifer et al., 2013; Rajan *et al.,* 2018; Yadav, 2019).

Table 2.1: Grading table created for analysing the fingerprints collected

Grade	Description / ridge count
0	No evidence or fully smudged mark. 0 ridge characteristics present
1	Several ridges are present but cannot lead to examination. 0 ridge characteristics present
2	1-5 ridge characteristics present
3	6-12 ridge characteristics present
4	13-17 ridge characteristics present
5	18-21 ridge characteristics present

It was developed using the grading scale in 'Nanocarbon powder for latent fingermark development: a green chemistry approach' (Rajan *et al.,* 2018) (see in appendix A.2). Rajan *et al.,* grading scale uses descriptions for each grade. That was used as a guide for the number of ridge characteristics that should be present in the fingerprint for each sample. This was done due to Rajan *et al.,* grading table being subjective. A way to reduce the subjectivity was to look at specific ridge characteristics. Twenty-one ridge characteristics were chosen from the participant's index finger (see figure 2.10), which are to be looked for each time for comparison. Depending on how many of those can be seen, will depend on which grade it will fit into.

2.2.3.2. Experimental details of fingerprint analysis and consistency

The right forefinger of a single participant was used throughout the research and for the comparisons (see figure 2.10 below).

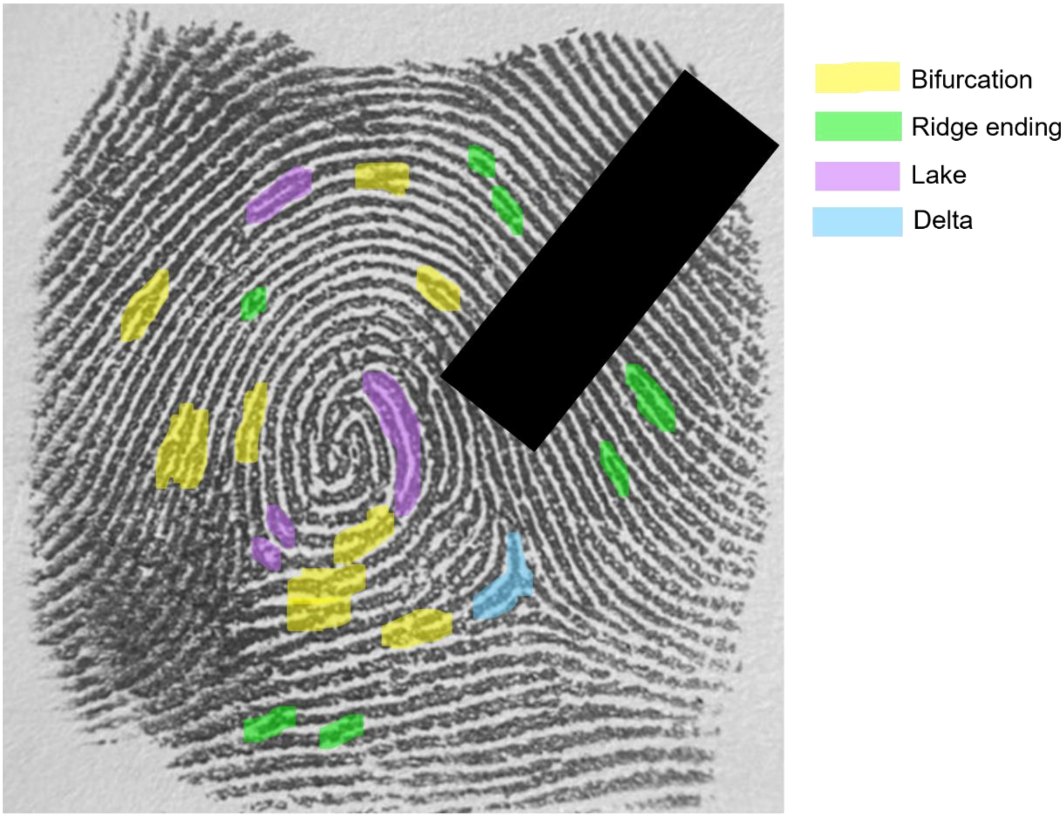


Figure 2.10: Showing participants right index fingerprint. The 21 characteristics highlighted, the colour showing the type of minutiae it is. Yellow = bifurcation, green = ridge ending, purple = lake and blue = delta. Black box are void areas.

The highlighted characteristics of the fingerprint are the twenty-one key characteristics that were looked for each time when analysing the fingerprints recovered from the samples (some examples see appendix A.3

To ensure that the characteristics were present and not due to smudge or too much or too little pressure, multiple inked versions of the same fingerprint were compared.

Each of the key characteristics are numbered, this can be found in appendix A.4.

Force/pressure is one of a few factors which can affect the degree of clarity of friction ridges in a fingermark/fingerprint. As more pressure is applied between the fingertip and the surface, the friction ridges become flattened which causes them to broaden out creating less distance between them. In previous research (Fieldhouse, 2014 and Fieldhouse, 2011) participants have been asked to provide a moderate amount of pressure, but this would be very subjective to human error. From using Fieldhouse (2011) 'see-saw design, fingerprint sampler' as a guide, a pressure device was made for this research (Fieldhouse, 2011).

The pressure device was made of an A5 sized notebook and fishing line weights tapped on to one side (see figure 2.11.)

Figure 2.11: Pressure device that was created

A notebook was used due it being able to open and close, as well as having a flat surface to apply weights. Fishing line weights were used, as their weight can be built upon, or can be reduced if needed. The fishing weights were positioned in a certain way, having five different areas (see figure 2.12).

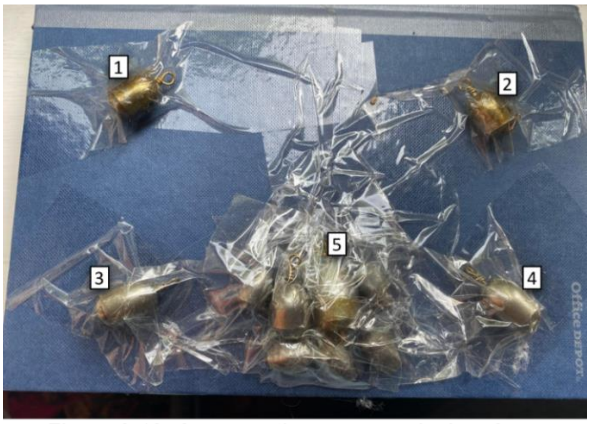


Figure 2.12: Areas on the pressure device. Area 1, 2, 3, 4 and 5, highlighted by the numbers

Area one, two, three, and four are calculated as all weighing 12 g each. Area five which is in the middle was made up of seven pieces, five small pieces weighing 7 g each, one piece weighing 22 g, and the last piece weighing 11 g. Giving the weight of area five as 68 g.

The way in which it worked was by lifting the top cover (the side with the weights) open and resting it on the finger (see figure 2.13 (a)). The participant will then slowly lower the finger and the weight of the top cover and weights will provide the appropriate pressure needed to make the fingerprint (see figure2.13 (b)).

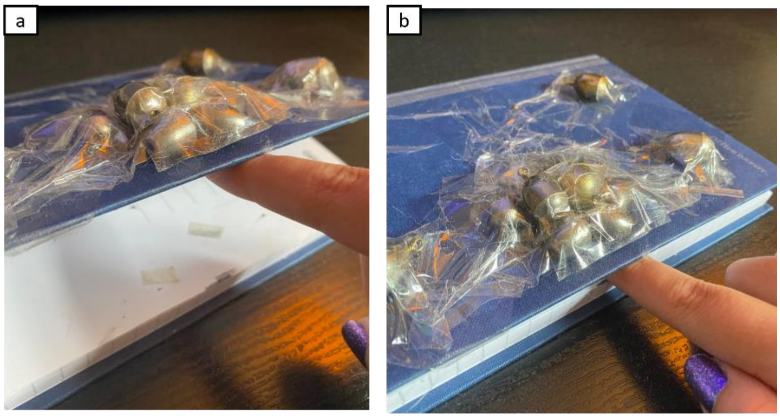


Figure 2.13: Pressure device process. (a) showing the cover resting on the forefinger, (b) showing the cover closed on the finger, providing the pressure

2.3 Fingerprint Development Methods

2.3.1. Physical developer – Magnetic powder

As mentioned in section 1.4.1, there are many different types of physical developers used within the forensic field. Magnetic developers are a type of physical developer which can be categorized into two different variations of magnetic powder, Magneta flake and standardised magnetic powder. Magnetic powders are made up of iron particles, iron oxide and fine non-magnetic particles. The non-magnetic particles then adhere to the aqueous and oily components with the ridges, enhancing visibility (Liu et al., 2019). This developer can be applied to a variety of porous and non-porous surfaces with a variety of textures such as human skin (live and deceased (Trapecar and Balazic, 2007), fruits, vegetables, and plant leaves (Hiroi, 2021). Using a magnetic applicator, termed ‘magnetic wand’, the powder attracts to it making the brush head at the end (figure 2.14). This causes the powder to be the only component that comes into contact with the latent fingermark. Excess powder can be removed by hoovering a ‘clean’ applicator over the area (Thonglon and Chaikum, 2010). This removal of excess powder is recommended for textured surfaces to limit the risks of overdevelopment.

Figure 2.14: Applicator for magnetic fingerprint powder, adhering to the end making the brush head (Arrowhead forensics, 2022)

2.3.1.1 Experimental details magnetic powder

Black and white magnetic powders were used with a clean magnetic applicator, to dust over the exhibits (feathers and leaves) to reveal latent fingerprints.

2.3.2 Chemical developer – Cyanoacrylate Ester Fuming

A chemical developer method known as Cyanoacrylate ester fuming (CEF) is used for developing latent fingermarks. This method is primarily used on non-porous surfaces such as plastic, finished wood, and glass (Bumbrah, 2017).

Cyanoacrylate is a specific type of acrylate resin, and cyanoacrylate esters are monomers that are colourless liquids. Alkyl 2-cyanoacrylate is an acrylate ester (figure 2.15), which contains triple-bond carbon-nitrogen, which is bonded inside an ester. Cyanoacrylate has a relatively low boiling point (approx. 80-100 ^{O}C), meaning that low temperatures are needed for a change of phase from liquid to gas. This property is exploited for the development of fingermarks as in vapour form, it interacts with the eccrine components within the latent fingermark. This interaction causes polymerization which imparts a white hard substance known as polycyanoacrylate on the fingermark (Bumbrah, 2017).

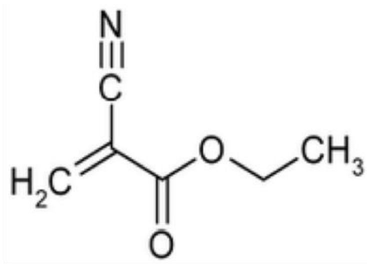


Figure 2.15: Chemical composition of Alkyl 2-cyanoacrylate (Bumbrah, 2017)

The standard way in which this method works is by placing exhibits into a secure fuming chamber. A few drops of cyanoacrylate in liquid form are placed into a suitable container alongside a container of water. These are placed into the secure fuming chamber with a heat source, such as a hotplate. The cyanoacrylate ester vapour will then develop the latent fingermarks as a white hard substance. This development will continue as long as there is a presence of cyanoacrylate ester within the chamber. If not checked regularly or stopped at the appropriate times, then overdevelopment of the ridges can occur (Bumbrah, 2017).

This chemical developer has been used on various surfaces and exhibits such a polymer banknotes, bullet cases, inside vehicles, and adhesive and non-adhesive tapes (Bumbrah, 2017). Pre-treatments such as re-hydrating the fingermark, and post-treatments such as powdering, can both be done to enhance the development and effectiveness of this method.

2.3.2.1 Experimental details of Cyanoacrylate Ester Fuming

A CEF chamber was fabricated for this research, and consisted of two boxes (see figure 2.16, (a)), one on top of the other. The box on the bottom has a hot plate, with foil draping over it. This was to prevent the hot plate from getting damaged by superglue. The wire of the hot plate was covered with tape to also prevent damage. The top box has a hole in the side/edge so the wire of the hot plate can fit through. There are twelve holes at the top (see figure 2.16 (b)), which have a treasury tag in, with a crocodile clip attached (see figure 2.16, (c)). These were also hot glued to the holes, making sure there is no space for vapour to be released, and to secure the clips. When operational, the hot plate was set to the desired temperature, and a beaker of water was placed into the chamber along with two tin cases containing the superglue. The twelve samples are clipped to the top, and the boxes are taped together around the edges with masking tape (see figure 2.16 (d - e)).

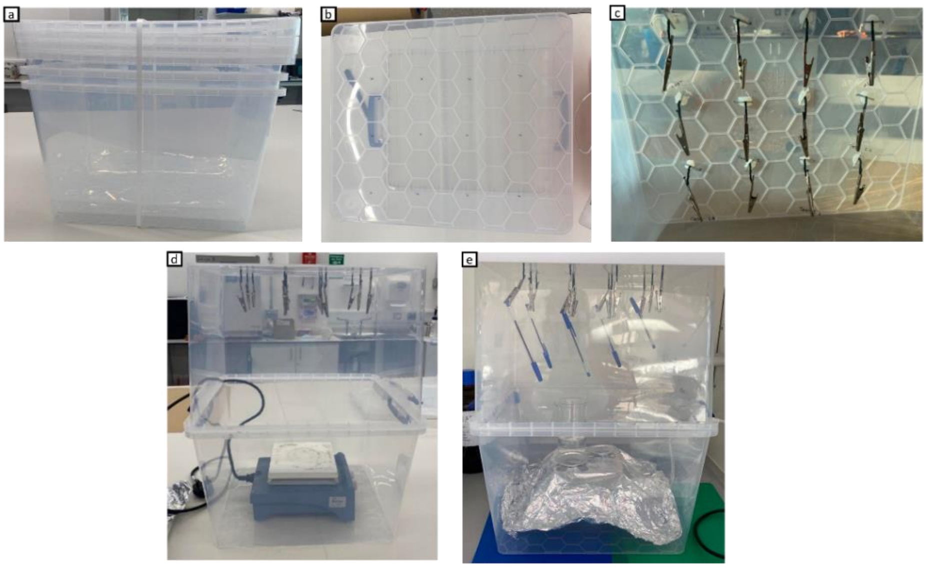


Figure 2.16: Showing the stages of making the CEF chamber. (a) showing the boxes when arrived, (b) showing the markings on the top box, (c) showing the tags put in place, (d) showing it finished with the hot plate in it, and (e) showing while in fuming process

2.4 Fingermark Recovery methods

Once fingermarks have been enhanced, these need to be recovered as it is the key to identification. Fingerprint experts typically compare the originally covered fingermarks with controlled fingerprints taken from the suspect. Various methods and techniques are available to recover these pieces of evidence from a scene. Similarly to developers, great care is needed when deciding upon the most appropriate recovery method (Shalhoub et al., 2008). A summary of those used within this research is summarised below.

2.4.1 Recovery using J-Lar

J-lar is a type of tape-lift that is used by forensic practitioners in the UK. It is a comprised of polypropylene tape and acrylic adhesive which makes it stronger than acetate or standard cellotape. It is widely used within practice due to the versatility and flexibility of the material (J Lar Lifting Tape 50mm, n.d.).

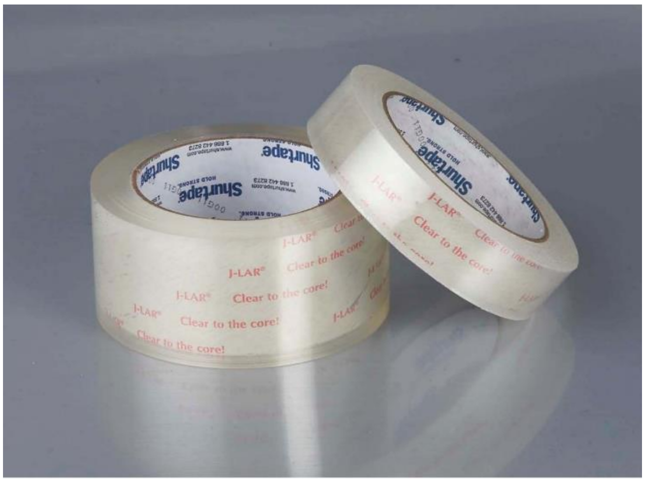


Figure 2.17: J-lar tape rolls (PNTA, 2022)

2.4.1.1 Experimental details using J-lar tape

J-lar tape was used throughout this research. These were cut into sections, where the size was dependent upon the exhibit. A slight excess was allowed for removal and manoeuvring purposes. Once removed from exhibits, these were placed onto acetate sheets.

Additionally, J-lar tape was used in the inking process of Provil, to remove excess ink as well as highlighting a presence of ridge detail.

2.4.2 Recovery using Gel lifts

Gelatine lifters (termed gel-lift) is made up of a woven flexible surface, with a thick layer of gelatine on top. When a piece of gel-lift is placed onto a mark (gelatine side down) the powders or dust particles will adhere to the gelatine side, which will then allow it to be lifted from the surface (Wiesner, Shor and Tsach, 2013)

Figure 2.18: Gel lifters, black and white colours (Lynn Peavey Company, 2022)

Gel-lifters are more frequently used on surfaces that are considered to be difficult e.g. curved surfaces. The advantages of this technique are numerous; some examples include the preservation of the recovered fingermarks and the recovery of trace evidence. An added advantage is that this material can cover large surface areas, is relatively cheap, and available in different colours for contrast (Harush-Brosh et al., 2020).

2.4.2.1 Experimental details using Gel-lift

White gel-lifts were used within this research. These were used in the standard way, (as described above).

2.4.3. Recovery using imaging

Photography is an important consideration within Forensic Investigation for the documentation of evidence. However, on occasions, the recovery of fingermarks is not possible, such as in the case of bitemarks. In these circumstances, photography plays an additional role as a fingermark recovery method.

Photographs need to maximise the perspective of the primary subject/object and minimise the view of background items that are not associated. Different angles, positions and distances from the primary subject/objects are needed to provide the best quality of imagery allowing for comparison. Other factors such as exposure, composition and focus all need to be considered each time a photo is taken (Robinson, 2010).

Lighting, including amount and quality, is essential when photographing exhibits and/or crime scenes as it will provide the correct exposure needed (Robinson, 2010).

Ambient lighting is the presence of existing lighting at the scene or in the lab, however, this is sometimes not adequate as it does not allow the correct exposure. When ambient lighting is insufficient, alternative lighting is used, this can include side lighting, electronic flash, and alternative light sources (ALS). Side lighting/ oblique is necessary when encountering three-dimensional patterns or textures within the piece of evidence, such as tyre tracts, bite marks, and indentation from writing. For example, if direct lighting is used to photograph a shoeprint made in dust, the flash will fill the texture of the pattern effectively causing the loss of detail, depth, and pattern of the shoeprint. When side lighting/oblique lighting is used instead, it provides better visualisation by creating shadows that will capture the three-dimensional pattern, detail, and depth of the shoe print (Robinson, 2010).

2.4.3.1 Experimental details of imagery

Within this research, there were two different types of lighting employed. The first is by using a light box (see figures 2.19 (a) and (b)). This was a portable Samtaian photographic light box that contains 2200 lumens and provided three times brighter lighting compares to ambient lighting.

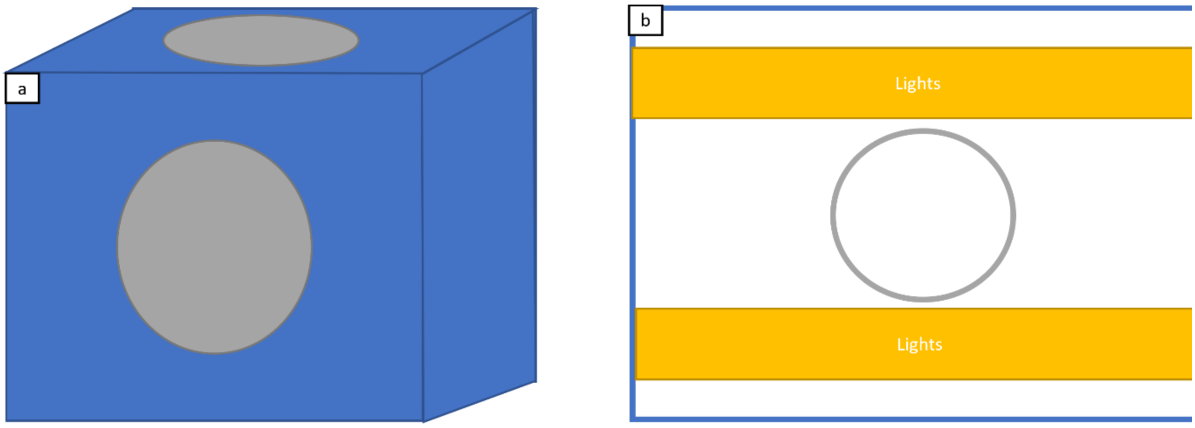


Figure 2.19: The light box, (a) showing the front of the light box. The openings, grey circles, allow visibility to exhibit inside to capture images. (b) showing the aerial view of light box, grey circle is the opening at the top, and yellow tangles are the detachable LED lights across the top

The second lighting method was a lamp (450 W), which was a standard type with a bendable arm used for changing angles (figure 2.20).

Figure 2.20: Lamp side lighting, with benable arm to change angles (Robert Dyas, 2022)

The camera used to capture the photographs was a Nikon DSS00, with a 18.0-55.0 mm lens model.

2.4.4 Recovery using resin

Epoxy resin has been used for multiple applications both outside and within the forensic field. Outside of forensic investigation, epoxy resin is used in paints and coatings, as an adhesive, in electronic materials (Jin, Li and Park, 2015), for creative usages, and for casts. Within the forensic field, the uses of epoxy resin are limited. This is primarily used for the analysis of trace evidence such as to embed tissues (Dittmar, Errickson and Caffell, 2015) and paint chips (Flynn et al., 2005) allowing for further analysis. Some research has also shown how resin can be used as a skull stimulant (Falland-Cheung et al., 2017).

Epoxy resins are composed of two liquids, the resin, and hardener which when mixed, results in a chemical reaction that is exothermic. It starts with both substances being a liquid, passes over a curing time in which its state is a gel, and ends with it being a solid (Epoxy Chemistry, 2022).

2.4.4.1 Experimental details using resin

In this research epoxy resin, brand name 'Gedeo Crystal Resin', was used (see figure 2.21). The ratio that was used was the recommended from the box, 2:1 resin:hardner. It was poured over the samples and allowed to cure/harden for 24 hours, as per the instructions (GÉDÉO KIT CRYSTAL RESIN 300 ML | Gédéo resin | Pebeo, 2022).

Figure 2.21: Resin 'Gedeo Crystal Resin' that was used in this study (Model shop, n.d.)

2.4.5 Recovery using silicon-based casting material

Silicone-based casting materials have been used within forensic investigation such as casting toolmarks, and outside of forensic science such as in dentistry.

Tools can be used by individuals to gain access to premises. These can leave behind tool or instrument marks caused by levering, drilling, or cutting. These marks are photographed and can be cast using commercially produced materials such as Xantropen, Mikrosil and Provil. The chosen material is applied to the area liberally which will allow for the recovery of macro and micro detail within the mark (Pepper, 2010). These materials are made of two parts, an activator, and the main putty material. When they are mixed together causes the mixture to harden which will create a cast of what it has been placed on/into.

2.4.5.1 Experimental details using Provil

The silicone-based material used in this research was Provil novo, also known as Provil, figure 2.22. It is composed of a base and a catalyst, which requires mixing for activation to occur. It comes in different viscosities which are light, medium, mono-phase, putty, and soft putty. There are two different set times, regular set or fast set. It is classed as silicone, which means that water cannot be absorbed by it. (Provil Novo: Medium Fast (2x50ml), 2022). This material was chosen due to its sensitivity allowing it to capture microscopic details within striation marks within forensic science impression. (McKenna and Butler, 2016)

*Figure 2.22: Showing the Provil novo medium fast set cartridges and the Provil dispense gun (*Crime scene investigation equipment, n.d.; DD group, 2022)

Provil was chosen due to the use of this material in previous research where the material was applied directly over a fingerprint that had been powdered prior with Magenta Flake. (McKenna and Butler, 2016) as well as, using Isomark to make a cast of fingermarks, which were then developed using cyanoacrylate ester fuming (Shalhoub et al., 2008)

Within this research, Provil was used in two different ways. The first was applying directly over a fingerprint, whether it had been powdered before with magnetic powder or not. The second way was by making Provil rings in which resin could be contained to prevent leakage. When using the Provil, the dispensing gun (as seen in figure_) was used. This made an easier application, as well as allowing for component mixing in the correct ratios.

2.5. Exhibit types

2.5.1. Anti-climb paint

Anti-climb paint is a non-drying, solvent based paint that can be applied to numerous outdoor materials, such a pipes, fences, wood and brickwork, and comes in multiple colours such as black, brick red, dark green, white and grey. The chemical makeup of anti-climb paint is not readily available. Its purpose is to deter possible intruders from entering a property as it can be slippery and will mark/stain anything that comes into contact with it. It is legal in the UK as long as it is applied to materials/surfaces two metres or above from the ground and has a warning sign nearby (Anti-Climb Paint - Blackfriar Paints, 2013; (Anti Climb Paint (Anti-Vandal Paint), n.d.)

Due to these properties, when an intruder does come into contact with it, marks including fingermarks may be captured.

2.5.1.1 Experimental details of anti-climb paint

There are many different types of brands and colours of anti-climb paint. Black anti-climb paint was chosen for this research (figure 2.23). Manufacturer details and application instructions are summarised in table 2.2.

Figure 2.23: The anti-climb paint that was used in this research, showing the back information and the front of the tin information

Table 2.2: Anti-climb paint information present on the tin

Description	Rapide Anti-climb paint is a quick to apply, non-drying black paint which stays slippery marking surfaces virtually unclimbable, whilst making hands and clothing to deter potential intruders. Ideal for use on drainpipes, fences, gutters, walls, and window ledges. For outdoor use only. Can be applied to concrete, metal, plastic, and wood.
Preparation	Ensure the surface is clean, dry and free of loose debris, oils, grease, and moisture. Seal porous surfaces with multi-surface primer and smooth surfaces should be sanded to provide a clean and smooth surface for the paint to adhere.

Directions	Stir well before use. Apply with a brush to give a thick protective coating. In the event of contamination, remove product with warm soapy water.
Caution	Warning signs should be displayed to identify the presence of anti-climb paint. Do not use in areas rightfully used in daily use. Do not apply below 2 metres height to avoid accidental contact. Do not use near ponds. Do not discharge into the environment.
Cleaning and storage	Clean brushes immediately with white spirits, rinse and dry thoroughly. Store in a cool, dry, well-ventilated area. Avoid direct sunlight and protect from frost Dispose of contents/container to as per local and national regulations
Coverage	Up to 2 m^2/ litre depending upon method and rate of application. Read instructions before use.
Contains	Alkanes, C14-17 Chloro, Quaternary ammonium compounds This product contains max 25 g/l VOCs (Volatile Organic Compounds) which contribute to atmospheric pollution.
Warning	- May cause harm to breast-fed children. - Very toxic to aquatic life with long lasting effects. - Do not breathe dust / fumes / gas / mist /vapours/spray - Avoid contact during pregnancy/while nursing - Wash hands thoroughly after handling - Do not eat, drink or smoke when using this product - Avoid release to the environment.

	- If exposed or concerned: Get medical advice / attention. - Collect spillage - Keep out of reach of children

For the purposes of this research, the anti-climb paint was applied to acetate sheets, and a fingerprint was made in it resembling primary transfer. This paint was kept on the finger and using fresh acetate sheets, secondary and tertiary transfers were then made. A development technique was implemented, and different recovery methods were investigated.

2.5.2 Leaves

In botany, the term leaf refers to a flattened outgrowth originating from the stem of a vascular plant. These are the primary food-producing organs of a plant. Their structure and composition are designed to be efficient in collecting and using light (Waldhoff and Parolin, 2011). The structure of a leaf can be seen in figure 2.24

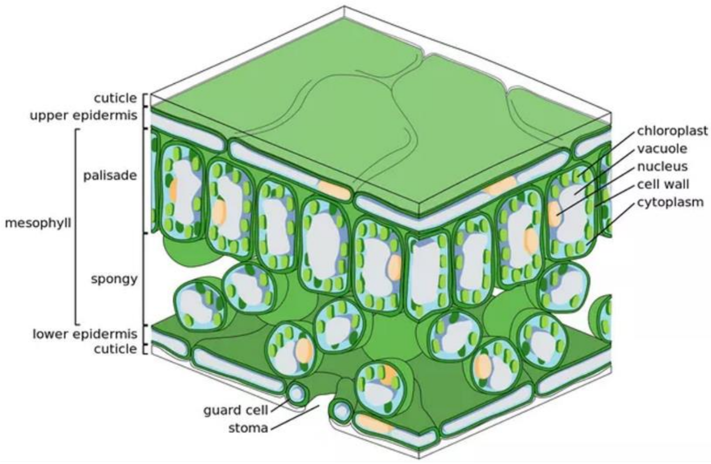


Figure 2.24: structure of leaf, labelled (Boundless, n.d.)

Within the leaf (see figure 2.24) there are structures called chloroplasts, and within these structures is chlorophyll. These are what give leaves their green pigment and are also needed in photosynthesis to absorb sunlight energy and store it as Adenosine Triphosphate (ATP). This ATP is then used within the Calvin cycle. The main function of a leaf is a process called photosynthesis, where plants will take in carbon dioxide (CO_2) and water (H_2O) and convert them into sugars (glucose) and oxygen (O_2). Leaves contain veins and venules which help with the transportation of water, nutrients and energy through the plant as well as providing structure and support (figure 2.25), and the waxy cuticle will also help in the loss of water (Waldhoff and Parolin, 2011).

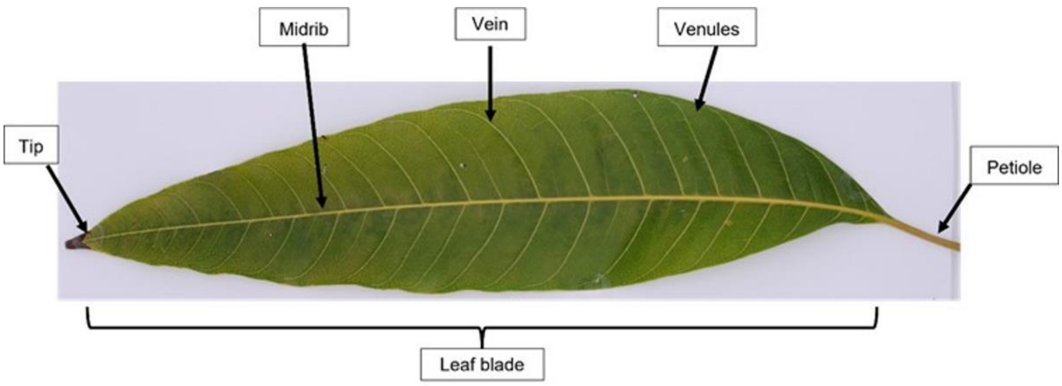


Figure 2.25: Showing the different sections of the green leaf (reference)

2.5.2.1 Experimental details of leaves

The leaves used for this research were those originating from the evergreen Manga Tree of the variety Lippen (Mejora del Mango en Canarias, n.d). This tress is cultivated in tropical environments close to sea level. The leaves used for this study originated from Tenerife (Canary Islands).

