The Recovery of Bloody Fingerprints from Skin using Forensic Sil instead of Alginate

K.M.A. Verbeek

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The Recovery of Bloody Fingerprints from Skin using Forensic Sil

A thesis presented by K.M.A. Verbeek

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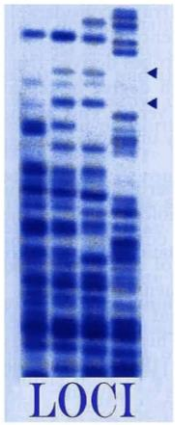

2nd supervisor: Daphne de Launaij

1st supervisor: Walter van Gils

Avans University of Applied Science

1st mentor: Martin Eversdijk

2nd mentor: René Gelderman

Loci Forensics B.V.

Preface

'Murder or suicide?'

A question that remains unanswered in the case of Eline Melters, a Dutch woman who was found dead on the 8th of October, 2009. Eline's body was found outside of a church, possibly with fingerprints placed with blood on her skin, but they were never recovered. Hence why headlines keep stating the unknown cause of her death. To this day there is still no method available for lifting the bloody fingerprints from the skin.

The quote 'murder or suicide?' in the case of Eline Melters really appeals to me. My graduation study on Forensic Sil can possibly lead to answering such significant questions and solving such cases. So I would like to thank Martin Eversdijk and René Gelderman, for giving me the opportunity to work on this study. They taught me a lot about forensics during my graduation internship at Loci Forensics. I have found a great interest in fingerprint examination and can take all this valuable information with me into my future career. I really had a fun, educational and foremost, meaningful time that I will cherish forever.

I would like to thank Daphne de Launaij for the supervision and help throughout my graduation and previous school years. Likewise, I want to thank Jip Sperber (my fellow intern) for the collaboration and good time. We had some long car rides to Nieuw-Vennep, but they were definitely worth it. I would like to thank Hans Teer (fingerprint examiner at police Amsterdam) for performing professional fingerprint identification on my results and sharing his knowledge. Lastly, thanks to Marlène Többen, Christy Haurissa, Lotte Kemps, Hannah van de Sande and Kimberley Lee for scoring the fingerprints and always providing help when needed.

Enjoy reading my thesis!

Kiki Verbeek

Nieuw-Vennep, The Netherlands

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Abstract

A stabbing incident took place in a house. A woman is found dead with multiple stabbing wounds in her chest. When forensic investigators take a closer look at her body, a knife appears to still be present in her neck. On the bloody skin around the wound, partial fingerprints are observed. Besides the blood on the neck, her hands are also covered in blood. The recovery of the bloody fingerprints in the neck is of great importance. These fingerprints can be placed by the victim and thus contribute to exclusion, but can also contribute to identification of the perpetrator. Transport of the body can destroy these fingerprints; friction in the body bag can cause the bloody fingerprint to be removed. In addition, large volumes of blood can run out of the wounds and destroy the fingerprint. The only option is recovery of the fingerprints on the crime scene. Currently, there is no lifting method for lifting bloody fingerprints from skin. Previous studies demonstrate the use of alginate as a lifting method of bloody fingerprints from various surfaces. The use of alginate as a lifting method is researched further in this study. In addition, a new lifting method is introduced, namely Forensic Sil. Forensic Sil can possibly provide optimal recovery of bloody fingerprints from skin in comparison to alginate.

The aim of this study is to determine whether Forensic Sil is more suitable than alginate for the lifting of fingerprints placed with blood on skin. This will be achieved by placing bloody fingerprints on skin and lifting them using both alginate and Forensic Sil. The lifted fingerprints will be enhanced with three different blood enhancement techniques. Results will be captured with a camera. Grading of the fingerprints is performed by a group of objective raters, at three stages; prior to lifting and enhancing (original), post lifting with alginate or Forensic Sil and post enhancement. This way, a conclusion can be drawn about the ability of both alginate and Forensic Sil to recover bloody fingerprints from the skin and the difference between the two methods.

Results showed that, based on fingerprint grading data, Forensic Sil yielded fingerprints with higher average scores than alginate. This means Forensic Sil provided higher amounts of continuous ridges and/or contrast. Grading of a split fingerprint shows that the half-impression lifted with Forensic Sil exhibits far greater ridge detail and/or contrast than the corresponding half-impression lifted with alginate. Besides, fingerprint identification matched 7 minutiae of an alginate lift with a reference print. For Forensic Sil, 13 minutiae were matched. The fingerprint examiner stated that Forensic Sil is an optimal method compared to alginate, but the surface (skin) remains a disruptive factor for identification.

In conclusion, the main question of this research is answered: ‘To what extent is Forensic Sil more suitable than alginate for the lifting of fingerprints placed with blood on skin?’. This study found that alginate is not as suitable as Forensic Sil for lifting bloody fingerprints from skin. Alginate is not able to lift the fine ridge detailing of fingerprints, providing a low quality lift with a high amount of diffusion. Also, the lift is highly impacted by time, making storage impossible. Forensic Sil has shown to have excellent lifting abilities with high amounts of ridge detailing; full fingerprints are lifted and enhanced. The only disruptive factor remains to be the skin. However, when Forensic Sil is further researched on human skin, there is a high chance the method will recover high quality fingerprints suitable for fingerprint identification. The case presented, in which a woman was found dead with bloody fingerprints on her skin, is an example of a case that can be solved through the findings of this study.

Key words: bloody fingerprints, skin, alginate, Forensic Sil, lift, ridge detail, identification.

Abstract Dutch

Een steekincident heeft plaatsgevonden in een woning. Een vrouw is dood aangetroffen met meerdere steekwonden in haar borst. Wanneer forensisch onderzoekers het lichaam beter bekijken, blijkt er een mes aanwezig te zijn in haar nek. Op de bebloede huid rondom de wond worden gedeeltelijke vingerafdrukken waargenomen. Naast het bloed op de nek zijn ook haar handen bedekt met bloed. Het liften van de vingerafdrukken in de nek is van groot belang. Deze vingerafdrukken kunnen door het slachtoffer zijn geplaatst en zo leiden tot uitsluitsel, maar kunnen ook geplaatst zijn door de dader en leiden tot identificatie. Het transport van het lichaam kan de vingerafdrukken vernietigen; frictie in de lijkenzak kan de bebloede vingerafdruk wegvegen. Daarnaast kunnen de grote volumes bloed die vrijkomen uit de wond de vingerafdruk wegspoelen. De enige optie is dan ook het liften van de bebloede vingerafdrukken op de plaats delict. Momenteel is er geen lift methode voor het liften van bebloede vingerafdrukken van de huid. Voorgaande studies demonstreren het gebruik van alginaat als lift methode van bebloede vingerafdrukken van verschillende oppervlakken. Het gebruik van alginaat als lift methode wordt verder onderzocht in deze studie. Daarnaast wordt een nieuwe methode geïntroduceerd, namelijk het gebruik van Forensic Sil. Forensic Sil kan mogelijk optimaal bebloede vingerafdrukken liften van de huid vergeleken met alginaat.

Het doel van deze studie is bepalen of Forensic Sil meer geschikt is dan alginaat voor het liften van vingerafdrukken geplaatst met bloed op de huid. Dit wordt onderzocht door bebloede vingerafdrukken te plaatsen op huid en vervolgens te liften met alginaat en Forensic Sil. De gelifte vingerafdrukken worden vervolgens verbeterd met drie verschillende bloedverbeteringstechnieken. Resultaten worden vastgelegd met een camera. Het scoren van de vingerafdrukken wordt uitgevoerd door een groep objectieve beoordelaars, bij iedere fase; voorafgaand aan lift en bloedverbetering (origineel), na de lift met alginaat of Forensic Sil en na de bloedverbetering. Op deze manier kan een conclusie getrokken worden over de mogelijkheid tot het liften van bebloede vingerafdrukken van de huid met alginaat en Forensic Sil en het verschil tussen de twee methodes.

Resultaten laten zien dat - gebaseerd op de scores van de vingerafdrukken - vingerafdrukken gelift met Forensic Sil gemiddeld hoger scoren dan vingerafdrukken gelift met alginaat. Dit betekent dat de Forensic Sil lift een grotere hoeveelheid continue papillair lijnen en/of contrast geeft. Het beoordelen van een ‘split’ vingerafdruk toont aan dat de halve-vingerafdruk gelift met Forensic Sil veruit een grotere hoeveelheid detail en/of contrast geeft dan de overeenkomstige halve-vingerafdruk gelift met alginaat. Daarnaast heeft vingerafdruk identificatie 7 overeenkomstige typica gevonden tussen een vingerafdruk gelift met alginaat en de referentieafdruk. De vingerafdruk gelift met Forensic Sil gaf 13 overeenkomstige typica met de referentieafdruk. De dactyloscoop gaf hierbij aan dat Forensic Sil een optimale methode blijkt vergeleken met alginaat. Maar de ondergrond (huid) blijft een storende factor voor identificatie.

Een conclusie wordt getrokken op basis van de hoofdvraag; ‘In hoeverre is Forensic Sil meer geschikt dan alginaat voor het liften van vingerafdrukken geplaatst met bloed op de huid?’. Deze studie toont aan dat alginaat niet even geschikt is als Forensic Sil voor het liften van bebloede vingerafdrukken van de huid. Papillair lijnen van vingerafdrukken kunnen niet gelift worden door alginaat, waardoor een lift van lage kwaliteit met veel diffusie wordt verkregen. Ook wordt alginaat sterk beïnvloed door tijd, waardoor opslag onmogelijk is. Forensic Sil blijkt uitstekende lift mogelijkheden te hebben met een hoge mate van papillair lijnen. Volledige vingerafdrukken worden door Forensic Sil gelift en worden verbeterd. De enige storende factor blijft de huid. Echter, wanneer Forensic Sil verder onderzocht wordt op humane huid bestaat de kans dat de methode hoge kwaliteit vingerafdrukken zal liften die geschikt zijn voor identificatie. De zaak die eerder werd geschetst, waarin een vrouw dood gevonden werd met bebloede vingerafdrukken op de huid, is een voorbeeld van een zaak die opgelost kan worden aan de hand van de bevindingen van deze studie.

Key words: bebloede vingerafdrukken, huid, alginaat, Forensic Sil, lift, papillair lijnen, identificatie.

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Glossary

This chapter highlights and explains common terms used in this thesis. This will help the reader to understand the terminology and prevent misinterpretation. The explanation of terms is obtained from the Home Office Fingerprint Visualisation Manual of the Centre of Applied Science and Technology (CAST). [1]

Background The appearance of the surface where the fingermark is present under the same conditions used to visualize the mark. The appearance of the background is influenced by a range of surface properties including colour, texture, reflectivity and any printed patterns that are present.

Development A subset of visualization where a process applied to the fingermark results in it becoming visible in a progressive way, producing a gradual change from invisible to clearly visible. Most chemical and physical processes can be considered to 'develop' fingermarks.

Enhancement The improvement of a fingermark that is already visible to some extent by the application of an additional process that either reveals additional ridge detail or makes that which is already visible more readily distinguishable from the background.

Evidence recovery The process by which forensic evidence of any class is first located and then translated into a form suitable for comparison and/or analysis by a person competent in that class of forensic evidence.

Examination A focused inspection of an item or surface with the objective of locating particular types of evidence.

Fingermark The mark left as a result of the uncontrolled contact of a finger with a substrate. The term may also be used as a general description for the marks left by the contact of any region of friction ridge skin, which includes palms, toes and the soles of the feet.

Fingerprint A reproduction of the friction ridge skin pattern of the fingertip obtained from a known donor under controlled conditions, e.g. inked or 'live scan' images obtained in a custody suite.

Fingerprint examiner A person competent in the comparison of fingermarks recovered from crime scenes with sets of fingerprints, and qualified to give opinions relating to identification (or exclusion) of fingermarks.

Identification One possible end result of a comparison process between a fingermark and a fingerprint, between two sets of fingerprints, or between two fingermarks. The result is considered an 'identification' when the examiner considers the level of agreement in the features occurring in the two marks/prints being compared is sufficiently high that they must have originated from the same donor.

Impression The outcome of a contact between a finger and a substrate where the substrate has deformed during contact, leaving indentations that reproduce the ridge detail on the finger.

Latent fingermark A fingermark that has been formed on a substrate as a result of contact with a finger and is not visible to a cursory visual examination. Marks of this type will require the application of visualization processes before they can be detected.

Mirrored marks A mark that due to a range of factors may be visualised as a mirror image of the correct orientation.

Ridge detail The patterns and features formed by the characteristic ridge structures found on the fingers, palms of the hands, toes and soles of the feet. Ridge detail may be reproduced both within fingerprints taken under controlled conditions and in fingermarks deposited under controlled conditions.

Visible fingermark A fingermark that has been formed on a substrate as a results of contact with a finger and is readily visible during a cursory visual examination. Where such marks have been deposited in visible contaminants, such as dirt, ink, blood, or paint they may occasionally be described as 'patent' fingermarks.

1. Introduction

A stabbing incident took place in a house. A woman is found dead with multiple stabbing wounds in her chest. When forensic investigators take a closer look at her body, a knife appears to still be present in her neck. On the bloody skin around the wound, partial fingerprints are observed. Besides the blood on the neck, her hands are also covered in blood. The recovery of the bloody fingerprints in the neck is of great importance. These fingerprints can be placed by the victim and thus contribute to exclusion, but can also contribute to identification of the perpetrator. Transport of the body can destroy these fingerprints; friction in the body bag can cause the bloody fingerprint to be removed. In addition, large volumes of blood can run out of the wounds and destroy the fingerprint. The only option is recovery of the fingerprints on the crime scene. A possible method for the recovery of bloody fingerprints from skin is the use of Forensic Sil.

Fingerprints are one of the most common forms of evidence found at a crime scene. They may be found on many surfaces, including the skin. Human skin is one of the least convenient surfaces for recovering the ridge impressions of fingerprints, since eliminating components are present in both the friction ridges of the fingerprint and the skin surface of the body. [1]

In serious crimes that involve physical contact, fingerprints that are placed with blood can be found on the skin of the deceased. These fingerprints can carry valuable information about the donor and thereby contribute to reconstruction of the crime. They could possibly be donated by the perpetrator. Recovering these fingerprints at the crime scene is of great importance, since they have high evidential values. Current protocols on recovering the bloody fingerprints from skin do not include any lifting methods. Previous studies demonstrate the use of alginate as a lifting method of bloody fingerprints from various surfaces. The use of alginate as a lifting method is researched further in this study. In addition, a new lifting method is introduced, namely Forensic Sil. Forensic Sil can possibly provide optimal recovery of bloody fingerprints from skin in comparison to alginate.

Goal

The aim of this study is to determine whether Forensic Sil is more suitable than alginate for the lifting of fingerprints placed with blood on skin. This will be achieved by placing bloody fingerprints on skin and lifting them using both alginate and Forensic Sil. The lifted fingerprints will be enhanced with three different blood enhancement techniques. Results will be captured with a camera. Grading of the fingerprints is performed by a group of objective raters, at three stages; prior to lifting and enhancing (original), post lifting with alginate or Forensic Sil and post enhancement. This way, a conclusion can be drawn about the ability of both alginate and Forensic Sil to recover bloody fingerprints from the skin and the difference between the two methods.

Hypothesis

Hypothesis 1: Forensic Sil is able to lift bloody fingerprints such that continuous epidermal ridges can be identified, while alginate is not able to.

Hypothesis 2: Both Forensic Sil and Alginate are able to lift bloody fingerprints such that continuous epidermal ridges can be identified.

Hypothesis 3: Both Forensic Sil and Alginate are not able to lift bloody fingerprints such that continuous epidermal ridges can be identified.

1.1 Research questions

This research focuses on the main question; 'to what extent is Forensic Sil more suitable than alginate for the lifting of fingerprints placed with blood on skin?'. In order to obtain an answer to this question, a total of five sub questions were defined. Table 1 describes the main question and sub questions.

Table 1 *Overview of the main question and sub questions regarding the research of Forensic Sil and alginate for the recovery of fingerprints placed with blood on the skin.*

Main question	**To what extent is Forensic Sil more suitable than alginate for the lifting of fingerprints placed with blood on skin?**
Sub question 1	What are the optimal lifting conditions of alginate and Forensic Sil?
Sub question 2	What blood enhancement techniques work when combined with alginate and Forensic Sil?
Sub question 3	Is alginate able to lift bloody fingerprints from skin in a way that continuous epidermal ridges are observed?
Sub question 4	Is Forensic Sil able to lift bloody fingerprints from skin in a way that continuous epidermal ridges are observed? If so, to what extent are the ridges observed more with Forensic Sil than with alginate?
Sub question 5	What is the impact of time on the alginate and Forensic Sil casts, regarding the dimensional stability and epidermal ridges?

2. Literature background

2.1 Dactyloscopy

Dactyloscopy (ancient Greek: dáktulos, "finger" and skopéō, "I look at") is the science of fingerprint identification. [2] It is one of the oldest and most important sorts of evidence in forensic science. The use of friction ridge skin patterns for personal identification dates back many centuries and is currently widely accepted as identifying evidence. [3] Fingerprints can be used to identify an individual because they are unique. Forensic science mainly uses fingerprints for locating, identifying and excluding suspects in criminal cases. Two features that are of great importance in fingerprint identification are: (1) every fingerprint is individual and unique, (2) fingerprints are immutable, they do not change unless the dermis is damaged. [3]

The fingers, palms of hands and soles of feet of humans bear friction ridge skin formed by dermal papillae (also referred to as 'valleys') and epidermal ridges . In a fingerprint image, ridges are represented as dark lines and valleys are bright (see figure 1). Ridges range in width from 100 µm for the thinnest ridges, to 300 µm for thick ridges. Generally, the length of a ridge/valley cycle is around 500 µm. On fingertips, these friction ridges and valleys form a number of basic patterns. Within these basis patterns there are many possible variations. Genetics probably play a significant part in determining the sizes and shapes of fingerprint patterns and ridges, since they are formed by the dermis in early embryonic development and remain the same throughout life. However, in the case of identical twins (who have identical genetics), different and distinguishable fingerprints are observed. Injuries such as superficial burns, cuts and abrasions do not disturb the epidermal ridging, when new skin grows the original pattern is duplicated. Thus despite the genetics and external factors, the fingerprint remains unique per individual. [3] [4]

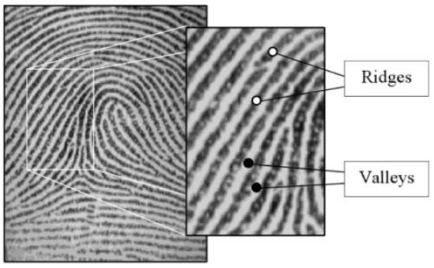


Figure 1 *The epidermal ridges (ridges) and dermal papillae (valleys) forming a fingerprint.* [3]

2.2 Fingerprint levels

Ridge detailing is generally described in hierarchical order at three levels; level 1 (ridge pattern), level 2 (minutiae) and level 3 (pores, ridge shapes, etc.).

Level 1

The global level (level 1) describes the distinctive shapes of ridges in certain regions. These regions, called singularities, can be classified into three basic patterns; arch (delta), loop and whorl (see figure 2).

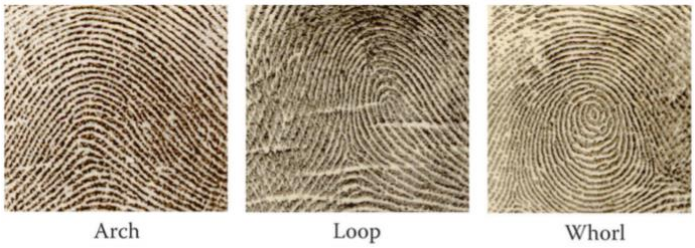


Figure 2 *The three basic fingerprint patterns: arch, loop and whorl. [7]*

The three main categories can be further extended into other categories. For example, the main category of arches can be extended to a plain or tented arch. The loop category can have radial or urnal loops, depending on the direction of the slope. Whorls are the most complex patterns with several categories; central pocket, double loop and accidental. Both loop and whorl patterns can be differentiated based on features called the core and the delta, pointed out in figure 3. These features are important in classification and comparing fingerprints. The figure below (see figure 3) describes the classification of fingerprints. [3] [5]

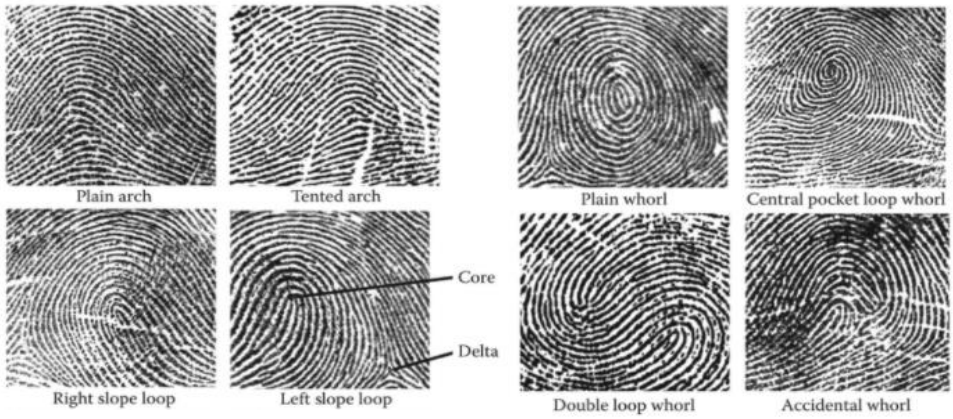


Figure 3 *Classification of fingerprint patterns: arches, loops and whorls, with the left slope loop showing the core and delta. [2]*

Level 2

At the local level (level 2), other important features called minutiae are found within the fingerprint patterns of level 1. When fingerprints appear to have the same ridging and pattern, minutiae are used to compare the fingerprints and determine whether they are from the same individual. Minutia stands for small detail; in fingerprints this refers to the way in which ridges discontinue and thereby form minutiae. There are three ways minutiae can be formed; (1) abrupt ending of the ridge (ridge ending), (2) dividing of the ridge into two ridges (bifurcation) and (3) the ridge is short in length (dot). Combinations of minutiae can also occur, for example two bifurcations facing each other and forming an island (see figure 4). [3] [4] [5]

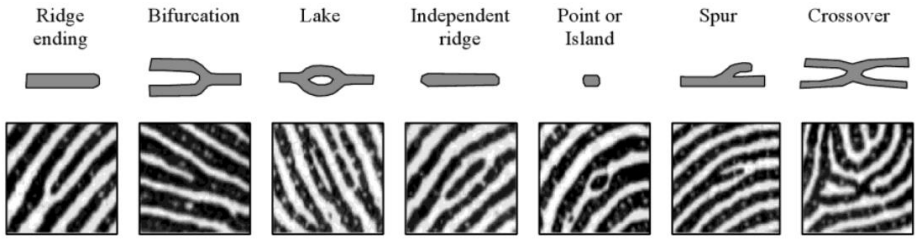


Figure 4 *Fingerprint minutiae; ridge ending, bifurcation, lake, independent ridge, point/island, spur and crossover.* [4]

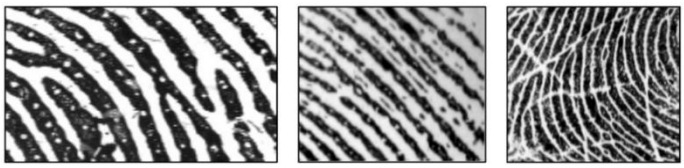
Minutiae are most commonly used in fingerprint identification. Over a hundred minutiae can be present in a full fingerprint. However, when matching fingerprints only 12 to 15 minutiae are required to claim a high confidence match. [4] The exact amount of minutiae requisite varies per country. In the Netherlands, a minimum of 12 minutiae is required for a high confidence match. However, the UK handles 16 minutiae and in the USA, each state determines the sufficient amount of minutiae separately. [3] [6]

Level 3

On a highly detailed level (level 3), further fine details can be identified in the fingerprint pattern. These details include the width, shape, contour of the edges, pores, incipient ridges, scarring, breaks and creases. Every epidermal ridge is spread with (sweat-)pores over its entire surface that originate from the dermis (see figure 5a). Incipient ridges are friction ridges that are only partially developed and are located between the epidermal ridges. They appear shorter, thinner and occur more periodically than the fully developed ridges. The incipient ridges do not contain pores, rarely bifurcate, can appear as a row of dots and are shallow on the surface (see figure 5b). Creasing in a fingerprint can be permanent or non-permanent and thereby can complicate matching (see figure 5c). [7] [5]

Despite the very distinct level 3 features and high importance of examining them, automated fingerprint matching techniques often do not use them in their algorithms. Third level feature-based matching requires high resolution scanners and good quality fingerprint images. [4] In the Netherlands, third level features

are only used for individualization when combined with first and second level features. [5]



(A) (B) (C)

Figure 5 *Level 3 features of a fingerprint: (A) pores in epidermal ridges with varying width, shape and contours, (B) incipient ridges located between normal ridging, (C) creasing of the fingerprint. [8]*

2.3 Blood

Blood consists of blood plasma (55%) and blood cells (45%). Blood plasma is an aqueous solution, it contains dissolved proteins and around 91 percent water. The blood cells are mostly composed of red blood cells, called erythrocytes. The rest of the cells are platelets and white blood cells, also called leukocytes. Erythrocytes contain large amounts of haemoglobin, an oxygen carrying protein that creates the red colour of blood. Haemoglobin is made up of heme and a globulin protein. Heme is the precursor of haemoglobin and is needed to bind oxygen. It consists of an iron molecule in the reduced state. Platelets are responsible for the clotting of blood, leukocytes are responsible for the body's immune defence system. [6] [8] [9] These components of blood – proteins and haemoglobin – can be of great usage in blood enhancement, especially to visualise and enhance fingerprints that are placed with blood.

2.4 Blood enhancement

Different reagents can be used to enhance blood prints. These blood enhancement techniques are generally divided into two categories: protein reagents and peroxidase reagents. [8]

2.4.1 Protein reagents

Protein reagents react with both the proteins present in blood plasma and the globular protein in haemoglobin. Generally, this makes the protein reagents highly sensitive. On the other hand, the reaction of protein reagents is less specific and cannot identify the presence of blood upon positive results. [8]

Amido Black

Amido Black (also called Acid Black 1) is an acidic dye for staining proteins. When proteins are stained by Amido Black, a dark blue-black colour change takes place. It is one of the most commonly used blood reagents in blood analysis and can be applied to both non-porous and porous surfaces. The use of Amido Black on porous surfaces can presumably cause significant background staining, which limits application. [8] [10]

In the early 1970s, Amido Black was first used as a method for latent blood enhancement. However, at this time the solvent contained methanol and acetic acid. [8] A safer, water-based solute of Amido Black was introduced in 1989. In contrast to the methanol based solution, this solution can be used on non-porous substrates only. The water-based staining solution of Amido Black provides a staining solution and fixing agent (sulfosalicylic acid) in one step and is available at and provided by Loci Forensics BV. The fixing agent prevents the blood trace from spreading, running out and dissolving. After staining, a washing solution of distilled water and 0.1% acetic acid can be applied to rinse away access reagent. [11]

Hungarian Red

Hungarian Red is a water-based staining solution that is also referred to as Fuchsin Acid. It contains Acid Violet 19, a triarylmethane dye that produces a strong change in colour. When Hungarian Red comes in contact with proteins, a red stained product is formed. [8] [10] [12]

Within the staining solution of Hungarian Red, a fixing agent (sulfosalicylic acid) is added to fixate the blood traces onto the surface. This prevents the blood trace from spreading, running out and dissolving, which causes loss of detail. After staining, a washing solution of distilled water and 0.1% acetic acid can be applied to rinse away access reagent. Hungarian Red is available at and provided by Loci Forensics BV. [10] [12]

2.4.2 Peroxidase reagents

Peroxidase reagents react with the heme-group of haemoglobin, hence why they are also referred to as haemoglobin reagents. One of the most commonly used peroxidase reagents for blood enhancement is, besides the well-known Luminol, Leucocrystal Violet. [8] [10]

(Aqua) Leucocrystal Violet

Leucocrystal Violet (abbreviated as LCV) is a blood staining and enhancing method that is based on the catalytic reaction of blood with hydrogen peroxide. During this reaction, the colourless LCV converts into the purple-coloured crystal violet. When the reagent (LCV) comes into contact with blood, the hydrogen peroxide is broken down by the haemoglobin present in blood. This way haemoglobin gets oxidized. The oxidized haemoglobin in turn can oxidize the colourless Leucocrystal Violet to the strongly coloured Crystal Violet. The haemoglobin is now back in the reduced state, meaning it can be oxidated again under the presence of hydrogen peroxide. A catalytic reaction takes place with haemoglobin being the catalyst (see figure 6). [8] [10] [13]

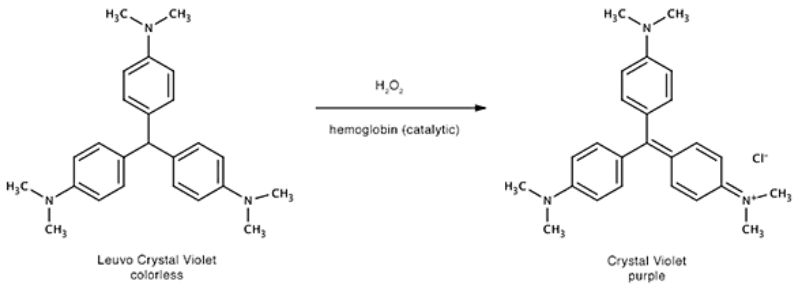


Figure 6 *Catalytic reaction of Leucocrystal Violet (LCV) and Crystal Violet, with haemoglobin as catalyst. The presence of hydrogen peroxide stimulates the oxidation of haemoglobin and thus the reaction of LCV to Crystal Violet. The reaction causes a purple stain.* [10]

The LCV staining solution can be prepared on a water-basis (Aqua Leucocrystal Violet, abbreviated as ALCV). ALCV is available at and provided by Loci Forensics BV. Here, the fixing agent sulfosalicylic acid is implemented into the staining solution. In order to activate the staining solution, hydrogen peroxide tablets are required. After staining, a washing solution of distilled water and 0.1% acetic acid can be applied to rinse away access reagent. ALCV can be applied to both porous and non-porous substrates. [13]

Amido Black, Hungarian Red and ALCV are three blood enhancement techniques that are commonly used for the enhancement of bloody fingerprints. Besides enhancing the fingerprint, recovering it is just as essential. Possible lifting methods for the recovery of bloody fingerprints are alginate and Forensic Sil.

2.5 Alginate

Human skin is considered to be one of the most inconvenient surfaces to recover fingerprints from, since eliminating components are present in both the friction ridges of fingerprints and on the surface of the skin (structured, flexible surface with carved intersecting lines, ridges, hair follicles and creasing). [14] [15] A method that can possibly recover fingerprints placed with blood from the skin surface is the use of alginate.

Alginate is a casting material that is often used in the field of dentistry for casting teeth. A number of different alginate sorts are produced by different companies, each with distinct characteristics and methods of usage. Generally, alginate is supplied as a white or coloured powder to which water is added for application. These powders contain sodium or potassium salts of alginic acid (11-16%), gypsum (11-17%), trisodium phosphate (1-3%) and fillers (inert). The sodium and potassium salts are the main reactive

ingredient, they cross-link with water to form a gel structure (shown in figure 7). Gypsum is the source of Ca^{+} ions that cross-link alginate chains. The working time of alginate is controlled by the amount of trisodium phosphate. For manipulation and flexibility of the alginate, the fillers are used. [16] [17]

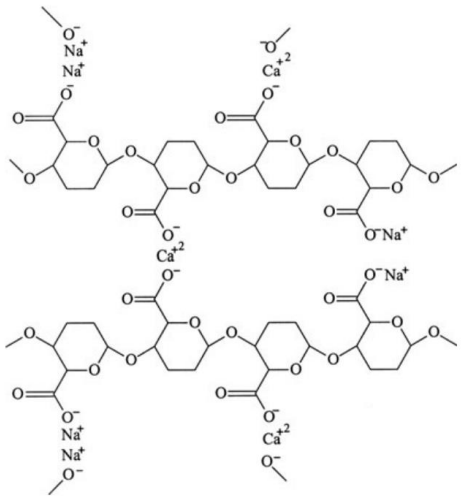


Figure 7 *Alginate gel network.* [18]

GC Aroma Fine Plus

Previous studies that looked into the use of alginate for the lifting of bloody shoeprints and fingerprints showed that Aroma Fine alginate (available at GC) gave superior results when compared to other alginates. [17] [18] [19] Primarily, GC Aroma Fine is produced for the casting of teeth in dental care. A preliminary alginate sort of GC is Aroma Fine Dust III, which is often referred to in articles. Recently, GC produced a new sort of alginate with upgraded mixing methods, called Aroma Fine Plus. The pink powder of Aroma Fine Plus incorporates rapidly into the water because of enhanced powder-water affinity, gaining a smooth and bubble free mixture in 20 seconds. [20] In this study, GC Aroma Fine Plus will be used to recover bloody fingerprints from skin.

2.6 Forensic Sil

Forensic Sil is a low-viscosity, thixotropic, elastic compression compound. It is applied to the surface using an automatic mixing device and forms highly detailed, elastic impressions of (damaged) surfaces. Forensic Sil is made of polyvinylsiloxane, which forms when mixing two components; a base and a catalyst. The mixing tip mixes both components together in a constant dosage. The mixing time is five seconds and the setting time around five minutes with the summer version (above 0 degrees Celsius). [21] The winter version is specially made for temperatures below 0 degrees Celsius, providing faster setting times. [22]

Currently, Forensic Sil is used in forensics for taking imprints from tool marks and bite marks. It has multiple advantages; it is non-toxic, quick with a simple application, suitable for comparison to previous imprints and constant in mixing ratio. Other important advantages are that no by-products (such as moisture) are formed during or after setting and Forensic Sil being dimensionally stable; flexible and shrink-proof. [21] Forensic Sil will be researched in this study as a possible new method for recovery of bloody fingerprints from skin.

3. Strategy

Goal

The aim of this study is to determine whether Forensic Sil is more suitable than alginate for the lifting of fingerprints placed with blood on skin. This will be achieved by placing bloody fingerprints on skin and lifting the fingerprints using both alginate and Forensic Sil. The lifted fingerprints will be enhanced with three different blood enhancement techniques. Results will be captured with a camera and additional light source. Grading of the fingerprints is performed by a group of objective raters, at three stages; prior to lifting and enhancing (original), post lifting with alginate or Forensic Sil and post enhancement. This way, a conclusion can be drawn about the ability of both alginate and Forensic Sil to recover bloody fingerprints from the skin and the difference between the two methods.

Strategy

To determine whether Forensic Sil can be used instead of alginate for the lifting of bloody fingerprints from skin, the two lifting methods are compared. A conclusion can be drawn about the lifting abilities based on the amount of continuous ridges that are observed on alginate and Forensic Sil casts. [23] [24] The fingerprints are captured with a Nikon D5100 camera and additional light sources. All results are analysed and a number of fingerprints are examined by a fingerprint examiner, who can perform professional identification. [24] Besides, a selection of fingerprints is graded by a group of five objective raters. The fingerprints are graded based on the amount of continuous ridging processed in a grading system (Centre of Applied Science and Technology – CAST). The system focuses on the surface area of developed ridge detailing relative to a full fingerprint. [24] All fingerprints are graded by the same rater for consistency. Three different stages are included in the grading; the original fingerprint (on skin), the lifted fingerprint (alginate or Forensic Sil lift) and the enhanced fingerprint. This allows for a comparison to be made between the original fingerprint on skin and the effect of lifting the fingerprint (positive, negative or neutral effect). The grading is based on scores varying between 0 (no evidence of fingerprint) and 4 (complete fingerprint with continuous ridges). Besides ridge detail, grading is focused on the amount of contrast observed, since this can vary per blood enhancement technique. In addition, a comparative scale is included to compare the alginate lifting method to the Forensic Sil lifting method. The UC (University of Canberra) comparative scale is set up to assess the relative performance of method A compared to method B. Since this scale can only be used in case of split fingerprints, it is only performed on the main research split alginate and Forensic Sil fingerprints. Comparative grading is set up with scores of -2, -1, 0, +1 and +2. With score -2 meaning that method B provides far greater ridge detail and/or contrast than method A and score +2 the other way around. Score 0 means no difference between the methods is observed. [24] Based on the data gained from the fingerprint grading, an intraclass correlation coefficient is calculated for inter-rater reliability. T-tests are performed to determine whether a significant difference between the three stages and the two lifting methods is present. A conclusion can be drawn about alginate and Forensic Sil as lifting methods.

Human skin is imitated using pig skin, since they show high similarities [25]. The skin is vacuum packed and stored in the freezer, defrosting is done by leaving it at room temperature. The bloody fingerprints are imitated with blood of mammal origin (cow). Mammal blood is chosen since it comes from one donor, can be stored in the freezer for a long time and remains constant. The cow blood contains EDTA, an anticoagulant preventing clot formation. Cellular components and the morphology of blood cells are well preserved. [26] Prior to using the blood in the experiments, it is sieved and centrifuged to create a homogenous substance of blood cells and plasma and remove possible clots formed by defrosting. The blood is stored in the freezer. During the experiments, the blood will be brought to room temperature (~20 °C) and used directly after.

Before starting the study, various experiments were carried out to gain insight in alginate and its lifting abilities. These experiments showed that alginate does not always provide a sufficient, high quality lift as

stated in literature. Due to these findings, a possible better method was sought. Based on small experiments, this seemed to be Forensic Sil; a product available at Loci Forensics BV. This gave rise to including Forensic Sil in the study, a new method that will be compared to the previously researched alginate.

Prior to the main study, a total of four preliminary studies are carried out. The results from these experiments help provide a narrowed method for the main study. The preliminary studies are focused on determining the optimal conditions of alginate, Forensic Sil and skin. Alginate and Forensic Sil lifts are performed on garbage bags to take away the possible deviant results caused by the relatively variable surface of the skin. Results from the preliminary studies are used to provide a specific, optimal method for the main research. Here, the alginate and Forensic Sil lifts are performed on skin under optimal conditions and in larger sample sizes.

Throughout the main study, the bloody fingerprints will be placed as depletion series on the skin by four individuals; two male and two female donors. This way, the variation that can exist between donors is included in the result. Deviant results cannot be distinguished when only one donor is included in the study. Depletion series are placed (with right thumb, medium pressure) on the skin in a series of nine, containing three triplicates with relatively constant volumes of blood. This prevents placing thick bloody fingerprints with high volumes of blood. Based on the properties of blood, the high volume will overload the fingerprint and thus close the epidermal ridges. Also, no latent fingerprints with low volumes of blood are placed. When the blood volume is too low, blood enhancement will not occur. Therefore the fingerprint ridges remain latent. Both thick and latent bloody fingerprints can give deviant results and thus will not contribute to gaining insight in the lifting abilities of Forensic Sil and alginate. However, the depletion series do contain small variations in volume, since it is not possible to dose exact amounts of blood on the fingerprint.

Only undiluted blood is used throughout the study. In practice, fingerprints placed with diluted blood can be found on skin. They can either be visible (due to low dilution factor) or invisible (due to high dilution factor). When the fingerprint is invisible to the human eye, it is not recognized and therefore not recovered. Hence why high dilutions factors are not taken into consideration. When a fingerprint is visible to the human eye, it is recognized and therefore must be recovered, regardless of the dilution factor. Therefore no low dilution factors are taken into consideration.

The alginate selected for this study is Aroma Fine Plus (normal set) provided by GC Corporation. Several studies regarding alginate brand comparison conclude that GC Aroma Fine provides optimal results. [17] [19] Hence why this brand of alginate was chosen to be used throughout the study. For enhancement, three blood reagents are used: Amido Black, Hungarian Red and ALCV. All blood enhancement techniques are water-based and available at Loci Forensics BV. Blood reagents were applied by immersing the samples for an even application and constant staining. The preparation and specifications are presented in appendix I.

In conclusion, the results of Forensic Sil lifts are compared to the results of the alginate lifts. Comparing the two methods shows the difference in lifting abilities, whether Forensic Sil is suitable for lifting and if so, to what extent Forensic Sil is more suitable than alginate. All variables per sub question are listed in table 2. Constant factors are also taken into consideration to lower variability and maximize the reproducibility (see appendix I).

Table 2 *Selected variables, their description and corresponding sub question.*

Variable	Description	Sub question
Donor fingerprints	Donor 1 (female) – donor 2 (male) – donor 3 (male) – donor 4 (female)	1-4
Blood enhancement technique	ALCV – Hungarian Red – Amido Black	1 & 3
Lifting method	Forensic Sil – Alginate lift	2 & 4
Time stamps (post lifting)	0h – 2h – 4h – 12h	5

4. Methodology

Prior to the main research, multiple preliminary experiments were performed. These experiments were set up to provide insight in the optimal conditions of alginate, Forensic Sil and the skin. The set optimal conditions were used throughout the main research with larger sample-sizes.

Optimal conditions of alginate

First, the optimal conditions of alginate were determined. This includes the mixing ratio, water temperature and mixing in blood reagents. The experiment was performed on black garbage bags to create a stable surface that does not influence the alginate lifting abilities.

Five mixing ratios of alginate (*GC Aroma Fine Plus, normal set*) to water were selected based on the ratios described in literature and provided by the manufacturer. The ratios include; 1:3, 1:2.7, 1:2.5, 1:2.3 and 1:2 (see table 3). Mixing was done with 21°C water. Five depletion series of six fingerprints were placed on the garbage bag and left to dry. Alginate was applied to the depletion series with a spatula. Once applied, a plastic plate was used to lightly press the alginate (for good contact and a flat cast). Alginate was left to set and dry (3-5 minutes). Subsequently, per mixing ratio a depletion series was lifted and enhanced with ALCV (*1% hydrogen peroxide solution, Loci Forensics BV*). Only ALCV was used to maintain a constant staining throughout every cast and variable. The alginate mixtures, fingerprints on the garbage bags, lifted fingerprints prior to blood enhancement and lifted fingerprints after blood enhancement were all photographed individually. The optimal mixing ratio is used to determine the optimal water temperature.

Table 3 *Optimal conditions of alginate included in sub study 1.*

Mix ratio	Water temperature	Blood reagents
1:2	21°C	ALCV
1:2.4	30°C	Hungarian Red
1:2.5	40°C	Amido Black
1:2.7	15°C	
1:3	10°C	

The experiment was repeated for the variable water temperature. Alginate mixtures were prepared using five different water temperatures, namely 21°C, 30°C, 40°C, 15°C and 10°C. Starting with 21°C, the other water temperatures were altered based on the results. Each depletion series (six fingerprints) was lifted using another water temperature mixture. ALCV was used to enhance the alginate casts. Results were photographed.

Lastly, the mixing of blood reagents with alginate was researched. This experiment was performed based on the findings of multiple research articles regarding alginate. ALCV, Hungarian Red (*Fuchsine solution, Loci Forensics BV*) and Amido Black (*Loci Forensics BV*) were mixed with alginate in a 1:2.5 ratio. In addition, Amido Black was prepared without citric acid (2 gram AB in 1000 ml distilled water), since the acid component may interfere with the alginate properties. All results were photographed.

Optimal conditions of Forensic Sil

Forensic Sil is, as mentioned earlier, provided in both a winter and summer version. This experiment determined which version provides an optimal lift of bloody fingerprints from garbage bags.

Three depletion series of five fingerprints were placed on garbage bags. One depletion series was lifted using the summer version, one depletion series was lifted with the winter version. The last depletion series were split fingerprints in which one half-fingerprint was lifted with the summer version and the other half-fingerprint with the winter version. The Forensic Sil lifts were enhanced using ALCV. The experiment was performed at room temperature and all results were photographed.

Optimal conditions of skin

For the optimal skin conditions, washing the skin and the impact of time were included. Skin was either unwashed or washed with green soap and ethanol, only green soap or only ethanol. For every washing condition a lift was performed 20 minutes and 2 hours after placing the bloody fingerprint. This was done to gain insight in the possible effects of skin conditions (oiliness, dryness, etc.) on the lifting mechanism.

Table 4 *Optimal conditions of the skin per depletion series: unwashed or washed skin (green soap and ethanol, green soap or ethanol) at two time stamps (20 minutes or 2 hours).*

	Skin condition	Time stamp
1	Unwashed	20 minutes
2	Unwashed	2 hours
3	Washed Green soap + ethanol	20 minutes
4	Washed Green soap + ethanol	2 hours
5	Washed Green soap	20 minutes
6	Washed Green soap	2 hours
7	Washed Ethanol	20 minutes
8	Washed Ethanol	2 hours

A total of eight depletion series were set up with varying skin conditions and time stamps (see table 4). First, the skin was either left unwashed or washed according to the corresponding method. Once the skin was dry, the depletion series of six fingerprints were placed on the skin with blood. 20 minutes after the blood was dried, the fingerprints of depletion series 1, 3, 5 and 7 were lifted using Forensic Sil. Enhancement of the Forensic Sil lift was done with ALCV. After two hours, the remaining depletion series were lifted using Forensic Sil followed by ALCV enhancement. All results were photographed.

In addition, the direct application of blood enhancement to bloody fingerprints placed on skin was researched. Depletion series of six fingerprints were made on both unwashed and washed (green soap + ethanol) skin. Three blood enhancement techniques (ALCV, Hungarian Red and Amido Black) were applied to each depletion series by immersing the skin in the reagent. No lift was performed, the condition of the skin was photographed.

The experiment was completed with researching the sequence of blood enhancement and lifting on skin. The methodology was set up based on previously obtained results. Both alginate and Forensic Sil were used in a split fingerprint, to enable comparison of the two lifting methods. First, the sequence of lifting followed by blood enhancement was performed. One depletion series of 8 fingerprints was placed on washed skin (green soap + ethanol). Each half-fingerprint was lifted using alginate and the other half-fingerprint using Forensic Sil. This was followed by ALCV enhancement. The other sequence regards blood enhancement followed by lifting. ALCV was applied directly to the depletion series of fingerprints on the skin. After which, each fingerprint was lifted with alginate and Forensic Sil. Both sequences were photographed.

Lifting abilities of alginate and Forensic Sil

To complete the preliminary studies, the lifting abilities of alginate and Forensic Sil under optimal conditions were researched. Instead of using skin as the substrate, garbage bags were used. The methodology of this experiment is based on all previously gained results.

Starting with alginate, a total of six depletion series containing six fingerprints were placed on garbage bags. Three of the depletion series are set up for the sequence alginate followed by blood enhancement, the three other depletion series are set up for the sequence blood enhancement followed by alginate. For enhancement, ALCV, Hungarian Red and Amido Black were used (see table 5). Alginate was prepared according to the optimal conditions obtained from sub study 1.

Alginate was applied to the first three depletion series. Once lifted, the first alginate lift of the depletion series was enhanced using ALCV. The other two alginate lifts were enhanced with Hungarian Red and Amido Black. Results were photographed. For the other sequence, three depletion series were enhanced prior to the alginate lift. Each series was enhanced using a different blood reagent; ALCV, Hungarian Red and Amido Black. Each depletion series was then lifted using alginate. Results were photographed.