Green leaves refer to fresh leaves which were pulled from the tree, and brown leaves refer to dried leaves that had fallen from the tree. The time frame of how long the leaves had fallen from the tree to the collection for this study is unknown, however, only those on the top layer were selected for this research.

2.5.3 Feathers

Feathers are appendages of a bird's skin. These serve important functions for the animal as they allow for flight and provide warmth and water repellence. They are additionally involved in mating. Depending on the species, a bird can have 20,000 – 80,000 feathers, that vary widely in size, colour and shape. The main component of feathers is a protein called keratin (Takahashi, Akahane and Arai, 2003). The basic components of feathers are rachis, barbs, and barbules (figure 2.26).

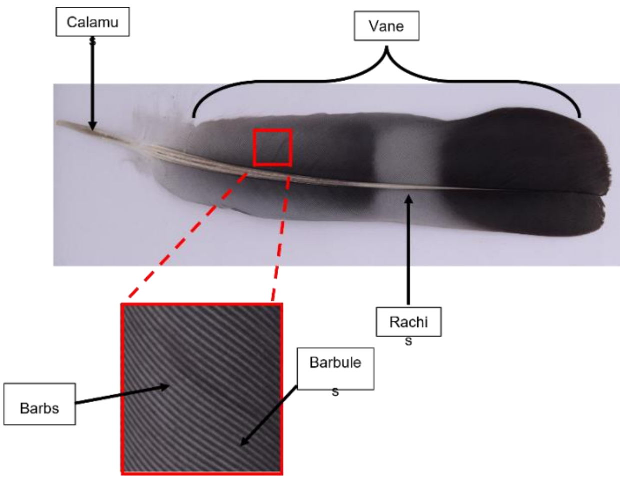


Figure 2.26: Showing the different sections of a feather labelled (reference)

Birds possess four main feather types listed below (see figure 2.27) (Yu et al., 2004).:

- Downy feathers
- Contour feathers
- Tail feathers
- Wing feathers

Figure 2.27: Different types of feathers, wings, down, tail and contour (Leach, Szuc and Thompson, 2014)

Downy feathers are mostly found in the ventral trunk, these are fluffy symmetrical feathers that aim to keep the bird warm. Contour feathers are also found on the trunk, where it has two functions. The distal part of the feather role is for communication and streamlining the body. The proximal part of the feather's role is to control temperature. The tail feather's function is control over flight, and wing feathers are for the purpose of flight. These feathers (wing feathers) vary within different species of birds, due to their different flight modes, causing them to have different designs and arrangements (Yu et al., 2004).

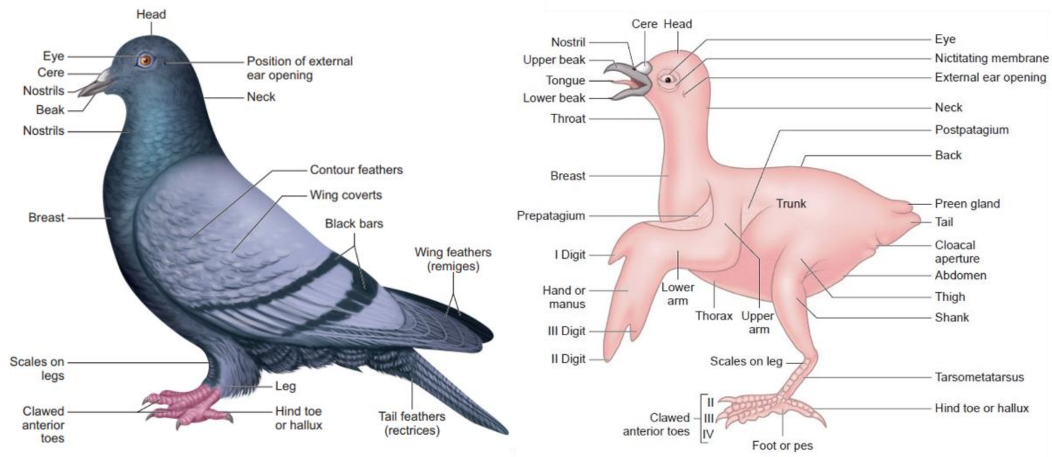


Figure 2.28: Parts of feathered and defeathered pigeon with labels (BrainKart, n.d.& BrainKart, n.d)

The colour of feathers can be vast, and formation can be due to physical colour, chemical colour or a mixture of both. Colour is made up of pigments, which is defined as chemical compounds that absorb light at specific wavelengths. Within birds, there are three major kinds of pigments: carotenoids, porphyrins and melanins. Carotenoids and porphyrins pigments originate from the diet of the bird and are liquid soluble. These are deposited at different times, in different parts of the feather. These pigments are bright red, magenta or yellow. Melanin as well as pigments called eumelanin, are synthesised by melanocytes. These pigments are black or can be lighter. Other coloured sections on the bird and feathers apply to their structure and iridescence (Yu et al., 2004).

Within birds, there are uropygial glands that can be found in the integument (tough layer) within the tail. The birds will carry out a process called preening, in which a bird will rub the uropygial gland with its beak. This will cause the emergence of secretions, and the bird will then rub this all over their plumage. This is an oleaginous secretion referred to as preen oil. Its composition is complex, but the main component is formed by lipids and waxes. There are many theories as to what this preening process does, but one hypothesis is linked to waterproofing (Moreno-Rueda, 2017) as this substance primarily contains lipids/waxes.

2.5.3.1 Experimental details:

The type of feathers used in this study were pigeon tail feathers (see figure 2.29), obtained through ebay.

Figure 2.29: Showing the average feather exhibits used within this study. (a) is the front, and (b) is thee back of the feather

They were used as a type of exhibit where fingerprints were deposited using either grease or moisturiser. Half of the exhibits were developed using CEF + physical developer, the other half were developed with physical developer alone. Different recovery methods were then implemented to determine the appropriate recovery method.

Chapter 3

Overcoming the difficulty in recovering fingermarks from anti-climb paint

3.1 Introduction

As discussed in chapter 1, there is an absence of literature regarding the development and recovery of fingerprints made in and from anti-climb paint. Within this chapter, existing methods used for the recovery and development of fingermarks as well those techniques intended for other uses were investigated to determine if these would be appropriate for the recovery of fingerprints made in or from anti-climb paint. Specifically looking at primary, secondary, and tertiary transfers.

Fingermark images presented in this chapter contain void areas. This is to comply with ethical guidelines (application ETH2122-0064)

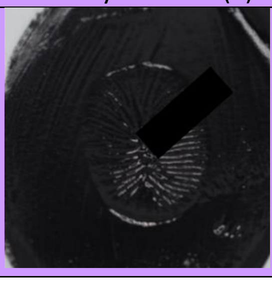
3.2 Development of an experimental procedure

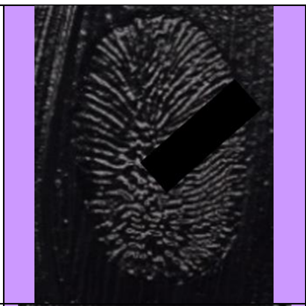
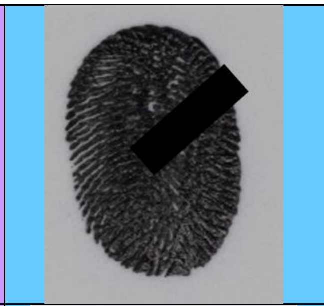
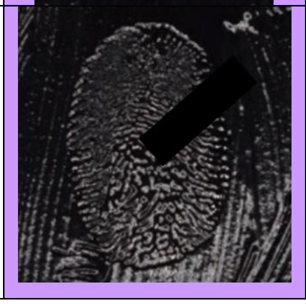
Several different experiments were conducted to develop the overall methodology. These are summarised below.

3.2.1. Tackiness

Due to the nature of anti-climb paint, various components are used to aid spread and prevent the setting of the material (Section 2.5.1). Initial observations noted that tackiness changed over time. To investigate this further a series of tackiness tests were conducted. In this experiment, the anti-climb paint was applied to three separate weighing boats using a paintbrush. These were denoted time zero (immediate application), one day, and four days. At time zero, the index finger was placed into the weighing boat, creating a fingerprint representing primary transfer. The index finger containing anti-climb paint was then used to make a fingerprint onto a fresh clean weighing boat to resemble secondary transfer, and this was repeated for tertiary transfer. This process was reproduced for time one-day and four-day exhibits. These were then analysed (see table 3.1.).

Table 3.1: Tackiness of anti-climb paint, comparison between time zero, one day and four days, on primary, secondary, and tertiary transfers

Time	**Transfer**		
	Primary transfer (a)	Secondary Transfer (b)	Tertiary Transfer (c)
Zero days			

One day			
Four days			

Time zero was still tacky, which meant that there were no ridges that could be seen in primary (a) or secondary (b) transfers and would both be graded as 0. However, there seemed to be some ridges present in the tertiary transfer (c), and this would be graded a 1 (see table 3.1) (see section 2.2.3.1 and 2.2.3.2 for grading system).

Time one day paint was still tacky and primary transfer (a') is still graded as 0 due to no ridges being visible. However, some differences in tackiness were observed upon closer observation, where this appears to show a greater adhesion of the anti-climb paint compared to time zero. Ridges can be seen in both secondary (b') and tertiary (c') transfers and would be graded as 2 (see table 3.1).

Time four days showed the anti-climb paint to have settled, meaning that the material showed greater adhesion whilst remaining 'wet' and spreadable. Primary transfer (a'') would be graded as 1 showing a presence of ridges. Secondary transfer (b'') and tertiary transfer (c'') would both be graded as 2 (see table 3.1).

These results show that the tackiness of the anti-climb paint reduces as time increases. Time zero gives the poorest results for fingerprint quality, however, quality improves with increasing transfers (table 3.1). This is due to there being less paint each time a transfer is made, showing that quantity is also a factor. As a result of this preliminary data, the decision was made to leave the exhibits out, within the controlled laboratory environment, for four days before fingerprints were applied.

3.2.2 Pressure

Pressure was an important factor when considering reproducibility as this will affect the overall quality of the fingerprints produced upon an exhibit. The difference between ‘normal pressure’ and ‘excessive pressure’ can be seen in figure 3.1.

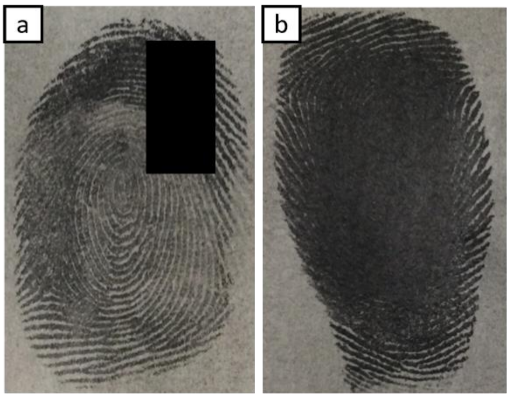


Figure 3.1: Impact of pressure on fingerprint. In (a), shows ‘normal’ pressure where the friction ridges can be seen and (b) shows ‘excessive’ pressure, where the friction ridges have been smudged/merged

To try and keep consistent pressure each time a fingerprint deposit was made, the pressure device, as discussed in section 2.2.3.2 was used.

3.2.3 Surface

Acetate sheets were chosen as the sample surface due to these being similar to many exhibit types which can be found in practice. An additional advantage was the possibility of writing on these.

3.2.4 Cyanoacrylate Ester Fuming

A cyanoacrylate ester fuming chamber was fabricated for this research which comprised of two boxes on top of each other as summarised in section 2.3.2.1.

Due to this chamber being larger than a standard size, some pre-testing was necessary to determine the correct development conditions such as temperature, time, and amount of superglue required. The optimum conditions were found to be 100^{o}C, 80 minutes, and 10-15 drops of superglue for each aluminium foil case.

3.2.5 Amount of anti-climb paint

For reproducibility, a consistent amount of anti-climb paint was used for each test. A series of tests were conducted, using various scoops of anti-climb paint on a microspatula (L x W = 2 x 2 mm).

3.3 Recovery of fingerprints

A summary of processes used in this research has been summarised in sections (3.3. to 3.3.4.3). The overall method that was used to produce and develop the fingerprints is detailed in appendix B.1.

Different techniques were used to determine the most appropriate recovery method. These include Provil, resin, and photography.

3.3.1 - Recovery using Provil

As previously discussed, (section 2.4.5) Provil is a substance used for the recovery of toolmarks. This material, as well as other silicone-based materials, have been used for the recovery of fingermarks, but to a lesser extent. Therefore, this research further investigated the use of this material for fingermark recovery.

A Provil cartridge (yellow) and the gun dispenser were used to apply the Provil directly onto the fingerprints. A method similar to that of casting toolmarks was used, where Provil was dispensed using a side-to-side motion, ensuring a slight overlap of the Provil between strokes to prevent the formation of air bubbles. This recovery was conducted on acetate sheets containing primary, secondary, and tertiary transfers. The Provil on each sample was then left to dry and removed.

Post-images were captured of the Provil, as well as the surface/exhibit after fingerprint removal.

3.3.2 - Recovery using Resin

Due to the liquid form of resin (section 2.4.4), rings of Provil were made to prevent the leakage of this material. Two methods for making the rings were attempted. The first method was using Provil to make a ring directly onto the exhibit and allowed to dry, multiple layers were applied before resin application. The second method was to make the Provil ring on a separate acetate sheet, then place it on the exhibit.

The rings, surrounding the fingerprint, were then filled with the resin mixture and left to harden/cure overnight.

3.3.3. Environments overview

As the intended use for anti-climb paint is for outside surfaces, different tests were conducted to resemble different conditions in the United Kingdom (UK). The main reasons for this were to determine the effect of environments on anti-climb paint, and also any difficulty in recovery.

For each of the environments, the anti-climb paint was left out for four days before fingerprints were deposited and the transfer fingerprints were made, as per findings summarized in section 3.2.1. Following this, these were placed into the relevant environments.

3.3.3.1 Control exhibit information

The fingerprints were in a controlled environment (room temperature in the laboratory) for 64 days. Pre- and post-images were taken for each exhibit. The exhibits were then placed into a CEF chamber and developed (summarised in section 3.2.4).

3.3.3.2 Oven exhibit information

The fingerprints were placed into an oven for 24 hours at 35^{o}C. Pre- and post-images were taken for each exhibit. The exhibits were then placed into a CEF chamber, and developed (summarised in section 3.2.4)

3.3.3.3 Fridge exhibit information

The fingerprints were placed in a fridge for 64 days at 4^{o}C. Pre- and post-images were taken for each exhibit. The exhibits were then placed into a CEF chamber, and developed (summarised in section 3.2.4)

3.3.3.4 Freezer exhibit information

The fingerprints were placed into a freezer for 64 days at 18^{o}C. Pre- and post-images were taken for each exhibit. The exhibits were then placed into a CEF chamber, and developed (summarised in section 3.2.4)

3.3.3.5 Wet exhibit information

The fingerprints were sprayed with a mist of cold water using five pumps of a spray bottle. Pre- and post-images were taken for each exhibit. The exhibits were then placed into a CEF chamber, and developed (summarised in section 3.2.4)

3.3.4 - Recovery using imaging

Photographs were captured at each stage (section 2.4.3.1). Similar to other forensic procedures, light positioning and angles needed to be considered to obtain high-quality images.

3.3.4.1 Imagery of exhibits

A lightbox, as detailed in section 2.4.4 and 2.4.3.1, was used for obtaining consistent images of the exhibits.

Primary transfer exhibits were placed into the lightbox parallel to the lights above in position A (see figure 3.2 (A)), and then turned 90° in position B (see figure 3.2. (B)). Photographs were captured in both positions. Secondary and tertiary transfer exhibits were captured in position B.

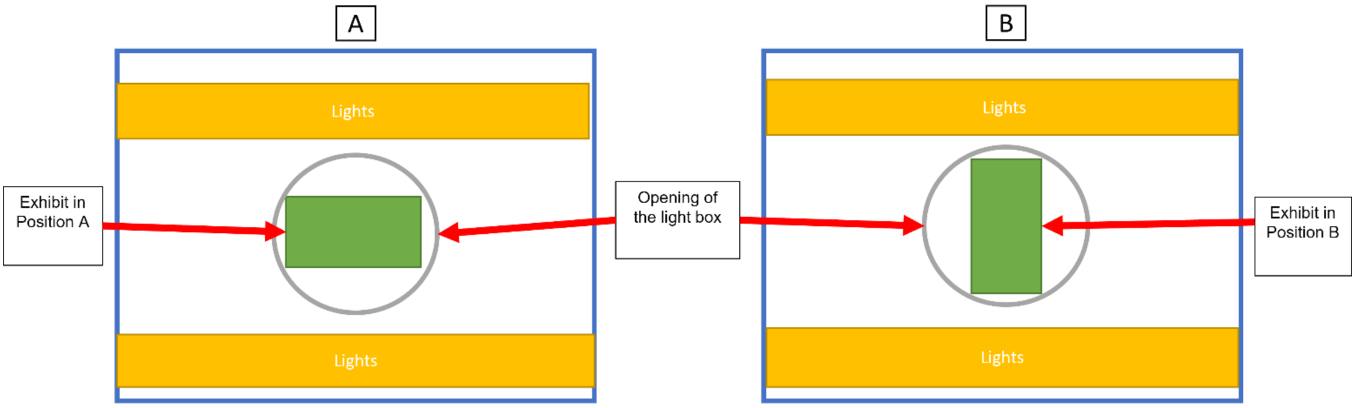


Figure 3.2: Aerial view of light box, showing exhibit in position A on the left (a), and exhibit in position B on the right (b)

Position C (see figure 3.3 (C)) has backlighting using the Light- emitting diode (LED) strips from the light box, this was used for primary transfer samples. One light strip would be removed from the top and placed at the bottom, the lights facing the front opening. The exhibit would be held up in front of the strip to allow light to come through. Secondary and tertiary transfers would occasionally use position C but mostly use position D (see figure 3.3 (D)). This would allow light behind the fingerprint but not direct light. The exhibit would also be held more angled towards the surface than the LEDs.

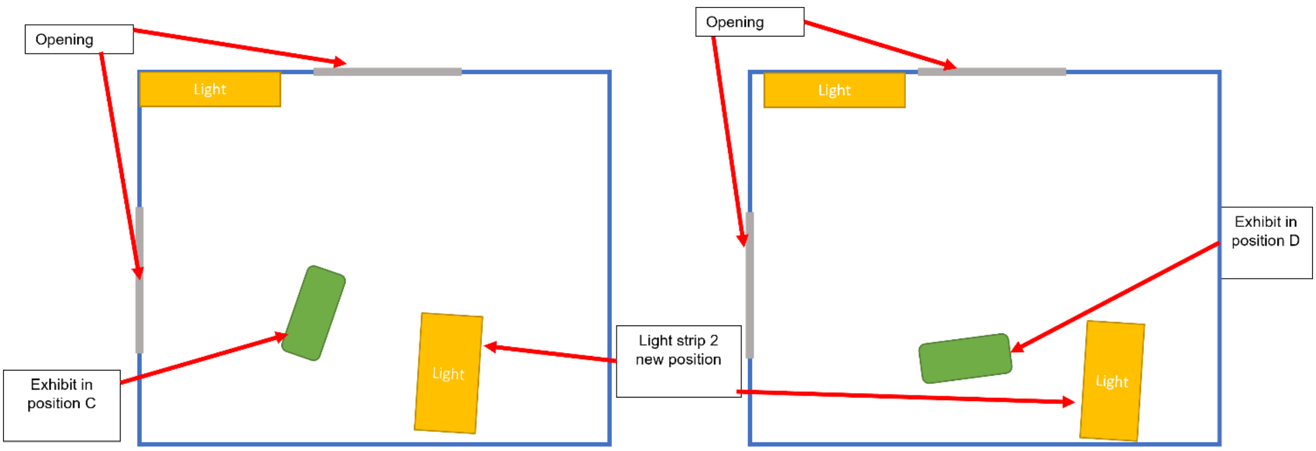


Figure 3.3: Side view of the light box, showing position C on the left (C), and position D on the right (d)

3.3.4.2 Provil enhancement

Secondary processing was needed on the Provil to improve the contrast of the fingerprint against the yellow cast. This was done by inking the Provil cast, applying J-lar tape to remove excess ink, and repeating.

Those exhibits possessing a grade of 3 – 4 were imaged using a lamp light (ranging from 60 ° - 165°) which showed contrast. All Provil casts (including grades 3 and 4) used this secondary enhancement technique to improve contrast. Procedure for enhancing contrast using Provil as a developer:

- Provil (fingerprint side) pressed down firmly into an ink pad
- This is taken out and placed under a Linen Tester for imaging
- J-Lar tape is placed over the Provil to remove excess ink
- An image is taken
- J-lar tape is removed, and an image taken
- This is then repeated until the removal of excess ink or until no further changes are observed

As Provil is made of silicone (see section 2.4.5), it causes the ink to agglomerate on the surface. The application of J-Lar tape causes the ink to spread over the cast.

3.3.4.3 Resin imagery

The resin exhibits were captured using the lightbox, as well as a linen tester.

3.4 Results and Discussion

3.4.1 R&D for development using CEF

Anti-climb paint is a commercial material designed to prevent an individual from obtaining a good grasp of a surface or object, thereby acting as a theft deterrent. Due to the intended use, the material remains 'wet' and spreadable over prolonged periods (see section 2.5.1), causing significant issues for the recovery of fingerprints. When considering potential developers, CEF was deemed to be a possible candidate for the recovery of these fingerprints as this method of recovery is known to produce robust fingerprints (see section 2.3.2).

Due to CEF requiring a heating source (see section 2.3.2), there were concerns that this could affect the anti-climb paint as well as the surface the fingerprint was deposited on (acetate sheet). Previous research has shown that the optimum conditions for fingermark recovery using CEF is 80-100°C (Bumbrah, 2017) and due to this research being novel, the effect temperature on the anti-climb paint was unknown. The boiling point of cyanoacrylate is 50-56°C (National Institute of Justice (U.S.), 2011). and therefore the temperature required would need to be above this, but also needed to be low as possible to avoid the risk of losing ridge detail within the fingerprint.

Preliminary tests were conducted to ascertain the optimum conditions needed for anti-climb paint, as well as the superglue chamber, constructed for this research (section 2.3.2.1). The tests were run at 100°C. This temperature did not cause any distortion to the anti-climb paint; therefore, this temperature was maintained. A development time ≤ 70 time resulted in underdeveloped fingerprints, whereas a time of > 90 minutes resulted in overdeveloped fingerprints. The optimum operating conditions were found to be 80 minutes at a temperature of 100°C and 10-15 drops of superglue.

Deposition of primary, secondary, and tertiary transfers occurred as mentioned in 3.2.1. There was one key issue with the primary transfer which could, occasionally, affect the secondary transfer. As seen in pre-CEF section of table 3.2, some anti-climb paint adhesion did occur (section 3.2.1) which causes the ridges to be masked, leading to these not being developed. This could be due to the thickness of the anti-climb paint, which would then also affect the secondary transfer, which can also mask the ridges. Other potential reasons could be due to the temperature of the finger used to make the fingerprints, as well as the anti-climb paint at the time of deposition. These were not controlled and could have varied between exhibits.

Development was carried out using the process discussed in section 3.2.4 and appendix B.1. Results (Table 3.2) show that the development of fingerprints deposited in anti-climb paint using CEF causes the formation of a robust fingerprint having a hard coating and matt appearance. Pre- and post-fingerprints were graded using the criteria specified in section 2.2.3.2, the results of which are shown in table 3.2. These results demonstrate that there is no effect on the quality of the fingerprint, signifying that the CEF development method proposed within this research is non-destructive for this material. Therefore, the CEF method proposed results in an increase in the durability of the fingerprint.

Table 3.2: Comparison of pre- and post- CEF development on primary, secondary and tertiary transfers

Time	**Transfer**		
	Primary transfer (a)	Secondary transfer (b)	Tertiary transfer (c)

Pre- CEF development			
Grades	0	1	2
Post- CEF development			
Grades	0	1	2

In order to ascertain the importance of the active component (cyanoacrylate ester) and humidity, a series of experiments were conducted using the procedure described in section 3.2.4 where:

1. Test one was conducted with humidity and no cyanoacrylate ester
2. Test two was conducted in the absence of both humidity and cyanoacrylate ester

Table 3.3: Primary transfer results from test 1, test 2 and CEF development procedure

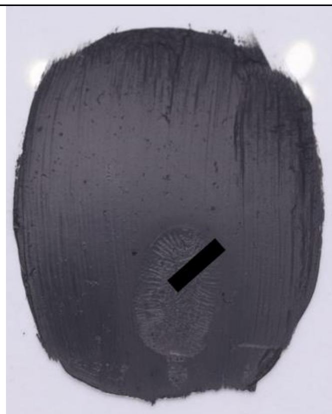
	Test 1	***Test 2***	***Developed CEF procedure***
Primary transfer exhibits			

Table (3.3) shows that in both tests 1 and 2, the anti-climb paint remains shiny and upon physical examination, it was noted that the surface remained tacky as well as 'wet' and spreadable. This signifies that the cyanoacrylate ester is the key component of the findings presented above.

3.4.2 R&D Recovery of fingerprints after CEF development

Section 2.3.2 highlights the possibility of creating durable fingerprints from non-solid material and preserving them in a non-destructive way. However, within practice, this needs to go further, as the recovery of evidence is critical. Therefore, the research expanded upon the possibility to recover these durable fingerprints.

3.4.2.1 Recovery using Provil

As discussed, the application of CEF for fingerprint development on anti-climb paint produces a hard and robust fingerprint. This can be considered to be a 3D impression. Several different recovery methods are available for 3D impressions such as dental stone, Mikrosil, and Provil (2.4.5 section). Provil was chosen as this has a dispenser gun that aided the application and is already used in laboratories and at scenes.

Similarly, to previous results, the quality of the developed fingerprint increases with increasing transfers (section 3.2.1), where tertiary transfer showed the highest number of observable ridge characteristics. This result also affected the grading of Provil casts. Lighting aided ridge visualisation, however, as discussed above (section 3.3.4.2), difficulties were encountered when reproducing angles between different exhibits. Therefore, the inking of the casts was considered to be a suitable alternative. Figure 3.4 shows the difference obtained through this inking process. Figure 3.4 (a) shows a secondary transfer whereas figure 3.4 (b) shows a tertiary transfer, where ridge characteristics appear much clearer in image (b) compared to (a). This difference in quality also affected the inking process as when there is a decreased gap between ridges, the ink tended to pool in one area. Increased gaps between ridges led to the ink depositing on raised portions of the cast. Examples of the step-by-step process of inking procedure see in appendix B.2.

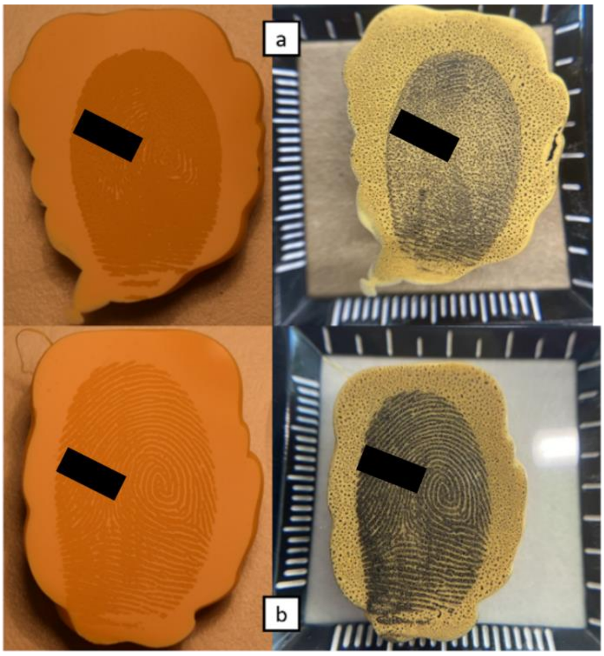


Figure 3.4: Showing (a) cast being poor quality and inking process does not improve it. The second cast (b) showing good quality cast which gives good quality contrast in the inking process

Table 3.4 shows the results obtained from the application of Provil to anti-climb paint. The robust fingerprint deposit created by CEF development meant that the application of the Provil did not disrupt the fingerprint. This allowed for multiple lifts to be obtained from the same exhibit. On some occasions, such as that for the secondary transfer, the grade of the cast improved with a second lift which may be due to the removal of excess materials/contaminants. The grade of the fingerprint did not decrease with multiple lifts which can be seen as an advantage of the technique. However, it was noted that on exhibits presenting with an increased amount of anti-climb paint (e.g. primary transfers), the Provil caused the appearance of tearing. To further investigate this occurrence, a second experiment was conducted with increased amounts of anti-climb paint. These results can be seen in table 3.4.