The same steps were repeated but with replacement of the alginate lift by a Forensic Sil lift (as shown in table 5). Again, all results were photographed.

Table 5 *Overview of sub study 4: the lifting abilities of alginate and Forensic Sil on garbage bags at different sequences of lift and blood enhancement.*

Sequence: lift > enhancement		***Sequence: enhancement > lift***	
Lifting method	**Reagent**	**Reagent**	**Lifting method**
Alginate	ALCV	ALCV	Alginate
Alginate	Hungarian Red	Hungarian Red	Alginate
Alginate	Amido Black	Amido Black	Alginate
Forensic Sil	ALCV	ALCV	Forensic Sil
Forensic Sil	Hungarian Red	Hungarian Red	Forensic Sil
Forensic Sil	Amido Black	Amido Black	Forensic Sil

Main Research: lifting bloody fingerprints from skin using alginate & Forensic Sil

The main research focuses on lifting fingerprints placed with blood from the skin using alginate and Forensic Sil. This is performed under the optimal conditions of alginate, Forensic Sil and skin as determined in the preliminary research.

Per lifting method and blood enhancement technique a grid is set up. This grid contains nine samples (fingerprints placed with blood) per donor. Three donors are included in the alginate grids, four donors in the Forensic Sil grids. A schematic overview of the main research setup is shown in table 6.

Table 6 *Main research overview: lifting methods (alginate/Forensic Sil) with corresponding grids and blood reagents. Per grid; 9 samples per donor; 3 donors for alginate, 4 donors for Forensic Sil.*

	Alginate			**Forensic Sil**		
	Grid A	Grid B	Grid C	Grid D	Grid E	Grid F
	ALCV	HR	AB	ALCV	HR	AB
Donor 1	9	9	9	9	9	9
Donor 2	9	9	9	9	9	9
Donor 3	9	9	9	9	9	9
Donor 4	x			9	9	9
Total	3 grids – 81 samples			4 grids – 108 samples		

To compare both lifting methods, two depletion series of fingerprints were lifted with alginate and Forensic Sil. This created a split-fingerprint that enables direct comparison. Both series were placed by donor 1 and lifted with a half-impression of alginate and a half-impression of Forensic Sil. One series was enhanced with ALCV, the other with Amido Black.

Main research: impact of time

Multiple alginate and Forensic Sil casts from the first part of the main research are subjected to an experiment regarding the impact of time. The casts are left at normal conditions (room temperature, 50% air humidity, away from direct sunlight) for a maximum of 24 hours. At time stamps of 0 hours, 2 hours, 4 hours and 12 hours the casts are photographed. Camera settings and light sources remain constant throughout the time stamps. The photographs of all time stamps are compared to each other and to the other lifting method.

Photography

Throughout all experiments, results were captured with a Nikon D5100 digital camera. The preliminary research results were photographed using a 18-55mm DX lens in RAW+FINE format. No fixed setup was used, since varying surfaces, colours and methods were captured. However, within an experiment fixed camera settings were used per surface and phase to prevent obtaining deviant results.

Table 7 *Camera settings of the main research: ISO-value, aperture and shutter time per phase of the research.*

Surface	ISO	Aperture	Shutter
Skin	800	F16	1/125
Alginate	800	F16	1/100
Alginate enhanced	800	F16	1/80 - 1/50
Forensic Sil	800	F16	1/100
Forensic Sil enhanced	800	F16	1/80

Results of the main research were captured with a macro-lens (*AF Micro Nikkor, 55mm, 1:2.8*), also in RAW+FINE format. This was done to capture optimal detail. Here, a fixed setup was used; fixed distance between camera and surface, fixed position of studio lamps and fixed camera settings as shown in table 7. Depending on the surface type, the shutter time and/or aperture were altered. Additional light sources were used to maintain a constant lighting in all photographs. Two studio lamps (*FalconEyes ®, 6200 kelvin, white light*) shone on the surface from left and right. A Lumatec® (*Superlite 400*) was used to create another light source of white light (400-700 nanometer, 1/3 light intensity). The room was free of daylight and other sources of light. Appendix I shows this fixed photo setup of the main research.

Fingerprint grading & identification

A selection of results from the main research were graded and identified. This regards fingerprints derived from donor 1 and 2. Five students with similar backgrounds (bachelor forensic science) were selected as a test panel. Grading forms were put together, containing photographs of 21 fingerprints: 4 original fingerprints (on skin), 8 alginate fingerprints (of which 6 enhanced) and 8 Forensic Sil fingerprints (of which 6 enhanced). One fingerprint is a split fingerprint lifted with both alginate and Forensic Sil. The raters were asked to grade the fingerprints following two score systems. Fingerprint 1-20 were graded following the CAST grading system (see table 8). A score ranging from 0 to 4 was granted based on the amount of continuous ridges and/or contrast. The split fingerprint was graded following the UC grading system with a comparative scale (see table 9). Here, a score -2, -1, 0, 1 or 2 was granted based on the difference of method A versus method B. The grading forms are shown in appendix IV.

Table 8 *CAST Grading System* **[24]**

Score	Details
0	No evidence of fingerprint
1	Fingerprint recognizable, less than 1/3 of continuous ridges, poor contrast
2	1/3 to 2/3 of continuous ridges, adequate contrast
3	More than 2/3 of continuous ridges but not quite a perfect fingerprint, good contrast
4	Complete fingerprint, continuous ridges and excellent contrast

Table 9 *UC Grading System - comparative scale* **[24]**

Score	Details
+2	Half-impression developed by method A exhibits far greater ridge detail and/or contrast than the corresponding half-impression developed by method B
+1	Half-impression developed by method A exhibits slightly greater ridge detail and/or contrast than the corresponding half-impression developed by method B
0	No significant difference between the corresponding half-impressions
-1	Half-impression developed by method B exhibits slightly greater ridge detail and/or contrast than the corresponding half-impression developed by method A
-2	Half-impression developed by method B exhibits far greater ridge detail and/or contrast than the corresponding half-impression developed by method A

Data was analysed and processed in Excel. The frequency of the granted scores per fingerprint of all raters were put together in a stacked bar graph. A two-way random intraclass correlation coefficient with absolute agreement was calculated in SPSS® (*IBM® SPSS Statistics*) to gain insight in the inter-rater reliability. In addition, t-tests were performed to determine if there is a statistically significant difference between two groups (original fingerprint versus lifted fingerprint). Appendix V provides further details regarding the methodology of statistical calculations.

In addition to the fingerprint grading, two fingerprints underwent professional identification by a fingerprint examiner (Police Amsterdam). One fingerprint is lifted with alginate and enhanced with Amido Black, the other fingerprint is lifted with Forensic Sil and enhanced with ALCV. A reference fingerprint of the donor was used by the fingerprint examiner for comparison and matching minutiae.

5. Results

In order to achieve the goal of the research, a total of four preliminary experiments and a main research were executed. The preliminary research was set up to provide insight in the optimal conditions of alginate, Forensic Sil and the skin. The main research was performed under these optimal conditions and contains large sample sizes of both lifting methods; alginate and Forensic Sil. Results of the main research were graded by a test panel based on a fingerprint grading system. In addition, an experiment regarding the impact of time on the casts was executed.

The results of the research are presented in this chapter. Additional results, images and data can be found in appendix II.

Optimal conditions of alginate

The lifting abilities of alginate can be influenced by both the mixing ratio of water to alginate and the water temperature. Therefore, both variables were tested to obtain an optimal lift.

The alginate to water mixing ratios range from 1:2 to 1:3. A mixing ratio of 1:2.5 results in a smooth mixture with sufficient mixing time. An image of the alginate lift enhanced with ALCV is shown in figure 8a. In comparison to the other mixing ratios, this cast shows the least amount of air bubbles and fading around the fingerprint ridges. Water temperatures of the alginate mixture range from 40°C to 10°C. When using a mixing ratio of 1:2.5, the optimal water temperature appears to be 21°C or below (see figure 8b). Water temperatures of 21°C, 15°C and 10°C obtain the same consistency and lifting abilities. However, the setting time elongates when the temperature decreases. This provides more time for mixing and application, hence why cold water of approximately 15°C is used in the rest of the research.

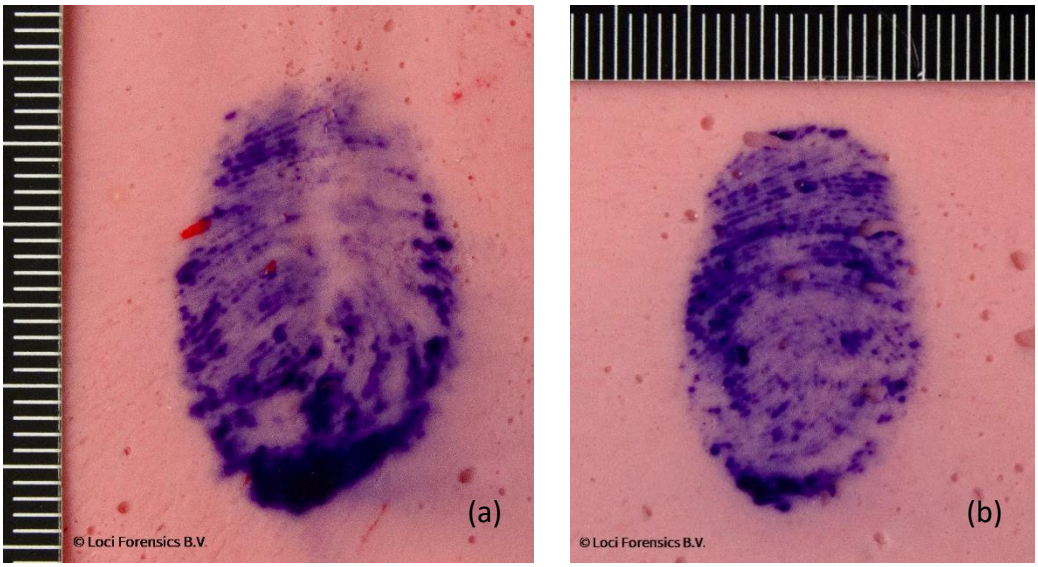


Figure 8 *Bloody fingerprint lifted with alginate from a garbage bag, enhanced with ALCV (a) alginate mixture with 1:2.5 powder to water mixing ratio, (b) alginate mixture with a 1:2.5 mixing ratio and 21°C water temperature.*

Previous studies demonstrate that alginate can be mixed with blood reagents instead of water. However, the acidic components of blood reagents either made the cast dry and crumbly or wet and viscous. Therefore, the blood reagent Amido Black was prepared without sulfosalicylic acid and mixed with alginate powder in a 1:1 and 1:2.5 ratio. The 1:1 mixing ratio of alginate and Amido Black (without acidic component) is described in literature as a good alternative preparation of alginate. [17] In this study, these experiments were reproduced. This showed that mixing alginate in a 1:1 ratio with Amido Black creates a crumbly consistency. Alginate is not mixed well enough and remains to be a powder. Therefore, the mixing ratio was altered to 1:2.5. This results in a thick, rubbery mixture that sets within 1 minute. Results show that, despite

the lower contrast due to the staining, the fingerprints are well lifted and remain highly detailed (shown in figure 9).

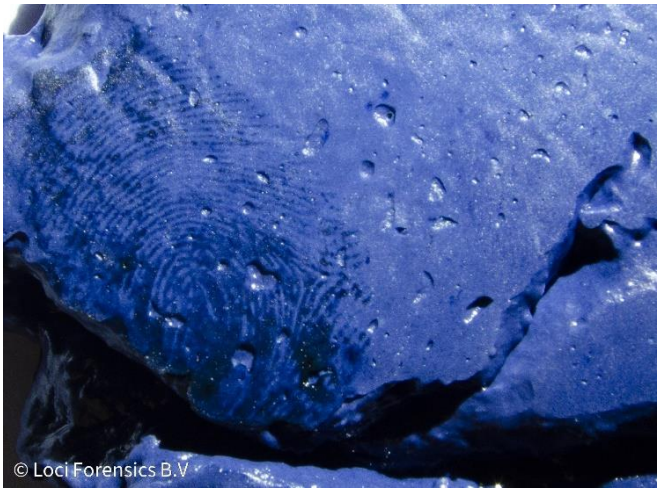


Figure 9 *Alternative preparation of alginate: mixing in Amido Black with alginate in a 1:2.5 mixing ratio. Subsequently the bloody fingerprint is lifted and enhanced.*

Optimal conditions of Forensic Sil

Forensic Sil is provided in both a winter and summer version. The lifting abilities of the two versions were compared to each other. Results show that the winter version provides optimal lifting: strong adhesion to the surface ensures a strong lift. Compared to the summer version, more blood is lifted from the surface. Blood enhancement shows an evident difference in these lifting abilities and is shown in figure 10. Since the winter version lifts more blood from the surface, more blood enhancement occurs. Due to these optimal lifting abilities, the winter version of Forensic Sil is used throughout the rest of the study.

Figure 10 *Forensic Sil winter version (left half-fingerprint) versus summer version (right half-fingerprint).*

Optimal conditions of skin

To gain insight in the conditions of the skin, bloody fingerprints were recovered from washed and unwashed skin. This was done 20 minutes or 2 hours past placement to include the impact of time. Subsequently, three different blood enhancement techniques were applied to the skin directly.

Washing & impact of time

Results show that unwashed skin leaves a layer of fat on the surface. When the fingerprint is lifted using Forensic Sil, there is less adhesion to the skin due to this fat layer, resulting in a minor lift. In addition, the bloody fingerprint does not dry properly due to this fay layer. This can be observed on both the skin and the lift: the blood and fat form an emulsion that causes the blood to deform through cohesion (shown in figure 11).

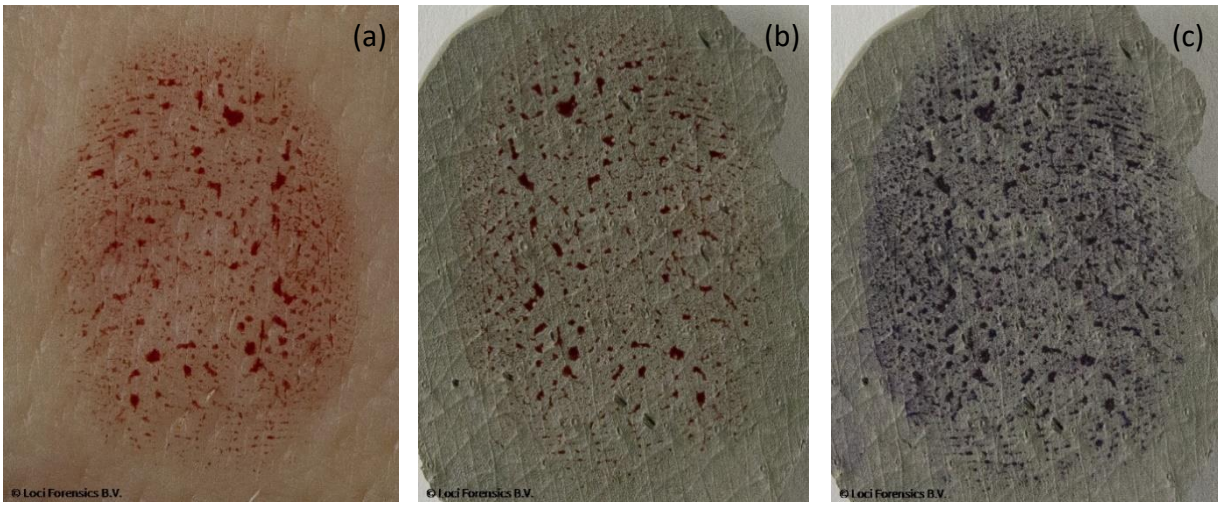


Figure 11 *Skin conditions of unwashed skin (a) original fingerprint on skin (b) Forensic Sil lift of the fingerprint, 20 minutes past placement (c) Forensic Sil lift enhanced with ALCV.*

Washing the skin takes away the fat layer, leaving a more dry surface (that is more likely to be found on human skin). The blood of the fingerprint is able to dry and the Forensic Sil lift has stronger adhesion to the skin. When enhanced with ALCV, the lifted fingerprint is more evident, higher in contrast and more continuous ridging can be observed (see figure 12). Therefore, washed skin provides optimal skin conditions and is used throughout the rest of the study.

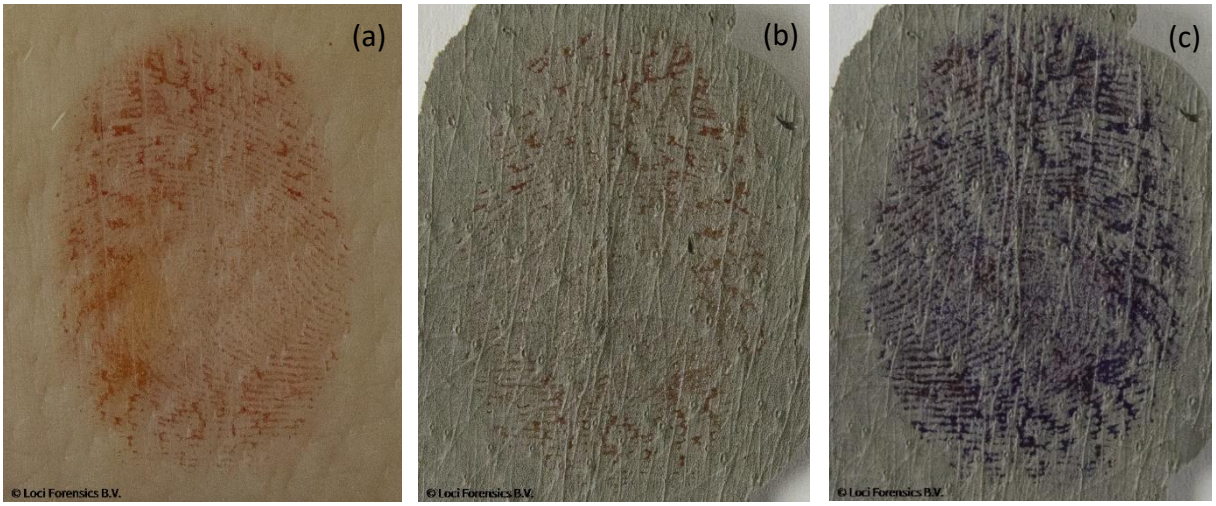


Figure 12 *Skin conditions of washed skin (a) original fingerprint on skin (b) Forensic Sil lift of the fingerprint, 20 minutes past placement (c) Forensic Sil lift enhanced with ALCV.*

In addition to studying unwashed and washed skin, the impact of time on the skin conditions was also researched. Time stamps of 20 minutes and 2 hours were taken between placing the fingerprint and recovery. This was done to observe whether variations in lifting quality are observed as time increases. Figure 13a shows the condition of the skin at the 20 minute time stamp, figure 13b at 2 hours. No changes appear to be present in the quality of the fingerprint on skin: both show continuous ridges (on the same spots). Looking at the Forensic Sil lift shown in figure 13c, sufficient continuous ridging seems to be obtained. The low impact of time provides a 2 hour time frame to place and recover the fingerprints in further experiments.

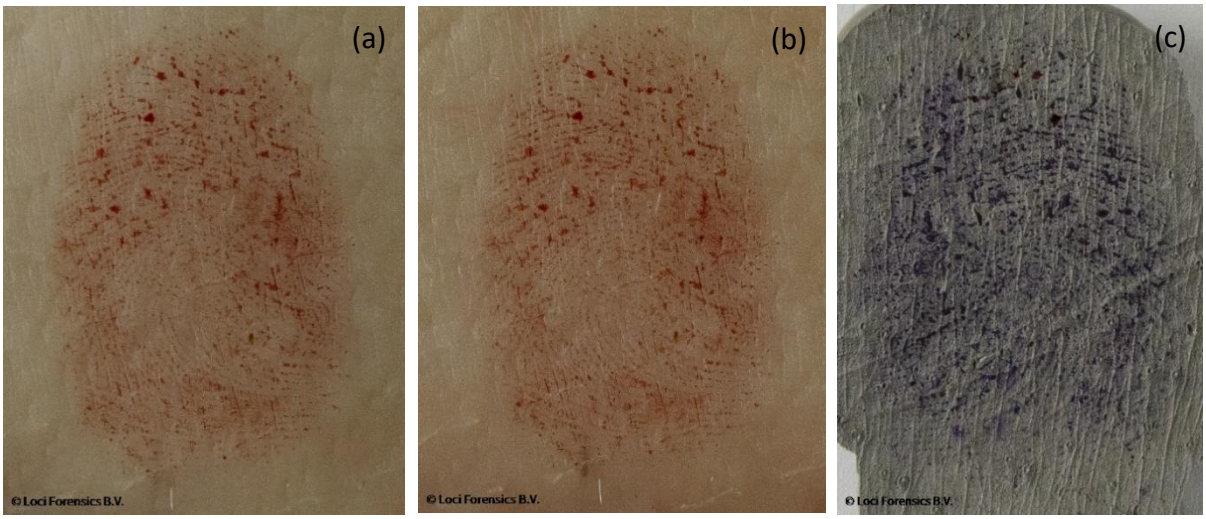


Figure 13 *Impact of time on skin conditions (a) original fingerprint on skin, 20 minutes past placement (b) original fingerprint on skin, 2 hours past placement (c) Forensic Sil lift of fingerprint enhanced with ALCV, 2 hours past placement.*

Blood enhancement directly on skin

Blood reagents were directly applied to unwashed and washed skin. Differences in the amount of staining and fats were observed. A better contrast is obtained when the skin is washed with green soap and ethanol and thus has less of a fat layer on the surface. The unwashed skin shows that the blood reagents clot onto the fat layer, which influences the staining of the fingerprint (see figure 14).

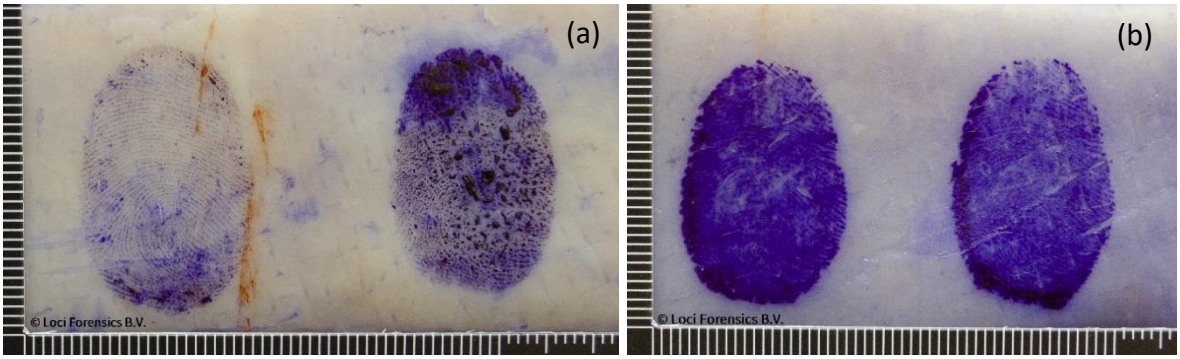


Figure 14 *Fingerprints placed with blood on skin, enhanced with ALCV (a) on unwashed skin, (b) on washed skin.*

Hungarian Red and Amido Black yield low contrast between the fingerprint and the skin. Since these blood reagents are based on protein staining, they react with both the proteins found in blood and the proteins present on skin (see appendix II). On the other hand, ALCV does provide a good contrast. This is likely due to the properties of ALCV in staining only haemoglobin, not proteins. Both on washed and unwashed skin a good contrast is observed, with optimal contrast on washed skin. On the unwashed skin, more continuous ridging is observed. In conclusion, only ALCV can be directly applied to the skin for blood enhancement.