Table 3.4: Showing original, exhibit surface post-recovery, Provil cast 1, grades for both control and exhibit 1. Exhibit 1 having Provil cast 2

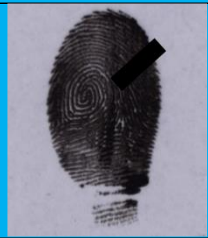
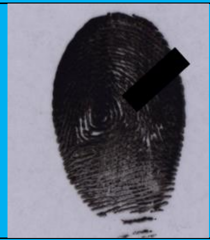
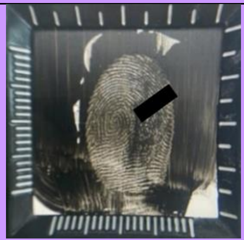
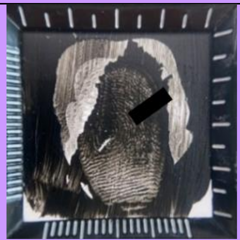
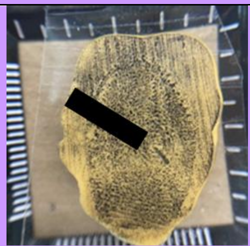
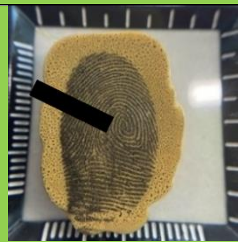
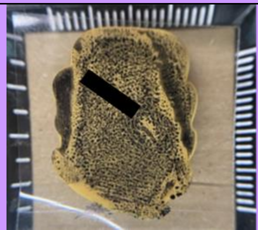
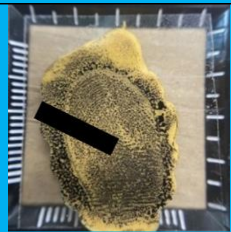
	Primary transfer (a)		**Secondary transfer (b)**		**Tertiary transfer (c)**	
	Control	*Exhibit*	*Control*	*Exhibit*	*Control*	*Exhibit*
Original						
Grade	2	2	3	2	4	4
Exhibit surface post-recovery						
Grade	2	2	3	2	4	4
PROVIL Cast 1						
Grade	2	1	3	1	4	4
PROVIL cast 2						
Grade		1		2		4

Table 3.5: Control 2(thin) and Exhibit 2 (thick) stages, original, exhibit surfaces post recovery, and Provil cast. Grades shown for each stage

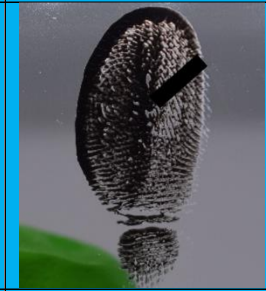
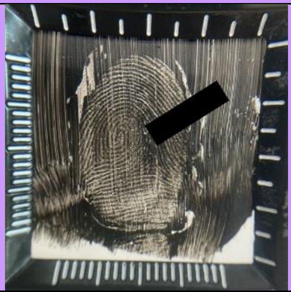
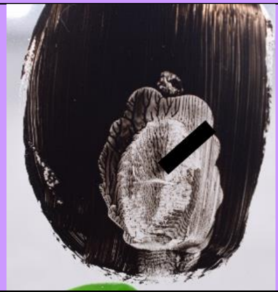
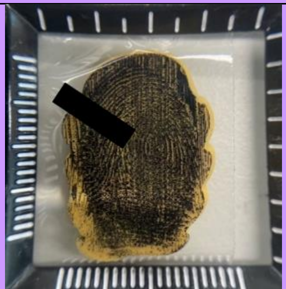
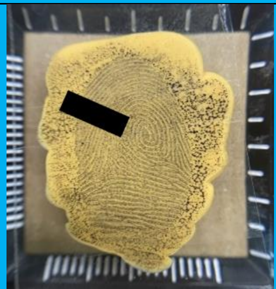
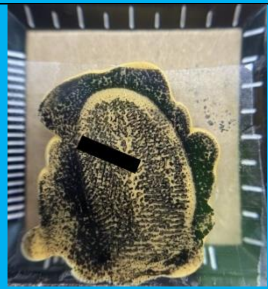
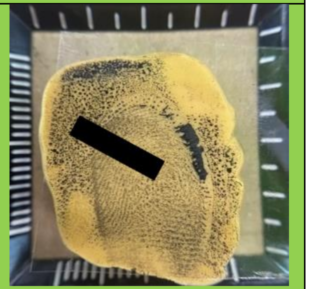
	Primary transfer (a)		**Secondary transfer (b)**		**Tertiary transfer (c)**	
	Control	*Exhibit*	*Control*	*Exhibit*	*Control*	*Exhibit*
Original						
Grades	2	0	4	1	4	3
Exhibit surface post-recovery						
Grades	2	0	4	1	4	3
PROVIL Cast 1						
Grades	2	0	3	1	4	2

Table 3.5 shows that increased quantities of anti-climb paint resulted in the production of void areas. This effect is more pronounced within the primary transfer compared to secondary and tertiary which may be due to the fingerprint being surrounded by the anti-climb paint. This may act as an anchor for Provil to adhere. This can be seen as a negative, however, it was noted that in these areas there were no ridges present.

To ascertain the importance of the CEF development procedure, an experiment was conducted using the Provil recovery procedure summarised within this section with the absence of CEF application, the results of which can be seen in table 3.6.

Table 3.6: Primary, secondary and tertiary transfer results, showing original (no CEF treatment), post-recovery, and Provil cast

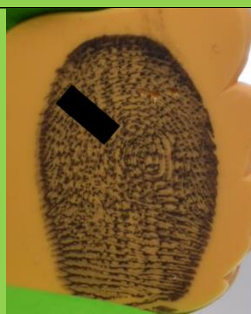
	Primary transfer (a)	**Secondary transfer (b)**	**Tertiary transfer (c)**
Original			
Grades	0	2	2
Post- recovery			
Grades	0	2	2
Provil Cast			
Grades	0	2	1

Table 3.6 shows that it is possible to recover fingerprint characteristics using this Provil recovery method in the absence of previous CEF development. However, during Provil application, great care

was needed to minimise the possibility of smudging. This could have originated from multiple sources such as contact between the nozzle of the Provil dispenser gun as well as any movement of the exhibit. Any errors at this stage would lead to the destruction of the fingerprint. Additionally, post application, smudging was still observed as well as a blotting pattern surrounding and connecting the ridges, this is highlighted in figure 3.5. With this method, enhancement for contrast was not needed, however, this would cause an issue with preservation as the anti-climb paint remained wet on the surface of the Provil cast. Further investigation of this preservation issue was not deemed necessary due to the poor quality of fingerprints obtained.

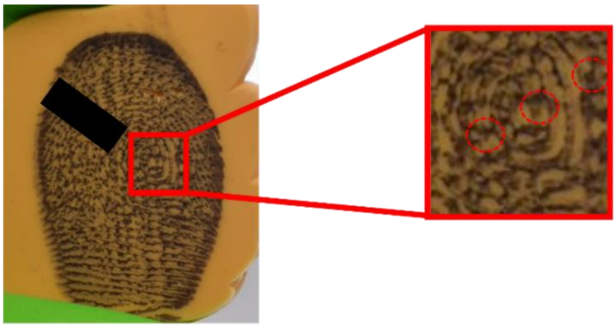


Figure 3.5: Tertiary transfer Provil with no CEF. Area of magnification shows the blotting pattern obtained from this process, highlighted in the circles

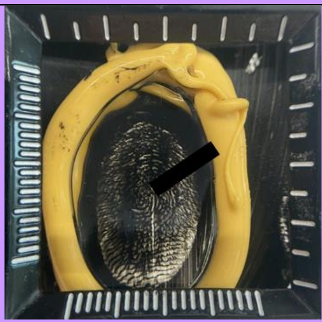
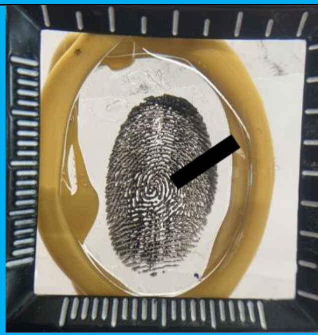
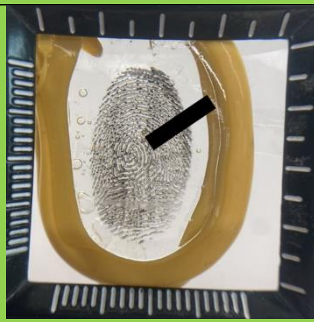
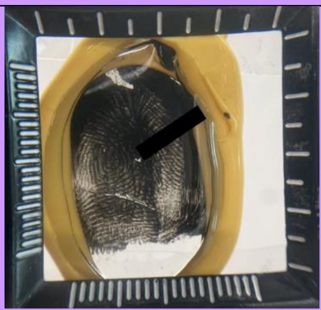
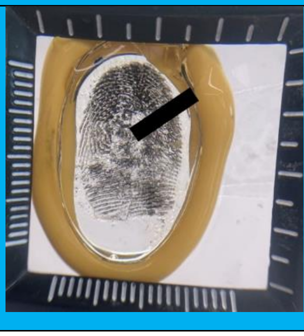
An advantage of using Provil on the samples after they have been put through CEF is it does not destroy the fingerprints and allows them to be recovered more than once. This also means that if the Provil does not capture all the detail in the fingerprint, it can still be used for imaging. Provil is already used within the forensic field for toolmark casts, so is already accepted within practice.

A disadvantage of using Provil when not run through CEF meant that an incorrect application can destruction of the fingerprint. However, this would not be an issue if CEF was run beforehand. As there was little contrast between the yellow Provil and the superglue (white), it caused issues, however, this can be overcome by either using the method stated above or applying stains during the CEF development process. This could be investigated for future applications.

3.4.2.2 Recovery using resin

As summarized in section 3.3.2, methods for the containment of resin were required. The results obtained by applying Provil directly onto the exhibit versus placing a ready-made Provil ring onto the exhibit are shown in table 4.7.

Table 3.7: Resin applied to primary, secondary, and tertiary transfers. Comparison of Provil ring applied directly to the exhibit, and ready-made Provil ring applied on exhibit

	Primary transfer (a)	**Secondary transfer (b)**	**Tertiary transfer (c)**
Provil ring applied directly on to exhibit			
Ready-made Provil ring applied to exhibit			

Results shown in table 3.7 highlight that there are no significant differences between the Provil ring applied directly to the exhibit or if it was made separate from this and placed onto the exhibit (see section 3.3.2). Some resin leakage on both methods occurred to different extents. This may be due to the presence of air bubbles in the Provil, the surface not being flat, or could be due to the curing time of the resin. Laboratory temperature and humidity fluctuations occurred, which were not possible to control, therefore this may have contributed to differing resin curing times.

The removal of resin from the acetate sheets varied considerably. On occasions, it was possible to detach the Resin-Provil complex from the acetate sheet (figure 3.6, (a)), whereas at times it was not possible to remove the resin and Provil complex (figure 3.6, (b)). Some of the reasons for this may be due to some resin leaking under the Provil rings which caused this to cure as one single piece. This meant that the fingerprint preserved in resin could not be detached from the exhibit surface and was then analysed as one complete exhibit. When there was no leakage, this allowed the resin piece to be removed which was then analysed separately from the exhibit surface. The non-detachment of Resin-Provil complex was not problematic within this research as a transparent acetate sheet was used, which allowed for possible grading to be completed. However, this would be problematic if a dark opaque surface was used in addition to a dark colour of the anti-climb paint. This should be an important consideration for practitioner applications.

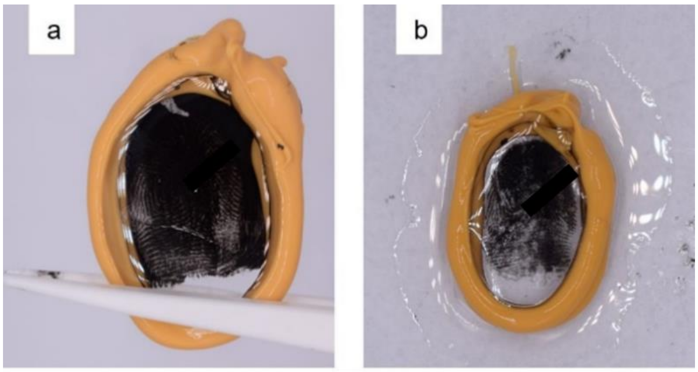


Figure 3.6: Showing (a) where it is possible for the Resin-Provil complex to be removed, and (b) showing when it cannot be removed due to leaking

The application of resin at times resulted in the presence of air bubbles (refer to table 3.7, tertiary transfer), but this did not affect the grading of the fingerprint. However, the application of Provil ring did occasionally obscure part of the fingerprint ridges, which affected grading. Due to the nature of resin, it was possible to carry out analysis on the reverse side of the Resin-Provil complex, as the fingerprint would be brought to the front plane and consequently, the air bubbles or parts of the Provil, would move to the backplane as can be seen in figure 3.7. This is similar to what may be encountered within practice. For example, the presence of surface contaminants such as hair, fibres, etc. would affect the overall quality of the developed (physical or chemical developer) fingermark.

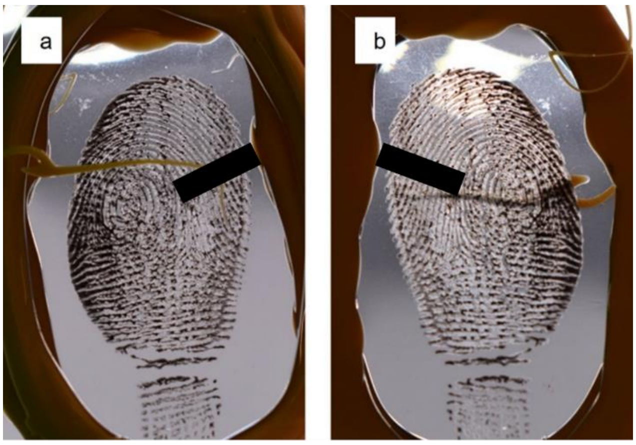
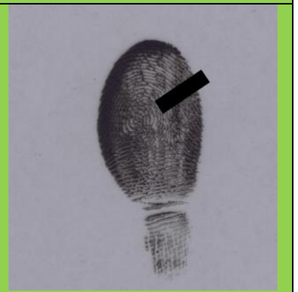
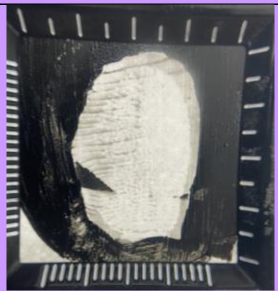
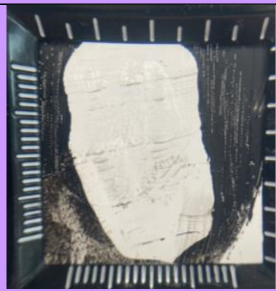
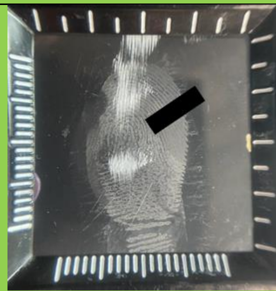
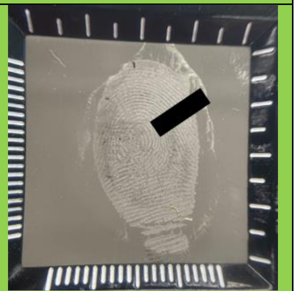
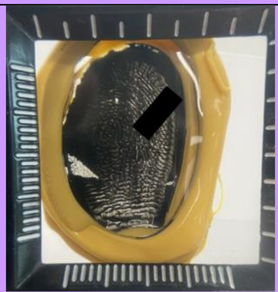
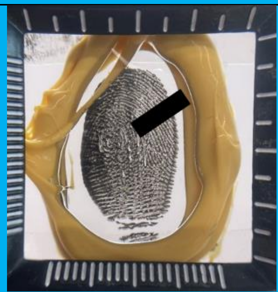


Figure 3.7: The front of Resin-Provil complex (a) and the back of the Resin-Provil complex (b)

Table 3.8: Comparison of Control and exhibit, on Original, Provil-Resin Complex, and Exhibit surface post-recovery. Grades included

	Primary transfer (a)		**Secondary transfer (b)**		**Tertiary transfer (c)**	
	Control	*Exhibit*	*Control*	*Exhibit*	*Control*	*Exhibit*
Original						
Grades	1	1	2	2	3	4
Provil – Resin complex						
Grades	0	0	1	2	2	2
Exhibit surface post-recovery						
Grades	1	1	2	2	3	4

As can be seen in table 3.8, similarly to CEF results presented previously (section 3.4.1 and 3.4.2), the quality of recovered fingerprints using resin improves as more transfers are made. It can be noted that within primary transfer, the ‘whole’ fingerprint was picked up by the Resin-Provil Complex, compared to secondary and tertiary transfers. In both results, it did not affect the quality of the fingerprint, but the reason this could have occurred is the resin using the surrounding anti-climb paint like an anchor. No further enhancements were needed such as the inking method for contrast unlike Provil (section 3.4.2.1). The grade stayed the same for the original exhibit and the Resin-Provil complex, showing that the resin does not affect the detail within the ridges. However, there were observations of some issues which did affect the quality and detail within the ridges. One of these issues is related to the ‘risk’ in removing the Resin-Provil complex, as sometimes it could potentially cause damage. As shown in figure 3.8, removing the Resin-Provil complex from the exhibit caused the loss and/or destruction of a section of the fingerprint, similarly to the tearing observed when using the Provil recovery methods (section 3.4.2.1.). Some potential reasons this could have happened may be due to a presence of impurities on the exhibit causing greater adhesion of the resin to the fingerprint, the presence of air bubbles leading to tearing once removed or the amount of anti-climb paint present could be uneven causing the resin to cure unevenly.

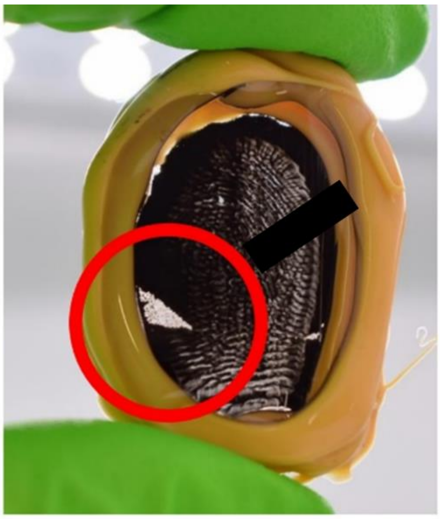


Figure 3.8: Primary control transfer (table 3.8), showing damage caused in the red circle

Other damage which could have been caused was focused on the acetate sheet, it could sometimes rip as highlighted in figure 3.9. This was not a trend and only rarely occurred.

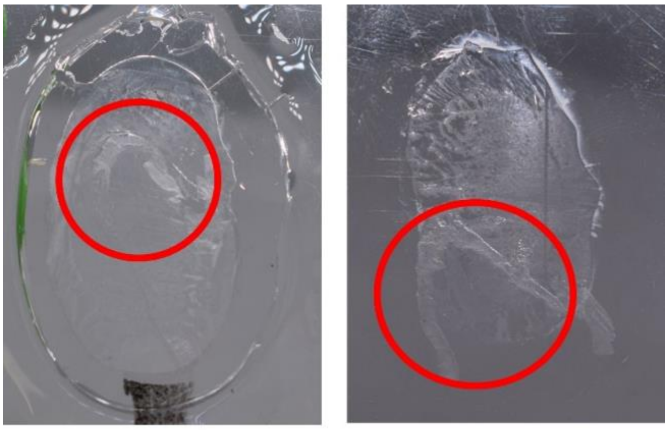


Figure 3.9: Two exhibits which when the Provil-Resin complex was removed, caused the acetate to rip (in the red circle)

There were a few samples where the fingerprint was not completely captured in the first resin lift, and a second resin lift was done to make sure the full fingerprint was collected. An example of this can be seen in figure 3.10. This is a procedure commonly employed in practice, particularly during the recovery of fingerprints enhanced with physical developers.

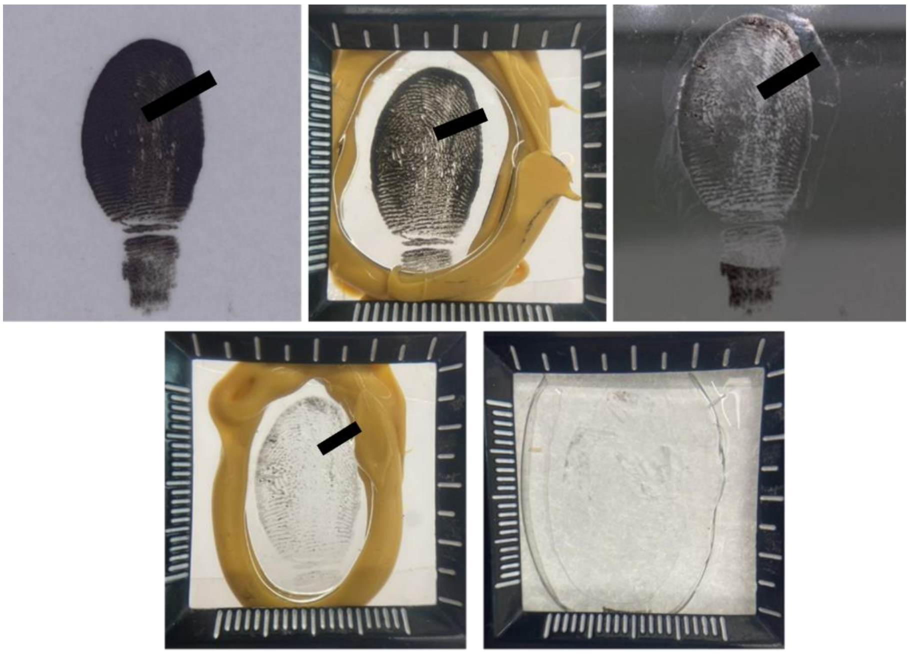
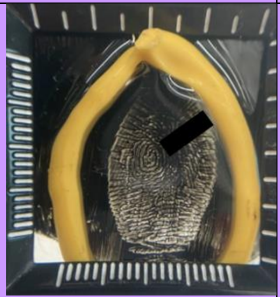
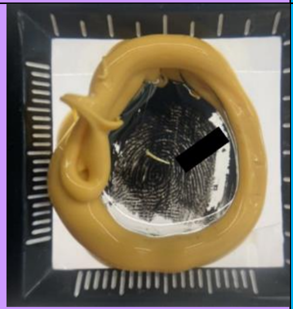
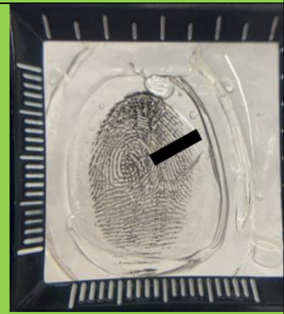
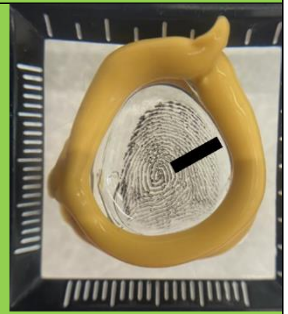
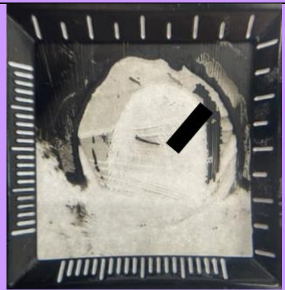
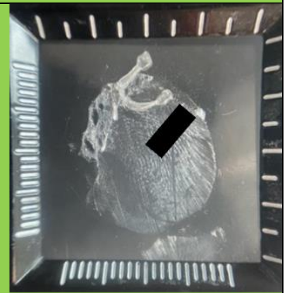


Figure 3.10: A showing after CEF, B shows the first resin piece, C is the surface after first removal, D shows the second resin piece, and E shows the surface after the removal

As discussed in section 2.4.1, fingerprint recovery is typically achieved by placing the lift on acetate sheets. This allows for the possibility of multiple lifts to be done on the exhibit, which is common practice within the field. An added advantage of fingerprint recovery using resin is the possibility of replicating this overlapping procedure due to the transparent nature of the material.

In order to ascertain the importance of the CEF development procedure, an experiment was conducted using the resin recovery procedure summarised within this section with the absence of CEF development. The results of which can be seen in table 3.9

Table 3.9: Comparison of Control and Exhibit, on fingerprints that have not been through CEF. Resin-Provil complex, Exhibit after removal and the grade

	Primary transfer (a)		Secondary transfer (b)		Tertiary transfer (c)	
	Control	*Exhibit*	*Control*	*Exhibit*	*Control*	*Exhibit*
Resin-Provil Complex						
Grade	2	2	3	2	3	3
Exhibit after removal						
Grade		0				1

The application directly onto the exhibit (see table 3.9), resulted in the resin leaking for all exhibits. As seen previously (see figure 3,6 (b) and table 3.7), no trends could be determined as to why leakage occurred.

Table 3.9 shows that it is possible to recover fingerprint characteristics using this resin recovery method in the absence of previous CEF development. However, it was noted that grades decreased greatly if the Resin-Provil complex was removed from the surface. A disadvantage of this technique is that the anti-climb paint remained 'wet' on the reverse side of the Resin-Provil complex. This caused issues as the paint would then transfer onto surfaces that it came into contact with including the examiner's hands. This meant that greater care was needed when handling the exhibit to preserve the fingerprint. This possibility was not investigated further.

Some advantages of resin include the fingerprint being contained in a resin complex, preserving it extremely well, without damaging or changing the fingerprint. Due to resin being transparent, it allows the fingerprint to be seen from both sides of the resin complex. The application of resin did not result in any distortion of ridge characteristics.

There were a few issues/disadvantages of using resin, one example is leakage. This did not cause problems in this research due to the acetate sheet and resin being transparent, but if this occurred on a fixed object, or a darker object, this could be an issue when visualising the fingerprint. Ways to improve on this could be experimenting with other forms of materials instead of Provil as a ring to keep the resin secure.

Other issues occurred when the Resin-Provil complex was hard to remove from the acetate sheet. This in turn can cause the fingerprint to become damaged/ripped in the process. This is also a destructive recovery method, which means the fingerprint present cannot be recovered again.

3.4.3 R&D for environment

Previous sections have shown the applicability of CEF for the development and recovery of fingerprints in anti-climb paint. However, these were conducted under controlled conditions within a laboratory environment. To show greater applicability to practice/real world, a series of experiments were conducted in various environments to replicate conditions in which anti-climb paint would be encountered in UK weather.

Two scoops (section 3.2.5) of anti-climb paint were used for the freezer, fridge, and control exhibits. This was done to determine if there was a difference in fingerprint transfer and thickness and improve the applicability of the research in practical scenarios. Wet and oven were done with one scoop of anti-climb paint. After that, they were placed in their respective environments.

3.4.3.1 Development and recovery of Oven exhibits

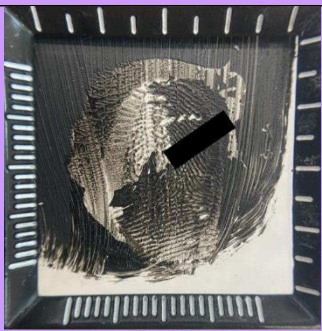
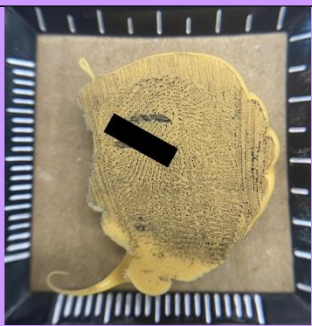
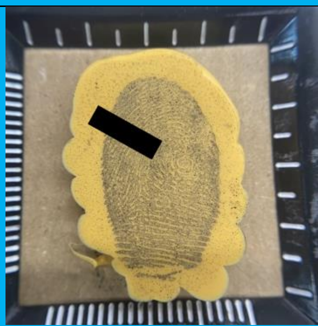
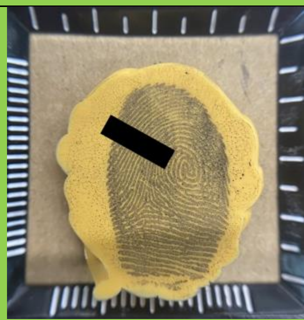
One set of exhibits was used for oven: primary transfer, secondary transfer, and tertiary transfer.

Table 3.10: Oven exhibits, showing pre-CEF, post-CEF and grades

	Oven exhibits		
	Primary transfer (a)	*Secondary transfer (b)*	*Tertiary transfer (c)*
Exhibits Pre-CEF development			
Grade	2	2	4
Exhibits Post- CEF development			
Grade	2	2	4

As seen in table 3.10, ridge characteristics are seen in all transfer types, however, quality improves with subsequent transfers as observed previously (section 3.2.1). Therefore, anti-climb paint does not show any significant changes to its nature and retains the integrity of the impression created at elevated temperatures (≥ 35°C). Equally, the application of the CEF method developed within this research does not affect the overall quality of the fingerprint in any of the transfer types, other than an increase in the matt appearance.

Table 3.11: Oven exhibits, post-recovery using Provil, Provil cast and grades

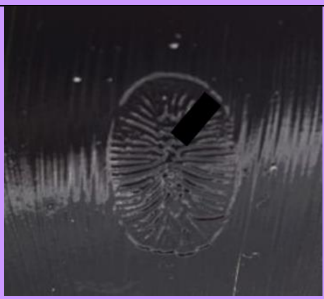
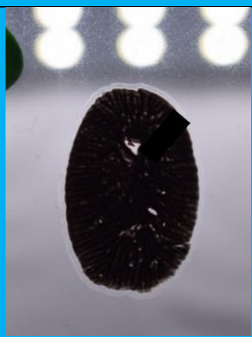
	Oven exhibits		
	Primary transfer (a)	*Secondary transfer (b)*	*Tertiary transfer (c)*
Exhibits post-recovery			
Grades	2	2	4
Provil Casts			
Grades	2	2	4

Results shown in table 3.11 highlight that temperature ≥ 35°C did not affect the anti-climb paint, or the ability to recover the fingerprint using the proposed method.

3.4.3.2 Development and recovery of Fridge exhibits

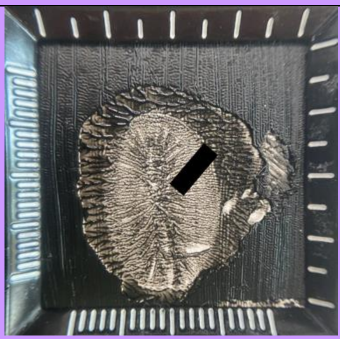
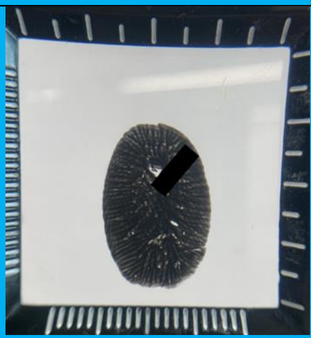
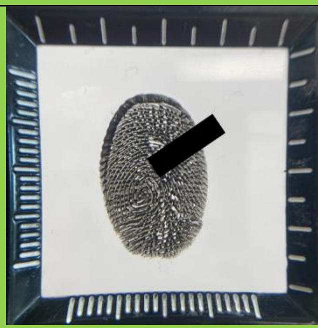
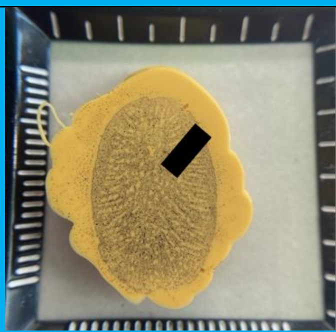
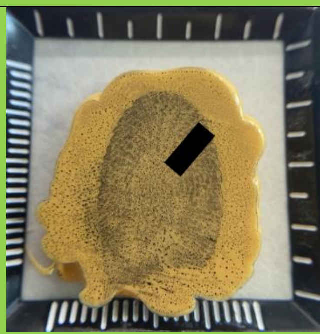
There were two sets of fridge exhibits, each set containing a primary, secondary, and tertiary transfer. There were no differences between set one and set two, therefore only set two was developed and recovered. Set one can be seen in appendix B.3.