Sequence of lifting and blood enhancement on skin

Results indicate that the sequence of lifting followed by enhancement provides a stronger lifting mechanism and is more detailed (see figure 15a) than lifting an enhanced fingerprint (see figure 16a). Figure 15b shows the skin surface after the alginate-Forensic Sil lift was performed. It can be observed that less blood is left on the skin, mainly with the half-fingerprint that was lifted with alginate. This can be caused by the possible lifting mechanism of alginate, in which blood is partly dissolved and encapsuled. [18] Forensic Sil seems to lift only a thin upper layer of the bloody fingerprint, explaining why sufficient blood remains on the skin. The other sequence (enhancement followed by lift) leaves higher amounts of blood on the skin surface, as shown in figure 16b. Figure 16a shows that the obtained lift is minimal; low contrast with partial ridging.

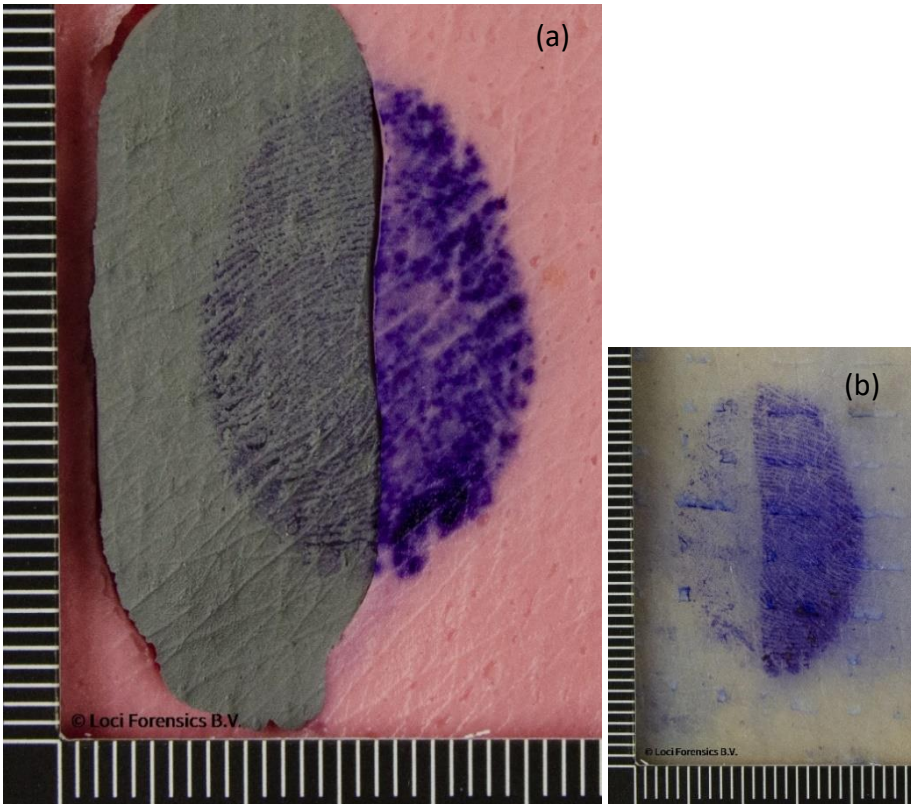


Figure 15 (a) *Split fingerprint lifted with alginate (right half-impression) and Forensic Sil (left half-impression), enhanced with ALCV* ***(b)*** *remaining fingerprint on skin surface post lifting with alginate (left half-impression) and Forensic Sil (right half-impression), enhanced with ALCV (mirror image).*

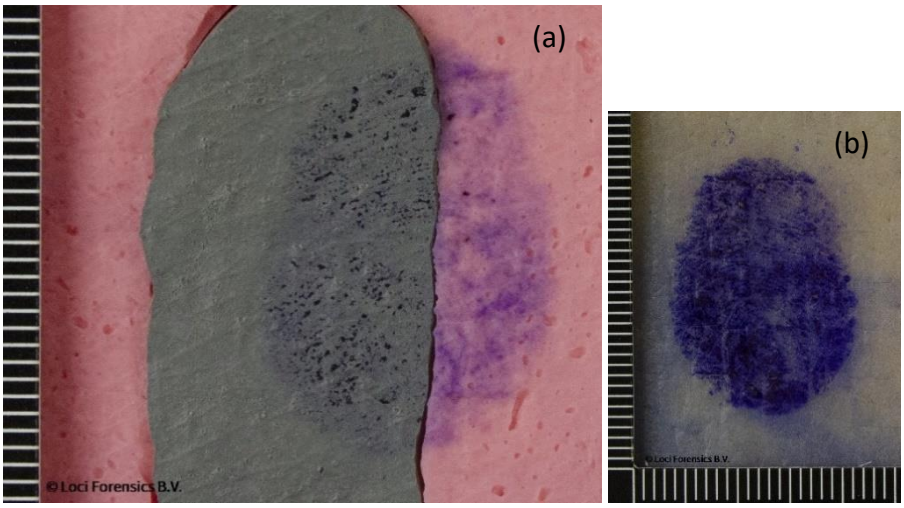


Figure 16 (a) *Split fingerprint enhanced with ALCV and lifted with alginate (right half-impression) and Forensic Sil (left half-impression) (b) remaining fingerprint on skin surface post lifting with alginate (left half-impression) and Forensic Sil (right half-impression) (mirror image).*

Lifting abilities of alginate and Forensic Sil

The sequence of lifting and blood enhancement was determined for alginate and Forensic Sil, but performed on garbage bags. Optimal conditions of alginate and Forensic Sil obtained from the previous experiments were used.

Alginate

First, alginate was applied after which the alginate cast was enhanced using ALCV, Hungarian Red or Amido Black. The results of this sequence are shown in figure 17. Alginate casts enhanced with Hungarian Red and Amido Black show dark staining over the whole cast, not only the fingerprint is stained (figure 17bc). Because of this, less contrast is observed. However, enhancement with ALCV shows clear contrast, no background staining is observed (figure 17a). All fingerprints have smudged edges and the cast remained wet for a long time.

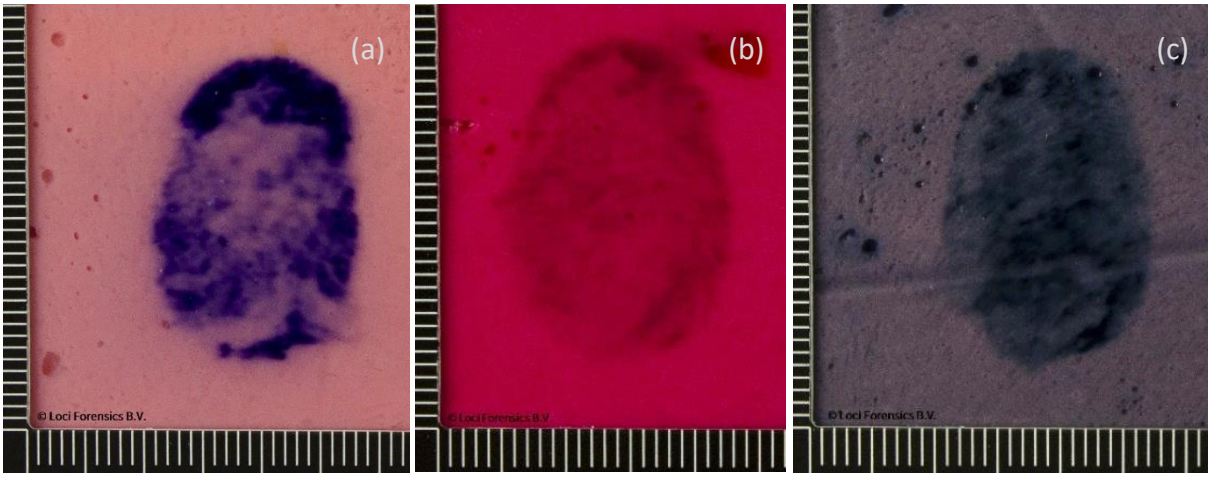


Figure 17 *Fingerprints placed with blood lifted with alginate followed by blood enhancement (a) ALCV (b) Hungarian Red (c) Amido Black.*

Changing the sequence changes the lifting mechanism of alginate. The fingerprints enhanced with Hungarian Red and Amido Black yield a minimal lift (figure 18bc). Faint fingerprints are observed with no continuous ridges and low contrast. On the other hand, the fingerprint enhanced with ALCV shows more continuous ridges and contrast when lifted (see figure 18a). The fingerprint appears to be more fixed compared to the other sequence (lift followed by enhancement). Less blurring is observed and the cast is less wet. This might be due to not adding the blood reagent directly to the cast.

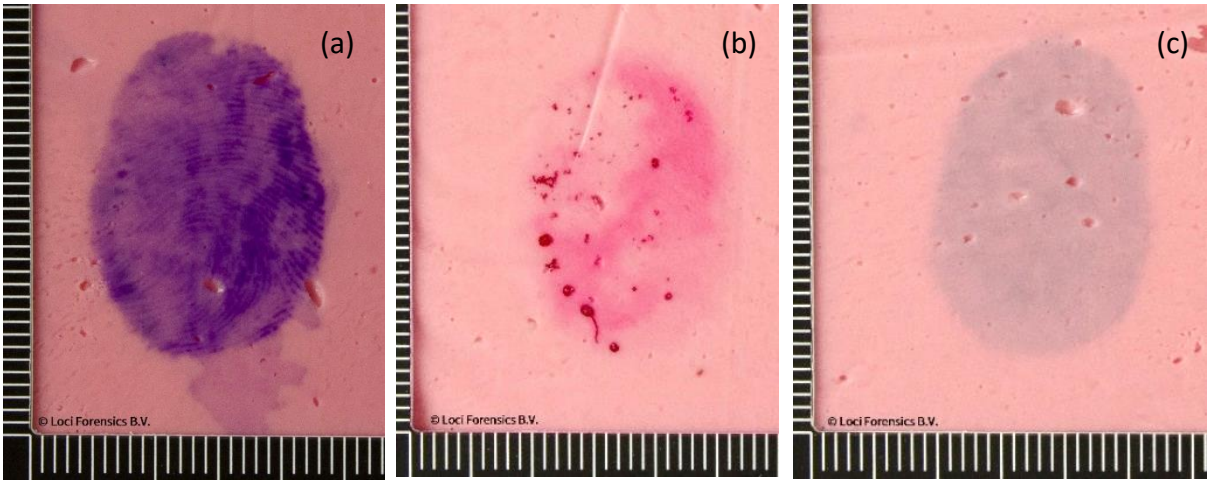


Figure 18 *Fingerprints placed with blood enhanced with blood reagents followed by an alginate lift (a) ALCV (b) Hungarian Red (c) Amido Black.*

Forensic Sil

The fingerprint was lifted from the surface after which it was enhanced using ALCV, Hungarian Red and Amido Black (see figure 19). This sequence provides a good lift: all fingerprints of the depletion series are properly lifted with good ridge detailing and contrast. Mainly ALCV and Hungarian Red gave good contrast, as shown in figure 19a-b.

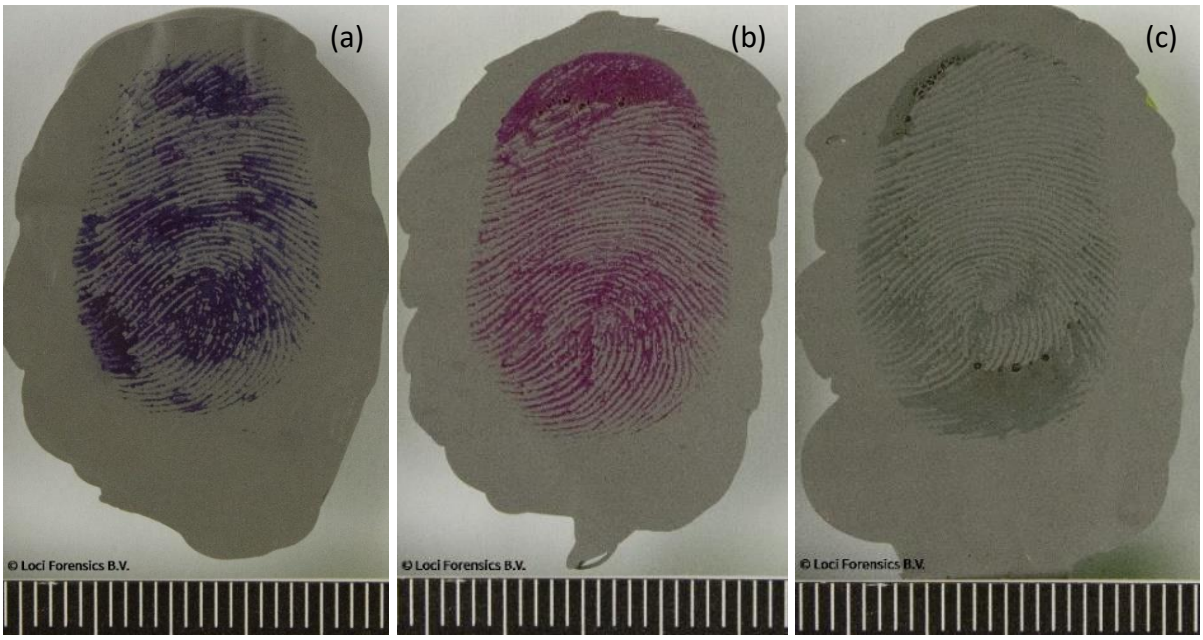


Figure 19 *Fingerprints placed with blood lifted with Forensic Sil followed by blood enhancement (a) ALCV (b) Hungarian Red (c) Amido Black.*

Altering the sequence seems to not change the lifting abilities of Forensic Sil. Equal amounts of continuous ridges and a good contrast can be observed (see figure 20). All of the fingerprints within the depletion series are lifted properly, providing high quality fingerprints. Results show that both sequences (lifting followed by enhancement and enhancement followed by lifting) provide high quality fingerprints with the Forensic Sil lift.

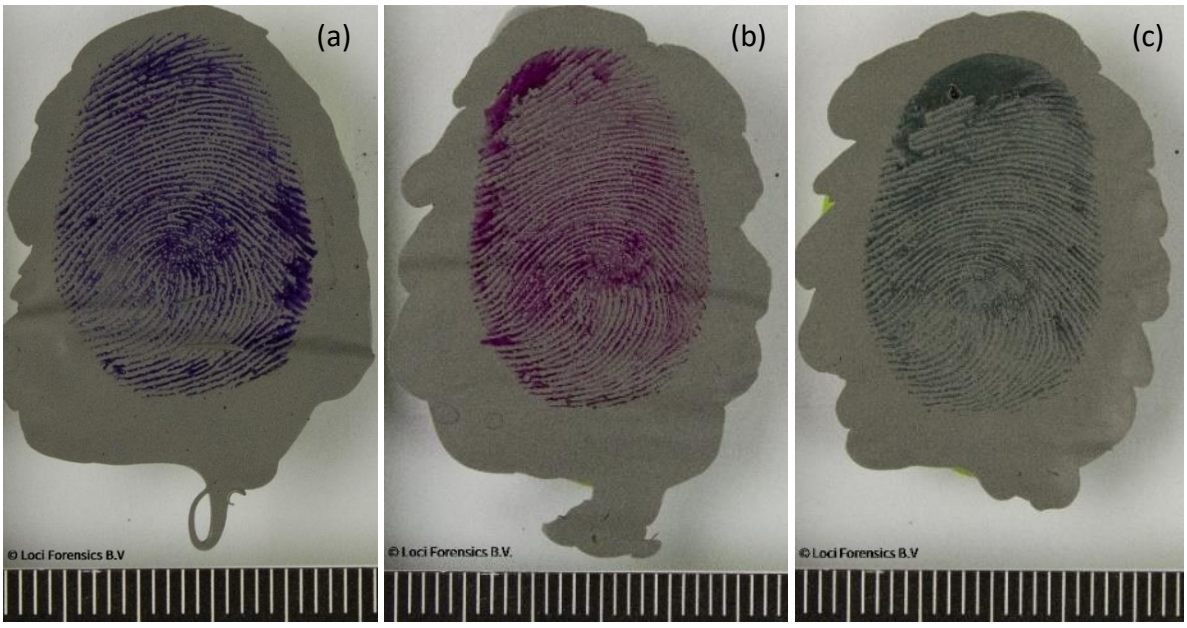


Figure 20 *Fingerprints placed with blood enhanced with blood reagents followed by a Forensic Sil lift (a) ALCV (b) Hungarian Red (c) Amido Black.*

Main research: Lifting fingerprints from skin with alginate & Forensic Sil

Based on the results of the preliminary research, the main research was executed. The lifting abilities of alginate and Forensic Sil were tested specifically on skin, in larger sample sizes. This was done to reach the goal of the study; determine whether Forensic Sil is more suitable than alginate for the lifting of fingerprints placed with blood from the skin. A selection of all fingerprints is shown in this chapter. The other fingerprints have been omitted for the overview and can be found in appendix II. The fingerprint selections included in this chapter are representative for the other obtained results.

Alginate

Three grids were set up, each grid containing nine samples of three donors and enhanced with a different blood reagent (ALCV, Hungarian Red or Amido Black). The results were gained using the following optimal conditions; washed skin (green soap and ethanol), a 1:2.5 alginate mixing ratio with 15°C water, performed in the sequence of alginate lifting followed by blood enhancement. The fingerprints were recovered within 2 hours after placement.

The results obtained by lifting the fingerprints of donor 1 with alginate are shown in figure 21a-c. Figure 21a shows the alginate cast enhanced with ALCV. Here, blurred edges and faded epidermal ridging can be observed. The alginate cast remains wet, causing a shiny surface that continues to blur out the lifted fingerprint. Essential fingerprint detailing seems to be lost when using ALCV. Hungarian Red provides low contrast, but has a lower amount of blurring (see figure 21b). Partial epidermal ridging can be observed. The third fingerprint, as shown in figure 21c, is enhanced with Amido Black. This fingerprint also shows partial epidermal ridges and has good contrast. The fingerprints obtained from donor 2 and 3 are presented in appendix II.

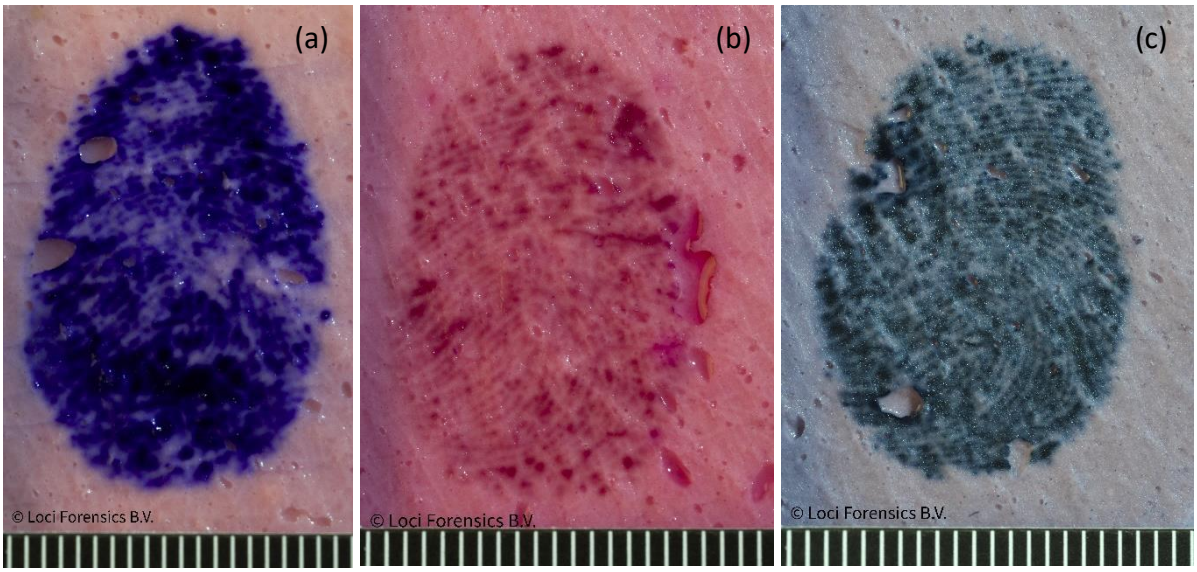


Figure 21 *Alginate casts of three lifted fingerprints, enhanced with three different blood reagents (a) ALCV (b) Hungarian Red (c) Amido Black.*

These observations can be substantiated with the data gained of the fingerprint grading. Each fingerprint was graded with a score from 0 to 4 by five raters, based on the amount of continuous ridges and contrast observed. Fingerprint a (see figure 21a) is graded with score 1 by all raters (*n=5*). This indicates that the fingerprint is recognizable, but less than 1/3 of the fingerprint contains continuous ridging and the contrast is poor. Fingerprint b (see figure 21b) is graded most with a score 2 (*n=4*). Score 2 describes the fingerprint as recognizable, with 1/3 to 2/3 of continuous ridges and adequate contrast. One rater granted score 3 (*n=1*); more than 2/3 of continuous ridges with good contrast. The third fingerprint (see figure 21c) is graded with a score 2 (*n=2*) and score 3 (*n=3*). The complete data set is presented in appendix IV.

To gain insight in the lifting abilities of alginate for recovering bloody fingerprints from skin, three phases were compared. Figure 22 shows the phases; the original fingerprint placed with blood on skin, the lifted fingerprint with alginate and the enhanced alginate cast with Amido Black.

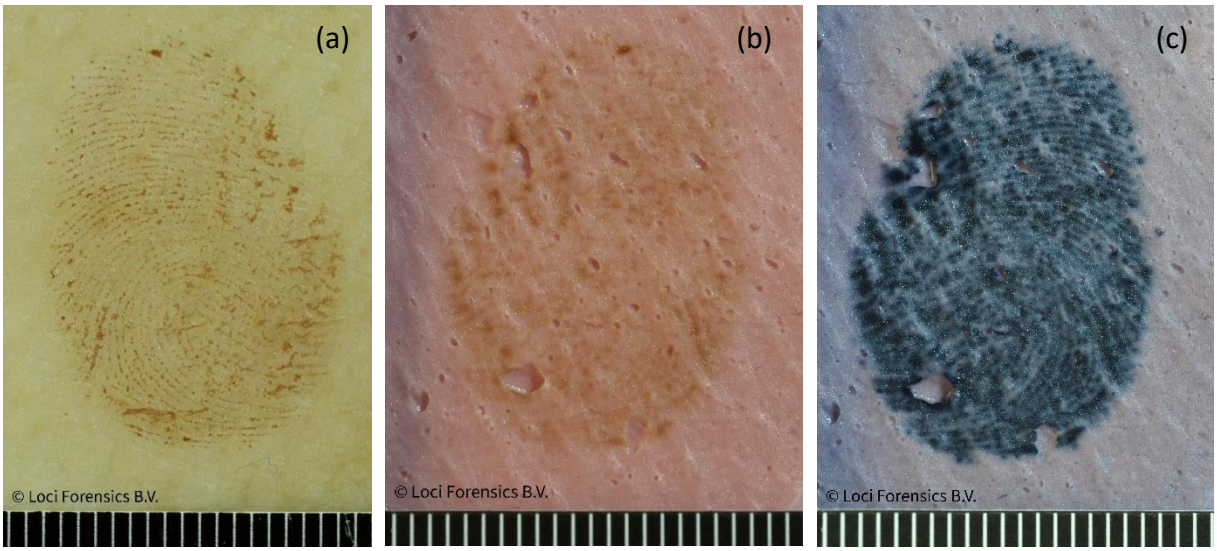


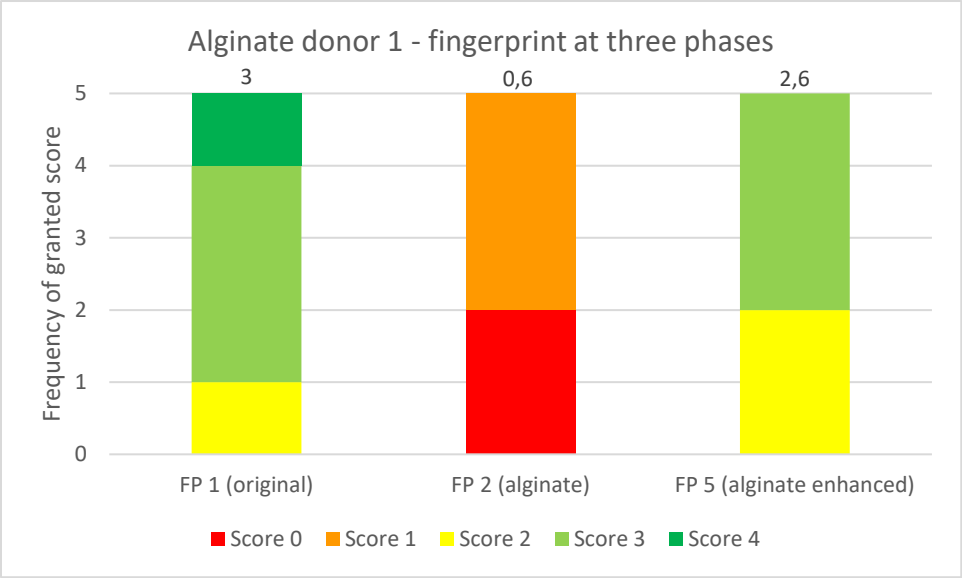
Figure 22 *Main research: three phases of alginate lifting (a) original fingerprint placed with blood on skin (b) lifted fingerprint with alginate (mirror image) (c) lifted fingerprint with alginate, enhanced with Amido Black (mirror image).*

Fingerprint grading data of the three fingerprints (figure 22a-c) are shown in table 10. The amount of times a score was granted to the fingerprint per phase is given. This data is converted to a stacked bar graph, as shown in graph 1.

Table 10 *Fingerprint grading data: frequency of the granted score (0-4) per phase (original, alginate lift, alginate lift enhanced).*

Alginate – Frequency of granted scores per phase					
Phase	*Score 0*	*Score 1*	*Score 2*	*Score 3*	*Score 4*
Original	0	0	1	3	1
Alginate	2	3	0	0	0
Alginate enhanced	0	0	2	3	0

The graph below shows the amount of times a score was granted to the fingerprint per phase (based on the test panel). Each score is represented by a different colour; score 0 (red), score 1 (orange), score 3 (yellow), score 4 (light green) and score 5 (dark green). Above the bars, the average score is displayed. The original fingerprint, as shown in figure 22a, is graded most with score 3. Fingerprint 2 (alginate) is graded most with score 1. The lifted and enhanced fingerprint, shown in figure 22c, is graded most with scores 2 and 3. According to these results, there appears to be no improvement between the original fingerprint and the fingerprint lifted with alginate. Besides, the original fingerprint has overall higher scores (average 3.0) than the lifted and enhanced fingerprint (average 2.6). To determine whether there is a significant difference between the original fingerprint and the alginate lift, a t-test is performed. This allows possible negative, positive or neutral effects of the alginate lift to be detected.



Graph 1 *Fingerprint grading data converted to a stacked bar graph: fingerprints (FP1, FP2, FP5) at three phases (original, alginate, alginate enhanced) with corresponding frequency of granted scores ranging from 0-4.*

It is calculated whether there is a significant difference in average scores of the original fingerprint (FP1) and the enhanced fingerprint lifted with alginate (FP5). This was done using an independent samples t-test with assumed unequal variances. The results of the t-test are shown in table 11. According to the p-value, no statistically significant difference is found between the two groups. This can be interpreted as the alginate lift not having a negative or positive effect on the original fingerprint.

Table 11 *Two-sided t-test independent samples, assumed unequal variances: original fingerprint (FP1) versus alginate lift enhanced with Amido Black (FP5), data derived from fingerprint grading using the CAST score-system. P-value < critical value shows that there is no statistically significant difference between the average scores of group 1 and group 2 (alpha = 0.05/n=5).*

Group 1	Group 2	P-value	Critical value
Original fingerprint (FP1)	Alginate lift (FP5)	0.346597	2.306

Forensic Sil

Three grids were set up with nine samples for each donor. The samples were lifted with Forensic Sil. The results were gained using the following optimal conditions; washed skin (green soap and ethanol), the Forensic Sil winter version and performed in the sequence of Forensic Sil lifting followed by blood enhancement. Recovery of the fingerprints took place within 2 hours past placement.

The results of lifting the fingerprints from donor 1 with Forensic Sil are shown in figure 23a-c. Figure 23a shows the Forensic Sil cast enhanced with ALCV. Here, a good contrast is obtained with overall good epidermal ridges. No blurring or fading of the fingerprint is observed and the surface does not remain wet. The fingerprint seems to be fully lifted. However, the skin causes the epidermal ridges to be interrupted, creating less continuous ridging. Hungarian Red creates an overall lower contrast, but the full fingerprint appears to be lifted with sufficient epidermal ridging. Here, interruptions caused by the skin seem to be less evident (see figure 23b). Lastly, the fingerprint enhanced with Amido Black as shown in figure 23c. Good epidermal ridging and contrast can be observed. Again, the skin causes the epidermal ridges to be less continuous. Overall, the lifting mechanisms appears to be relatively constant and accurate. The fingerprints obtained from donor 2, 3 and 4 are presented in appendix II.

To ensure these findings, all fingerprints were subjected to fingerprint grading. The fingerprints were graded with scores ranging from 0 to 4 based on the amount of continuous ridges and contrast (as previously explained). Fingerprint a (see figure 23a) is graded with scores 2 (*n=1*), 3 (*n=3*) and 4 (*n=1*). Score 3 meaning more than 2/3 of the fingerprint has continuous ridges and good contrast. Fingerprint b (see

figure 23b) is graded most with score 4 (*n=3*) and with score 3 (*n=2*). Score 4 is described as a complete fingerprint with continuous ridges and excellent contrast. Fingerprint c (see figure 23c) is graded most with score 3 (*n=4*). One rater granted score 2 (*n=1*). These scores indicate that 1/3 to 2/3 of the fingerprint has continuous ridges, with adequate to good contrast. The complete data set is presented in appendix IV.

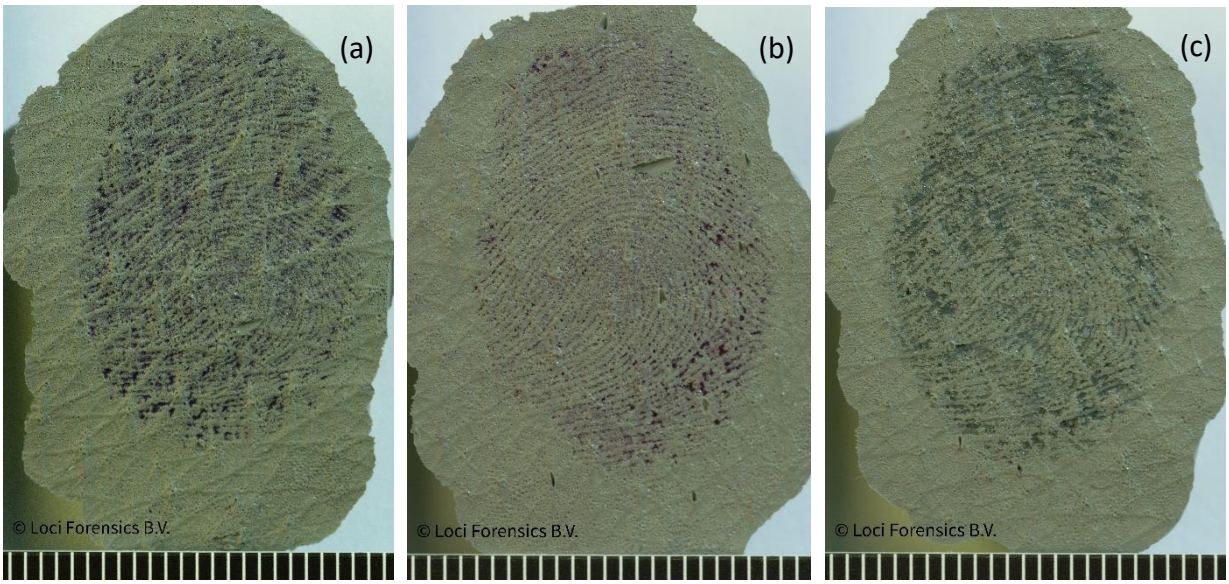


Figure 23 *Forensic Sil casts of three lifted fingerprints, enhanced with three different blood reagents (a) ALCV (b) Hungarian Red (c) Amido Black.*

To gain insight in the lifting abilities of Forensic Sil, the three phases were compared; original fingerprint on skin, lifted fingerprint with Forensic Sil and the enhanced lift with ALCV (see figure 24a-c).

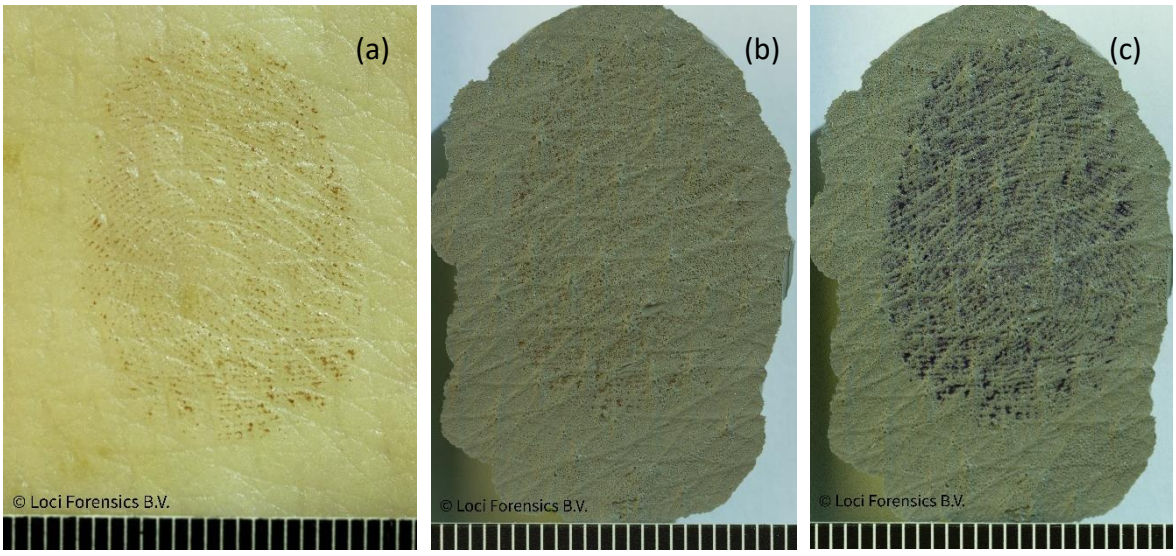


Figure 24 *Main research: three phases of Forensic Sil lifting (a) original fingerprint placed with blood on skin (b) lifted fingerprint with Forensic Sil (mirror image) (c) lifted fingerprint with Forensic Sil, enhanced with ALCV (mirror image).*

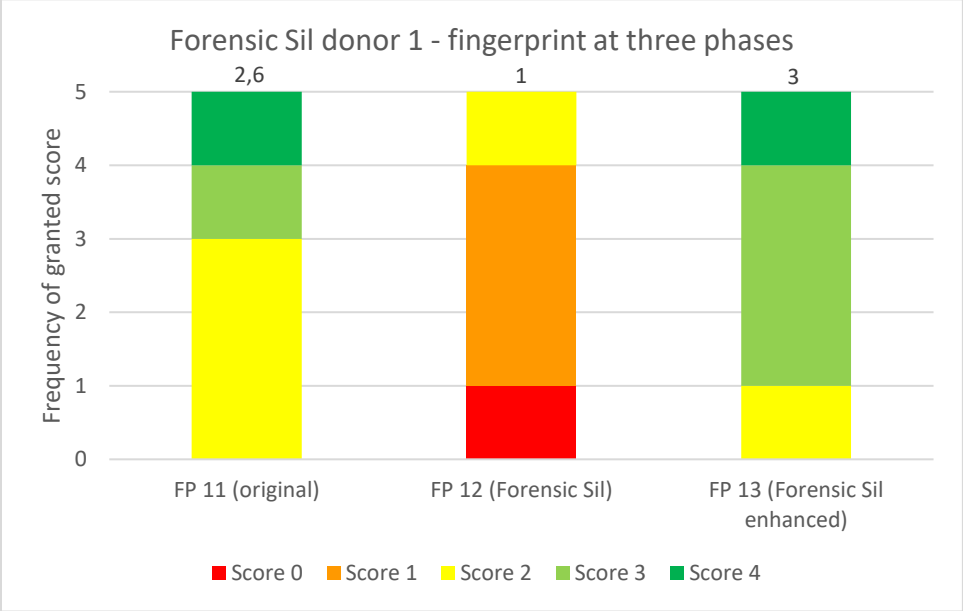
The comparison was done based on the fingerprint grading data. Per phase, a score was granted to the fingerprint (see table 12). The data is converted to a stacked bar graph, as shown in graph 2.

Table 12 *Fingerprint grading data: frequency of the granted score (0-4) per phase (original, Forensic Sil lift, Forensic Sil lift enhanced).*

Forensic Sil – Frequency of granted scores per phase					
Phase	*Score 0*	*Score 1*	*Score 2*	*Score 3*	*Score 4*
Original	0	0	3	1	1

Forensic Sil	1	3	1	0	0
Forensic Sil enhanced	0	0	1	3	1

The frequency of the granted scores per phase is shown in the graph. Above the bars, the average score is displayed. Fingerprint 11 (original fingerprint on skin) is graded most with score 2. The Forensic Sil lift without enhancement is graded most with score 1. However, when the Forensic Sil lift is enhanced with ALCV, scores rise. Here, a score 3 is granted most. When comparing the original fingerprint (FP11) to the Forensic Sil enhanced fingerprint (FP13), an increasement in scores can be observed. This indicates a positive effect of Forensic Sil lifting when compared to the original fingerprint. To determine whether this assumed difference is statistically significant, a t-test is performed.



Graph 2 *Fingerprint grading data converted to a stacked bar graph: fingerprints (FP11, FP12, FP13) at three phases (original, Forensic Sil, Forensic Sil enhanced) with corresponding frequency of granted scores ranging from 0-4.*

It is calculated whether there is a significant difference in average scores of the original fingerprint (FP11) and the enhanced fingerprint lifted with Forensic Sil (FP13). This was done using an independent samples t-test with assumed unequal variances. The results of the t-test are shown in table 1. According to the p-value, no statistically significant difference is found between the two groups. This indicates that Forensic Sil has a neutral effect on the lifting of the original fingerprint.

Table 13 *Two-sided t-test independent samples, assumed unequal variances: original fingerprint (FP1) versus alginate lift enhanced with Amido Black (FP5), data derived from fingerprint grading using the CAST score-system. P-value < critical value shows that there is no statistically significant difference between the average scores of group 1 and group 2 (alpha = 0.05/n=5).*

Group 1	Group 2	P-value	Critical value
Original fingerprint (FP11)	Forensic Sil lift (FP13)	0.455366	2.306

Alginate & Forensic Sil

A series of nine fingerprints were lifted using both alginate and Forensic Sil; a half-impression lifted with alginate and a half-impression lifted with Forensic Sil. These split fingerprints make a comparison between the two lifting methods possible. Figure 25 shows one of the obtained split fingerprints, enhanced with ALCV.

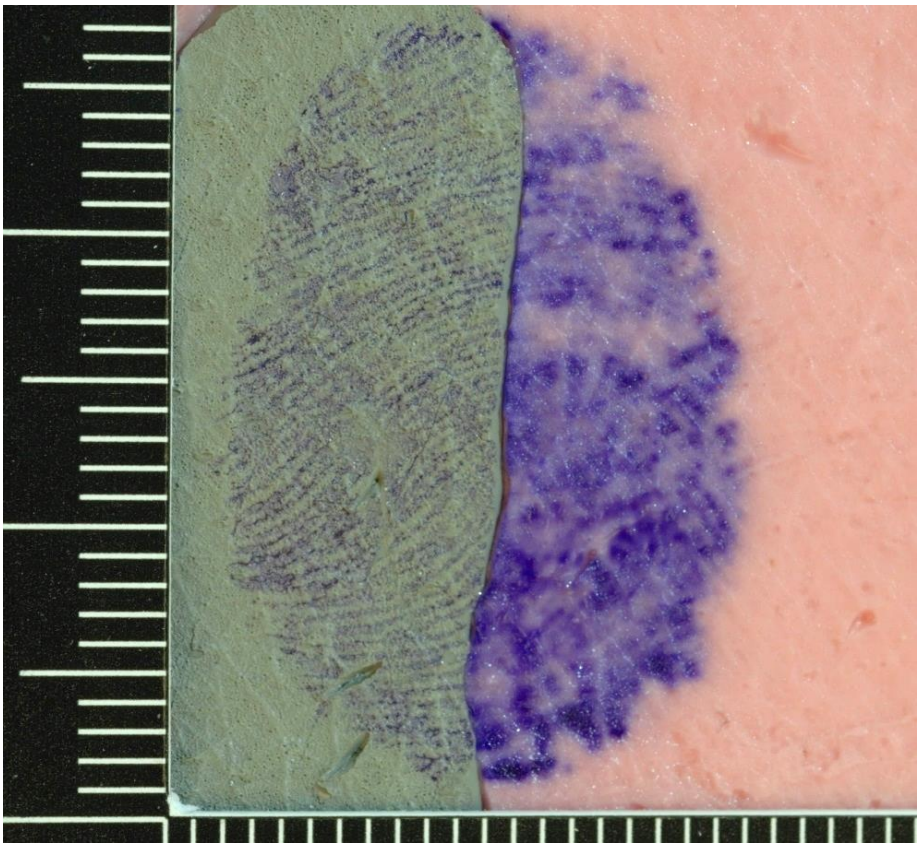


Figure 25 *Split fingerprint: half impression lifted by method A (left - Forensic Sil) and half-impression lifted with method B (right - alginate), enhanced with ALCV.*

It can be observed that the Forensic Sil half-impression (left) shows clear continuous ridging throughout the fingerprint, it is highly detailed. On the other hand, the alginate half-impression (right) seems to have faded ridges and remains to have a moist surface. To substantiate this difference, fingerprint grading was performed. A new split fingerprint was made (lifted with both alginate and Forensic Sil) and enhanced with Amido Black. This was done due to Amido Black yielding the highest average score (2.6) in fingerprint grading of the full fingerprints, and ALCV the lowest average score (1.0) (for donor 1).

In order to combine all previously obtained results, the methods were compared via fingerprint grading with a comparative scale (UC score system). Figure 26 shows the fingerprint that was submitted for grading by the test panel. This fingerprint was graded with a score ranging from -2 to +2, based on the difference in continuous ridges and contrast of the lifting methods. Results show that all raters (n=5) granted a score +2 to the split fingerprint. This indicates that the half-impression lifted with method A (left, Forensic Sil) exhibits far greater ridge detail and/or contrast than the corresponding half-impression developed by method B (right, alginate). According to the fingerprint grading, there is a significant difference between lifting with alginate and Forensic Sil, in which Forensic Sil provides an optimal lift compared to alginate.

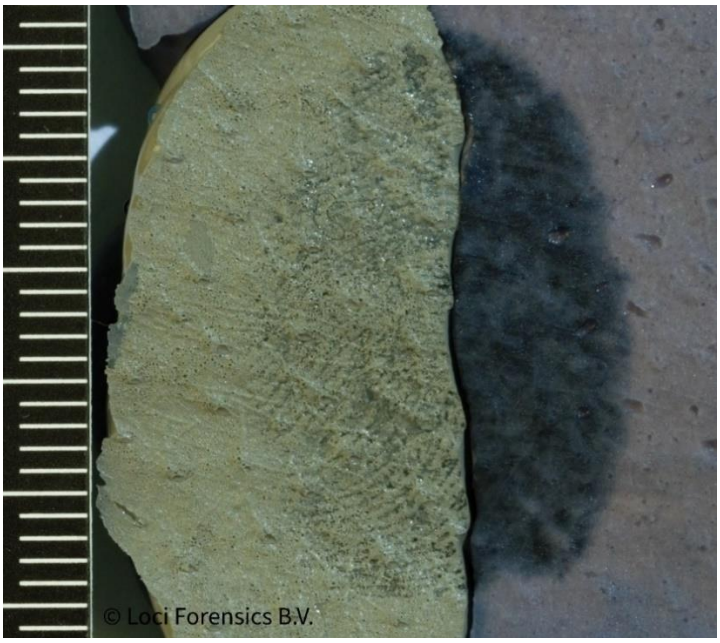
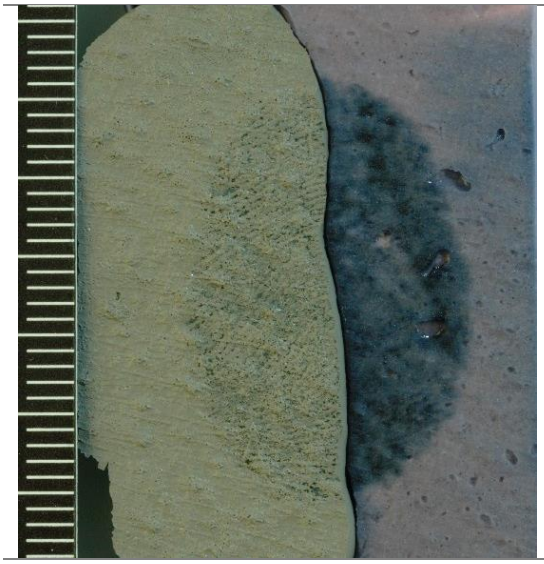
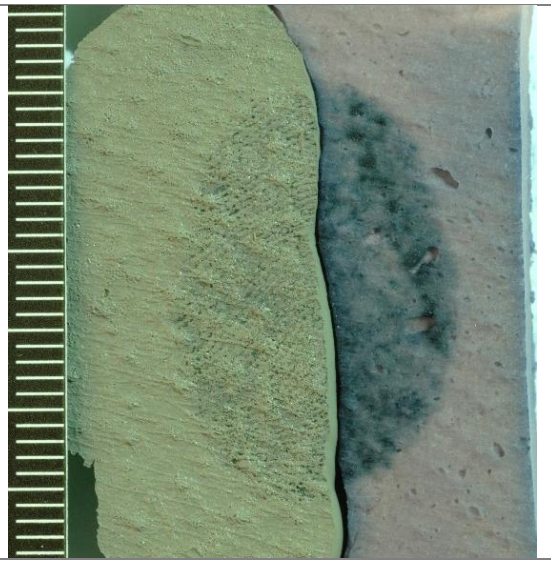


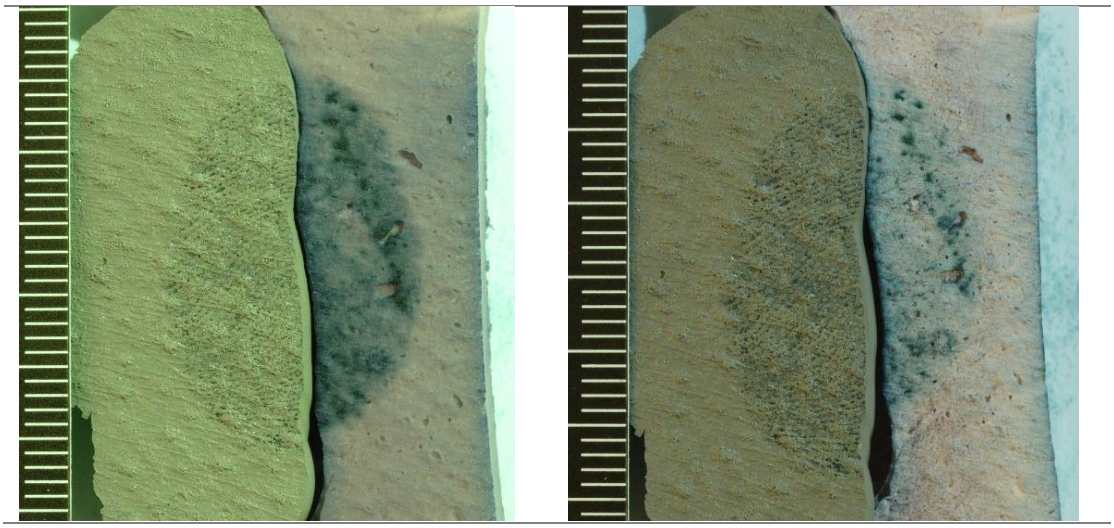
Figure 26 *Split fingerprint: half-impression lifted with method A (left - Forensic Sil) and half-impression lifted with method B (right - alginate), enhanced with Amido Black.*

Main research: impact of time

Subsequently, the split fingerprint (shown in figure 26) was tested on the impact of time. This way, a direct comparison between the impact of time on an alginate cast and a Forensic Sil cast could be made. The impact time makes on both casts is tracked by focusing on the amount of shrinkage, the stability of the cast and the amount of continuous ridges and contrast observed at every time stamp (0 hours, 2 hours, 4 hours and 12 hours). Results are shown in table 14.