Table 3.12: Fridge exhibits, showing pre-CEF development, post-CEF development and grades

	Fridge exhibits		
	Primary transfer (a)	*Secondary transfer (b)*	*Tertiary transfer (c)*
Exhibits Pre-CEF development			
Grades	0	0	2
Exhibits post-CEF development			
Grades	0	0	2

Results shown in table 3.12. illustrate that a temperature of ≤ 4ºC has no effect on the development of fingerprints using the CEF procedure proposed within this research.

Table 3.13: Fridge exhibits, showing post-recovery using Provil, Provil casts and grades

	Fridge exhibits		
	Primary transfer (a)	*Secondary transfer (b)*	*Tertiary transfer (c)*
Exhibits post-recovery			
Grades	0	0	2
Provil casts			
Grades	0	0	0

Each stage of primary and secondary transfer was graded 0. Tertiary transfer was graded 2 for each stage other than the PROVIL cast which was graded 0 (see table 3.13).

The reason these exhibits were not of better quality (grades 0), is due to the anti-climb paint being thick, as discussed within section (section 3.2.1). Additional reasons for the poor quality obtained may be due to contraction/expansion factors, this should be investigated further within future research.

3.4.3.3 Development and recovery of Freezer exhibits

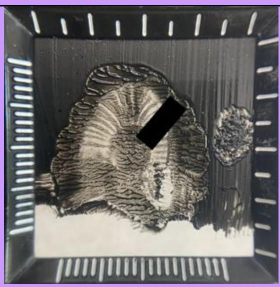
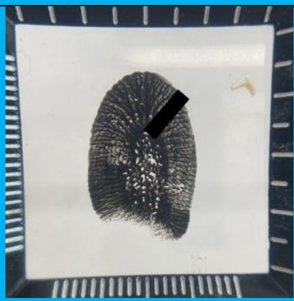
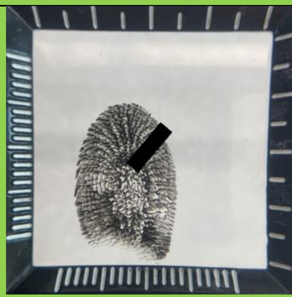
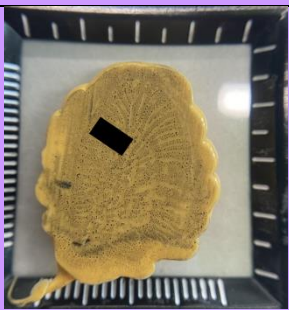
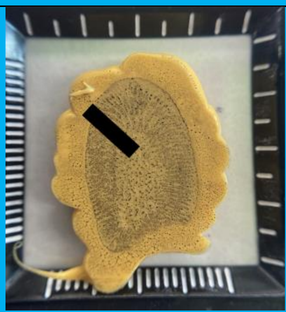
There were two sets of freezer exhibits, each set containing a primary, secondary, and tertiary transfer. There was one slight difference between set one and set two, but it was not great enough to develop and recover both exhibits. Set two can be seen in appendix B.4.

Table 3.14: Freezer exhibits, showing pre-CEF development, post-CEF development and grades

	Freezer exhibits		
	Primary transfer (a)	*Secondary transfer (b)*	*Tertiary transfer (c)*
Exhibits pre-CEF development			
Grade	0	1	1
Exhibits post- CEF development			
Grade	0	1	1

Results shown in table 3.14 illustrate that a temperature of ≤ -18°C has no effect on the development of fingerprints using the CEF procedure proposed within this research.

Table 3.15: Freezer exhibits, showing post-recovery using Provil, Provil casts and grades

	Freezer exhibits		
	Primary transfer (a)	*Secondary transfer (b)*	*Tertiary transfer (c)*
Exhibits post-recovery			
Grade	0	1	1
Provil casts			
Grade	0	1	1

Similarly, to previous findings, the grade improves with increased transfers. However, within these findings, the quality of the fingerprints was not found to contain any presence of ridges which may be due to the increased moisture within this environment (table 3.15). As with previous findings, this discrepancy can be related to the amount of anti-climb paint used. Recovery of fingerprints at ≤ -18°C is not thought to have an impact on the development and recovery process using the technique specified within this research. However, future testing would be needed to confirm this finding.

3.4.3.4 Development and recovery of Wet exhibits

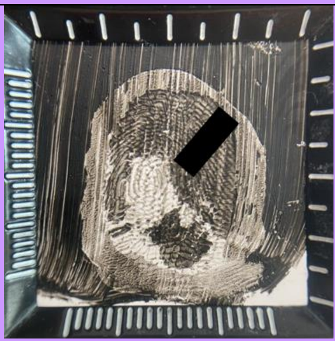
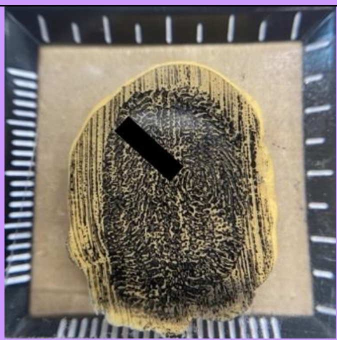
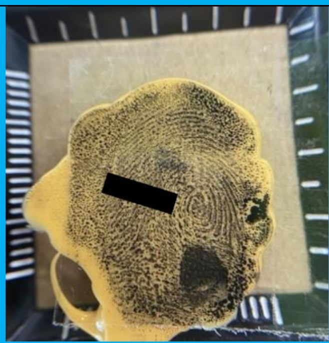
One set of fingerprints was used for this section of the research. Fingerprints were sprayed with a mist of water.

Table 3.16: Wet exhibits, showing pre-CEF development, post-CEF development and grades

	Wet exhibits		
	Primary transfer (a)	*Secondary transfer (b)*	*Tertiary transfer (c)*
Exhibits before CEF development			
Grades	2	3	3
Exhibits after CEF development			
Grades	2	3	3

The presence of moisture in these exhibits did not cause any distortion to the anti-climb paint (see table 3.16). Therefore, the water did not have any effect on the quality of the fingerprint produced. Grading remained consistent for pre- and post-recovery.

Table 3.17: Wet exhibits, showing post-recovery using Provil, Provil casts and grades

	Wet exhibits		
	Primary transfer (a)	*Secondary transfer (b)*	*Tertiary transfer (c)*
Exhibits post-recovery			
Grades	1	3	3
PROVIL cast			
Grades	1	2	3

Provil recovery did affect the quality of the exhibit post-recovery causing a slight decrease in the associated grade for the primary transfer (see table 3.17). A similar result has been obtained previously which may be due to the quantity of anti-climb paint present. A slight change occurred for the secondary transfer post-recovery; however, the grade was not reduced as ridge characteristics were still present upon closer magnification. The water caused a dilution of the colouration of anti-climb paint in this area. The effect of this dilution also transfers over to the Provil cast where an increase in coloration is observed after the inking process.

This shows that recovery is not greatly affected if the sample is put into CEF chamber wet. However, the presence of water droplets on the exhibit causes areas of dilution which have minimal effect on the overall quality of fingerprint produced. However, this trend decreases with increasing transfers (i.e. primary to tertiary).

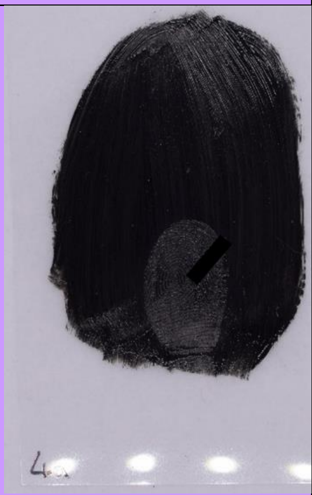
3.4.4 R&D for imaging

As previously discussed, (see section 2.4.3, 2.4.3.1, and 3.3.4 to 3.3.4.3), it is important to capture high quality images, showing all evidential materials on the exhibit. This section summarises angles, lighting, and positioning required to capture ridge characteristics upon feathers and leaves.

3.4.4.1 Exhibits recovery using imaging

As mentioned in section 3.3.4.1, primary transfer was captured in position A and position B. The difference of these are highlighted in table 3.18.

Table 3.18: Showing positions A and B for imagery, comparing two sets of exhibits

Position A (1)	Position B (1)	Position A (2)	Position B (2)
			

The difference between set one, and set two (see Table 3.18), is the amount of anti-climb paint. Set one, is made from one scoop of anti-climb, and set two is made from two scoops of anti-climb paint. The difference that can be seen between both A positions is that the first is shinier, caused by direct light impingement upon the exhibit. The key difference between both B positions is that the first sample looks more matte. The reasons for both of these differences are due to the amount of anti-climb paint.

However, there is a need for both of these positions due to each position highlighting different areas within the fingerprint. These positions ensure that all ridge detail is captured.

When the primary transfer was flat on the surface, the detail of the ridges (if present) cannot be seen. This is why position C (see section 3.3.4.1) was also used alongside positions A and B. An example of the difference between positions A , B and C can be seen in figure 3.11.

Figure 3.11: Showing from left to right, position A, position B and position C. All the same exhibit

Therefore, for primary transfers, images needed to be obtained in positions A, B, and C. However, this finding did not apply to secondary and tertiary transfers. Imaging these exhibits using position C, caused some of the ridges to be lost in the image taken. This was due to there being direct light behind it which can cause some of the ridges to look thinned. A way to resolve this issue was to have the exhibit a few inches off the surface, so some light can get behind, but not enough to lose some of the ridges. An example of the difference between them can be seen in figure 3.12.

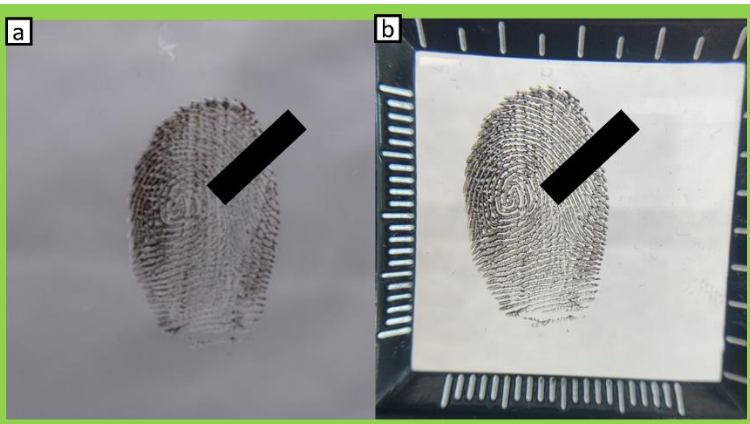


Figure 3.12: Showing different positions. (a) shows position C and (b) shows position D. The same exhibit

3.4.4.2 Provil enhancement results

Yellow Provil was used for this research, which made it hard to see the recovered fingerprint causing analysis to be difficult, due to poor contrast. A lamp was used when the fingerprint was of good quality (grade 3 or 4), due to it being able to show the contrast of the superglue and the Provil, at a certain angle.

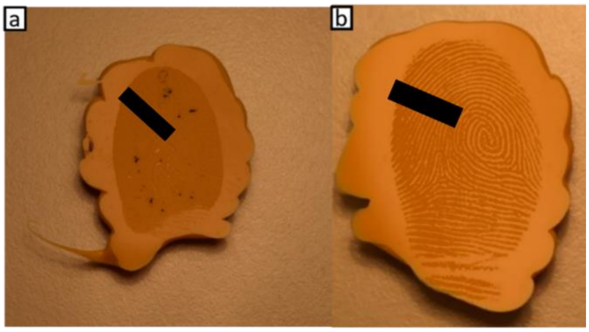


Figure 3.13: Provil of poor quality (grade 0-1) in (a) compared to Provil good quality (grade 3-4) in (b), using a lamp

As can be seen in figure 3.13, the lamp provided contrast between the ridge details and the Provil cast. However, this method will only work on good-quality Provil casts, i.e. those showing good ridge depth. This ridge depth allowed for a different texture to be observed which improved the visualisation of ridge detail. Due to this technique not being appropriate for all grades, a method stated in 3.3.4.2 was developed to use on all Provil casts.

Black ink was considered to be a suitable method for enhancing ridge detail on these Provil casts. The cast was first pressed into an ink pad however, this resulted in an accumulation of ink which masked ridge detail. A method, therefore, needed to be developed to remove excess ink, without this leaking into the furrows of the positive impression created in the Provil cast. A series of methods were attempted however, the use of J-lar tape was the most successful method investigated. The J-Lar tape allowed for the removal of excess ink as well as aiding the transfer of this into the creases. Repeating applying the tape, and removing it, is necessary to provide the best contrast as differences in the amount of ink deposited as well as the quality of the cast varied between exhibits. Excess ink could either make the ridges stand out more or conceal them. The figure below 3.14 shows this inking process on a Provil cast.

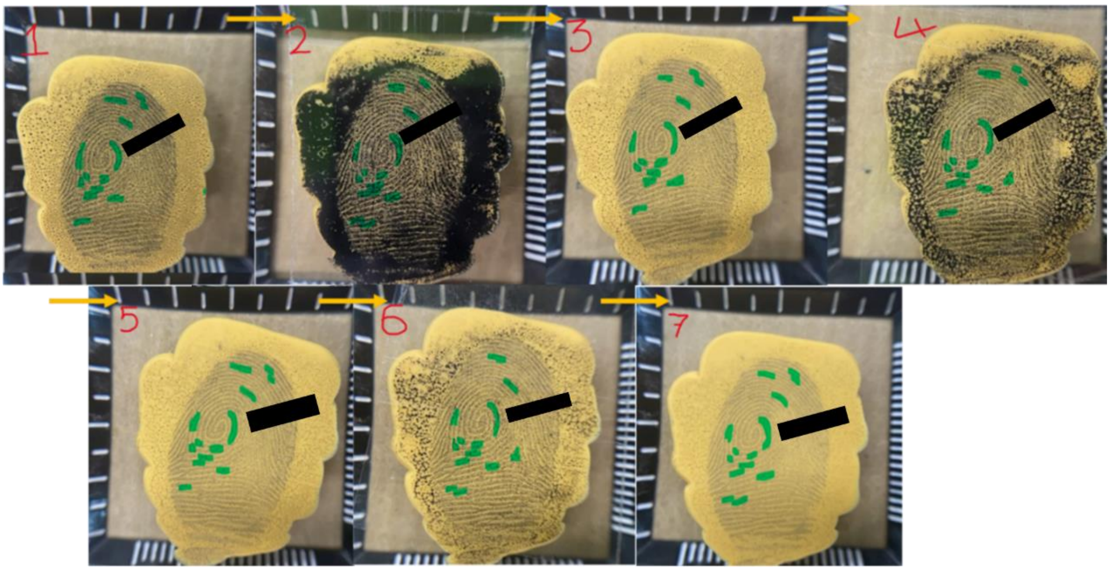


Figure 3.14: The steps of the inking process on one Provil cast

Once all the steps have been photographed, they are then analysed and graded. From the data, the best one which shows the best grade will be used to represent that cast, which can be seen in figure 3.15. This is done instead of finding the mean, as the cast is not changing. It is just the ink which is being dispersed into the ridges which are revealing the characteristics.

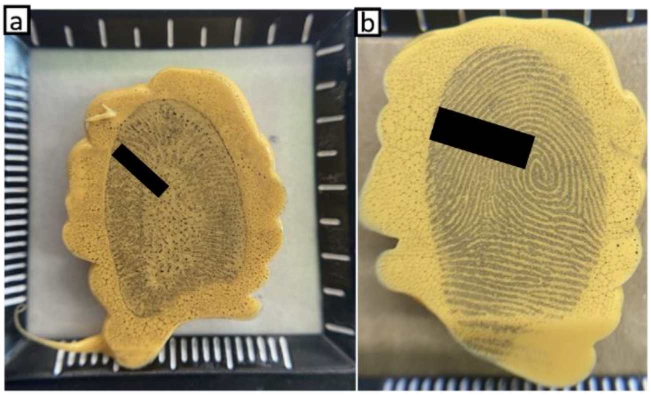


Figure 3.15: Provil of poor quality (grade 0-1) in (a) compared to Provil good quality (grade 3-4) in (b), using inking method

The method that was developed was better, as the ink was able to get into the grooves of the cast or attach to the ridges that were present. J-Lar tape was used to remove the excess ink as it is widely used in forensic investigation for the recovery of fingerprints. Each stage would be shown for each sample, but the final grade would be the point at which the Provil cast shows the most detail, which varies between casts. The reason for a mean not being shown to be used for the final grade is due to the method revealing details as it progresses. In some cases, the J-lar piece on top is showing more detail of the fingerprint than without and vice versa. Therefore, each removal and placement of the tape need to be photographed.

Using J-lar tape not only removes the excess ink but also creates a lift of the fingerprints present (see 3.16 image) on the Provil cast.

Figure 3.16: J-lar tape created ink fingerprint from the inking process

The ink can also be removed without causing damage to the Provil or the impressed ridge characteristics present on it. A disadvantage is that it is a time-consuming process, due to the number of photos captured, and the time to take on and off the J-lar tape. Another disadvantage is the ink could be smudged by a glove when placing the J-lar tape on, meaning the process would have to be repeated (showed in figure 3.17)., but would not lead to the destruction of evidence.

Figure 3.17: The inking process, showing when the glove can get caught in the tape, causing the ink to be removed

3.4.4.3 Resin results for imagery

The light box was the best option for pre-and post-images. There were only a few disadvantages, caused by the shine and transparency of the resin, causing light reflection. This would only become an issue if the reflection was obscuring the ridges, meaning the full fingerprint would not be able to be seen (see figure 3.18)

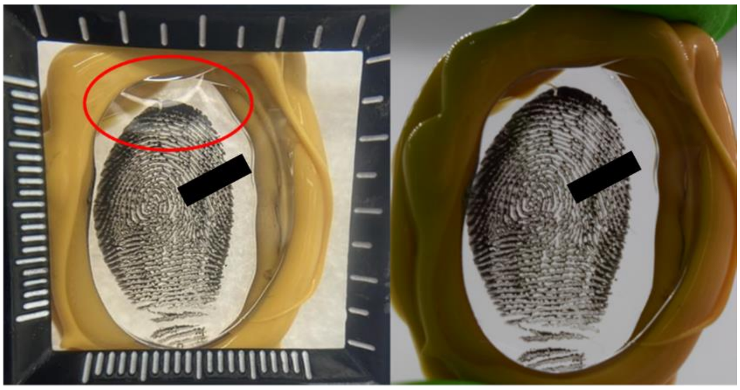


Figure 3.18: Issue with reflection highlighted in the first image, compared to no reflection in the second image where it was captured in the lightbox

3.5 Conclusion

To conclude, it is possible to develop and recover fingerprints that have been made from anti-climb paint. Due to the ‘wet’ and ‘slippery’ composition of the anti-climb paint, the best way to preserve the fingerprints is to run them through CEF. This technique caused the anti-climb paint to become matte, allowing room for error. For example if something may happen to touch the exhibit by accident, it will not disturb the paint or the fingerprint. This would also be applicable when needing to transport the exhibit. If a safe transportable CEF chamber was made, samples can be run in-situ. This then limits the chances of losing or damaging the fingerprint.

Provil and resin were chosen to be investigated to determine if they would be an appropriate methods for recovering the fingerprints. They both had advantages and disadvantages when tested on CEF anti-climb paint as well as non-CEF anti-climb paint.

Provil with CEF allowed for fingerprints to be captured without destruction. The only time this was not true, was with primary transfers when there was an increased amount of anti-climb paint. The Provil cast would reflect the anti-climb paint fingerprint. When there was a good quality fingerprint this would create a good quality cast. When there was too much anti-climb paint, it caused a bad quality cast.

The Provil cast itself, had some issues with contrast. The first method to solve this was with the use of a lamp implementing side-lighting. However, this would only provide good contrast on casts which were of a grade 3 or 4. The other difficulty with this method was the angle of the lamp was hard to replicate each time. Due to this the second method was developed, known as the inking process. This provided good contrast for the white residue on the Provil cast. Depending on the grade of the cast, would depend on where the ink was pushed into, either the cyanoacrylate fingerprint ridges on the Provil surface, or the crevices made from too much paint. Due to the non-destructive feature of Provil, it meant that if not all of the ridges were captured, the original fingerprint is still intact and can be used for imaging comparison instead. Another way in which contrast could be improved is by using stains within the cyanoacrylate ester before fuming. This was not investigated within this study but potentially can be within future research.

Disadvantages within Provil was that occasionally, upon removal, it would pull away/tear the paint. This only, on average, happened a few times within the primary transfers. This was not considered an issue within this research as it did not remove any of the ridges present, however it should be noted as it could potentially happen within exhibits.

Another disadvantage is due to the size of the chamber. It takes a long time to run the samples (80 minutes), however, this issue could be overcome by potentially making/using a smaller chamber. Different experiments would have to be run with the new chamber, as there could be the issue of overdeveloping the fingerprint, leading to the ridges not being able to be seen in recovery. Future improvements could look at carrying this out in the field, and on sample surfaces that are more applicable to the real world.

It was discovered that Provil can be used on fingerprints made from wet anti-climb paint, without the need for enhancement. However, due to the wet paint, it meant that greater care was needed when handling the exhibit as well as the Provil cast. For example, if errors were made this could destroy the fingerprint

Resin with CEF allowed for the fingerprints to be recovered and preserved in a hard transparent shape. Resin did not affect the quality of the grade or cause any damage in the process of hardening. As it is transparent, it reflects the grade of the fingerprint present. For example, if there was a bad grade of 0, then the resin piece would also be 0, and if the fingerprint was a grade 3, the resin piece would also be a grade 3.

Provil rings were made to put the resin in to harden on the fingerprint. However, there were issues with the resin leaking which meant that removal of the Resin-Provil complex could not happen. This was not an issue within this study, due to black anti-climb paint and transparent acetate sheets. This could be a potential issue on exhibits where there is a lack of contrast in colours. Due to this, other materials should be investigated to figure out what would be the best way to prevent leaking.

Removing Resin-Provil complex, there came some potential risks, however these did not occur all the time, just in some samples. The removal caused the ripping/tearing of the anti-climb paint, where the ridges were present causing the loss of them. There was also an occasion where the acetate also ripped upon removal of the complex. These issues could be associated with the acetate sheet; however this is not determined and would need to be further investigated.

When CEF was not used, the only difference was the Resin-Provil complex would transfer the anti-climb paint to other surfaces, meaning the fingerprint could not be preserved.

The use of the environments showed that anti-climb paint can be developed and recovered from temperatures up to 35C and down to -18C, as well as wet. This would apply to situations of the 'real-world' weather conditions in the UK. Relating to this, the average person will not measure out the anti-climb when using it, so thick and thin quantities were compared. It was sufficiently supported throughout this study, that as more transfers increase, the quality of the fingerprint increases. It was understood that this occurred due to the decrease in anti-climb paint. If this is applied to 'real world' situations, when there is too much paint within the primary, or secondary transfers to capture ridges, the following transfers will capture.

Chapter 4

Overcoming the gap in recovering fingermarks from leaves and feathers

4.1 Introduction to leaves and feathers

As discussed previously, there is currently a limited amount of literature regarding the development of fingerprints on leaves and feathers. Those studies published have focussed primarily on the development of fingermarks from these exhibits, with recovery techniques not considered.

In this chapter, leaves and feathers were investigated to determine if there was an appropriate method in developing and recovering fingermarks placed on them. A primary focus was placed on those techniques currently used within forensic investigation intended for the purpose of developing and recovering fingerprints, as well as other methods which are not intended for the use of fingerprints.

4.2 Development of an experimental procedure

A summary of exhibit types and information, as well as any pre-treatment that was needed, is summarised within this section.

4.2.1. Exhibit information

4.2.1.1 Green leaves information

The green leaves that were used as exhibits originated from Manga Trees of the variety Lippen as shown in figure 4.1.

Figure 4.1: The Manga Tree, variety Lippen. Green leaves on the tree, the brown leaves on the ground

This tree is cultivated in tropical environments, close to sea level. The leaves used for this study originated from Tenerife (Canary Island) (Mejora del Mango en Canarias, n.d). Figure 4.2 highlights a typical exhibit used within this research.

Figure 4.2: Green leaf exhibits, on average

The leaf blades on average were 35 cm long and 10 cm wide in size. The veins, midrib, and petiole were yellow/orange in colour, while the leaf blade was green (see figure 4.2). The majority of the leaves had impurities on them such as dirt and did not slit flat on the surface.

4.2.1.2 Brown leaves information

The brown leaves were dried-out exhibits that originated from Manga Trees of the variety Lippen as shown in figure 4.1. Leaves used fell naturally from the tree and were collected from the surrounding area.

The leaf blades on average were 15 cm long and 5 cm wide. The veins, midrib, and petiole were a red-brown colour, and the leaf blade was brown. The leaves had impurities such as dirt, did not sit flat on the surface and were very fragile which led to some having damage in nearly all exhibits (see figure 4.3).

Figure 4.3: Examples of brown leaves which were damaged before being used as exhibits

4.2.1.3 Feathers information

The feathers used for exhibits were tail feathers originating from pigeons. They were approximately 15 cm – 18 cm in length, and had a gradient colour of black, light grey, and dark grey (see figure 4.4). There were no obvious impurities on the feathers, and they did sit flat on the surface.

Figure 4.4: Example of how the feathers and their gradients of colours looked within this research

4.2.2 Pre-treatment

4.2.2.1 Green and Brown Leaves pre-treatment

The Leaves were washed and cleaned prior to any deposition of fingerprints. Pre- and post- images were taken. This was done for both green and brown leaves. A summary of the procedure can be seen below:

- Put leaves in warm water (in a beaker) with some liquid soap
- Allowed to sit for 5 minutes
- Cleaned individually with a soft sponge
- Left to dry on tissue paper for 10 minutes
- Gently dried with tissue paper

4.2.2.1.1 Sectioning of green leaves

Due to the long length of the green leaves, these were cut up into four or five sections depending upon the length. The approximate length of these sections ranged from 5 cm to 10 cm. Fingerprints were then deposited either using forehead grease or moisturiser using the pressure gauge summarised in section 2.2.3.2

4.2.2.1.2 Sectioning of brown leaves

Due to the brown leaves being small in length, these were cut up into either two or three sections depending on the overall length. The approximate length of these sections ranged from 5 cm to 10. Fingerprints were then deposited either using forehead grease or moisturiser. These were applied with gentle pressure due to the fragility of this exhibit type.

4.2.2.2 Feathers pre-treatment

The feathers were cut up into three sections. These section lengths would depend on the colour gradient of the feather (see figure 4.4), however, they ranged from 3cm – 10cm. Fingerprints were then deposited either using forehead grease or moisturiser using the pressure gauge summarised in section 2.2.3.2.

4.3 Recovery of finger-marks

4.3.1 Recovery using Provil

Provil was applied straight over the powdered fingerprint, left to dry and then removed for both leaves and feathers.

4.3.2 Recovery using Resin

For both leaves and feathers, Provil was used to make a ring around the powdered fingerprint (see section 3.3.2), placed directly onto the exhibit surface. The resin was made (2:1 resin:hardener), poured into the rings (see section 2.4.4) and left to dry for 24 hours.

4.3.3 Recovery using J-Lar

For both leaves and feathers, small sections of J-Lar tape were applied directly onto the powdered fingerprints. Pressure was applied to the tape over the fingerprint and was then removed.

4.3.4 Recovery using gel lift

For both leaves and feathers, small sections of gel-lift (white background) were applied directly onto the powdered fingerprints. Pressure was applied to the gel-lift over the fingerprint and was then removed.

4.3.5 Recovery of wet conditions

Moisture was applied to leaves (green and brown), and feathers in order to investigate the suitability of various development methods for the recovery of fingermarks from wet exhibits.

4.3.5.1 Recovery of wet Leaves

The leaf (each section) was sprayed with five pumps of cold water. These were then placed into the CEF chamber.

4.3.5.2 Recovery of wet Feathers

Two exhibits were sprayed with five pumps of water and left on the lab bench to dry. Two other exhibits were sprayed with five pumps of water and were not allowed to dry. All four of these exhibits were then placed into CEF on the same day.

4.3.6 Recovery using imaging

Both types of leaves needed direct lighting and angles created from side-lighting in order to capture the full fingerprints.

Feathers needed direct lighting and angles of the exhibit in order to capture the full fingerprint.

4.4 Results and discussion

4.4.1 Results and discussion of using Cyanoacrylate Ester Fuming

Some preliminary tests were conducted to find the optimum development conditions for leaves and feathers. These are summarised individually below.

4.4.1.1 R&D recovery of fingerprints using CEF from leaves

Typical development times and temperatures for cyanoacrylate ester fuming vary greatly. However, previous research has shown an optimum development method of 18 – 25 minutes at 120 ^{o}C (Hiroi, 2018) for similar exhibits. Therefore, leaves were developed at 120^{o}C for 23 minutes. A white hard residue was observed, this was then visualised using white light at multiple angles which resulted in the visualisation of fingerprint characteristics.

Previous results (chapter 3) showed that a lower temperature (100^{o}C) was successful in the development. Therefore, a series of tests were conducted at this temperature between 18 – 25 minutes, however, this proved unsuccessful.

Using the optimum conditions, two green leaves were developed using CEF. One using grease from a forehead to apply the fingerprint, and the other using moisturiser. This was done to determine if the moisturiser would have any effect on the leaf in addition to the grading of the developed fingerprint, as well as determining if there was a significant difference between them.

Table 4.1: Comparison of fingerprints deposited with grease and moisturiser on green and brown leaves

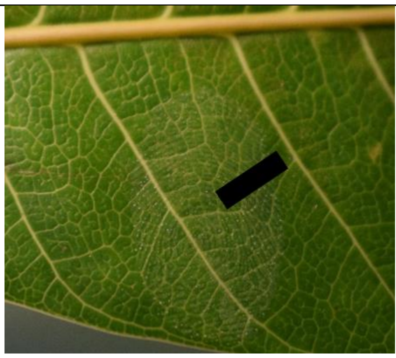
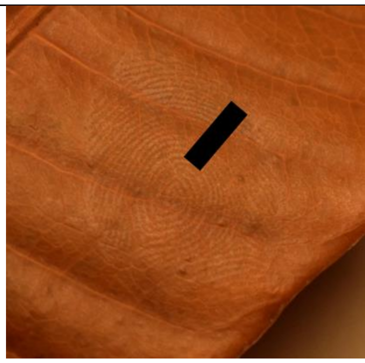
Description	Green leaf	Brown leaf
Fingerprint deposited using Grease	 Grade: 2	 Grade: 3
Fingerprint deposited using moisturizer	 Grade: 2	 Grade: 2

Table 4.1 shows the difference between the deposition of fingerprints on leaves using moisturiser and grease. In relation to the fingerprints deposited upon green leaves, the grading remained consistent throughout the multiple exhibits used. However, it was noted that on occasions, a shiny transparent feature appeared on those exhibits where the fingerprint was deposited with moisturiser, as highlighted in figure 4.5. For this research, this feature has given the term ‘halo’.