Table 14 *Impact of time: split fingerprint lifted with alginate and Forensic Sil, enhanced with Amido Black, at time stamps of 0 hours, 2 hours, 4 hours and 12 hours.*

0 hours	**2 hours**
	
4 hours	**12 hours**



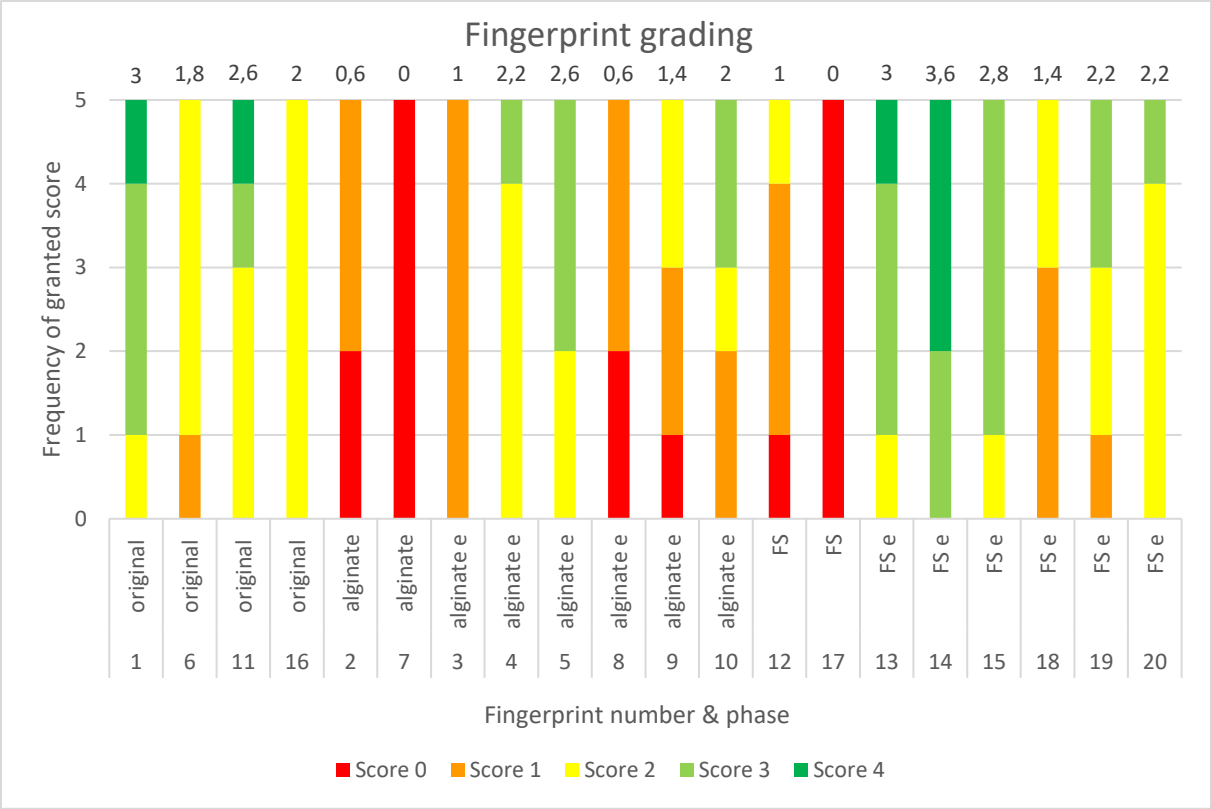
It can be observed that alginate is more likely to shrink and lose detail (continuous ridges) and contrast, especially after 12 hours. Since alginate is water-based, it is prone to evaporate the water and thus be dimensionally unstable. The shrinkage is visible in figure 2-4; the gap between the alginate and Forensic Sil casts grows and the width of the alginate cast decreases (right side of the image). On the contrary, Forensic Sil is more stable and does not lose its detail and contrast. Due to this high dimensional stability, it could be conserved and reassessed throughout the study (approximately 10 weeks).

Fingerprint grading & identification

Fingerprint grading

A total of 20 fingerprints were graded by a group of five raters. Each fingerprint was graded with a score from 0 to 4, based on the amount of continuous ridges and contrast. Data obtained from the fingerprints is shown in graph 3. The frequency of the granted score per fingerprint is processed in a stacked bar graph, with 5 being the maximum frequency. Every fingerprint is labelled with the corresponding phase.

The graph shows the average scores granted per fingerprint above the bars. Original fingerprints are graded with average scores ranging from 1.8 to 3.0. The lowest scores are granted to the lift without enhancement (alginate and FS in graph), with scores from 0.0 to 1.0. This shows enhancement is a necessary step when lifting fingerprints. The average scores are highest for Forensic Sil enhanced fingerprints (ranging from 1.4 to 3.6). On the other hand, alginate enhanced fingerprints have overall lower scores (ranging from 0.6 to 2.6).



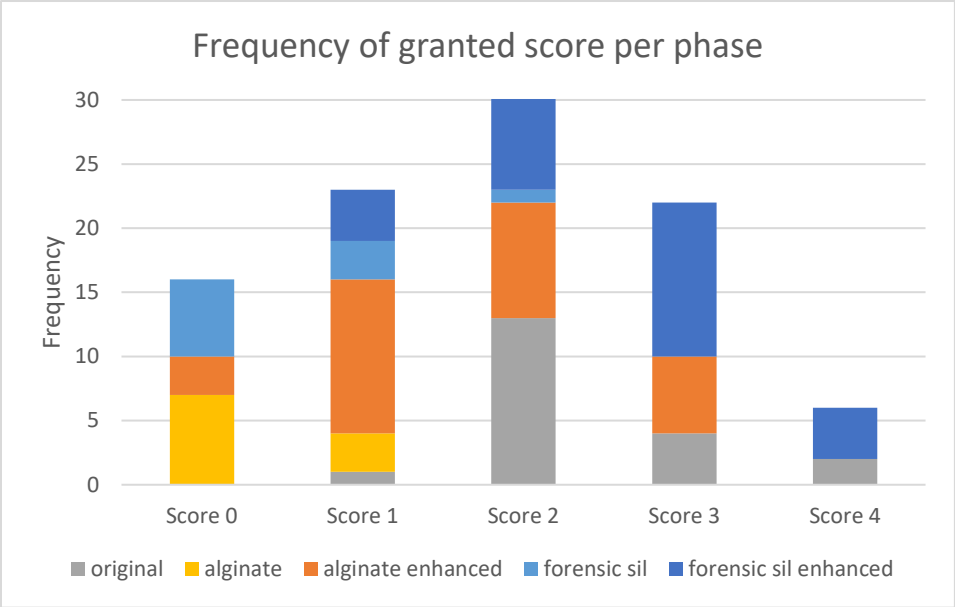
Graph 3 *Fingerprint grading data: frequency of the granted scores per fingerprint (n=5) with scores ranging from 0 to 4 (e = enhanced, FS = Forensic Sil).*

The fingerprints from graph 3 are converted into categories per phase; original fingerprints, alginate lifted, alginate enhanced, Forensic Sil lifted and Forensic Sil enhanced fingerprints. The total amount of fingerprints per phase is given and the corresponding frequencies of scores. In addition, the most frequent score is mentioned to gain insight in the differences in scores per category (see table 15).

Table 15 *Frequency table of scores granted in fingerprint grading per category (phase); original fingerprint, alginate, alginate enhanced, Forensic Sil (FS), Forensic Sil enhanced. With the total amount of fingerprints per phase and the most frequent score per phase.*

	FP nr.	Score 0	Score 1	Score 2	Score 3	Score 4	Total	Most frequent
Original	*4*	0	1	**13**	4	2	20	score 2
Alginate	*2*	**7**	3	0	0	0	10	score 0
Alginate enhanced	*6*	3	**12**	9	6	0	30	score 1
Forensic Sil	*2*	**6**	3	1	0	0	10	score 0
FS enhanced	*6*	0	4	10	**12**	4	30	score 3

The data is converted to a stacked bar graph (see graph 4). Here, a clear overview is provided of the least and best graded phases. Notable is that the alginate enhanced fingerprints are graded with scores ranging from 0 to 3 (most frequent score 1), while the Forensic Sil prints are graded with scores ranging from 1 to 4 (with most frequent score 3). According to the data obtained from fingerprint grading, Forensic Sil enhanced fingerprints yield the overall highest scores. Additional data from fingerprint grading is presented in appendix IV.



Graph 4 *Stacked bar graph: frequencies of the granted scores per phase (original, alginate, alginate enhanced, Forensic Sil, Forensic Sil enhanced), with scores ranging from 0 to 4.*

To determine if there is an overall agreement between the raters, an intraclass correlation test was carried out. A high agreement ensures a higher reliability of the obtained data (within a 95% confidence interval). The selected method for calculating the intraclass correlation coefficient (ICC) is a two-way random intraclass correlation with absolute agreement for multiple raters. Results of the intraclass correlation test are shown in table 16. Single measures (comparing one measure to another measure) obtained an ICC-value of 0.741, which indicates a good absolute agreement between these values. The ICC-value that is important to determine inter-rater reliability is that of average measures. An ICC-value of 0.935 (95%CI: 0.868-0.972) was found for average measures. This means there is excellent agreement between the raters. The high correlation ensures a high reliability of the data obtained from the raters (averaged).

Table 16 *Output of the SPSS reliability analysis based on the fingerprint grading data. The table contains the corresponding two-way random intraclass correlation coefficient with absolute agreement for multiple raters, for single and average measures, with corresponding 95% confidence interval.*

Intraclass correlation coefficient			
	Intraclass correlation	95% CI	
		Lower bound	Upper bound
Single measures	0.741	0.568	0.873
Average measures	0.935	0.868	0.972

Fingerprint identification

Two lifted fingerprints were sent in for professional fingerprint identification; one fingerprint lifted with alginate (FP5), one fingerprint lifted with Forensic Sil (FP13). The lifted fingerprints were compared to a reference fingerprint of the donor. Matching the fingerprints is done based on (the amount of) minutiae. When sufficient matching minutiae are found (in fingerprint and reference), this can lead to fingerprint identification. In the Netherlands, a minimal amount of 12 minutiae is required to identify a fingerprint. When identification is not possible – due to insufficient minutiae – it can still contribute to exclusion.

Figure 27 shows the matching of the fingerprint lifted with alginate (FP5) with the reference fingerprint. According to the fingerprint examiner, this fingerprint has the lowest quality (when compared to FP13). Comparison leads to a total of 7 matching minutiae. Due to disruptive factors in the fingerprint,

identification is not possible. However, the fingerprint (FP5) can contribute to exclusion of an individual. These matching minutiae are shown as blue dots and are numbered in figure 27. Besides the matching minutiae, a few other minutiae have been found that cannot be matched. This can be due to the disturbance in the fingerprint or possible deformation of the surface (skin). When placing the fingerprints, softness of the skin can deform the fingerprint. Also, movement can cause deformation while placing or lifting the fingerprint.

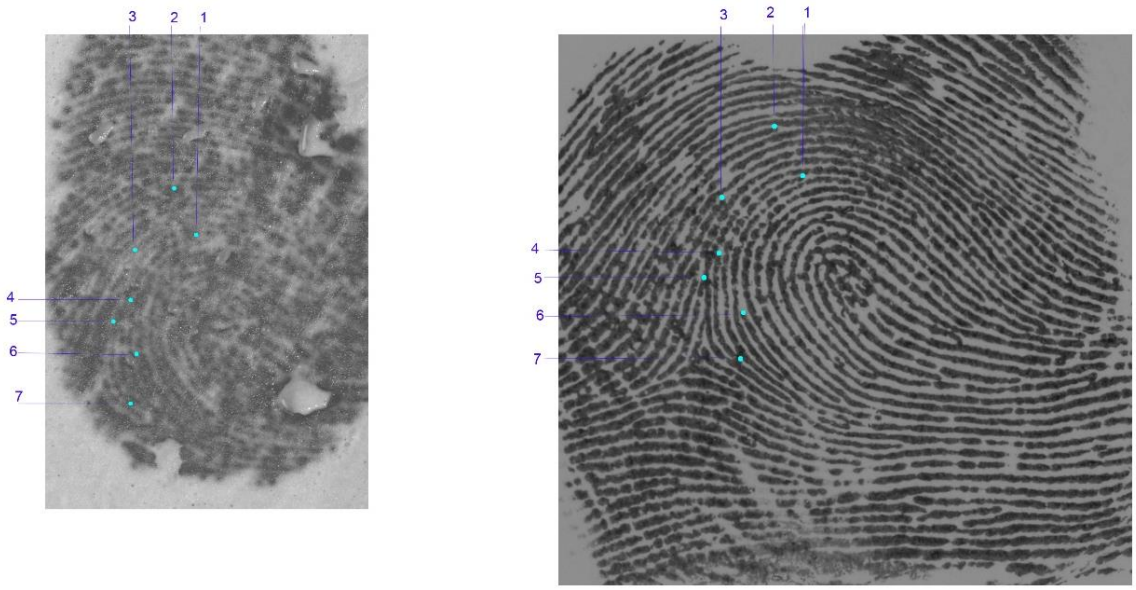


Figure 27 *Fingerprint identification of the alginate lift enhanced with Amido Black (FP13), compared to the reference fingerprint (donor 1). A total of 7 minutiae are matched (blue dots).*

Figure 28 shows the matching of the fingerprint lifted with Forensic Sil (FP13) with the reference fingerprint. According to the findings of the fingerprint examiner, a total of 13 matching minutiae are found when comparing the fingerprint to the reference. Some of these minutiae have been matched with 'tracing'; finding minutiae from the reference, in the fingerprint (this should typically be the other way around). Again, the fingerprint has disruptive factors. These disruptions can cause the minutiae to be relatively further apart from each other then they originally were. This can also be caused by softness or resilience of the surface (skin) while placing the fingerprint. Because of the disruptions, epidermal ridges can translocate. Three epidermal ridges can be observed between two minutiae in the fingerprint, while the reference only has two epidermal ridges between those minutiae. Despite the 13 matching minutiae – which should be sufficient for identification – no identification can take place. The disruptions and translocations of epidermal ridging complicates the process of identification. In a regular research, the fingerprint can only contribute to exclusion. The fingerprint examiner adds: 'the Forensic Sil method for lifting the fingerprint is a lot better than the alginate method. The surface seems to be the disruptive factor'. Additional results of fingerprint identification and the reference fingerprints of all donors are presented in appendix III.

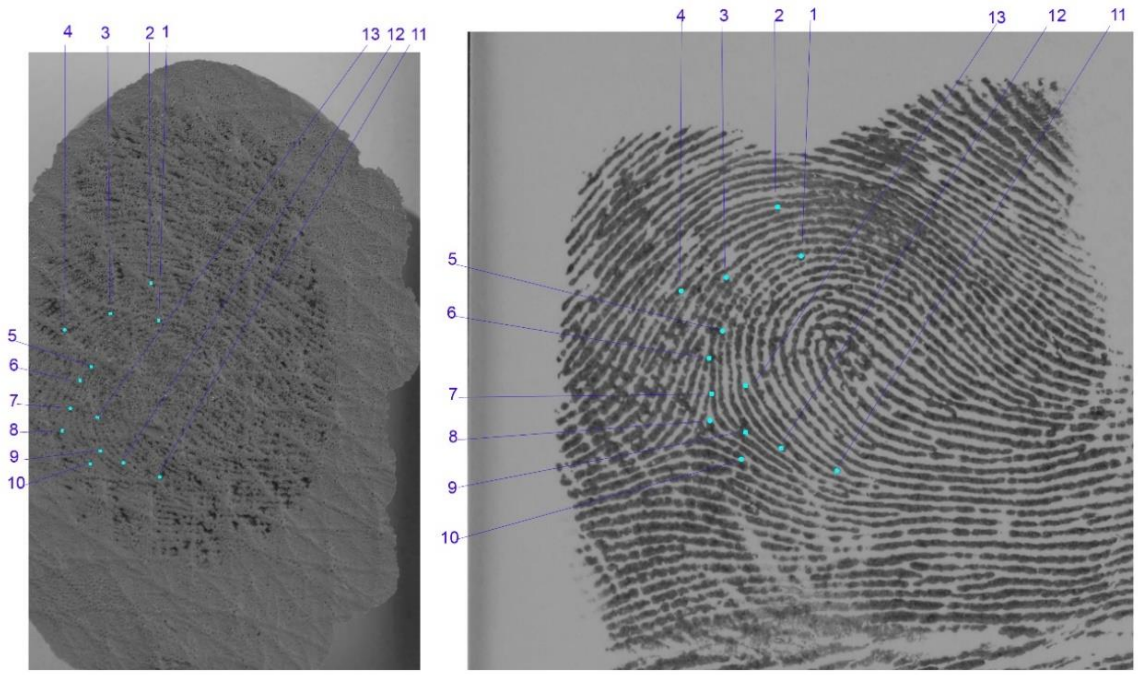


Figure 28 *Fingerprint identification of the Forensic Sil lift enhanced with ALCV (FP13), compared to the reference fingerprint (donor 1). A total of 13 minutiae are matched (blue dots).*

6. Discussion

The aim of the research was to determine whether Forensic Sil is more suitable than alginate for the lifting of fingerprints placed with blood on skin. This study originally started with researching further into the lifting abilities of alginate. Based on multiple scientific articles, alginate was put out as a promising method for lifting bloody fingerprints and shoeprints from multiple surfaces. [17] [27] [19] The use of alginate on skin had not been researched yet, even though it appeared to be a promising method for lifting bloody fingerprints from skin. Hence why the study started with focus on alginate as a lifting method. During the research it soon appeared to have multiple negative factors. For example, the preparation and application are not optimal. Relatively much material is needed and the process of application is messy, which can cause deformation of the fingerprint and loss of detail. Also, alginate casts remained wet for a long time (sometimes up to 24 hours) due to it being water-based and additionally applying blood reagents. This causes the fingerprint to diffuse quite fast. So, when lifting with alginate, the process of recovery and photography has to be done fast. All of these factors can have a negative effect on the fingerprint evidence. Hence why the study shifted towards a new lifting method; Forensic Sil. This method was never used before for this purpose, but soon appeared to be yielding great results. Due to Forensic Sil seeming more optimal than alginate, it was incorporated into the study. Positive sides to Forensic Sil were the dimensional stability; the cast was not influenced by water, other liquids, time or temperature. But the method needed further testing to substantiate these findings. Therefore, the focus was on comparing the two lifting methods and gain insight in their lifting abilities. Optimal conditions were established and the main research contained larger sample sizes. This way, a conclusion could be drawn about the optimal lifting method.

It is important to keep in mind that this regards a pilot study, since this is the first time Forensic Sil is researched for lifting bloody fingerprints from skin. Because of this, many variables are not yet researched. These variables can be included in a follow-up optimisation study. In some ways this study already focuses on optimisation; multiple donors, time stamps and the comparison between two methods. [24] A recommendation about further optimisation will be made (chapter 8 'Recommendations').

Preliminary research

The preliminary research was focused on determining the optimal conditions of alginate, Forensic Sil and skin. This way, the main research is narrowed down in variables. Including too many variables might lead to unambiguity in results or deviant results. Also, the pre-set optimal conditions make sure the focus lies solely on determining the lifting abilities of alginate and Forensic Sil (the aim of the research).

The first preliminary experiment concerned the optimal conditions of alginate, including the mixing ratio, water temperature and mixing in blood reagents. An optimal mixing ratio of 1:2.5 and water temperature of <21°C were established. When looking at a previous scientific article on alginate, the mixing ratio used was either that of the manufacturer or an altered ratio around 1:2.5. [17] However, the temperature of water was not mentioned. This gave rise to researching those factors for this study, since it can highly influence the process of application and the obtained results. The results showed that the lifting abilities of alginate are highly dependent on the water temperature used. Temperatures above 30°C lower the mixing and setting time of alginate. Because of this, there is less time for a good application and lift. It is considered that the low setting time leaves insufficient time for the alginate to encapsulate blood of the fingerprint, thus creating a minimal lift. On the contrary, a low water temperature gives a relatively long setting time. This enables alginate to encapsulate and lift sufficient blood from the fingerprint. A water temperature below 21°C is essential when lifting with alginate.

Subsequently, the optimal conditions of Forensic Sil were determined. Results showed that the winter version of Forensic Sil provides an optimal lift compared to the summer version. The winter version had stronger adhesion to the surface and thus creates a strong lift with high contrast. However, the winter version is made to be used at low ambient temperatures (<0°C). When using this version at room

temperature or higher temperatures, the setting time will decrease. At room temperature (used in this study), the setting time is approximately 15 seconds. When ambient temperatures are higher than room temperature, the setting time will be too short for good application. In this case, the summer version of Forensic Sil is necessary. Further work on the lifting abilities of the Forensic Sil summer version is needed.

The preliminary experiment regarding optimal conditions of the skin showed that a layer of fat forms on the surface of the pig skin. This caused the bloody fingerprint to lay on top of the skin and deform. To obtain optimal results, the skin was washed with green soap and ethanol, creating a more dry skin surface. This was done to imitate the relatively dry human skin (under normal circumstances). Washing the skin gave a stronger adhesion of Forensic Sil to the surface and provided a stronger lift. In addition, findings of the fingerprint examiner were that no identification is possible for Forensic Sil, due to the skin surface creating disturbances. When compared to human skin, the pig skin was more textured and flexible (since it was not present on a body). This might cause the disruptions in the Forensic Sil lift. Without these disruptive factors in human skin, it is more likely that fingerprint identification is possible. This gives rise to researching the lifting abilities of Forensic Sil on human skin further (see chapter 8 'Recommendations').

Main research

In the main research the lifting abilities of alginate and Forensic Sil are tested in larger sample sizes. For alginate, three donors were included. They each placed a triplicate of nine samples in a depletion series. Each depletion series consisted of three fingerprints. All fingerprints were placed with the right hand thumb. Per variable, nine samples were included (*n=9*). In total, three grids with 81 samples were lifted using alginate (*n=81*). Due to limited amounts of alginate present and the disadvantages of the lifting method, no further samples (from extra donors) were set up and recovered. For Forensic Sil, a total of four donors were included. Again, depletion series of nine samples were placed per variable (*n=9*). In total, three grids with 108 samples were lifted using Forensic Sil (*n=108*). The large sample sizes of alginate and mainly Forensic Sil higher the reliability of the research. The consistency of the obtained results is high. Within the depletion series or within variables, no deviant results were found that lower the reliability of the research.

The positive control involved the depletion series placed with blood of nine fingerprints (three triplicates) for each variable (donor, blood reagent, lifting method) on skin. Negative controls were considered, but were believed to not be of any added value to the research. Since the fingerprints were placed on a clean surface and photographs were taken at each stage, that was regarded as a negative control. Optimisation studies might consider including a negative control in the depletion series.

Statistically significant differences were not found between the original fingerprint and alginate and Forensic Sil lifted fingerprint (95% CI). This indicates that the data of the two groups is accurate. With alginate the original fingerprint had a higher average score (average 3.0) compared to the enhanced alginate lift (average 2.6). On the contrary, with Forensic Sil the original fingerprint had a lower average score (average 2.6) than the enhanced lift (average 3.0). Though no statistically significant difference was determined, Forensic Sil is considered to positively enhance the fingerprint. The calculated intraclass correlation coefficient (ICC = 0.935) gave an excellent absolute agreement between raters (> 0.9), within a 95% confidence interval. This indicates a high inter-rater reliability. Consistency is obtained by letting the same group of raters grade all fingerprints. This allowed the comparison of fingerprints prior and post lifting and enhancement.

Fingerprint grading on the results of the main research showed that alginate combined with Amido Black enhancement gave good continuous ridges with the most detail (FP5, average score 2.6). ALCV showed higher degree of diffusion (FP3, average score 1.0) and Hungarian Red (FP4, average score 2.2) provided relatively low contrast. These findings correspond to the findings in literature. Multiple articles [17] [19] regarding alginate research also find Amido Black to be superior to ALCV when enhancing alginate casts.

Only results of donor 1 and 2 were included in fingerprint grading. This was a time-bound limitation of the study, the amount of raters and the amount of fingerprints could not be increased. Chapter 5 'Results' only presents and describes the data obtained from donor 1, the fingerprint grading data obtained from donor 2 was omitted for the overview (see appendix IV). Varying donors show varying results; one donor has more defined epidermal ridges than the other. The best fingerprints were placed by donor 1 (female), hence why they were included in chapter 5 'Results'. Donor 2 provided the second best fingerprints with sufficient epidermal ridges throughout the depletion series. Because of this, results from donor 1 and 2 were included in the fingerprint grading. Donor 3 and 4 provided low quality fingerprints; epidermal ridging was less defined and disruptive factors such as creasing were found (3rd level feature). Because the original fingerprints were already low in quality, the obtained lifts were not as suitable for further examination. The results of donor 3 and 4 are presented in appendix II.

Lastly, the impact of time on the alginate and Forensic Sil casts was tested. This showed that the alginate cast is very prone to shrinkage and loss of detail. However, few articles [17] [18] state that the alginate casts are left to dry overnight, after which they were enhanced and analysed further. This study has found that the alginate cast can best be applied, enhanced and photographed in a short period of time. Diffusion of the fingerprint can occur within minutes. Time has a high influence on the quality of the alginate lift, leaving it overnight obtains deviant results. For Forensic Sil, time appears to not impact the cast. After 5 to 10 weeks, the casts can still be analysed and seem to not have lost any detail. Further work should be done to gain insight in the impact of time on Forensic Sil casts.

Hypotheses

A total of three hypotheses were set up; (H1) Forensic Sil is able to lift bloody fingerprints such that continuous epidermal ridges can be identified, while alginate is not able to, (H2) both Forensic Sil and alginate are able to lift bloody fingerprints such that continuous epidermal ridges can be identified and (H3) both Forensic Sil and alginate are not able to lift bloody fingerprints such that continuous epidermal ridges can be identified. These hypotheses were either accepted or rejected, based on the results of the research.

No significant difference was found between the original fingerprint and the alginate lifted fingerprint. However, the average score of the original fingerprint was higher than the average score of the alginate lift, indicating a negative effect. This was also calculated for the original fingerprint versus the Forensic Sil lift. Again, no significant difference was found between the two phases. The average score of the Forensic Sil lift was higher, indicating a positive effect. In addition, the graded split-fingerprint showed that Forensic Sil exhibits far greater ridge detail and/or contrast than alginate. Fingerprint identification matched a total of 7 minutiae for the alginate lift, thus insufficient for identification. 13 minutiae were matched for the Forensic Sil lift. According to the fingerprint examiner, Forensic Sil provided a higher quality fingerprint than alginate. When the skin surface causes less disruption, the Forensic Sil lift would be able to provide a fingerprint that can be identified. Combining all obtained results, hypothesis 1 is accepted: Forensic Sil is able to lift bloody fingerprints such that continuous epidermal ridges can be identified, while alginate is not able to. Hypothesis 3 is rejected. Hypothesis 2 is questionable, alginate is able to provide a fingerprint lift with identifiable continuous ridges. However, this is dependent on many factors (optimal circumstances, good application, preparation et cetera). Forensic Sil is less variable in this manner, it has shown to provide a constant lifting mechanism with constant results. Therefore, Forensic Sil is proven to be an optimal lifting method compared to alginate.

7. Conclusion

The case presented in the introduction, in which a woman was found dead with bloody fingerprints on her skin, is an example of a case that can be solved through the findings of this study. To this day, there is no method for recovering these fingerprints, despite their high forensic relevance. Forensic Sil provides a method that cannot only lift the bloody fingerprint from skin, but also positively enhance it.

Based on the preliminary research, the following conclusions can be drawn regarding the sub-questions and optimal conditions of alginate and Forensic Sil;

- Optimal lifting conditions of alginate are a 1:2.5 mixing ratio with <21°C tap water,
- Forensic Sil provides an optimal lift with strong adhesion when the winter version is used,
- Alginate can best be enhanced with Amido Black. This provides the highest amount of ridge detail, but low contrast between the cast and fingerprint,
- Forensic Sil can be enhanced with ALCV, Hungarian Red and Amido Black. All blood reagents provide high ridge detail, but optimal contrast is obtained with ALCV,
- When lifting bloody fingerprints with alginate, continuous ridges can be observed,
- Forensic Sil provides higher amounts of continuous ridges than alginate and provides a stronger lift,
- Based on fingerprint grading data, Forensic Sil yields higher average scores than alginate,
- Alginate casts are highly impacted by time. Within minutes, diffusion of the lifted fingerprints occurs. The casts are prone to shrinkage and loss of ridge detail,
- The dimensional stability of Forensic Sil is exceptionally high; there is no change in ridge detail within 24 hours and the cast does not shrink.

In conclusion, the main question of the research is answered: ‘To what extent is Forensic Sil more suitable than alginate for the lifting of fingerprints placed with blood on skin?’. This study found that alginate is not as suitable as Forensic Sil for lifting bloody fingerprints from skin. Alginate is not able to lift the fine ridge detailing of fingerprints, providing a low quality lift with a high amount of diffusion. In addition, the lift is highly impacted by time, making storage impossible. Forensic Sil has shown to have excellent lifting abilities with high amounts of ridge detailing; full fingerprints are lifted and enhanced. The only disruptive factor remains to be the skin. However, when Forensic Sil is further researched on human skin, there is a high chance the method will recover high quality fingerprints suitable for fingerprint identification.

8. Recommendations

In order to achieve improved results and insight based on this study, multiple recommendations are made. In general, Forensic Sil provided a more promising lifting method than alginate. Therefore, it is recommended that further work is focused on using Forensic Sil for lifting bloody fingerprints from skin.

The use of alginate for the lifting of bloody fingerprints from skin is not recommended to be researched further. However, results of the preliminary research regarding mixing in blood reagents with alginate obtained promising results when Amido Black was mixed with alginate instead of water. As another scientific article states [17], the mixture can lift the fingerprint in a way that enhancement directly occurs on the alginate cast. These results provide promising lifting abilities of alginate, compared to the water-based alginate mixture. Further work on this alternative alginate preparation can be performed to gain more insight in the lifting abilities.

This study is considered a pilot-study on Forensic Sil; a foundational research that gives rise to a follow-up study. It is recommended that an optimisation study is performed that further researches the lifting abilities of Forensic Sil. Here, more donors (5 to 15 good, average and poor fingerprint donors) [24], more variables and more samples are recommended to be included in the research. In addition, fingerprint grading can be performed on a larger scale to obtain more data. Expanding this study with these factors will provide more insight in the lifting abilities of Forensic Sil for lifting bloody fingerprints from skin.

Subsequently, it is recommended that the lifting abilities of Forensic Sil are tested on human skin instead of pig skin. Despite their high similarities, pig skin has shown to become more greasy and flexible than human skin (under normal conditions). This can give deviant results. Hence why a follow-up study should include human skin as a surface for lifting bloody fingerprints with Forensic Sil. In addition, Forensic Sil lifts can be tested even further on multiple skin conditions. For example, on living and deceased subjects, different stages of decomposition, varying locations and/or temperatures, et cetera. This can give insight into the circumstances under which Forensic Sil can lift a bloody fingerprint from skin.

The optimisation studies on Forensic Sil should include experiments regarding the impact of time. This study has shown Forensic Sil casts to not be influenced by time within 24 hours. Even after 10 weeks the casts seemed to not be impacted by time. It is recommended to research how long the Forensic Sil casts can be stored for and if time influences the quality of the lifted fingerprint. This is valuable information, for example in cold cases in which evidence is usually and preferably stored for a long time. When time appears to have no impact on the Forensic Sil cast this can enable fingerprint identification, even years after recovery.

References

[1] Home Office - Centre of Applied Science and Technology (CAST), *Fingermark Visualization Manual,* 1 ed., 2014.

[2] WordSense Dictionary, "Dactyloscopy," WordSense Online Dictionary , 22nd February 2021. [Online]. Available: https://www.wordsense.eu/dactyloscopy/. [Accessed 22nd February 2021].

[3] R. Gaensslen and K. Young, "Fingerprints," in *Forensic Science: An Introduction to Scientific and Investigative Techniques*, Boca Raton, CRC Press, 2009, pp. 355-375.

[4] D. Maltoni, Handbook of Fingerprint Recognition, London: Springer, 2009.

[5] Politie, "Dactyloscopisch onderzoek sporen," September 2015. [Online]. Available: https://www.politie.nl/binaries/content/assets/politie/algemeen/onderwerpteksten/algemeen/vakbijlage-dactyloscopisch_onderzoek-sporen-2015.pdf. [Accessed 26 February 2021].

[6] A. Gunn, Essential Forensic Biology, 2 ed., Liverpool: Wiley Blackwell, 2009.

[7] Austin Hicklin, "ANSI/NIST Comittee to Define an Extended Fingerprint Feature Set," April 2006. [Online]. Available: https://www.nist.gov/system/files/documents/2016/12/19/p18_hicklin_extfpfeatures_2006-04.pdf. [Accessed 26 February 2021].

[8] R. S. Ramotowski, "Blood Reagents," in *Advances in Fingerprint Technology*, Boca Raton, CRC Press, 2013, pp. 129-156.

[9] Sanquin, "Over bloed," Sanquin, February 2021. [Online]. Available: https://www.sanquin.nl/over-bloed/bloedcellen. [Accessed 27 February 2021].

[10] BVDA, "Kleuren van bloedsporen," BVDA, 2021. [Online]. Available: https://www.bvda.com/nl/hongaars-rood. [Accessed 2 March 2021].

[11] Loci Forensics B.V., "Chemical Enhancement Kit - Amido Black," Loci Forensics B.V., 2021. [Online]. Available: https://www.lociforensics.nl/products/blood-evidence-enhancement-search/chemical-enhancement-kit---amido-black-3-x-30-ml-and-3-x-30-ml-cleaning-solution-. [Accessed 4 March 2021].

[12] Loci Forensics B.V., "Chemical Enhancement Kit - Acid Red," Loci Forensics B.V., 2021. [Online]. Available: https://www.lociforensics.nl/products/blood-evidence-enhancement-search/chemical-enhancement-kit---acid-red-3-x-30-ml-and-3-x-30-ml-cleaning-solution. [Accessed 3 March 2021].

[13] Loci Forensics B.V., "Chemical Enhancement Kit ALCV," Loci Forensics B.V., 2021. [Online]. Available: https://www.lociforensics.nl/products/blood-evidence-enhancement-search/chemical-enhancement-kit---alcv-3-x-30-ml-and-3-x-3-x-activation-tablets. [Accessed 3 March 2021].

[14] M. Trapecar and J. Balazic, "Fingerprint recovery from human skin surfaces," *Science and Justice,* vol. I, no. 47, pp. 136-140, 2007.

[15] W. Montagna and Y. Yun, "The skin of the domestic pig," *The Journal of Investigative Dermatology,* vol. I, no. 42, pp. 11-21, 1964.

[16] J. F. McCabe and A. W. Walls, Applied Dental Materials, Oxford: Blackwell Publishing, 2008.

[17] M. Munro, P. Deacon and K. J. Farrugia, "A preliminary investigation into the use of alginates for the lifting and enhancement of fingermarks in blood," *Science and Justice,* vol. I, no. 54, pp. 185-191, 2014.

[18] S. Wiesner, E. Izraeli, Y. Shor and E. Domb, “Lifting Bloody Footwear Impressions Using Alginate Casts Followed by Chemical Enhancement,” *Journal of Forensic Sciences,* vol. III, no. 58, pp. 782-787, 2013.

[19] K. J. Farrugia, N. NicDaéid, K. A. Savage and H. Bandey, “Chemical enhancement of footwear impressions in blood deposited on fabric - Evaluating the use of alginate casting materials followed by chemical enhancement,” *Science and Justice,* vol. I, no. 50, pp. 200-204, 2010.

[20] GC Australasia, “Aroma Fine Plus,” 27 October 2017. [Online]. Available: http://www.gcaustralasia.com/Products/37/Impressioning/AROMA-FINE-PLUS. [Accessed 4 March 2021].

[21] Loci Forensics BV, “Forensic Sil,” Loci Forensics BV, 2021. [Online]. Available: https://www.lociforensics.nl/forensic-sil/forensic-sil/forensic-sil-grey-50ml-cartridge-met-castingmaterial--harder-included-50-mixingtips-10-pcs. [Accessed 4 June 2021].

[22] Loci Forensics BV, “Forensic Sil Below-zero,” Loci Forensics BV, 2021. [Online]. Available: https://www.lociforensics.nl/forensic-sil/forensic-sil/forensic-sil-below-zero-grey-50ml-cartridge-with-casting-material--harder-included-50-mixing-tips-10. [Accessed 4 June 2021].

[23] D. Hockey, A. Dove and T. Kent, “Guidelines for the use and statistical analysis of the Home Office fingermark grading scheme for comparing fingermark development techniques,” *Forensic Science International,* vol. I, no. 313, pp. 1-7, 2021.

[24] International Fingerprint Research Group (IFRG), “Guidelines for the Assessment of Fingermark Detection Techniques,” *Journal of Forensic Identification ,* vol. II, no. 64, pp. 174-200, 2014.

[25] A. Summerfield, F. Meurens and M. E. Ricklin, “The immunology of the porcine skin and its value as a model for human skin,” *Molecular Immunology,* vol. I, no. 66, pp. 14-21, 2015.

[26] G. Banfi, G. L. Salvagno and G. Lippi, “The role of ethylenediamine tetraacetic acid (EDTA) as in vitro anticoagulant for diagnostic purposes,” *Clin Chem Lab Med,* vol. V, no. 45, pp. 565-576, 2007.

[27] A. Bentolila, S. Reuveny, D. Attias and M. Elad, “Using Alginate Gel Followed by Chemical Enhancement to Recover Blood-Contaminated Fingermarks from Fabrics,” *Journal of Forensic Identification,* vol. I, no. 66, p. 1, 2016.

[28] M. Trapecar, “Lifting techniques for finger marks on human skin previous enhancement by Swedish Black powder - A preliminary study,” *Science and Justice,* vol. I, no. 49, pp. 292-295, 2009.

[29] E. F. B. Frederic H. Martini, Anatomie en Fysiologie: een inleiding, 4 ed., Amsterdam: Pearson Education, 2008.

[30] Kenniscentrum Dermatologie, “De Huid,” Slingeland Ziekenhuis, 2021. [Online]. Available: https://dermatologie.slingeland.nl/kenniscentrum/Algemene-informatie/Anatomie-van-de-huid/1059/1221. [Accessed 16 Februari 2021].

[31] R. B. Weller, J. A. A. Hunter, J. Savin and M. Dahl, Clinical Dermatology, New Jersey: Blackwell Publishing , 2013.

Appendix I

In this appendix, additional methods are given to substantiate the strategy of chapter 3 and methodology presented in chapter 4. Materials, methods and variables that form the basis of this study are elaborated.

Constant factors

Besides the variables given in chapter 4 'Strategy', constant factors are also taken into consideration to lower the variability and thus maximize the reproducibility. The constant factors are shown in table 17.

Table 17 *Selected constant factors with the corresponding description and sub study.*

Constant	Description	Sub-study
Temperature		1-5
• **Environment**	~20°C	
• **Blood**	~20°C	
• **Skin**	~20°C	
Time (post deposition)	Maximum of 1 hour	1-5
Pressure (placing fingerprints)	Medium	1-5
Humidity	Average (50%)	1-5

Preparation and specifications of blood reagents

Table 18 *Blood reagents and the corresponding materials and preparation.*

	Preparation
Aqueous fixative solution	2% w/v aqueous 5-Sulfosalicyclic acid (5-SSA): 10 grams 5-Sulfosalicyclic acid 500 mL Distilled water *(use when not incorporated in the blood reagent)*
Aqueous Leucocrystal Violet (ALCV)	Aqueous Leucocrystal Violet solution: 11 grams 5-Sulfosalicyclic acid 1 gram Leucocrystal Violet 3.7 grams Sodium acetate Hydrogen (activation) tablets dissolved in distilled water: 1 tablet in 30 ml for a 1% solution
Hungarian Red (Acid Fuchsin)	Acid Fuchsin dye solution (with fixative): 11 grams 5-Sulfosalicyclic acid 11 mL Citric acid 1.5 grams Acid Fuchsin 489 mL Distilled water
Amido Black (Acid Black 1)	Amido Black dye solution (with fixative): 11 grams 5-Sulfosalicyclic acid 11 mL Citric acid 1.5 g Amido Black 10 or Acid Black 1 489 mL Distilled water
Aqueous rinse solution	0.5% v/v aqueous rinse solution: 2.5 mL Glacial acetic acid 497.5 mL Distilled water

Materials and photo set-up

Figure 29 *GC Aroma Fine Plus alginate (normal set, 1000 grams).*

Figure 30 *Forensic Sil with the dispenser gun and mixing tip.*

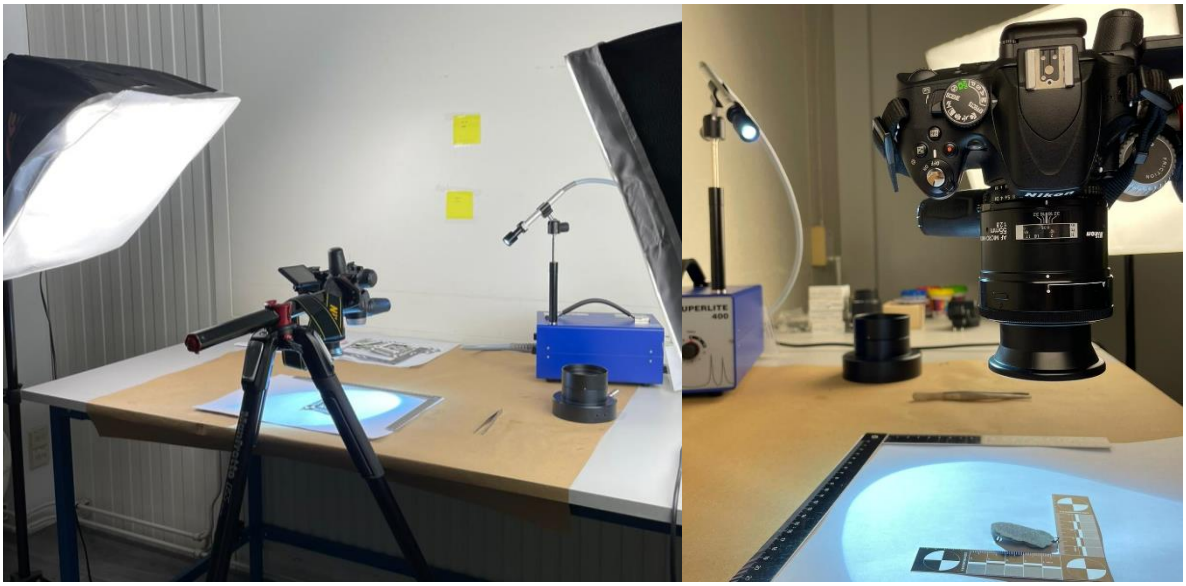


Figure 31 *Photo set-up of the main research (left) general set-up with additional light sources (2x studio lamp, 1x lumiscene white light), captured with a Nikon D5100 with fixed settings and set-up (right) detailed image of the set-up with rulers and a white background.*

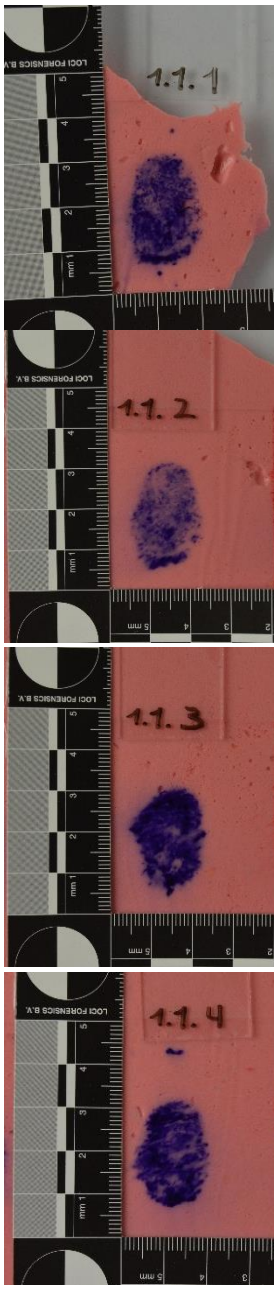
Appendix II

This appendix contains all photographs taken during the preliminary research and main research, but have been omitted for the overview in chapter 5 'Results'. The selection of photographs shown in this appendix only includes the lifted and enhanced fingerprints (last phase). Photographs of the original fingerprints and the lifted fingerprints without blood enhancement are stored externally and can be provided via request.