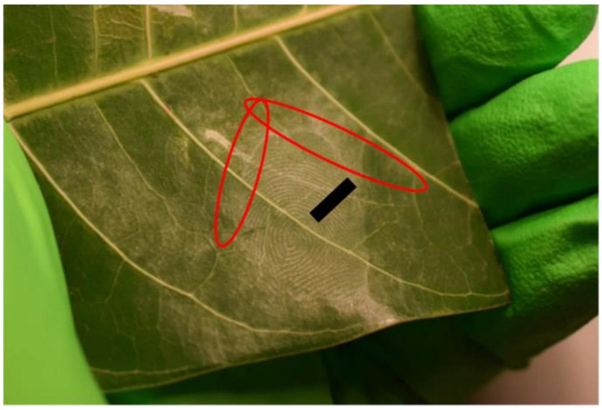


Figure 4.5: section of green leaf, fingerprint deposited with moisturiser. Highlighted in red shows the feature termed ‘halo’

The appearance of the 'halo' (see figure 4.5) did not affect the grading for the exhibits used within this research, however, it must be taken into account for future exhibits, as it may lead to the masking of ridge detail. It was noted that the 'halo' only appeared in green leaf exhibits. This may be due to the difference in porosity between green and dry leaves. However, this would need to be further investigated in the future.

In relation to green leaves, grading was affected by the venules present on the leaf. These characteristics as well as dipped and raised areas, caused by the veins, affected visualization of ridge detail which led to a lower grading being assigned. When compared to brown leaves, the grading decreased for the fingerprint deposition using moisturizer however, this may be due to the fragility of the leaves causing the pressure gauge to not be used (section 4.2.2.1). This caused increased difficulty when trying to replicate pressure and stability over multiple exhibits. This issue was not as pronounced with those fingerprints deposited with grease, as it was easier to control deposition. These problematic issues combined with the use of moisturiser may have caused the slipping of the finger resulting in a smudged fingerprint. Due to these issues, a greater focus was placed on fingerprint deposition using grease, however, it is not possible to replicate the amount of sebaceous deposits, therefore moisturizer was used as a control as this can be replicated over multiple exhibits.

Another noticeable difference between green and brown leaves was contrast. In green leaves, the texture presented light and dark tones which hindered the visualisation of the white residue fingerprint. When compared to brown leaves, a consistent tone was observed which provided a good contrast for the white residue fingerprint, leading to a higher grade being assigned.

4.4.1.2 R&D recovery of fingerprints using CEF from feathers

Based on the research observed from leaves (section 4.4.1.1) using the CEF chamber, the same optimum temperature and time were investigated for feathers. However, these conditions did not produce any visible white hard reside as observed previously. The exhibits were also powdered post-development which did not produce any visible fingerprints.

Following some research (McMorris, Farrugia and Gentles, 2015, and McMorris *et* al., 2019), a second test was carried out by increasing the time to 45 minutes at 120^{o}C. A series fingerprints deposited with moisturiser and grease were developed on feathers using these optimum conditions. One using grease from the forehead as a deposit and the other using moisturiser, similarly to the procedure summarised previously. This was done to determine if the moisturiser would have any effect on the feather in addition to the grading of the developed fingerprint, as well as determining if there was a significant difference between them.

Table 4.2: Comparison CEF+physical developer and physical developer alone, on depositions made with grease and moisturiser

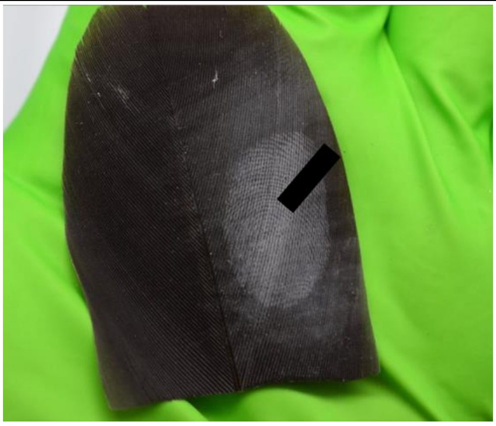
Development method	Grease	Moisturiser
CEF & physical developer (white magnetic powder)	 Grade: 2	 Grade: 2
Physical developer (white magnetic powder)	 Grade: 2	 Grade: 2

Table 4.2 shows the comparison of the fingerprints deposited with grease and moisturiser in the presence and absence of CEF. Unlike other samples, no hard white residue was observed when developing fingerprints on feathers, however, when powdered the fingerprints were made visible. Enhancement was also possible with the sole use of a physical developer. The physical developer that was chosen was black and white magnetic powder. Having both black and white magnetic powders, was due to contrast as the feather has a gradient of black, light grey and dark grey (figure 4.4). This meant that black magnetic powder would not be visible on the black areas of the feather, so white was needed to provide this contrast in these areas.

No differences were observed when handling and grading these exhibits, showing that the CEF development had no observable effect on the quality of fingerprints produced. All fingerprints shown in table 4.2, were graded as 2, however the barbs (section 2.5.2) severely hindered grading on all exhibits. Equally the substance used for the production of fingerprints (grease and moisturiser) had little to no effect on the grading of the fingerprint produced.

A potential reason for the increased development time for feathers may be related the differences in structure. As summarised in figures (2.25 figure leaf components and 2.26 figure for feather component), the structure of feathers is held in place by the presence of barbs and barbules whereas for leaves the blade structure is made of venules and veins. These allow for a more stable structure. It is believed that there is a presence of voids within feathers which could affect cyanoacrylate ester attachment, this is something which should be investigated in the future.

In order to determine the usefulness of CEF application, an experiment was conducted by applying physical developer with the absence of prior CEF treatment. These results are shown in table 4.3.

Table 4.3: Showing pre- and post- application of physical developer on fingermarks deposited with grease and moisturiser

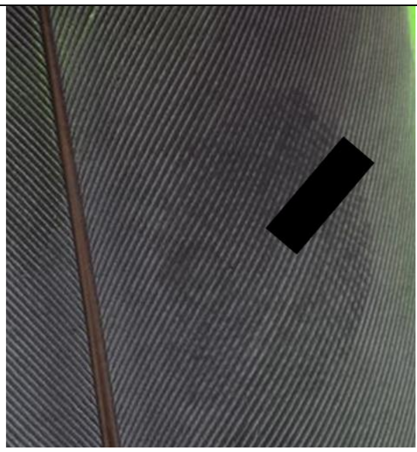
	Grease	**Moisturiser**
Pre-application of physical developer	 Grade: 0	 Grade: 0
Post-application of physical developer	 Grade: 2	 Grade: 2

Table 4.3 shows that there is no difference in grade obtained between CEF & physical developer with physical developer alone.

A noticeable occurrence that occasionally happened with this exhibit type were patterns termed ‘dilution patterns’. These were observed for both fingerprints deposited with grease and moisturiser and developed with CEF & physical developer as well as physical developer alone. This dilution pattern can be seen in figure 4.6. where (a) shows the ridges appear to stop abruptly with the diluted pattern occurring parallel to them. Reasons for this happening could be due to the fingerprint being too ‘wet’ or ‘fresh’ before development or also due to the makeup/material of the feather (see section 2.5.3), it could have absorbed the fingermark deposit.

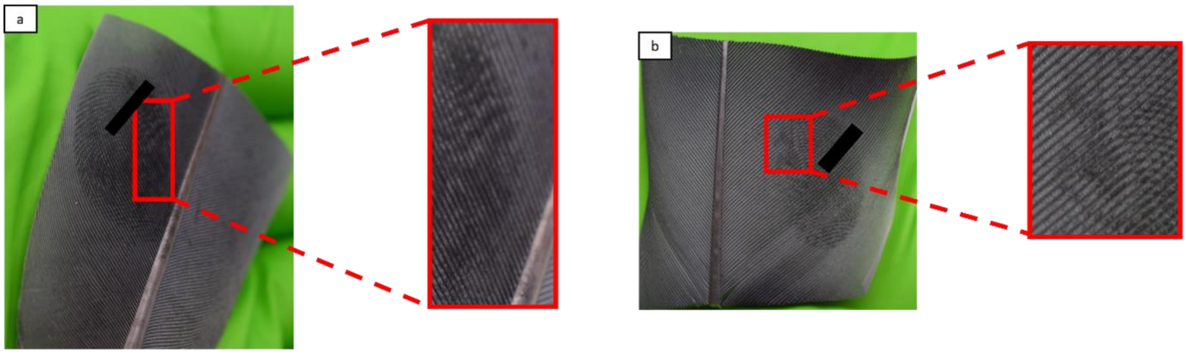


Figure 4.6:Showing feathers examples (a) and (b), showing magnification in red box where the dilution pattern occurred

4.4.2 Results and Discussion on recovery using Provil

As mentioned previously Provil can be used for many areas inside and outside of the forensic field (see section2.4.5). This Provil method was tested with various other fingerprint powders.

4.4.2.1 Green Leaves (physical developer)

Figures 4.7 and 4.8 shows the difference between moisturiser and grease after the application of physical developer (black magnetic powder) and the recovery using Provil. Black magnetic powder was chosen as the physical developer for this exhibit due to it being able to work well on surfaces with texture (see section 2.3.1). It allows development on dipped and raised surfaces without causing ‘caking’ (Rajan, Zakaria, Shamsuddin and Nik Hassan, 2020).

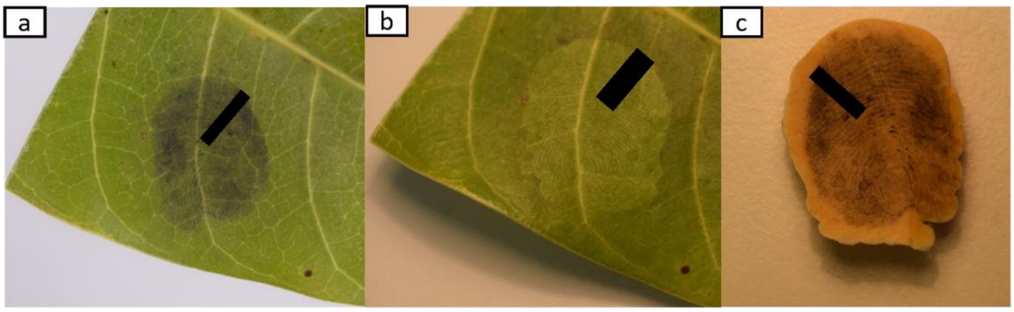


Figure 4.7: Moisturiser used to deposit the fingerprint on green leaf. (a) showing the physical developer (black magnetic) on fingerprint, (b) showing the exhibit surface post-removal of Provil, and (c) the Provil cast

From the figure above (figure 4.7), the powdered fingerprint which was deposited with moisturiser was of low quality, grade 1. Reasons for this could be the superglue did not adhere, so the moisturiser was still ‘wet’ so smudged (4.4.1.1). After the removal of the Provil cast, the outline of it can be seen, as seen in figure 4.8 (a), which also occurred within other samples 4.8 (b).

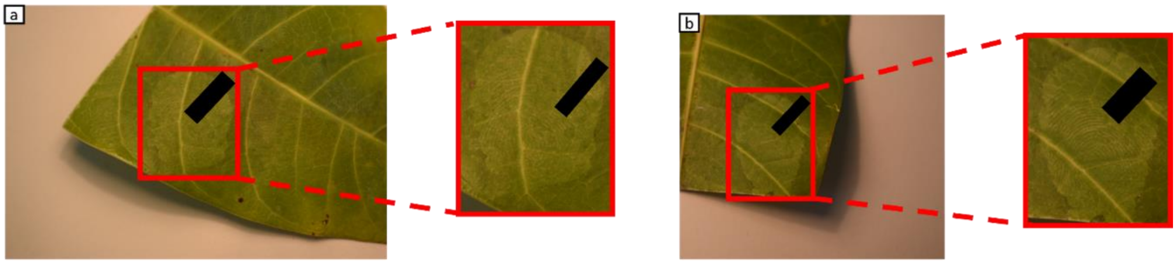
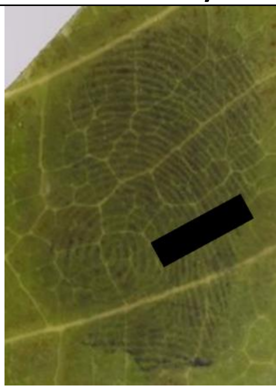
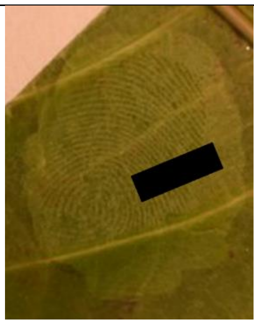


Figure 4.8: Green leaves powdered with black magnetic. Magnification shows the mark left by Provil, seen in both (a) and (b)

This could be due to the powdering. There could be a presence of the powder surrounding the fingerprint area, and the removal of the Provil cast has removed all the of powder in the section. However, this is not a definite conclusion, as it could be the Provil which is making the leaf lighter, but this would need to be further investigated within future research. Additionally, post-removal ridge characteristics were still visible on the leaf.

Table 4.4 : Green leaf grease fingerprint deposit, developed with black magnetic powder and recovered with Provil

	1st recovery	2nd recovery	3rd recovery
Development with physical developer (black magnetic powder)	 Grade: 3	 Grade: 3	 Grade: 3
Post-recovery with Provil	 Grade: 3	 Grade: 3	 Grade: 3
Provil casts	 Grade: 3	 Grade: 3	 Grade: 3

As seen in table 4.4, the grading of each fingerprint remains consistent throughout each step, from development to recovery. This highlights that the procedures are non-destructive as no damage or change to the fingerprint occurred.

As mentioned previously within this section, ridge characteristics were still visible on the leaf post-recovery. Therefore, secondary and tertiary recovery techniques were attempted using the same procedure as that used for primary recovery (i.e., development with black magnetic powder and recovery with Provil). This was done to just see if it was possible to be recover multiple lifts without the decreasing quality or grade.

Comparing the first, secondary and tertiary casts, an observation can be made that ridge characteristics are more prominent within the secondary cast. This may be due to a better contrast occurring due to the presence of additional developer or due to the powder having better adhesion. However, it was not deemed necessary to recover the fingerprint more than once as no noticeable improvement to quality or grade was observed. Secondary or tertiary recovery should only be attempted if surface contaminants are present, causing the masking of ridge characteristics.

Due the morphology of the leaf as well as the presence of venules and veins, the Provil cast does not cure flat. Once cured, the cast cannot be manipulated. This could be seen as a disadvantage due to the Provil surface (side with the fingerprint on) 'bending/curving', see figure 4.9, meaning imaging may not pick up all of the ridge detail present. Multiple images may need to be captured if this occurs.

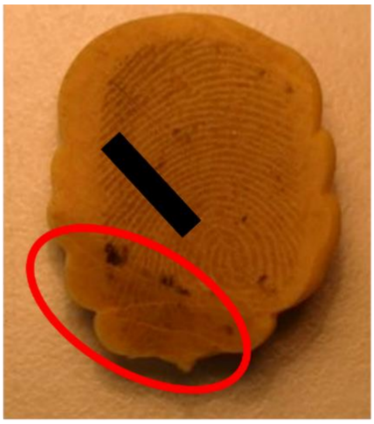


Figure 4.9: Provil cast which has the 'bending' hightlighted in red due to the uneven surface of the leaf

An advantage of recovering with Provil after powdering means that there is no need for enhancement for contrast. It also allowed recovery to be done multiple times without the deterioration or degradation of the grade of the fingerprint, showing it is non-destructive.

4.4.2.2 Brown Leaves (physical developer)

Figure 4.10 and table 4.5 shows the difference between moisturiser and grease after the application of physical developer (black magnetic powder) and the recovery using Provil. Similarly to green leaves (section 4.4.2.1), black magnetic powder was chosen due to it being able to work well on surfaces with texture (see section 2.3.1). It allows development on dipped and raised surfaces without causing 'caking' (Rajan, Zakaria, Shamsuddin and Nik Hassan, 2020).

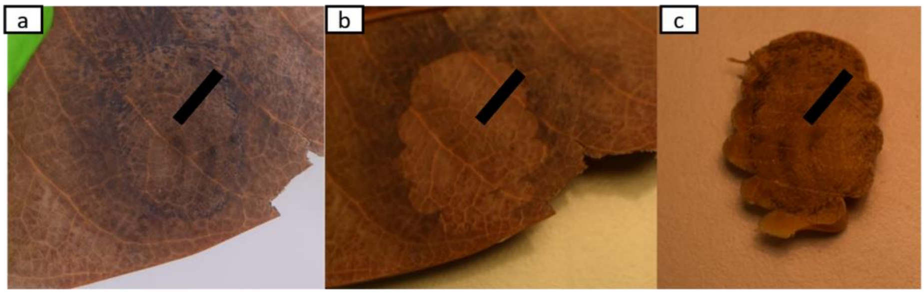
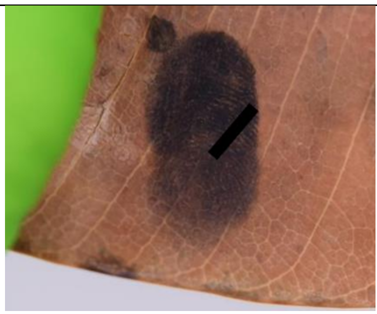
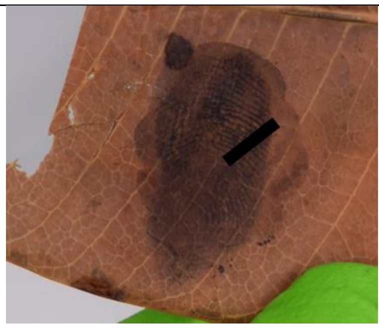
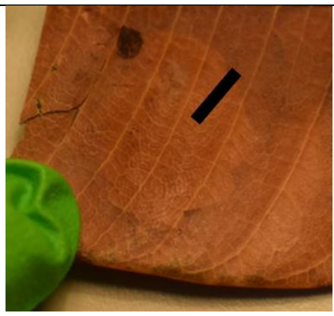
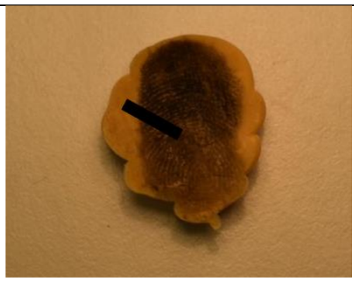
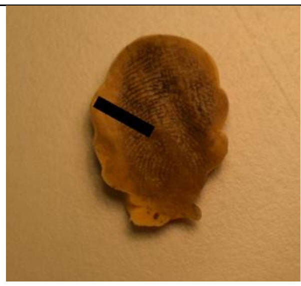


Figure 4.10: Moisturiser used to deposit the fingerprint on brown leaf. (a) showing the physical developer (black magnetic) on fingerprint, (b) showing the exhibit surface post-removal of Provil, and (c) the Provil Cast

From the figure above 4.10, the powdered fingerprint which was deposited with moisturiser was of low quality, grade 1 consistent with observations made for green leaves (section 4.4.2.1). Similarly, to green leaves, the removal of Provil caused the shape to be left on the exhibit surface. However, in this case it seems more obvious that it is black magnetic powder surrounding the fingerprint area. This seems to be the cause of the pattern, as the fingerprint area does not look any lighter compared to the areas further out. The surface does not show any presence of fingerprint after the removal of Provil. The Provil picked up the powder that adhered to the fingerprint, so it is the same grade 1 (poor) as the fingerprint.

Table 4.5: CEF+physical developer application, post-removal of Provil, and the Provil cast. Shows first recovery and second, on brown leaf

	1st recovery	2nd recovery
Development with physical developer + CEF (black magnetic powder)	 Grade: 2	 Grade: 2
Post-recovery with Provil	 Grade: 1	 Grade: 1
Provil cast	 Grade: 1	 Grade: 2

As seen in table 4.5 (first recovery) the physical developer showed good adhesion to the fingerprint, where sections of the fingerprint have been overdeveloped. As seen in figure 4.10 (a), very little physical developer adhesion occurred, therefore sections in this exhibit can be considered to be underdeveloped. This variability occurred over multiple samples, where no consistency was obtained. As discussed in section 4.2.1.2, brown leaves were recovered from the area surrounding the tree. No control could have been put into place with the aim of recovering leaves within a certain timeline. Therefore, it is highly likely that different aged brown leaves were used in this study. This could possibly affect the waxiness as well as other factors within the leave, which could contribute to physical developer adhesion.

This variability in adhesion also affected the grade of the casts recovered, where the primary cast was assigned a grade of 1 and the secondary cast was assigned a grade of 2. In this case, multiple recoveries were deemed necessary as it allowed for improved quality. This finding is similar to processes carried out within practice, where J-lar tape is used to remove excess physical developer as well as recovering the fingerprint. The differences between the recovery using J-lar tape and Provil recovery is that Provil picks up all of the physical developer present (4.11 (a)), whereas the J-lar tape only picks up small sections on each lift (figure 4.11 (b)). An example of these differences can be seen in figure 4.11.

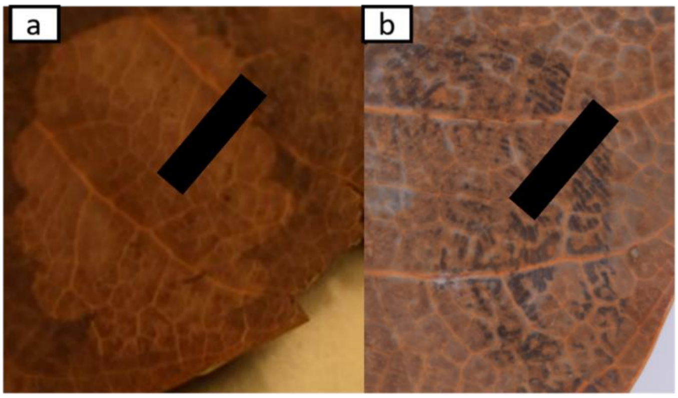


Figure 4.11: Provil captures all of the powder (a), and J-lar does not (b)

4.4.2.3 Feathers (physical developer)

As summarised previously (section 4.4.1.2), it is possible to recover high-grade fingermarks from feathers. There was no observable difference in grade when comparing the use of CEF+physical developer with physical developer alone. In order to determine if there is any benefit for recovery between CEF+physical developer and physical developer, a series of tests were conducted.

Table 4.6: Comparison of CEF+physical developer, and physical developer alone on Provil recovery process

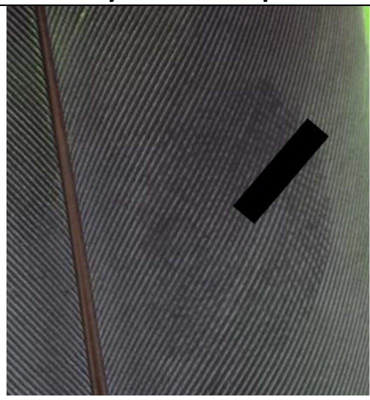
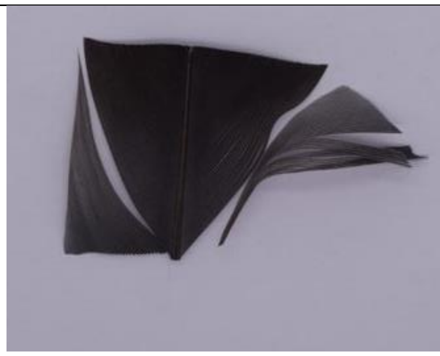
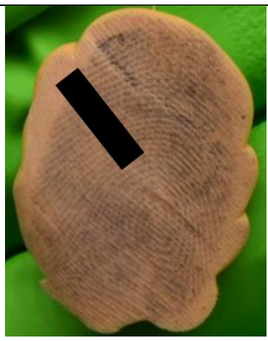
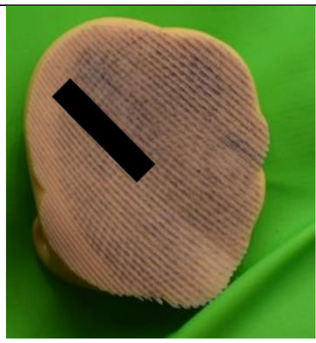
	CEF & physical developer	Physical developer
Post-treatment	 Grade: 3	 Grade: 2
Post-Provil recovery	 Grade: 0	 Grade: 0
Provil cast	 Grade: 3	 Grade: 0

Table 4.6. shows the effect of Provil recovery. On average, a higher grade was obtained when recovering fingermarks using Provil after CEF application. An observation can be made that the barb texture was more predominant in the physical developer compared to CEF&physical developer. This is possibly due the CEF adding a layer of cyanoacrylate ester onto the fingerprint and feather preventing some seepage of the Provil. Additionally, the presence of barbs and barbules are thought to contribute to the quality of fingermark recovered. Provil recovery resulted in damage to the exhibit, however it was noted that different amounts of damage occurred for different sections of the feather.

The removal of the Provil looks to have caused more damage from the middle section of the vanes, compared to the bottom area (see section 2.5.2). This could be due to the rachis/shaft being thinner, implying that there is less support for the barbs. As mentioned in section 2.5.2 between the barbs, there are barbules. The Provil has caused the separation of these barbules and the barbs. Potential reasons this could have happened due to the initial state of Provil where this is applied in a viscous liquid form, which could have imbedded in between the barbs but not the barbules, and when it dried/hardened, it caused pulling. In some exhibits, the Provil cast removal additionally resulted in the barbs curling backwards, and caused separation, as seen in figure 4.12. This could have been due to the removal technique or the thicker shaft causing the barbs to be more intact.

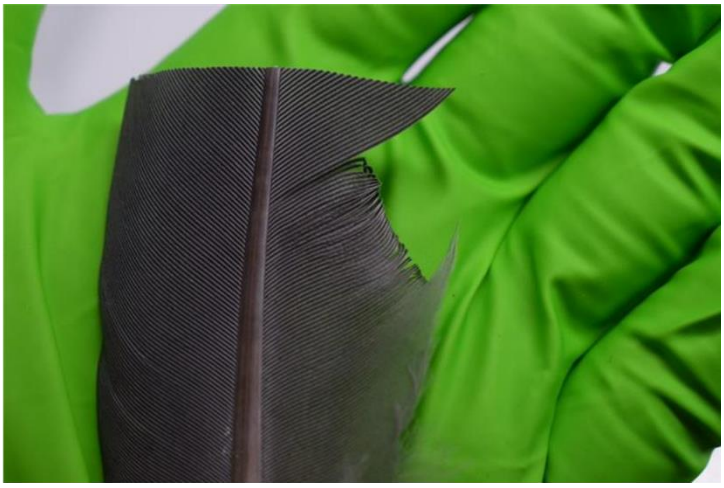


Figure 4.12: Barbs curling backwards due to the removal of Provil

Therefore, this Provil recovery is method is destructive to the feather so it would not be the best method to recover for feathers.

4.4.3 Results and Discussion on recovery using Resin

As mentioned previously (section 2.4.4), Epoxy resin has been used a limited amount within the Forensic field (Dittmar, Errickson and Caffell, 2015; Jin, Li and Park 2015; Falland-Cheung et al., 2017). It has been used to embed tissues and paint chips, as well as used for a skull stimulant. However, it has not been used on leaves, or feathers (as of date of submission that could be found) to recover powdered fingerprints. Therefore, this technique was investigated for green and brown leaves as well as for fingermark recovery from feathers. These results are shown in the following sections.

4.4.3.1 Green leaves recovery with Resin

As summarised in section 4.3.2, a Provil ring was applied to the exhibit in order to contain the liquid resin complex until this has cured. Epoxy resin was used as specified in user instructions (section 2.4.4). The development and recovery process for green leaves is summarised in figure 4.13.

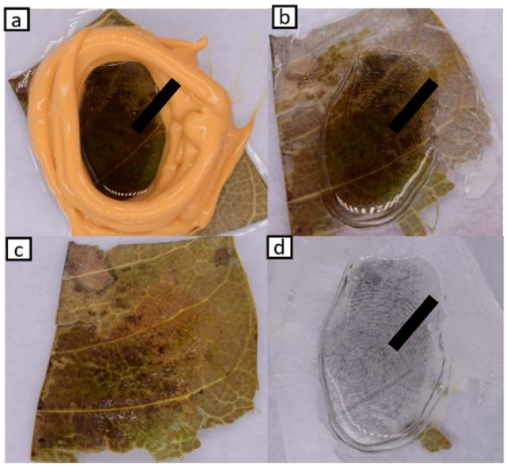


Figure 4.13: Green leaf process with Resin. (a) is set resin, (b) the removal of Provil ring, (c) surface post- removal of the resin, and (d) is the Resin Piece.

As shown in figure 4.13, the grade post- powdering was a 3, however after the setting of the resin and the removed resin piece it was graded a 2. This was due to contrast reasons. When the resin piece is on the leaf, the powder and the leaf colour looked too dark to provide enough contrast. This could be due to the Provil ring blocking the light that is being allowed in.

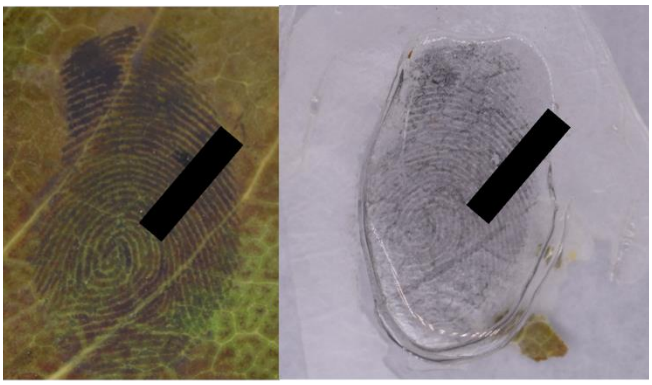


Figure 4.14: The comparison of powdered fingerprint, and the Resin piece post removal from green leaf

When the resin piece has been removed (figure 4.14), it looks as though the resin has not set flat causing there to be an increased level on one side, making visibility difficult. Unlike chapter 3 (section 3.4.2.2), where the resin could be turned over for visibility, the underside of the resin captured the texture of the leaf (see figure 4.15) which has caused the ridges to be difficult to see. A small amount of damage was caused from the removal of the Resin-Provil complex, where a part of the leaf has been picked up in the removal process (figure 4.15). This method does preserve the fingerprint, but it does limit the chances of recovery multiple times if it is needed.

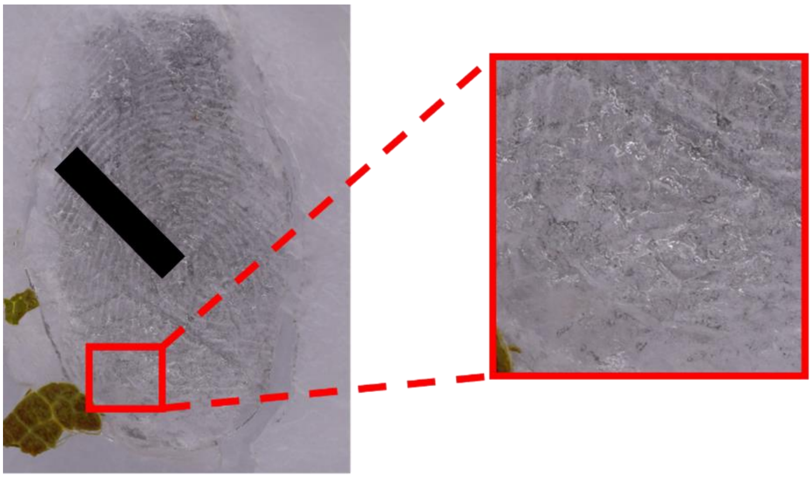


Figure 4.15: The reverse side of the resin piece from the green leaf. In the red box shows the magnified version, highlighting the textured surface made from the leaf.

It is believed post removal of the resin piece left the leaf 'wet' or not cured all the way through. It is believed this due to the leaf having a shiny appearance after the removal of the Resin-Provil complex (see figure 4.16). Factors which could affect the curing time could be the temperature and humidity of the laboratory room, the temperature of the resin and Provil ring, and/or incomplete mixing of the resin and hardener mixture.

Another factor that was noticeable was a slight leakage of the resin. This could be due to the leaf surface not being flat, the texture causing gaps between the Provil ring and the surface of the leaf, or there could have been gaps within the Provil rings. However, this leaking did not seem to cause an issue, as the Resin-Provil complex could still be removed. This could have come off as mentioned before the resin could have still been partially 'wet'.

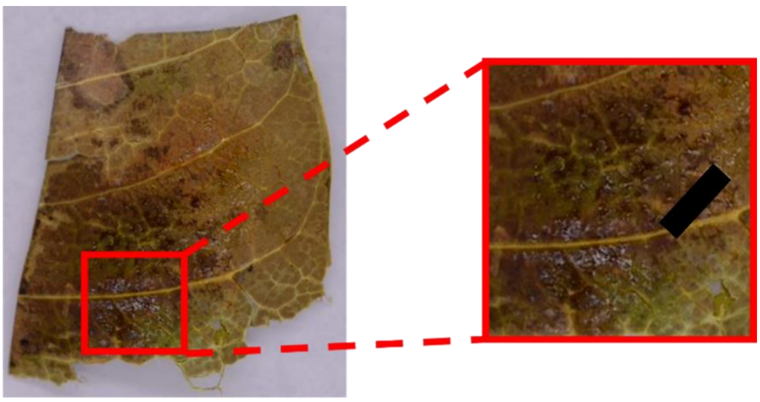


Figure 4.16: Section of a green leaf after the removal of resin. Magnified section in the red box, showing the 'wet' area

4.4.3.2 Brown leaves recovery using Resin

As summarised in section (4.3.2), a Provil ring was applied to the exhibit in order to contain the liquid resin complex until this has cured. Epoxy resin was used as specified in user instructions (section 2.4.4). The development and recovery process for green leaves is summarised in figure 4.17.

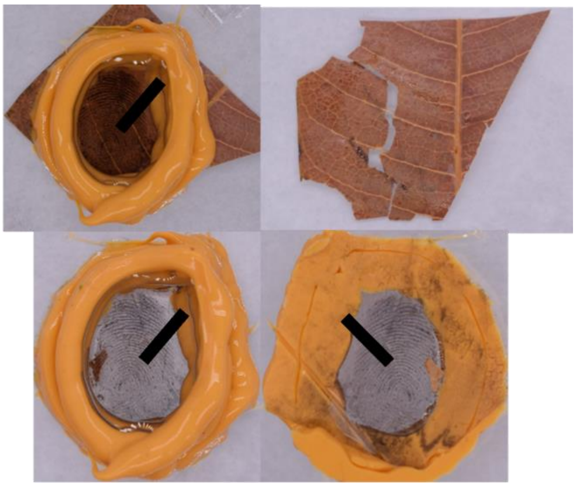


Figure 4.17: Brown leaf resin method. (a) resin set, (b) surface post- removal Resin-Provil Complex, (c) Resin-Provil complex front, (d) Resin-Provil Complex back

As shown in figure 4.17, the powdered fingerprint and the resin set over the fingerprint was graded a 3, however the Resin-Provil complex was graded a 2. The decrease in grade was due to the presence of 'bubbles' which appeared in the Resin-Provil Complex, this is highlighted in red within figure 4.18). These bubbles did obscure some of the ridges on the front side of the Resin-Provil complex. Similar to the green leaf resin piece (see section 4.4.3.1), the Resin-Provil complex could not be turned over for better visibility due to the bubbles present, which still obscured the ridges.

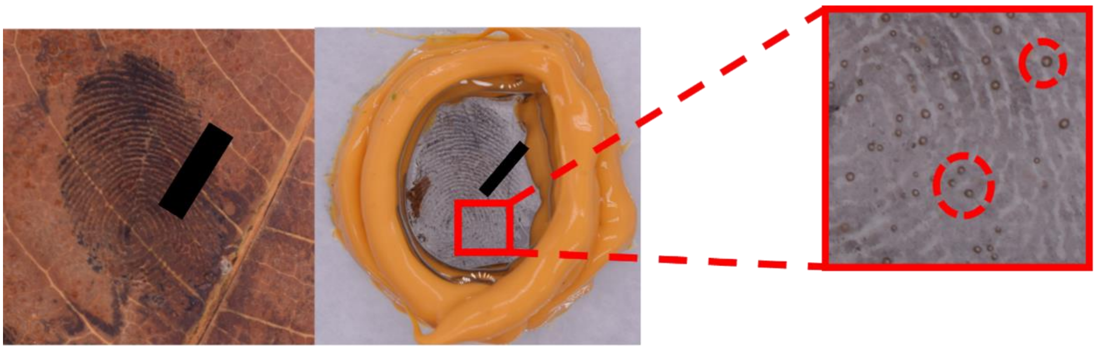


Figure 4.18: The comparison of powdered fingerprint, and the Resin-Provil complex removed from brown leaf. Highlighted in the red box, magnification showing the 'bubble' pattern in the red circles

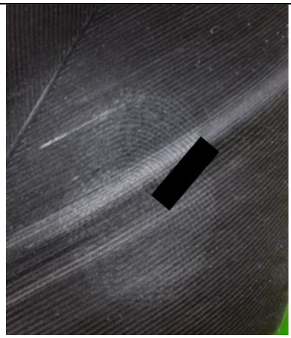
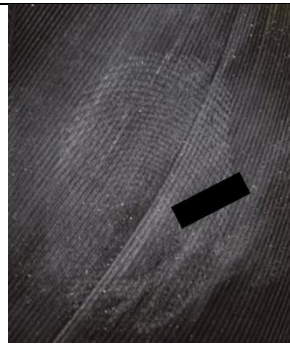
These bubbles are not believed to be air bubbles due to them not being similar to the ones found in chapter 3 (see section 4.18) as these were found to have a dark outer ring. According to the manual, mixing too vigorously (GÉDÉO KIT CRYSTAL RESIN 300 ML | Gédéo resin | Pebeo, 2022) can cause 'bubbles' to appear. However, the mixing process was kept consistent between different exhibits. Other reasons this could have occurred is the Resin process being affected by the brown leaf, the leaf not being as moist, the age of the leaf, and increased fragility causing a crumbling type texture.

It was noted that contrast was not an issue with the black magnetic powder on the brown leaf, even after the resin had set/cured. The resin did not leak from the Provil ring however, the removal of the Resin-Provil complex did cause the leaf to break and a small section attached itself to the resin. The reason the leaf could have broken may be due to its fragility, and not due to the resin method being destructive.

4.4.3.3 Feathers recovery using resin

The resin procedure was followed in order to determine the applicability for recovery of fingermarks from feathers after development with CEF&physical developer as well as physical developer alone. These results are shown in table 4.7.

Table 4.7: Comparison of CEF+physical developer and physical developer alone, using fingerprints deposited with grease and moisturiser, of the recovery using resin steps

	CEF&physical developer		Physical developer	
	Grease deposit	Moisturiser deposit	Grease deposit	Moisturiser deposit
Pre – treatment	 Grade: 0	 Grade: 0	 Grade: 0	 Grade: 0
Post – treatment	 Grade:2	 Grade: 2	 Grade: 2	 Grade: 2
Resin Provil complex	 Grade: 1	 Grade: 1	 Grade: 2	 Grade:1

There was no difference observed between the deposition of fingerprint using grease or moisturiser, with these being assigned a grade of all 2. However due to the barbs causing visibility issues, these could have been higher. Black and white magnetic powder was chosen for contrast. The white magnetic was chosen for the top section of the vane, and black magnetic powder was chosen for the bottom section of the vane. This gave the best results for contrast due to differences in coloration of the feathers.

The powdered fingerprint for grease deposit was graded 2. With the resin set on top, it was graded a 1. The Resin-Provil complex was not attempted to be removed due to the fragility of the feather, and the noticeable resin leakage which occurred. The reason the resin leaked could be due to the barbs and barbules having gaps or could be the presence of air bubbles within the Provil ring. The decrease in the grade is due to contrast issues. A reason for this could be the resin affecting the powder. As resin is a liquid, it could be washing away some of the powder, or could be diluting it into the resin. However, this would need to be further investigated.

The powdered fingerprint deposited with moisturiser was graded a 2. With the resin set on top it was graded a 1. The Resin-Provil complex was not attempted to be removed due to the fragility of the feather, as well as this feather having Provil barrier underneath. This was done to see if this would prevent the resin from leaking, which proved to be correct. However in doing so caused there to be a blocking of light making it very difficult to see the fingerprint, making no improvement for the quality of the fingerprint.

There was no difference that could be observed between the deposition of the fingerprint using grease of moisturiser in physical developer alone. The reason for the grease deposit is has more powder surrounding the fingerprint is due to a different way of powdering. Instead of going with the motion of the barbs, a side-to-side motion was carried out. This was done to see if it would make a difference to the quality of the fingerprint, however no difference in quality was observed. It caused the adherence of the white magnetic powder to the surrounding area and the fingerprint. Reasons could be due to the texture of the barbs which led to an increase in the capture pf physical developer.

The fingerprint deposited with grease was graded 2, and with the resin set on top it was graded a 2. As mentioned before, the original grade of the fingerprint could have been higher, but due to the barbs on the feather, it caused visibility issues. The Resin-Provil complex was not attempted to be removed due to the feather being fragile. This feather also has the Provil barrier underneath to prevent the leakage of resin. It can be seen with the table 4.7, that after the application of resin, the white magnetic powder is not as bright as before, which causes a lack in contrast. Reasons for this could be due to resin affecting the powder, as mentioned previously. At the start the resin is liquid, this could be causing the washing away or dilution of the powder. However, would need to be further investigated.

The fingerprint deposited with moisturiser was graded 2, and with the resin set on top it was graded a 1. The grades could be higher, but due to the barbs texture, the clarity of the grade was affected. The Resin-Provil complex was not attempted to be removed due to the resin leaking, and the feather being fragile. Also as mentioned before, the white magnetic contrast decreases after the resin, due to the resin and powder mixing.

4.4.4 Results and Discussion of recovery using tape lift

As mentioned previously (section 2.4.1), tape-lift is a standardised piece of equipment used within forensic science to recover fingerprints and DNA (Steadman et al., 2015). It is used by CSIs within a crime scene, as well as within the laboratory for exhibits. It was used on fingerprints powdered with black or white magnetic powder, on leaves and feathers.

4.4.4.1 Green leaf recovery using tape lift

Due to previous results (section 4.4.1.1) showing the improved quality of fingermarks deposited using grease, the investigation of tape-lift recovery was only conducted using those deposited in grease.

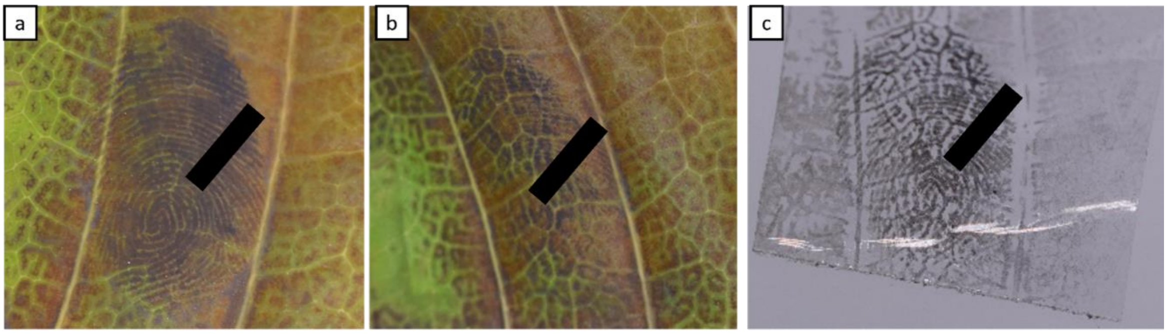


Figure 4.19: Showing the process of tape-lift. (a) is the powdered fingerprint, (b) post-recovery of the surface, and (c) is the tape-lift with the recovered print

Black magnetic powder was used to develop the fingerprint, as it provided good contrast against the green leaf, where this was assigned a grade of 3. After the removal of the tape, ridges can still be seen, without there being powder on them. This post- recovery sample was given a grade of 1. However, the presence of further ridges on the exhibit, signified that the fingerprint could potentially be recovered again to create a better-quality tape-lift, or 'fill in the gaps' of the first tape lift. This is common practice within forensic field, multiple lifts are recovered, layered on top of each other to create a full fingerprint. As can be seen in figure 4 (c), the tape-lift captured ridges but also the textured surface of the leaf. This was graded 1 due to difficulties with clarity when grading, as visibility is limited resulting in a decreased grade. Another interesting observation is that black magnetic powder was picked up from the surrounding area of the fingerprint, which is not visible on the leaf in section a (figure 4.19 (c)).

4.4.4.2 Brown leaf recovery using tape lift

Similarly to reasons presented above (section 4.4.1.1) the fingerprint on these exhibits were only deposited with grease. The results of which can be seen in figure 4.20.

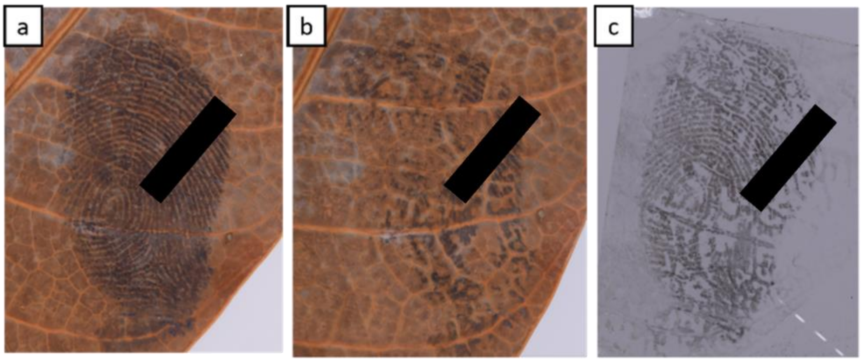


Figure 4.20: Showing the process of tape-lift on brown leaf. (a) is the powdered fingerprint, (b) post- recovery of the surface, and (c) is the tape-lift with the recovered print

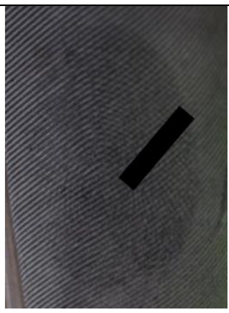
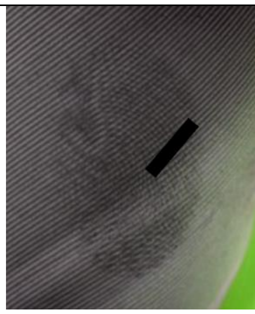
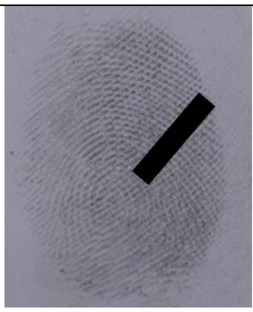
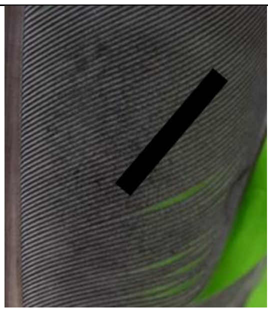
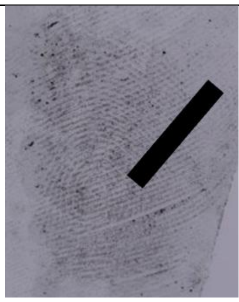
As seen in figure 4.20, the grade of the powdered fingerprint is 3, where the black magnetic powder that was used provided good contrast on the leaf (see figure 4.20 (a)). The post-recovery grade is a 1, due to some powdered ridges that can be seen (see figure 4.20 (b)). The recovered fingerprint on the tape-lift is graded a 2, showing that some of the detail was not captured (see figure 4.20 (c)). This is considered a minor issue as another tape-lift can be done, which is common within practice (see section 2.4.1), to be layered over the top. However, this was not attempted due to the fragility of the leaf. Careful consideration is needed by the examiner before attempting further lifts on this type of exhibit.

Some reasons for the poor capture of ridge retail could be due to the uneven texture of the venules and veins. This could make it difficult for the tape-lift to get into the grooves and can also provide visibility issues of the ridges as the texture has also been captured within recovered fingerprint. Overall the fingerprint that was captured was of good quality, the texture did not allow for the key characteristics which were seen in the powdered fingerprint to be collected.

4.4.4.3 Feather recovery using tape lift

Feathers that have been developed with CEF&physical developer and physical developer alone were tested to see how effective J-lar tape was at recovering fingerprints deposited with grease and moisturiser.

Table 4.8: Comparison of fingerprints deposited with grease and moisturiser using CEF+physical developer on feathers, recovery using J-lar

	Grease	**Moisturiser**
Post physical developer	 Grade: 2	 Grade: 2
1st J-lar lift	 Grade: 3	 Grade: 3
Post- J-lar -lift recovery	 Grade 1	 Grade: 0
2nd J-lar lift	 Grade: 2	

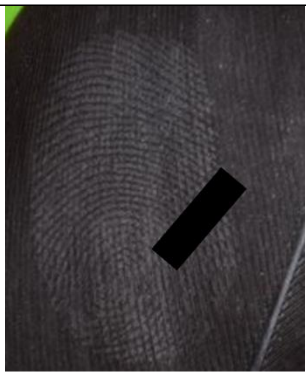
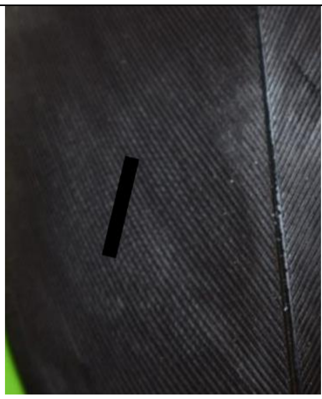
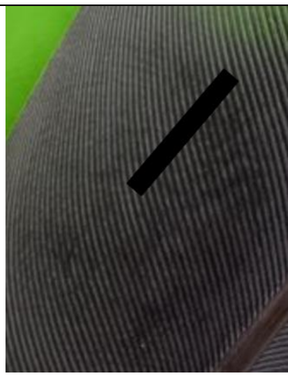
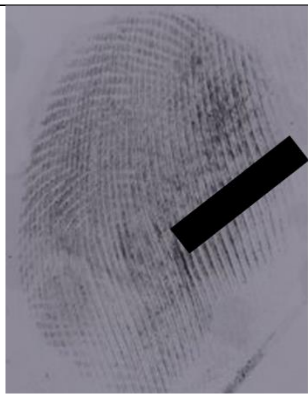
The grade for both deposition types is 2, however this could be due to the barbs causing issues to visualise the ridges. Additionally, a dilution pattern (as discussed within section 4.4.1.2), could have impacted upon the overall grade assigned. Black magnetic powder was used on these exhibit, as white magnetic would not have provided enough contrast on the light grey colour.

The exhibit surface post- recovery was graded a 1 for grease and graded 0 for moisturiser. This was because the tape-lift was able to lift the full fingerprint made by moisturiser. Reasons for this could be due to error made by the examiner, there could have been more pressure applied on the tape-lift before removal. However, in both cases it did not negatively affect the grade of the recovered fingerprint but did positively affect it where the grade increased to 3. It can be determined here that the visibility of the fingerprints improved on the tape-lift compared to on the feather/exhibit surface. This is because the tape-lift provided a better contrast compared to the textured surface of the feather.

In the case of the fingerprint deposited in grease, ridge characteristics were still visible post-recovery. Therefore, a further tape-lift was carried out. This resulted in a grade 2, as shown in table 4.18. No further improvement in grade or quality was obtained from a second lift.

A small amount of damage was caused, as can be seen in the moisturiser first tape-lift section (see table 4.8, section 1st recovery moisturiser). There was a piece of the feather attached. This method can be slightly destructive, however, to limit this the tape-lift should be removed in the flow of the barbs, starting from the shaft and moving out. Pulling from the other direction can cause the bars and barbule to separate which can cause damage to the exhibit and to the fingerprint present.

Table 4.9: Comparison of fingerprints deposited with grease and moisturiser, using physical developer alone on feathers. Recovery using J-lar

	Grease	Moisturiser
Post physical developer	 Grade: 3	 Grade: 3
Post- J-lar -lift recovery	 Grade: 1	 Grade: 1
J-lar lift	 Grade: 3	 Grade: 2

Both white and black magnetic powder were used on these feathers. White magnetic was used on the black vane of the feather, and black magnetic was used on the grey vane of the feather. These provided the best contrast.

The grade for the powdered fingerprint was clearer to see when using the white magnetic powder, compared to the black magnetic powder. This could be due to the loss of the ridge details for the moisturiser deposit or could be due to the curvature of the vane making it harder to see. The grade for grease deposit was 3, and the moisturiser fingerprint deposit was 1. However this could have been higher, but the texture caused an issue with visibility.

The exhibit surface post recovery shows that in both deposit types, there were ridges still present giving them a grade of 1. It would not be necessary, to do a second lift with the fingerprint deposited with grease, due to the lifted fingerprint and the pre-recovery fingerprint having the same grade (3). A second lift may be needed on the fingerprint deposited with moisturiser, due to the uncertainty of the grade. An advantage of this recovery method is that there were no obvious signs of damage made by the tape-lift on the feathers.

A noticeable difference between the recovered fingerprints on the tape-lift, is the moisturiser deposit has captured a large amount of the texture of the barbs. This makes it difficult to grade as it has merged with the ridges.

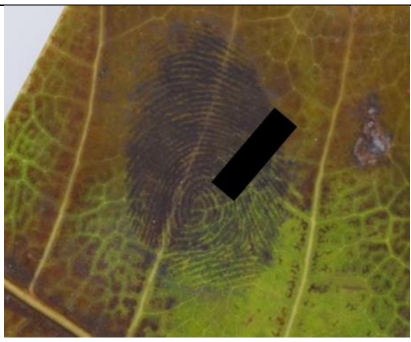
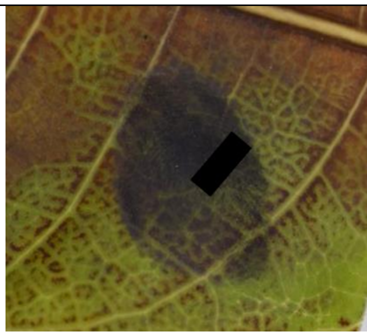
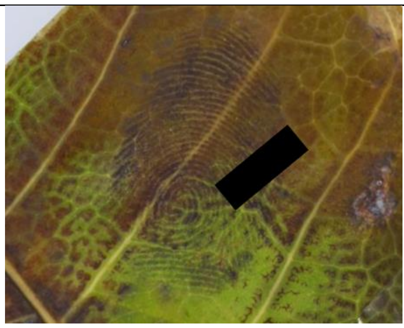
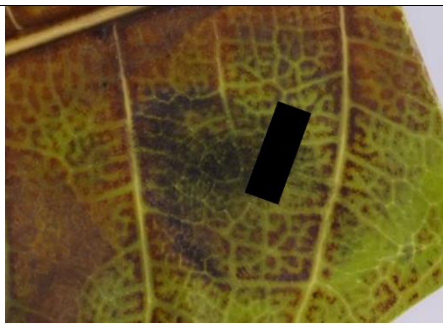
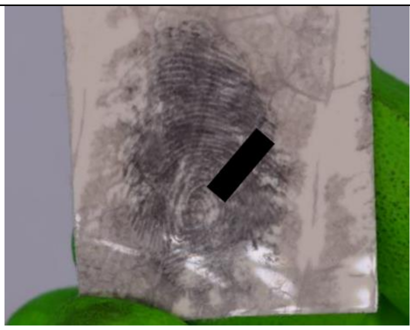
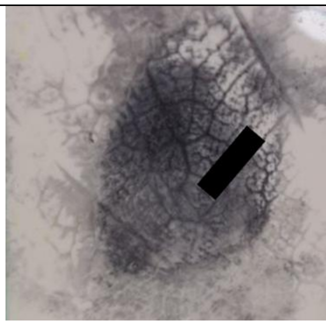
4.4.5 Results and Discussion on recovery using gel lift

As mentioned previously (section 2.4.2), Gel-lifts are a standardised piece of equipment used within forensic science to recover fingerprints. It is used by CSIs within a crime scene, as well as within the laboratory for exhibits. It was used on fingerprints powdered with black or white magnetic powder, on leaves and feathers. The colour of the gel-lift that was chosen was white.

4.4.5.1 Green leaf recovery using gel lift

As summarised previously (section 4.2.1.1), green leaves were recovered from a Lippen tree and used throughout this research. The leaves were preserved in a zip lock bag at low temperatures. However, some aging occurred where this was visualised as a change in leaf colour. Other than colour, all other leaf properties remained consistent, therefore these were still classified as green leaves for the purposes of this research.

Table 4.10: Comparison of fingerprints deposited with grease and moisturiser, using CEF+physical developer on green leaves, recovery using gel-lift

	Grease	**Moisturiser**
Post CEF+ physical developer	 Grade: 3	 Grade: 1
Post- gel-lift recovery	 Grade: 3	 Grade: 1
Gel-lift	 Grade: 2	 Grade:1

There was a significant difference in the quality of the fingerprint when it was deposited with grease and moisturiser. The fingerprint deposited with grease was graded 3, and the fingerprint deposited with moisturiser was graded a 1. There was clear ridge definition with grease, but moisturiser looks to have smudged the fingerprint as discussed previously in section 4.4.1.1.

Post-recovery on the exhibit surface, showed that the grease deposit still presented as grade 3 fingerprint. The fingerprint that was deposited with moisturiser, post recovery was graded a 1. An observation can be made that there was more powder lifted from the moisturiser deposit compared to the grease deposit. This could be due to examiner error, where more pressure was applied to the gel-lift over the fingerprint deposited with moisturiser compared to grease. Other reasons could be greater retention/absorption of powder. A second lift (for the grease deposit) would have been beneficial due to the first lift being a grade 2, and there was a grade 3 fingerprint still present. However, a disadvantage of multiple recoveries with this recovery type is the impossibility of overlaying these recovered lifts. The gel-lift for the moisturiser deposit stayed a grade 1. Both gel-lifts did capture the detail of the leaf, which was more prominent within the moisturiser deposit compared to the grease deposit. Reasons for this could be more pressure, limited presence of ridges or the use of moisturiser.

4.4.5.2 Brown leaf recovery using gel lift

Only a grease deposit was carried out for the brown leaf, due to previously obtained results.

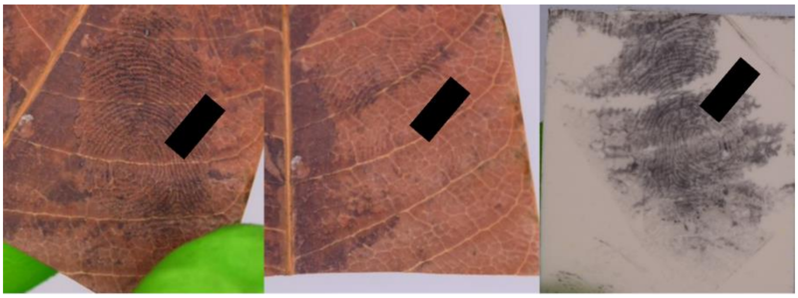


Figure 4.21:. Pre- and post- exhibit surface, using gel-lift for recovery on brown leaf

Black magnetic fingerprint powder was used for this brown leaf; however, it did not appear as dark as on the green leaf (section 4.5.5.1) which is thought to be due to powder adhesion. This reduces the contrast from a distance, but upon closer inspection, the contrast is more apparent, showing a grade of 3. Post- recovery of the exhibit surfaces as a grade of 1, due to ridges still being visible. The gel-lift has a grade of 2. This decrease in the grade is due to the areas which did not pick up any ridges, as there appear to be sections missing/void areas (as seen in figure 4.21). This could be due to the raised areas and furrow of the venules and veins of the leaf causing areas to not be captured. Other factors could be due to the fragility of the brown leaves, the researcher did not apply enough pressure as a precaution which in turn caused the missed sections of the fingerprint.

4.4.5.3 Feather recovery using gel lift

As previously mentioned, (section 4.4.1.2), there is no significant difference in quality of fingerprints deposited with grease and moisturiser, therefore fingerprints were deposited with grease. In order to determine if there is any benefit for recovery between CEF+physical developer and physical developer, a series of tests were conducted.

Table 4.11: Comparison of CEF+physical developer, and physical developer alone, using Gel-lift recovery process on feathers

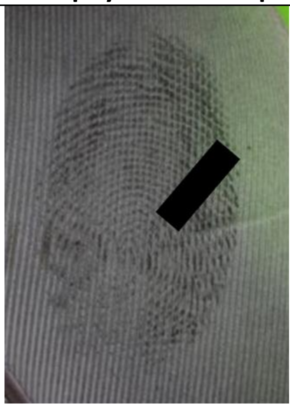
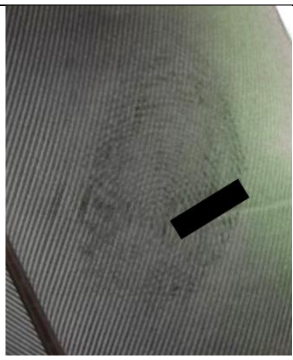
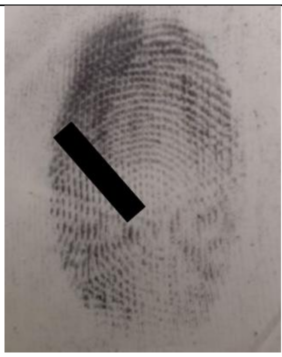
	CEF & physical developer	**Physical developer**
Post-treatment	 Grade: 3	 Grade: 2
Post-Gel-lift recovery	 Grade: 2	 Grade: 2
Gel-lift	 Grade 2	 Grade 2

Table 4.11 shows the effect of Gel-lift recovery. On average, a higher grade was obtained when recovering fingermarks using Provil after CEF application. The CEF+physical developer fingerprint was graded a 3, however the physical developer alone grade was only a 2. This could be higher but due to the barbs texture and the dilution pattern, the ridges were masked. A clear difference between this stage is the powder (black magnetic) appears to be darker within physical developer alone compared to CEF+physical developer, showing there was a greater adhesion.

There was no difference between the comparison of the post-recovery exhibit surface, as they were both graded a 2. As previously mentioned with leaves analysis (section 4.4.5.1), multiple recovery lifts are not a possibility as of this time, making this a disadvantage of this technique on this type of exhibits. There was no difference between the grades on the gel-lifts. However, appearance shows that the barbs texture is more apparent in the gel-lift recovered with physical developer alone, compared to CEF+physical developer. This could be due to the examiner applying more pressure to the gel-lift during the recovery stage or could be due to the placement of the fingerprint. In this instance, the barbs texture which was captured did not affect the grading.

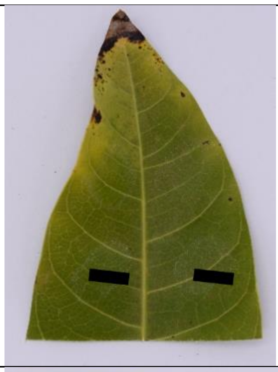
4.4.6 Results and discussion of Wet recovery

As mentioned in section 4.3.5.2, both of the exhibit types (leaves and feathers), were investigated to determine the effect on development and recovery when wet.

4.4.6.1 Green leaf wet recovery

The comparison of wet to dry leaves can be seen in table 4.12. The analysis of the dry leaf has been discussed previously (4.4.1.1.), therefore this data has only been included for comparison purposes. Due to the 'slippage' of the deposits made with moisturiser (see section 4.4.1.1), fingerprints deposited with grease were investigated here. The recovery method chosen was Provil.

Table 4.12: Comparison of green leaves, wet and dry post CEF development

	Wet green leaf	Dry green leaf
Section one		
Section two		

Section three		
Section four		
Section five		

The difference in the number of sections was due to an increase in size with one of the leaves. This had no effect on the quality of the fingerprints developed or recovered.

The fingerprints within both dry and wet were visible prior to any enhancements made. A clear observation between wet and dry is the presence of white and coloured ‘splodges’ on the wet leaves. This has occurred due to the leaf being wet during the CEF development stage. It is believed that these areas of moisture allowed for greater cyanoacrylate ester adhesion. This affected the grading of the fingerprints due to them obscuring the ridges. These white splodges, were also captured within the Provil cast, as seen in figure 4.22.

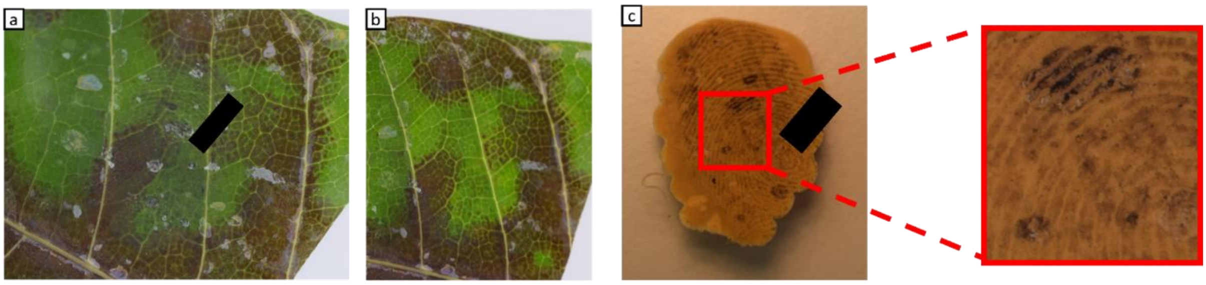


Figure 4.22: Wet green leaf. (a) being powdered fingerprint post-CEF, (b) exhibit surface post-recovery using Provil, and (c) is the recovered Provil Cast. Magnification highlighted in the red box showing the 'splodges' present

A consistent technique and quantity of powder were used between wet and dry exhibits. However, as can be seen in figure 4.22 faint ridge characteristics are present. This difference is thought to be due to water causing the dilution of components within the fingerprint.

The grade of the powdered fingerprint made on the wet leaf was a grade of 1, and after the removal it was a grade of 0. However, the Provil cast was graded a 3. Reasons for this could be due to the Provil cast providing better contrast for the black fingerprint powder, compared to the green leaf. This could mean that other fingerprints that have been powdered, where there is limited contrast, could have more ridge detail than what can be seen so should be recovered. The droplets from the leaf transferred over to the Provil cast, however, this did not seem to be an issue as the ridges can still be seen in these areas (see figure 4.22). Additionally, the difference in powder adhesion discussed previously, could be considered to be an advantage as there was limited background texture present in the Provil casts.

In some instances, it can be seen that the Provil cast grade is higher than the grade that can be seen on the leaf. This could be due to contrast issues. From this it can be assumed that the fingerprints which have little contrast should still be recovered as there can be more detail than what is seen.

4.4.6.2 Brown leaf wet recovery

The comparison of wet to dry leaves can be seen in table 4.13. The analysis of the dry leaf has been discussed previously (see section 4.4.1.1.), therefore this data has only been included for comparison purposes. Due to the 'slippage' of the deposits made with moisturiser (see section 4.4.1.1), fingerprints deposited with grease were investigated here. The recovery method chosen was Provil.

Table 4.13: Comparison of brown leaves, wet and dry post CEF development

	Wet brown leaf	Dry Brown leaf
Top section		
Bottom section		

Similarly to green leaves, the main observation can be seen (see table 4.13) that wet leaves have the presence of white 'splodges', which are different from the white-hard residue on the developed fingerprints. As discussed within green leaves, it is determined that this is due to the wet droplets present on the leaf before the CEF process.

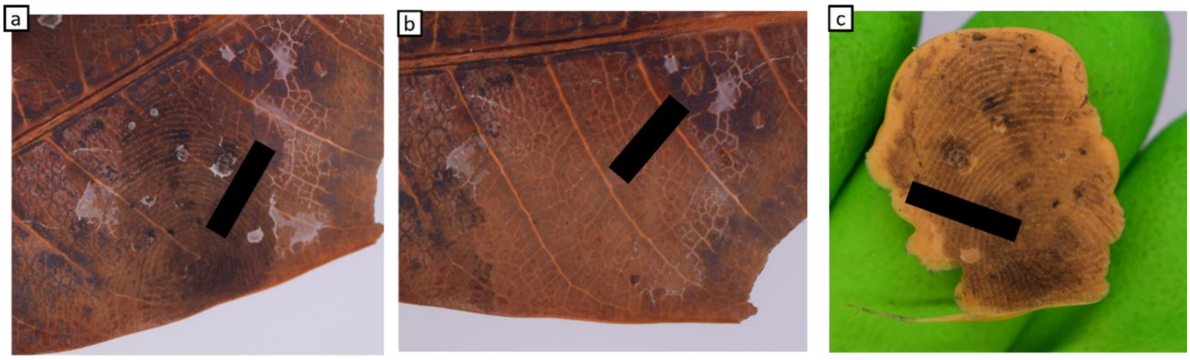


Figure 4.23: Wet brown leaf. (a) being powdered fingerprint post-CEF, (b) exhibit surface post-recovery using Provil, and (c) is the recovered Provil Cast

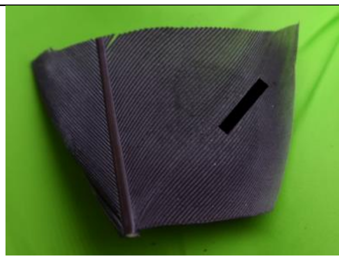
As discussed previously (section 4.4.2.2) physical developer adhesion on this exhibit type was variable. Figure 4.23 shows that wet brown leaves where good physical developer adhesion is seen, allowing for better contrast.

The grade of the fingerprint made on the wet leaf was a grade of 2, and after the removal it was a grade of 0. The Provil cast was graded 2. Unlike the green leaf, the recovered fingerprint was the same as that developed, showing that the black magnetic powder provided good contrast. The splodges and marks, from where the leaf was wet prior to development, did transfer over to the Provil cast. However, it did not cause any issues of masking or interfering with the ridges as the grades stayed the same.

4.4.6.3 Feather wet recovery

Within this investigation, a mixture of fingerprints deposited with grease and moisturiser was used. This was primarily due to there being no significant differences between the deposits on this exhibit type (see section 4.4.1.2). Due to the nature of feathers (section 2.5.3) being water repellent, two different methods of wet development were chosen. Fingerprints were deposited on the test exhibits. One set (termed wet-prior) was moistened with a mist of water and allowed to dry for 48 hours before development. The second set (termed wet during) was moistened with a mist of water and developed immediately. The chosen method for both sets was CEF+ physical developer, no recovery method was chosen.

Table 4.14: Comparison of feather, wet during and wet prior, post CEF development

	Wet during CEF	**Wet prior to CEF**
Top section	 Grade =1	 Grade =2
Middle section	 Grade = 0	 Grade = 1

The notable difference between the two sets of exhibits shown in table 4.14, is the wet (wet during CEF) feather shows a series of white splodges. These features were also visualised within wet leaves; therefore, it can be concluded that this is due to the exhibit being wet and not anything due to the exhibits themselves. This was also present within wet anti-climb paint (see section 3.4.3.4).

When comparing wet prior exhibits with wet during, an overall higher grade is obtained. This lower grade is partly due to the presence of white 'splodges' which mask some ridge characteristics. However, these characteristics are not the sole reason for lower grades being assigned. As can be seen throughout the study, dry feathers showed a better definition of ridge detail whereas this is not seen for wet feathers. Therefore, moisture is having an effect on quality which may be due to water repellent nature of feathers. As summarised in section 2.5.3 birds have uropygial glands which contribute to the water repellent nature of feathers by preening. These glands release a substance that is a complex mixture of lipids and waxes. As discussed previously (4.4.1.1.), conditions of the exhibit were found to influence fingerprint quality. Because this preening process is an uncontrollable variable, the amount distributed over the body/feathers is unknown and may be contributing to the visualisation of ridge detail. A factor that should be investigated further within future research.

4.4.7 Results and Discussion of imaging

As mentioned within section 2.4.3, angles and lighting are important when capturing exhibit images. This section summarises those techniques used to capture ridge detail on feathers and leaves.

4.4.7.1 Green & Brown leaves imaging

<u>Pre-treatment:</u>

At this stage, the leaves were captured using the lightbox, giving it direct lighting (see section 2.4.3.1). This was needed to highlight any impurities present on the exhibits.

<u>Post-CEF treatment:</u>

Within this stage the leaves were photographed with the lightbox, where the presence of CEF fingerprint could be visualised. However, in cases where this was not present, the use of side-lighting was implemented. This allowed the latent fingerprints to become visible and provided better contrast (as can be seen in figure 4.24).

Figure4.24: Section of green leaf, after CEF treatment, under direct lighting. Magnification highlighted in the red box, showing visible fingerprint under side lighting.

This use of side lighting also showed the presence of the 'halo' pattern (see section 4.4.1.1), which could not be seen with direct lighting within the lightbox (see figure 4.25).

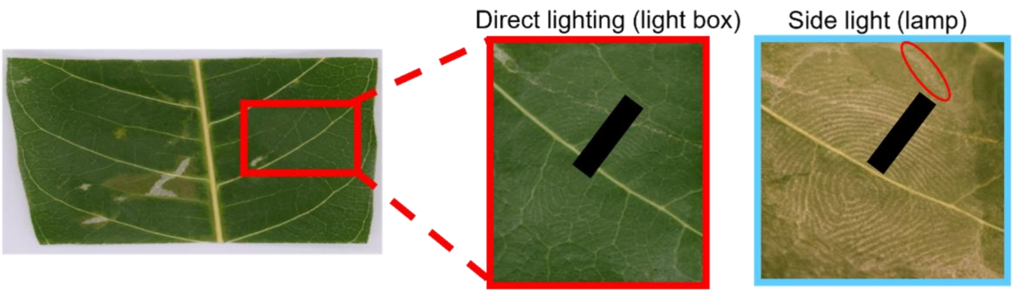


Figure 4.25: Section of green leaf after CEF treatment. Magnification in the red box shows the fingerprint under direct lighting. Magnification in the blue box shows the fingerprint under side lighting, highlighting 'halo'

<u>Post-physical developer treatment:</u>

The green and brown leaves used the lightbox, implementing direct lighting to capture the powdered fingerprints present.

<u>Recovery exhibits</u>

Post recovery on the exhibit surface was captured using side lighting (lamp source). The use of this allowed the latent fingerprint left post-recovery, to be visible, so could be captured (see figure 4.26).

Figure 4.26: Visible fingerprint post-recovery using Provil

The Provil casts used side lighting (lamp source), to highlight the visible fingerprint.

Resin, J-lar and Gel-lift all used direct lighting within the lightbox, being held by the examiner in order for it to be closer to the camera.

4.4.7.2 Feathers imaging

Pre-treatment

The feathers were photographed within the lightbox to provide direct lighting.

Post-CEF

The feathers that were run through CEF, were captured after treatment within the lightbox.

Post-physical developer

At this stage the powdered fingerprints were photographed in the lightbox, changing the angle of the feather. This was needed as (it is assumed that) the texture of the barbs (raised and dipped surface), caused the 'hiding' of the ridges, particularly when looking straight at the exhibit (90^{o}). Therefore multiple angles were required in order to capture all ridges present. An example of this difference can be seen in figure 4.27.

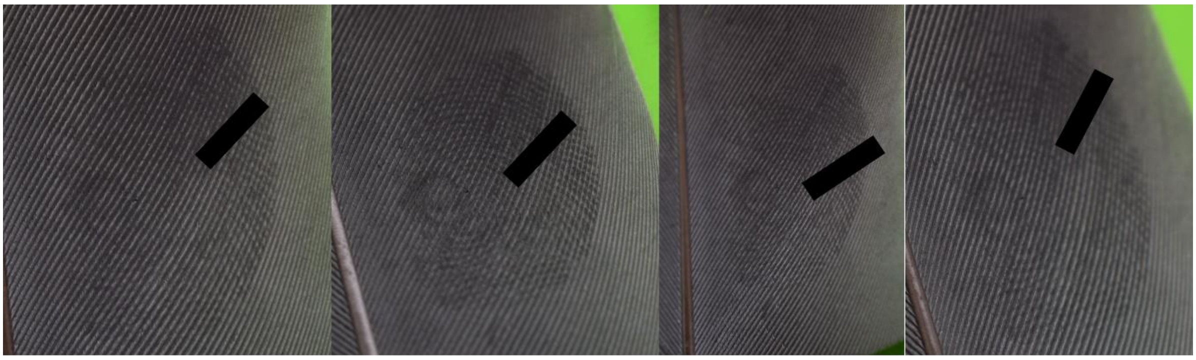


Figure 4.27: Multiple angles of the same fingermark on feathers. Limited visibility

In some of the exhibits, visibility of the ridges was limited due to having too much light behind the exhibit (see figure 4.28). This is when the examiner placed the feather on to the palm of the gloved hand, which allowed the ridges to be seen.

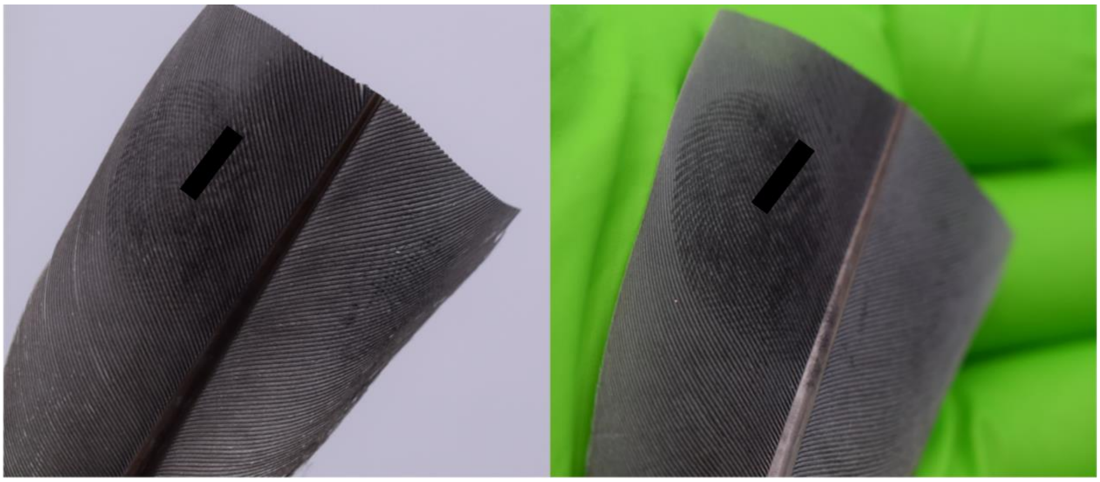


Figure 4.28: comparison where use of palm aided visibility

Alternatively, as seen in figure 4.29, within some exhibits having the examiners hand behind the feather caused the ridges to not be visible. In this case, position C was used to capture the ridges (see section 3.3.4.1).

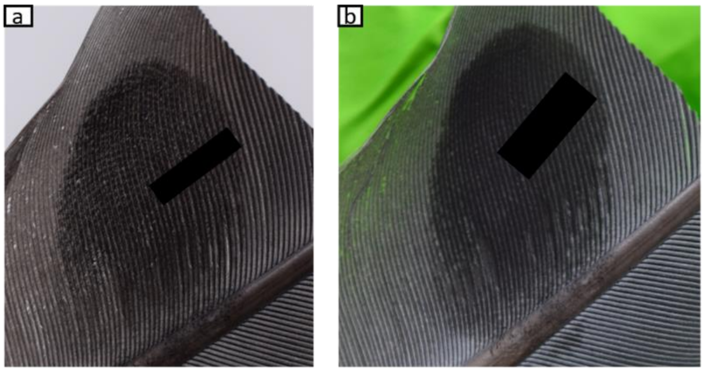


Figure 4.29: Example of feather post-treatment. (a) showing fingerprint ridges with light being allowed behind. (b) showing fingerprint ridges visibility issues when limiting light behind/palm of examiner

<u>Recovery exhibits</u>

Within all recovery types Provil, J-lar, Gel-lift and Resin, the light box was used to give the best lighting.

The feather post-recovery also used the lightbox to provide lighting for the photographs.

4.5 Conclusion

This chapter has shown a series of experiments conducted with the aim of developing and recovering fingermarks from both feathers and leaves.

Throughout moisturiser and grease was compared on both exhibit types. There were no differences between feathers, but a pattern did occur within both types, that was termed ‘dilution’. The definite conclusion for this is unknown but it is thought that it could be due to the fingerprint being ‘wet or too fresh’ which could have had an affect due to the makeup of feathers. There was also no difference between CEF and physical developer alone on the quality of the fingerprints developed.

However there were a few differences on leaves. Within green leaves, there was a presence of, a feature termed ‘halo’ pattern. This would only be visible under side-lighting and only when using moisturiser. Within this study, it did not affect grading, but further consideration is needed as it could potentially cause issues within future work. Within both types of leaves, when moisturiser was used there were times when there was slippage of the finger in the process of deposition, which caused the fingerprint to smudge. This was more apparent within the brown leaves due to the pressure device not being used due to fragility. It was also noted that fingerprint deposition, grades, development and recovery were variable within brown leaves which could be due to the age, which could affect the waxiness of it, which could influence the processes. A factor which was not considered within this study.

Provil recovery on leaves revealed an outline of the Provil cast after removal on both green and brown leaves. It is thought that this could be due to the presence of powder surrounding the fingerprint. This is theorised for two reasons. One being that the colour after removal is similar to sections which have not been in contact with powder. The second reason being the use of J-lar tape lift showed presence of powder surrounding the fingerprint, which could not be seen on the exhibit.

Provil was non-destructive on both types of leaves, there was no need for enhancement, and it was able to be recovered multiple times. Due to the inconsistency of magnetic powder adherence on brown leaves, overdevelopment and underdevelopment occurred. However, due to the non-destructive properties of Provil, it was able to be applied and all of the powder would be collected. Powder could then be applied again, where development and recovery can be repeated.

Within feathers, Provil was destructive, the extent of which was depended on the section; however a high grade was obtained when Provil casts were recovered after CEF development. When it was not placed into CEF, the barbs texture was prominent which then caused issues with visibility.

A series of issues were encountered when recovering fingerprints using resin. Within Green leaves, the resin picked up the texture, which caused visibility issues. Within brown leaves there were a presence of a feature termed 'bubbles' which masked some ridge characteristics. This method did preserve the fingerprint, however removal of the Resin-Provil complex caused slight breakage in the green leaf and complete breakage in the brown leaf, possibly due to fragility.

Within the feathers, the Provil was not removed. It was noted that the powder did not seem as bright after the curing of resin. This could be due to the resin starting off as liquid, which could have diluted or washed away some of the powder. This is supported by the wet prior and wet during section, where the definition of the ridges was not as clear/defined as when they were dry. Linking to the idea that water/liquid does have some effect on the feathers and quality of fingerprints developed, but this would need to be further investigated within future work.

Recovery using tape-lift on leaves captured the texture of the venules and veins mixed in with the ridges. This was an issue when assessing the grade of the recovered fingerprint. However, it did not cause any damage to the leaves.

It can be concluded that this method provided the best results for the recovering fingerprints on feathers. This is due to there being limited background texture, and the grades increasing after removal, due to the contrast being better. It can be assumed that the grade present on the feather may be higher than can what be seen, therefore recovery should be attempted. This method was slightly destructive when the tape lift was removed in the opposite direction to the grain of the barbs, but no destruction occurred when this was removed with the grain. Some advantages are that multiple difference coloured magnetic powder can be used without being an issue of contrast, and multiple lifts can be overlayed if the full fingerprint was not captured, which is common in practice.

In relation to gel-lifts, these proved successful within both green leaves and feathers. However, multiple lifts would need to be carried out to capture the full fingerprint, which is a disadvantage as gel-lifts cannot be overlayed. In relation to brown leaves, there were sections of ridge detail missing from the gel-lifts, this was due to the fragility and texture.

Dry vs wet within all exhibit types, showed a presence of a feature termed 'splodges' when the exhibit was wet in the development process which affected the grade assigned pre-recovery. It is thought that these were due to the white hard residue, created during cyanoacrylate ester development, causing adhesion to these moist surfaces. However, further investigation of this needs to be carried out in order to confirm this hypothesis. Although these features did not affect grading post-recovery with Provil. This could be due to an improvement in contrast.

Chapter 5

Conclusion

Fingerprint evidence has long been an important type of evidence in forensic investigation due to their uniqueness, probability of encountering these within scenes as well as the high evidential value placed upon them.

Within practice there are various techniques and methods used to enhance and recover fingermarks, including both physical and chemical. These are constantly being developed as well as innovative methods such as developers incorporating the use of nanoparticles. It is well known that the type of developmental technique, as well as recovery, needs to be considered before an appropriate method is chosen. One of the key considerations is the surface type. Some surface types are still seen as problematic to develop and recover from, such as vertical surfaces and paints. Other unusual surfaces can include feathers, leaves, and specifically anti-climb paint which can all potentially be evidence within crime scenes. There is a limited amount of research regarding the development of latent fingermarks on feathers and leaves, and at this present time, there is no research regarding the recovery of the fingerprints on feathers. Alongside this, there is no research regarding anti-climb paint in the development and recovery of fingermarks. Therefore, this research focussed on these three types of exhibits.

Anti-climb paint is a used for security reasons and is a non-drying shiny paint. This makes it difficult to develop and recover fingermarks. Using the traditional method of CEF, fingerprints made in and from anti-climb were able to be developed, specifically looking at primary, secondary and tertiary transfers. In doing this, it was observed that as more transfers increased, the quality of the fingerprint increased. It was thought to be due to the quantity of anti-climb paint which decreases with each transfer. When applied to real world, the average person will not measure out the anti-climb paint that they use. Within a crime scene, if the first few transfers smudge because of the quantity of anti-climb paint, the following transfers will increasingly become better quality.

Through this research, it was found that cyanoacrylate ester fuming is an effective technique to make the fingermark durable. In the optimal conditions proposed, the method did not affect the quality of the fingerprint but caused these to become matte and robust allowing for recovery to be carried out.

Traditional methods such as J-Lar tape and gel lifts were not considered appropriate recovery techniques due to the 3D nature of the developed fingermark. Therefore, casting was considered appropriate for this purpose. Resin and Provil were chosen due to current applications within the forensic field.

Resin allowed for the fingerprint to be captured and preserved as a hard transparent piece that took the shape of the mold ring it was placed within. This mold ring was made from Provil and was used as the barrier to keep the resin over the fingerprint whilst curing, however, there were factors that caused the resin to leak. This meant that the Resin-Provil piece could not be removed. This was not an issue within this study due to the exhibit surface being transparent (acetate sheets). Due to this, other materials for the ring barrier should be investigated to determine if there is a more appropriate one. When leaking did not occur, the resin-Provil piece could be removed. This was not necessary within this study but due to real-world applications, this was investigated. There were only a few issues with removal which were not consistent, occasionally some ridges were lost and in one case the acetate sheet ripped. This can be seen as a negative as if those ridges are lost, this cannot be recovered due to its destructive nature. Further investigation is needed for determining the applicability of the technique on other surfaces such as brick, pipes, and fences.

Provil was used over the superglued fingerprint. The cast produced a copy of the original fingerprint i.e. a positive impression, there the quality of fingermark produced was dependent upon the quantity of anti-climb paint present. Occasionally, the Provil did not capture all the ridges present, but this would only happen when the fingerprint was of grade 2 and lower. However, if this did happen, the benefit of using Provil is that it was non-destructive so can be used for imaging comparison instead. A disadvantage of the Provil was the lack of contrast. When the Provil was a grade 3 or above, contrast could be provided using side lighting. However, when the grade was 2 and below, this was not sufficient. This is where the inking process was developed.

Similarly to previous findings, original fingerprint quality dictated cast quality. When the inking process was implemented on low-grade casts, no ridge details were visible but equally no additional features were visualised within the fingerprint. In comparison with high-grade casts, this inking process highlighted ridges providing excellent contrast. The ink only highlighted what was present limiting both the subjectivity and possible bias. Additionally, environmental conditions showed no effect on the ability to develop and recover fingermarks.

Consistency and reproducibility are of vital importance within research. In relation to latent fingermarks, it is impossible to determine the amount of residue (amino acids, sebaceous deposits, sweat, etc.) present. Therefore, moisturiser was considered to be a suitable control for keeping consistency. Limited differences were observed between latent fingermarks deposited using grease and moisturiser with feathers, however more pronounced differences were observed for leaves.

Existing methods for fingerprint recovery as well as novel methods were investigated for the enhancement and recovery of latent fingermarks on feathers and leaves. These comprised of lifting (J-lar tape and gel lifts) and casting methods (resin and Provil).

In relation to development of fingermarks on feathers, magnetic developers were considered to be the most appropriate developer type consistent with previous research (REF). The application of CEF did not aid the development of ridge characteristics on this exhibit type. Equally, CEF did not improve the robustness of the feather (particularly the barbs) as initially thought, however it is possible that an increased development time was necessary. This should be researched further in the future, particularly as a comparison of fingermark recovery with and without CEF, showed an increased presence of barb texture when there was an absence of CEF.

All recovery methods (gel lifts, tape lifts, resin, and Provil), showed the presence of fingerprint characteristics. Resin was not considered appropriate for recovering fingermarks from feathers due to poor contrast as well as leakage, additionally, the fragility of feathers limited the ability to recover the resin complex from this exhibit type. Similar results were obtained for Provil, where improved ridge characteristics were obtained, but cast removal resulted in the separation of barbs and barbules. In relation to lifts both types were non-destructive to the feather. Gel lifts allowed for the recovery of ridge characteristics; however, a large amount of background was also recovered. In comparison, tape lifts provided more ridge detail with little background. If removal is done correctly, e.g. with the grain, the lift can be removed without causing damage to the feather.

In relation to the development of fingermarks on leaves, physical developer adhesion differed within brown leaves but was consistent within green leaves. This is thought to be due to the age of the exhibit which was not controlled in this study. Additionally, differences were observed between deposits made with grease and moisturiser. A higher incidence of smudging was observed with moisturiser, this is partly due to the presence of waxes on this exhibit type. Enhancement of ridge characteristics was possible with physical developer (magnetic powders), however the grade differed considerably between green and brown leaves which again is thought to be due to the age of the exhibit. A factor that should be investigated further.

With recovery, resin did not prove successful. The material showed a high degree of leakage which varied between exhibits causing damage upon removal. Equally, resin caused additional features, in the form of bubbles, within the resin-Provil complex, which hindered grading. Tape and gel lifts allowed for the recovery of ridge detail; however, leaf texture was also recovered. This superimposition of ridge and leaf texture hindered grading where subjectivity could be considered high, increasing the likelihood of bias occurring. In contrast, Provil allowed for the recovery of ridge detail with minimal effect from leaf texture. Additionally, this material was non-destructive to the exhibit, allowing for multiple recoveries to be made. One noticeable occurrence within the use of Provil was the appearance of an outline on the exhibit after cast removal. This is thought to be attributed to excess powder, however further research would need to be conducted to confirm this hypothesis.

Due to the waxiness of leaves and water repellent nature of feathers, the proposed method was investigated on wet surfaces. In relation to leaves, results obtained were similar to those of the dry counterparts, however additional features were observed post development. This thought to be due to the presence of droplets present during the development stage. Causing the transfer when recovering. Regarding feather, moisture hindered fingermark recovery, where a lack/minimal detail was recovered.

Within practice, problematic surfaces are still encountered. This can have an impact on the fingerprint expert's comparison, as alternative methods may not provide sufficient quality for analysis. Current research has primarily focussed on development, where recovery methods are rarely explored hindering applicability to real-world applications. This research has explored development and recovery simultaneously, on three surfaces considered to be problematic within practice. It is envisioned that this work will contribute positively to the field providing further avenues for investigation.

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Appendix A

Appendix A.1: showing table A1, further fetal development

Table A1: 10- 40 weeks, fetal development

10-13 weeks	Around 10 weeks flexion crease beings to form on the toes Around 10.5 weeks ridges will being to form Around 11 weeks within the parm the distal transverse flexion crease forms and volar pads begin to regress from the palms, which will be followed by the fingertips Around 13 weeks also within the palm the proximal transverse flexion crease forms
14-27 weeks (second trimester)	Within this period sweat glands will mature. By 15 weeks, Primary ridges experience two directions of growth – downwards/penetration from sweat glands, and new cell growth causes an upward push. 15-17 weeks secondary ridges develop on the underside of the epidermis, in between the primary ridges The volar pads by 16 weeks will now have completely merged into the contours of fingers, soles of the feet and palms of the hands and minutiae, which are randomly located, are set in place

	By the end of this period, the sweat ducts as well as pores will start to appear on the epidermal ridges
28-40 weeks (third trimester)	The key part of the third trimester is protected growth

Appendix A.2: showing figure A1, the grading system used for guidance

Grade	Description
0	Fully smudged outline of a mark or no evidence of mark
1	Presence of several ridges and cannot lead to identification
2	Major part of the mark is smudged, several ridge details are present and analysis cannot be performed
3	Minor part of mark is smudged, most ridge details are visible and analysis can be performed
4	Full mark and ridge details are clearly visible, some ridge lines maybe thinned or smudged but identifiable mark
5	Full mark and all ridge details are clearly visible; identifiable mark

Figure A1: The grading system (Rajan et al., 2018)

Appendix A.3: examples of grading (figure A2-A5)

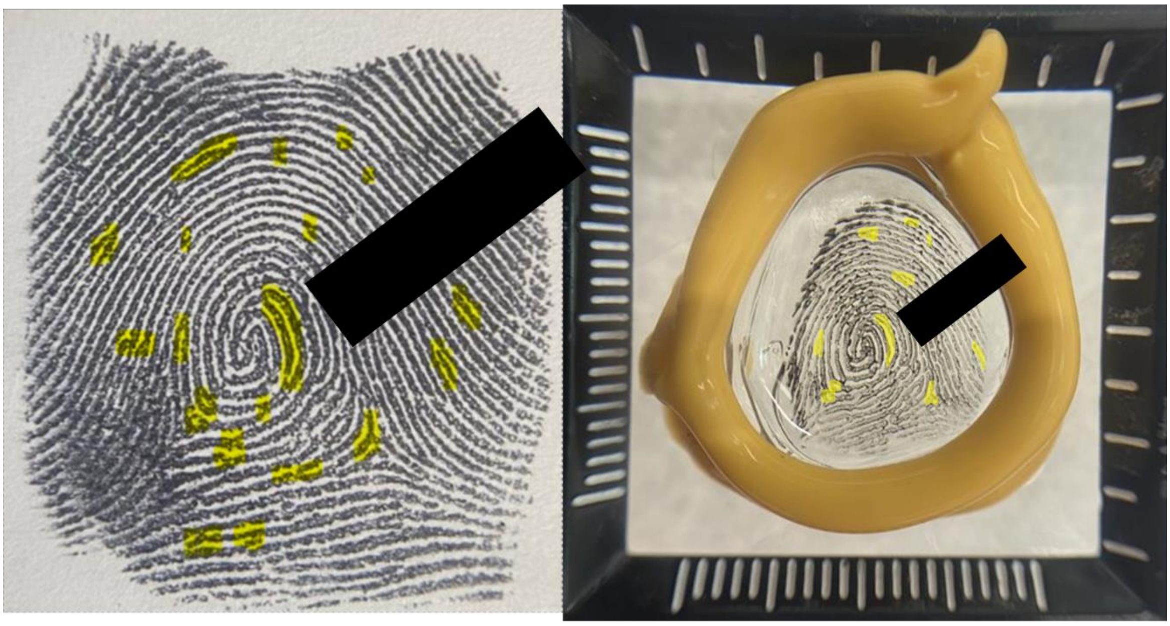

Figure A2: Example one of grading on resin

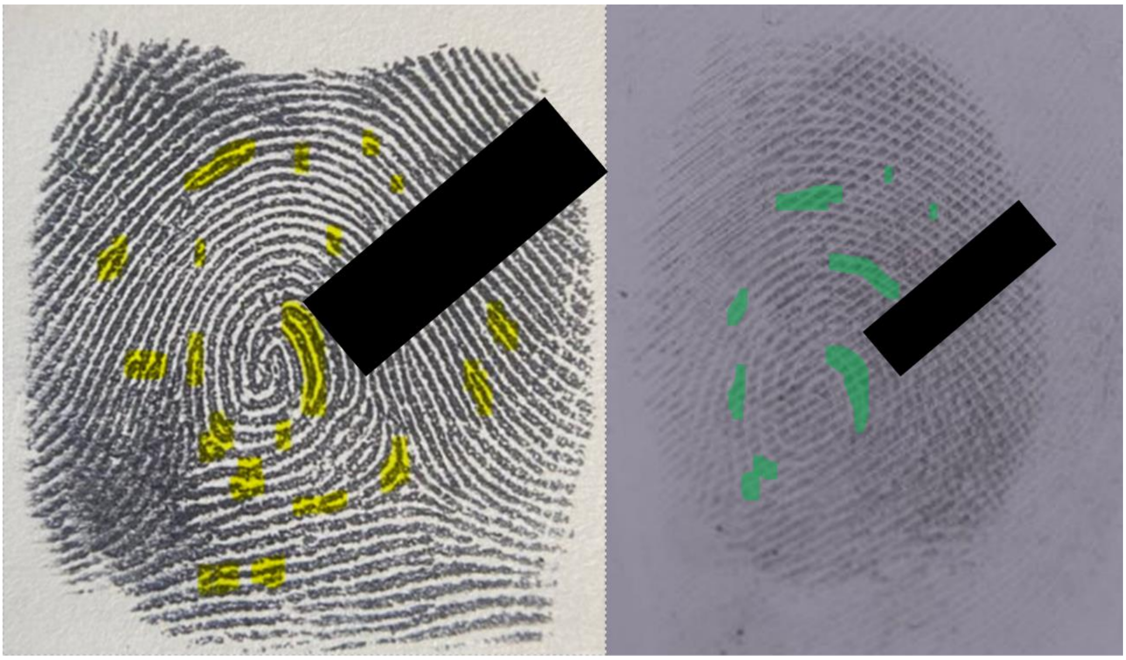

Figure A3: Example two of grading on J-lar

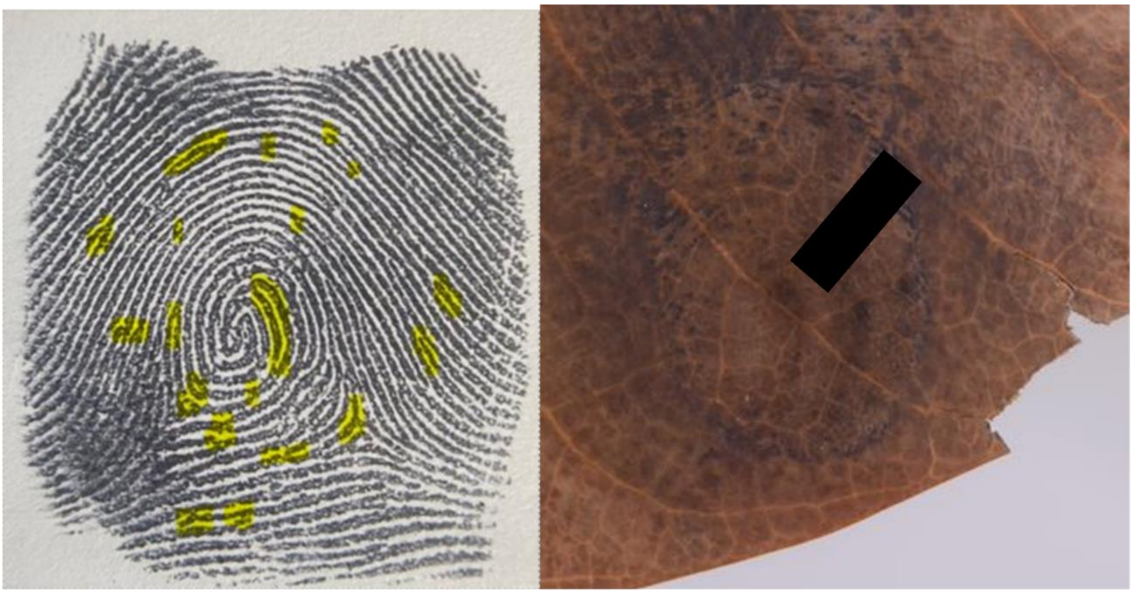

Figure A4: Example three of grading on leaf

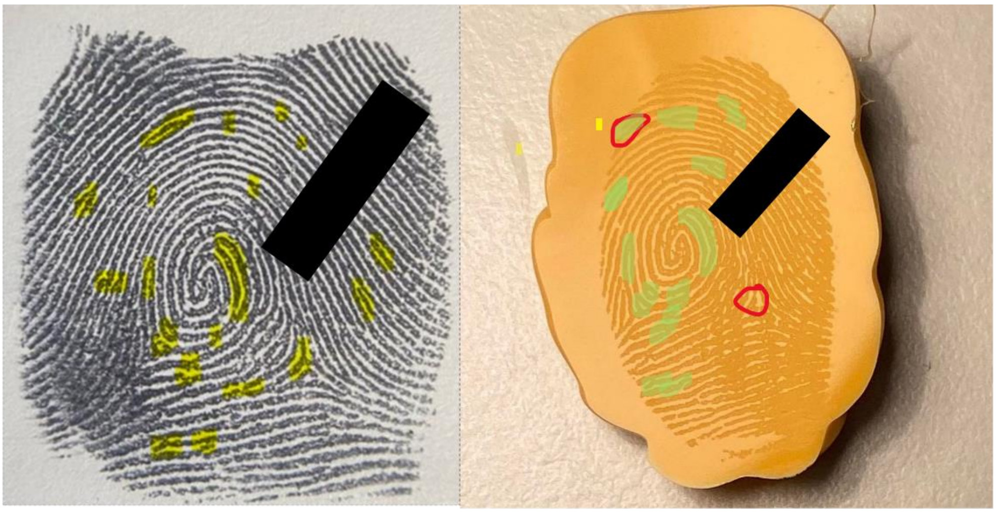

Figure A5: Example four of grading on Provil. The red circles shows area show areas which are similar to the 21 characteristics but it is not 100% the same so were not included

Appendix A.4: The 21 highlighted characteristics (figure A6 – figure A9)

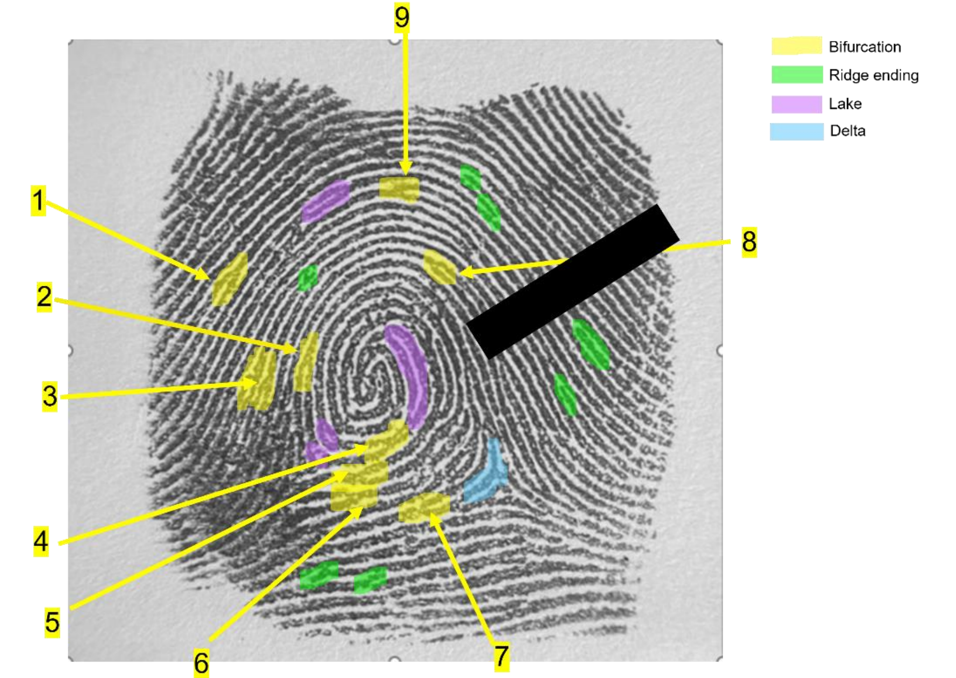

Figure A6: Participants fingerprint. 9 bifurcation numbered and highlighted in yellow, part of the 21 characteristics

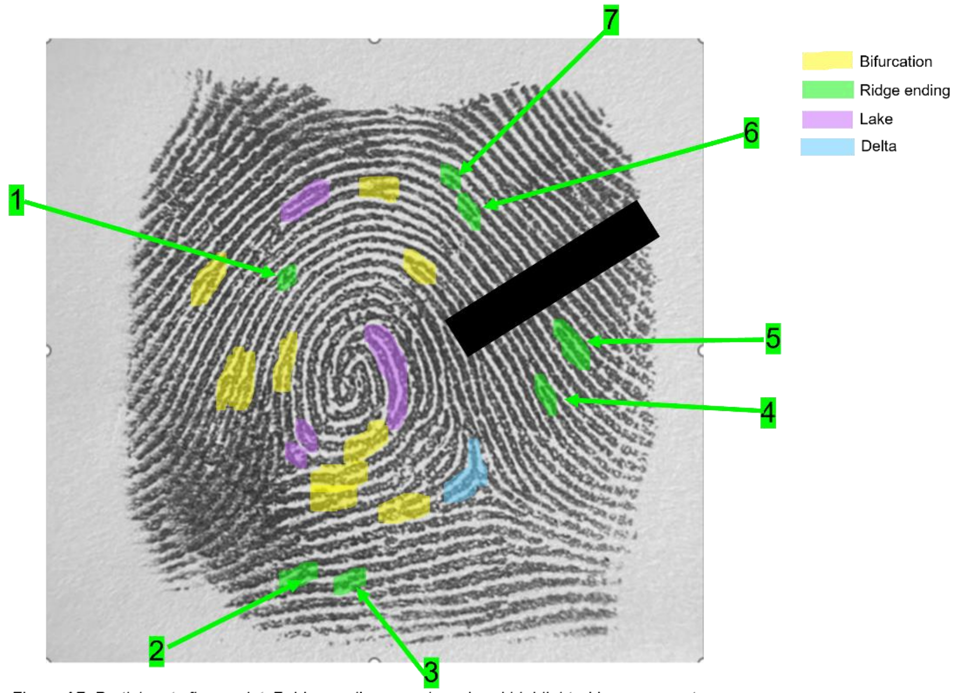

Figure A7: Participants fingerprint. 7 ridge endings numbered and highlighted in green, part of the 21 characteristics

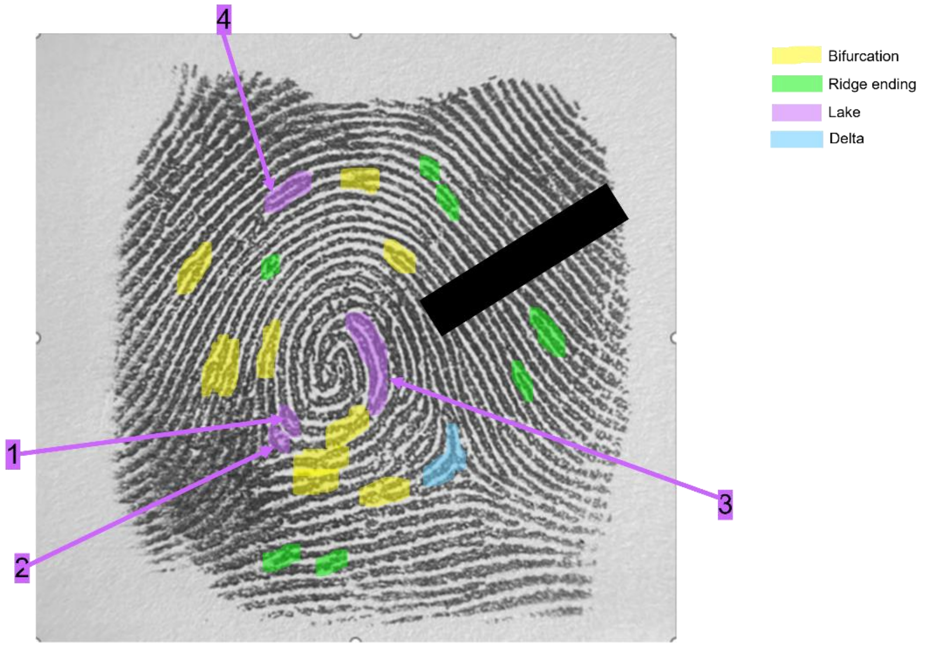

Figure A8: Participants fingerprint. 4 lakes numbered and highlighted in purple, part of the 21 characteristics

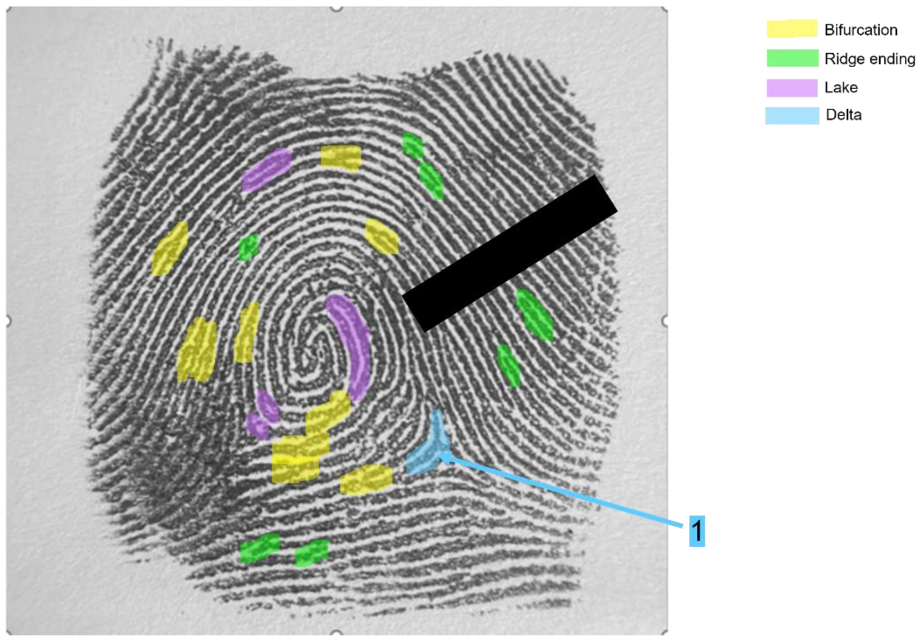

Figure A9: Participants fingerprint. 1 delta numbered and highlighted in blue, part of the 21 characteristics

Appendix B

<u>Appendix B.1: overall method that was used to produce and develop the fingerprints.</u>

- Three acetate sheets were used, sheet A represents primary transfer. Acetate sheet B represents secondary transfer, and acetate sheet C represents tertiary transfer.
- A metal spatula was used to scoop the anti-climb paint straight out of the tub. The bottom of the spatula would be scraped on the rim of the tub.
- The scoop of paint would be placed onto acetate sheet A using a clean paint brush. The same paint brush would be used to spread it/paint it on the acetate sheet.
- This acetate sheet A was left out for two days.
- After two days, the sheet was placed into the pressure device, making sure the 'lid/cover' does not touch the sample.
- The 'lid/cover' was placed on top of the index finger, which was then lowered onto acetate sheet A, depositing the finger-mark.
- The 'lid/cover' was then pulled open, and acetate sheet A was removed.
- The anti-climb paint that is now on the index finger is not wash off.
- Acetate sheet B (fresh acetate sheet) was then placed into the pressure device, using the same technique, the finger-mark was deposited.
- Acetate sheet B was removed from the pressure device and index finger is not washed again.
- Acetate sheet C was placed into the pressure device, and the finger-mark was deposited using the same technique as before.
- Acetate sheet C was removed.
- Hands were then washed.
- Pictures were taken here.
- The samples were then placed into the superglue chamber, attaching them to the crocodile clips.
- They were run for 80 minutes at 100^{o}c with 10-15 drops of superglue in two tart tins.
- Pictures were then taken after CEF.

Appendix B.2: Steps of the inking process (figure B1 and B2)

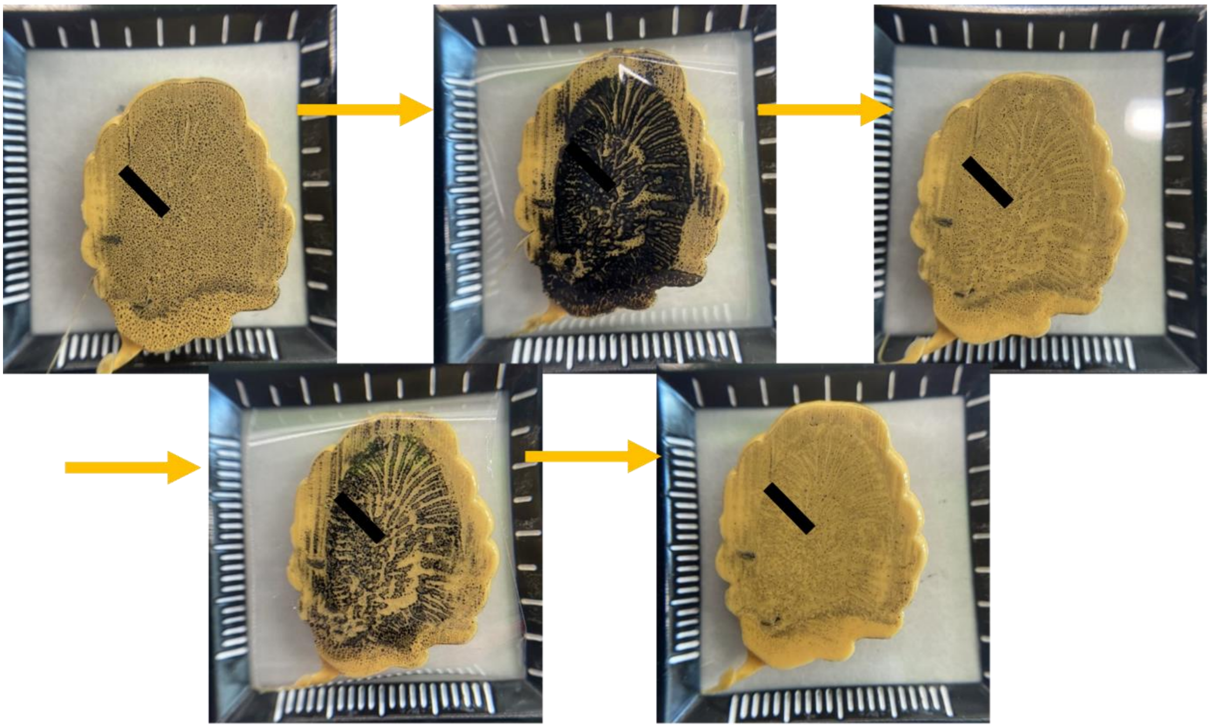

Figure B1: inking process in low grade exhibit

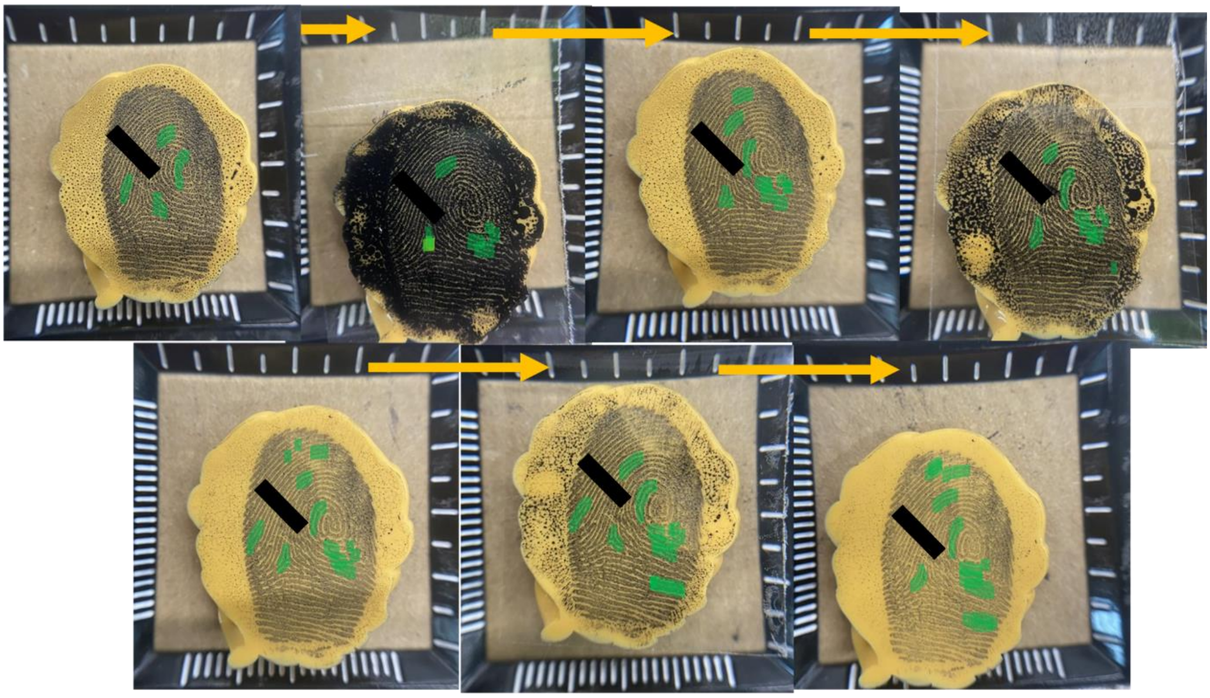

Figure B2: inking process in high grade exhibit

Appendix B.3: set one fridge exhibits (Figure B3- B5)

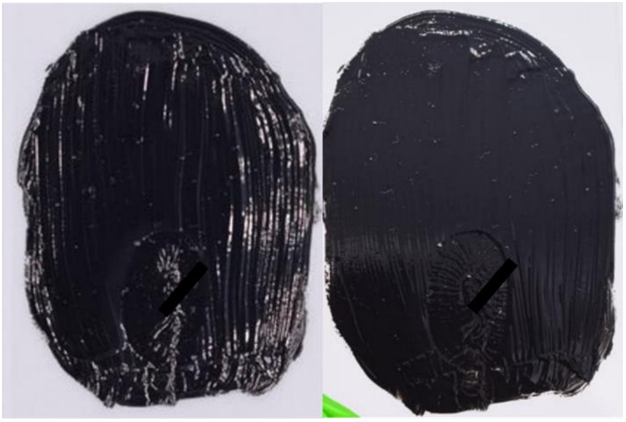

Figure B3: Fridge set one exhibits, primary transfer. No development.

Figure B4: Fridge set one exhibits, secondary transfer. No development.

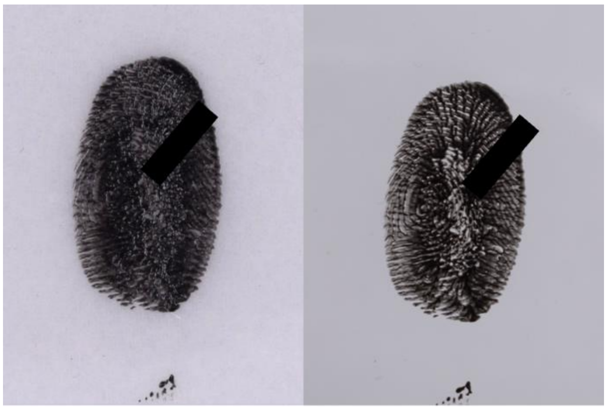

Figure B3.5: Fridge set one exhibits, tertiary transfer. No development.

Appendix B.4: <u>set one freezer exhibits (Figure B6- B8)</u>

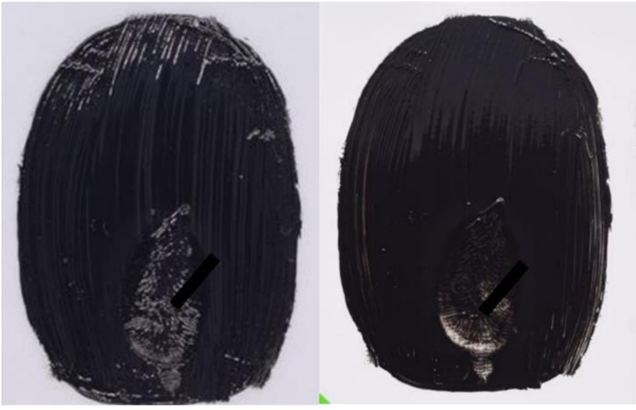

Figure B6: Freezer set two exhibits, primary transfer. No development.

Figure B7: Freezer set two exhibits, secondary transfer. No development.

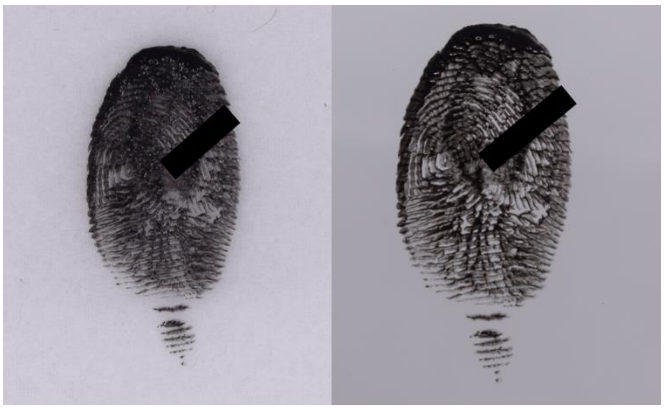

Figure B8 Freezer set two exhibits, tertiary transfer. No development.