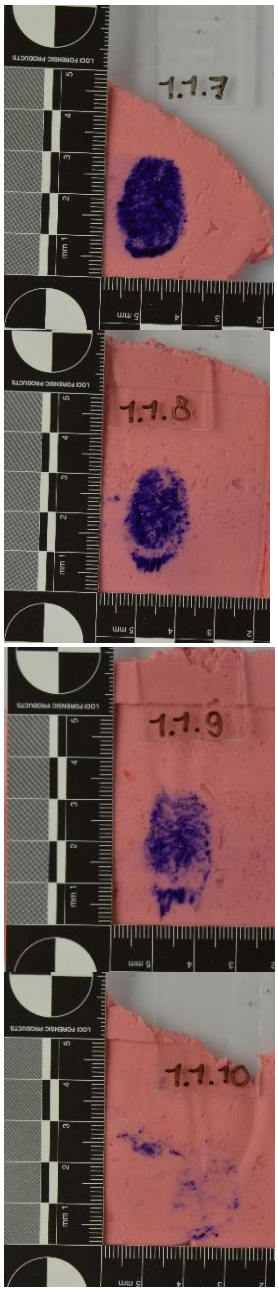
Preliminary research

Mixing ratio of alginate

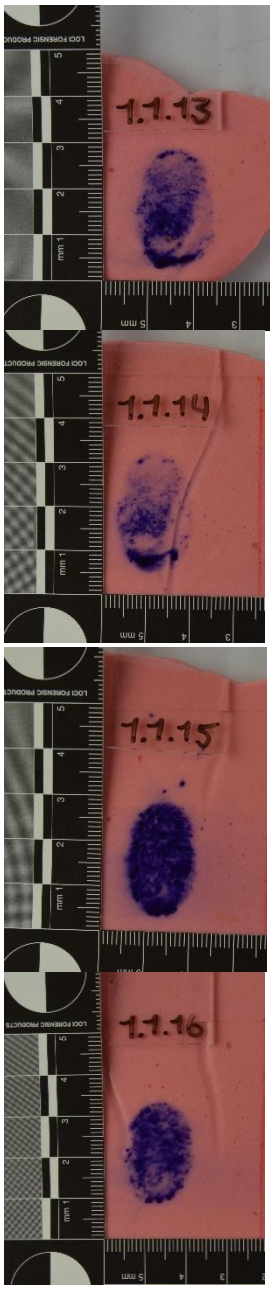
1:2.5



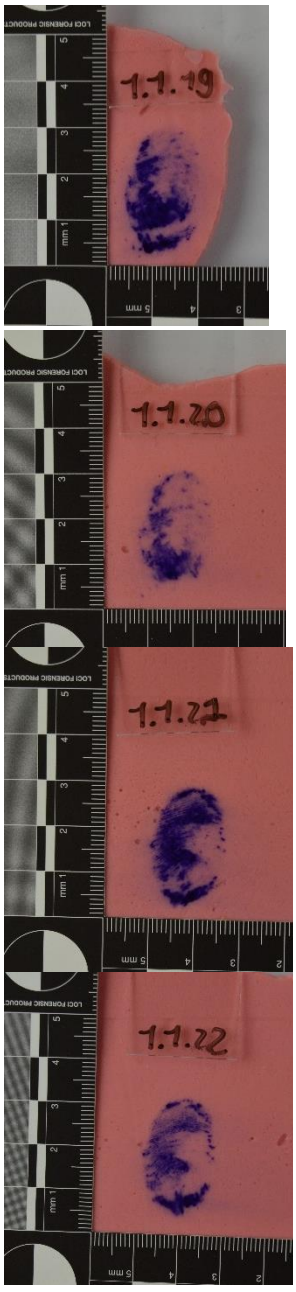
1:2



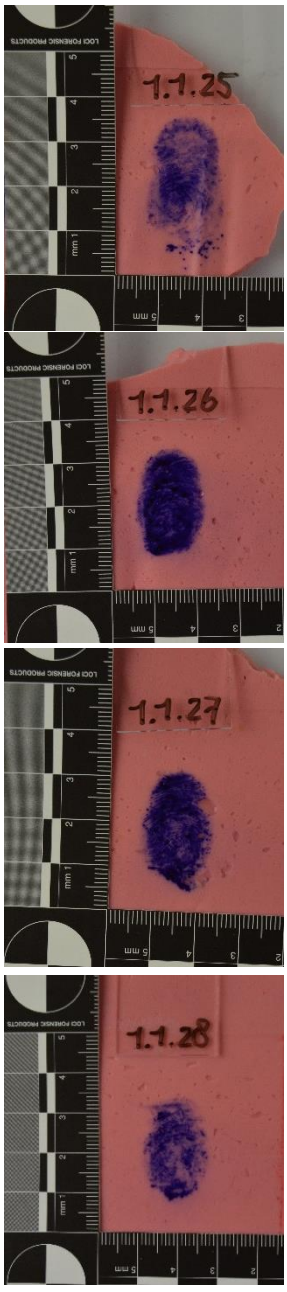
1:3

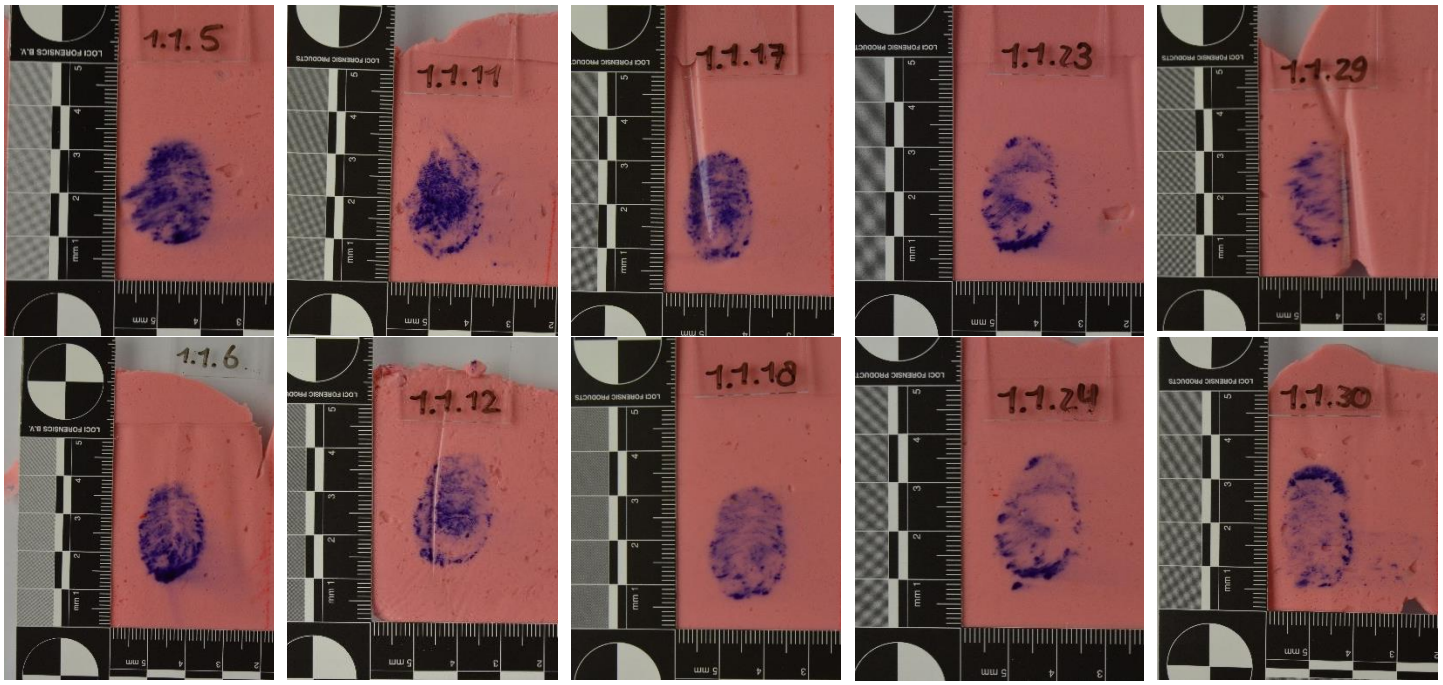


1:2.7



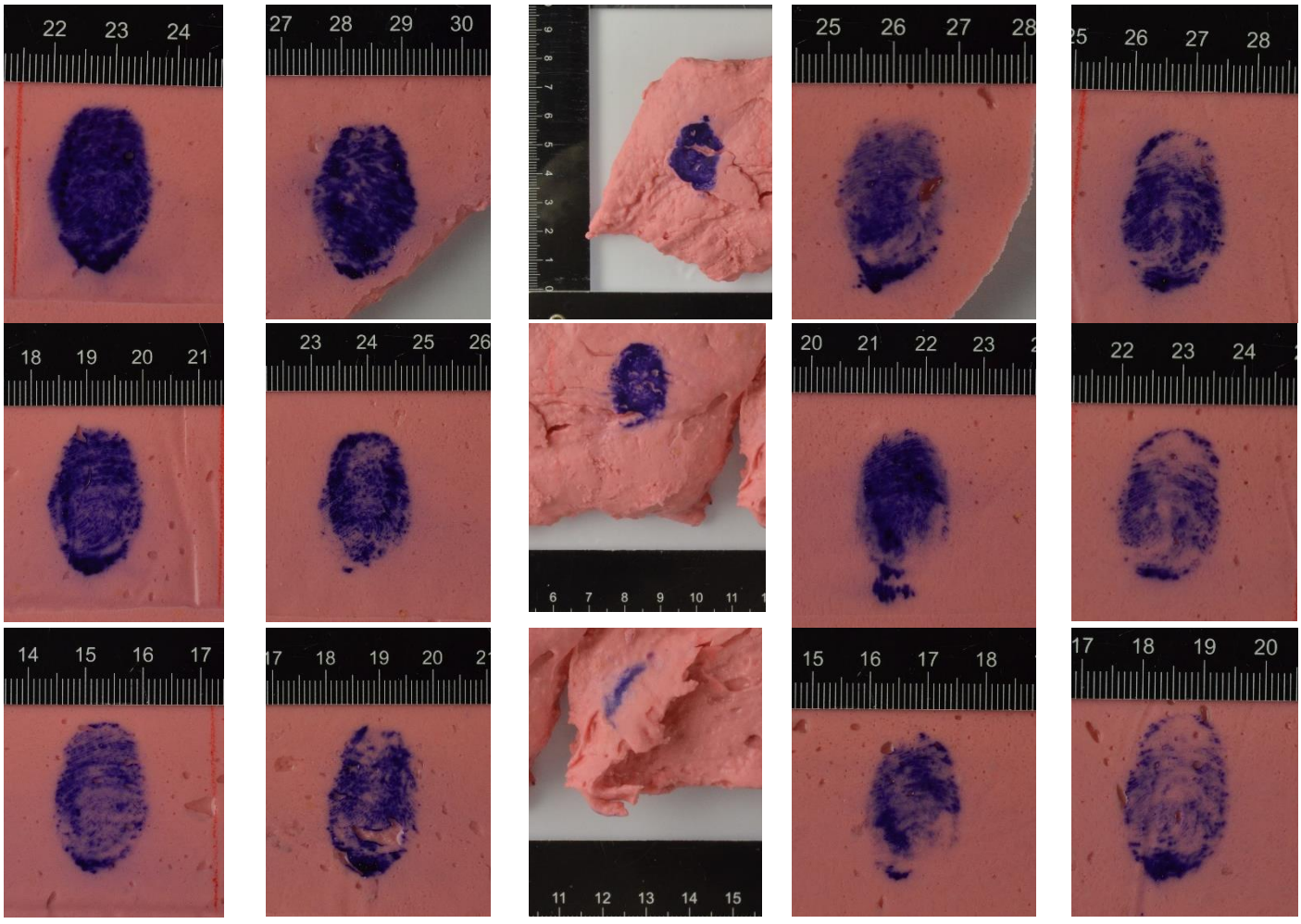
1:2.4

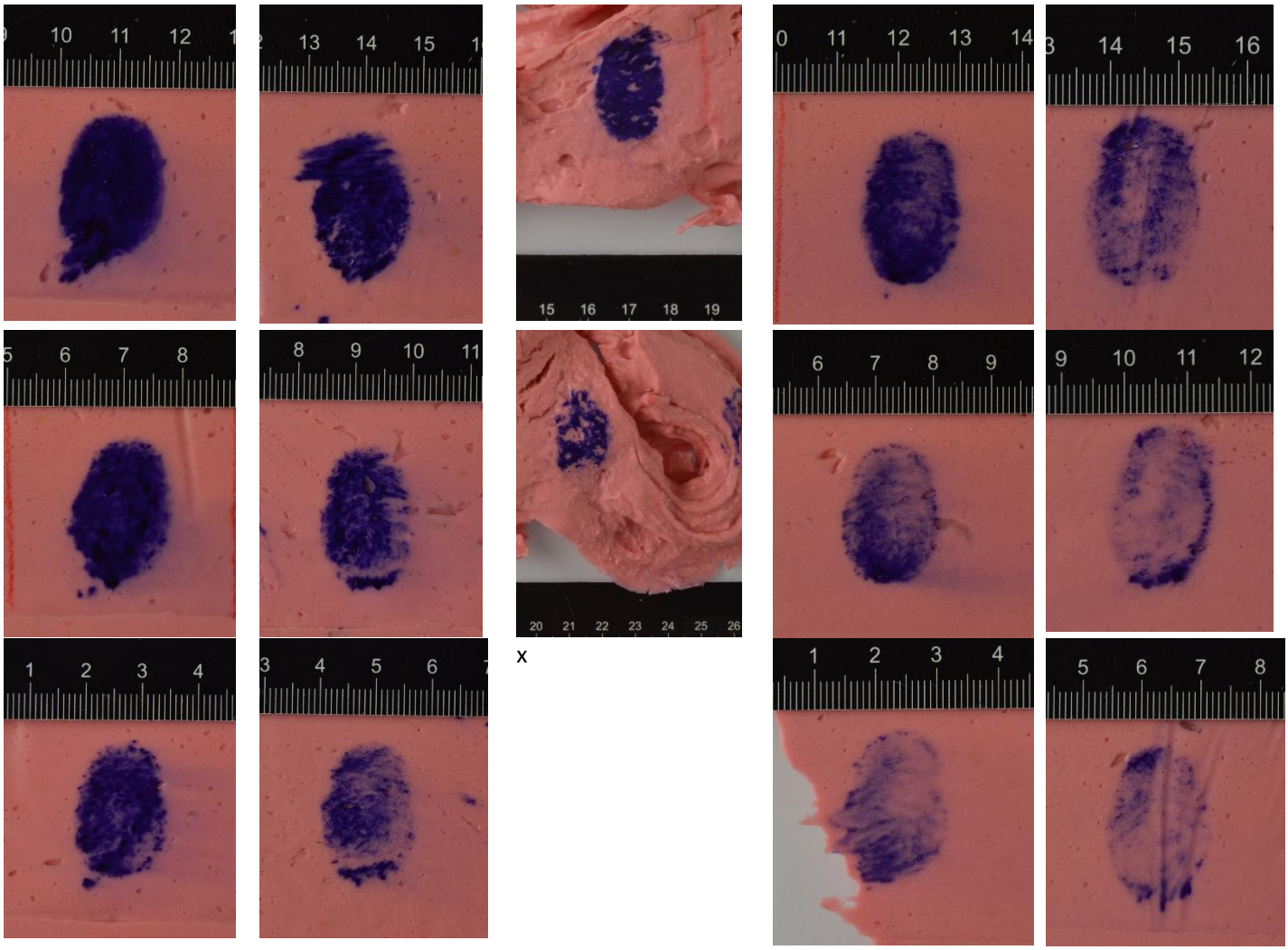




Water temperature of alginate

21°C **30°C** **40°C** **15°C** **10°C**

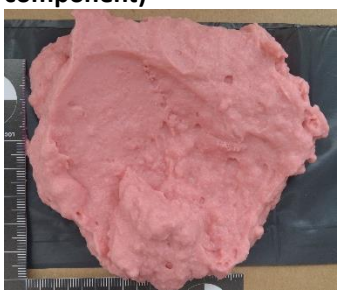




x

Alginate blood reagent mixture

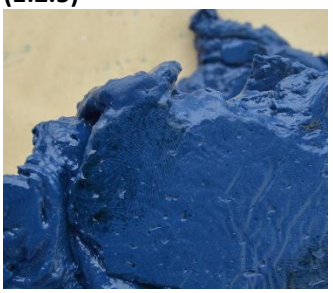
Alginate + ALCV (with acidic component)



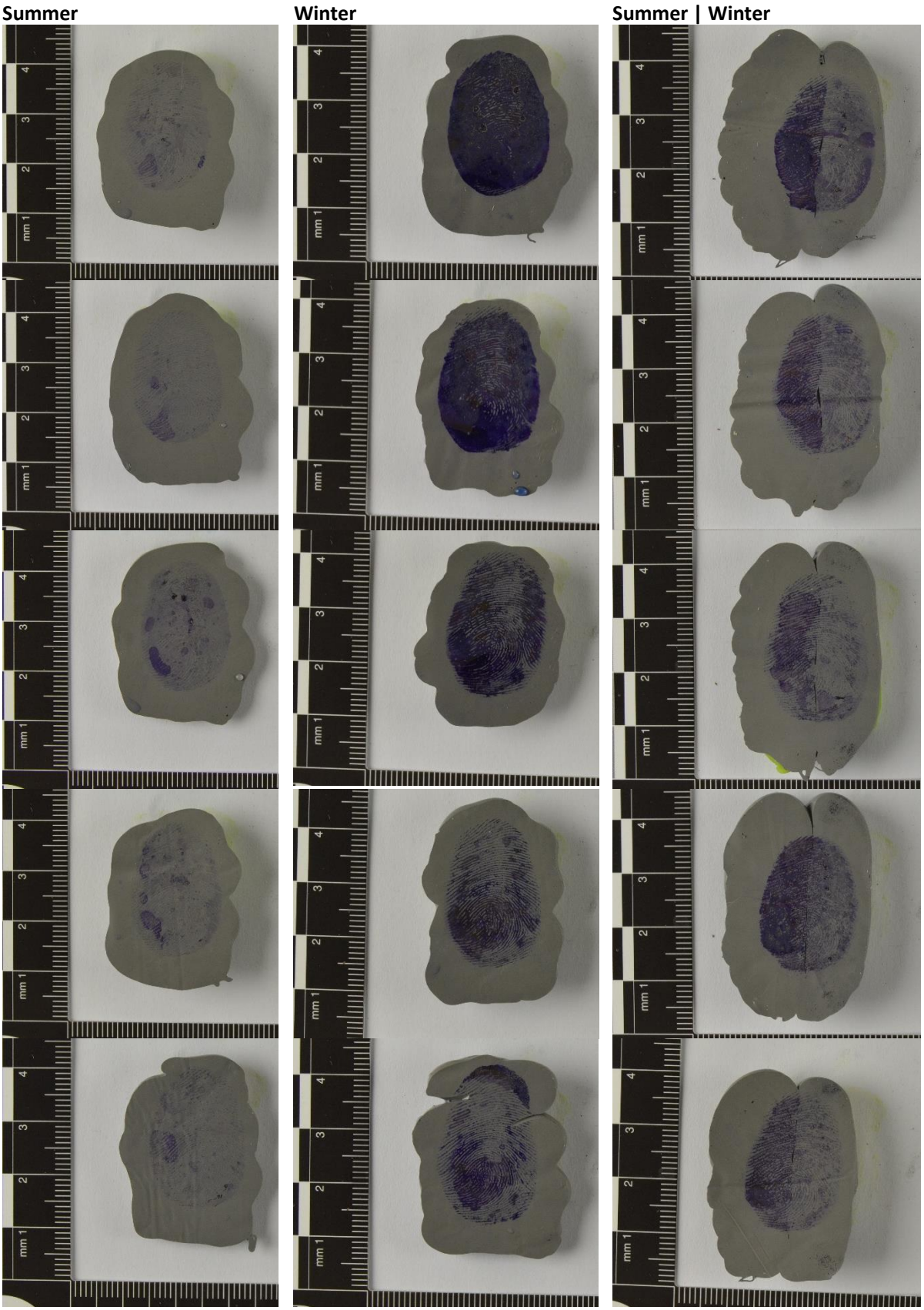
Alginate + Hungarian Red (with acidic component)

Alginate + Amido Black (with acidic component)

Alginate + Amido Black (1:2.5)



Forensic Sil summer and winter version



Skin conditions

Unwashed skin

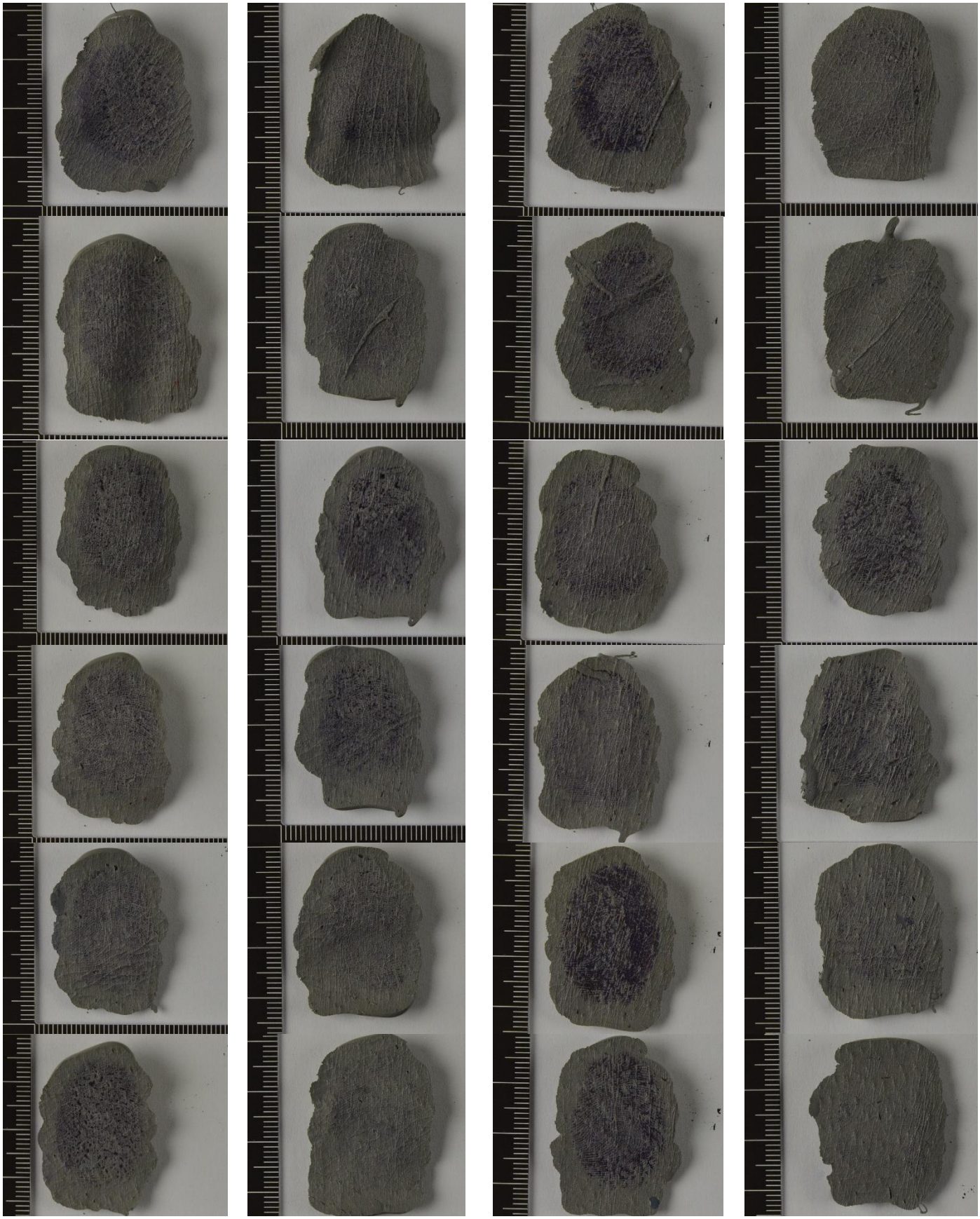
20 minutes

2 hours

Washed skin (green soap + ethanol)

20 minutes

2 hours

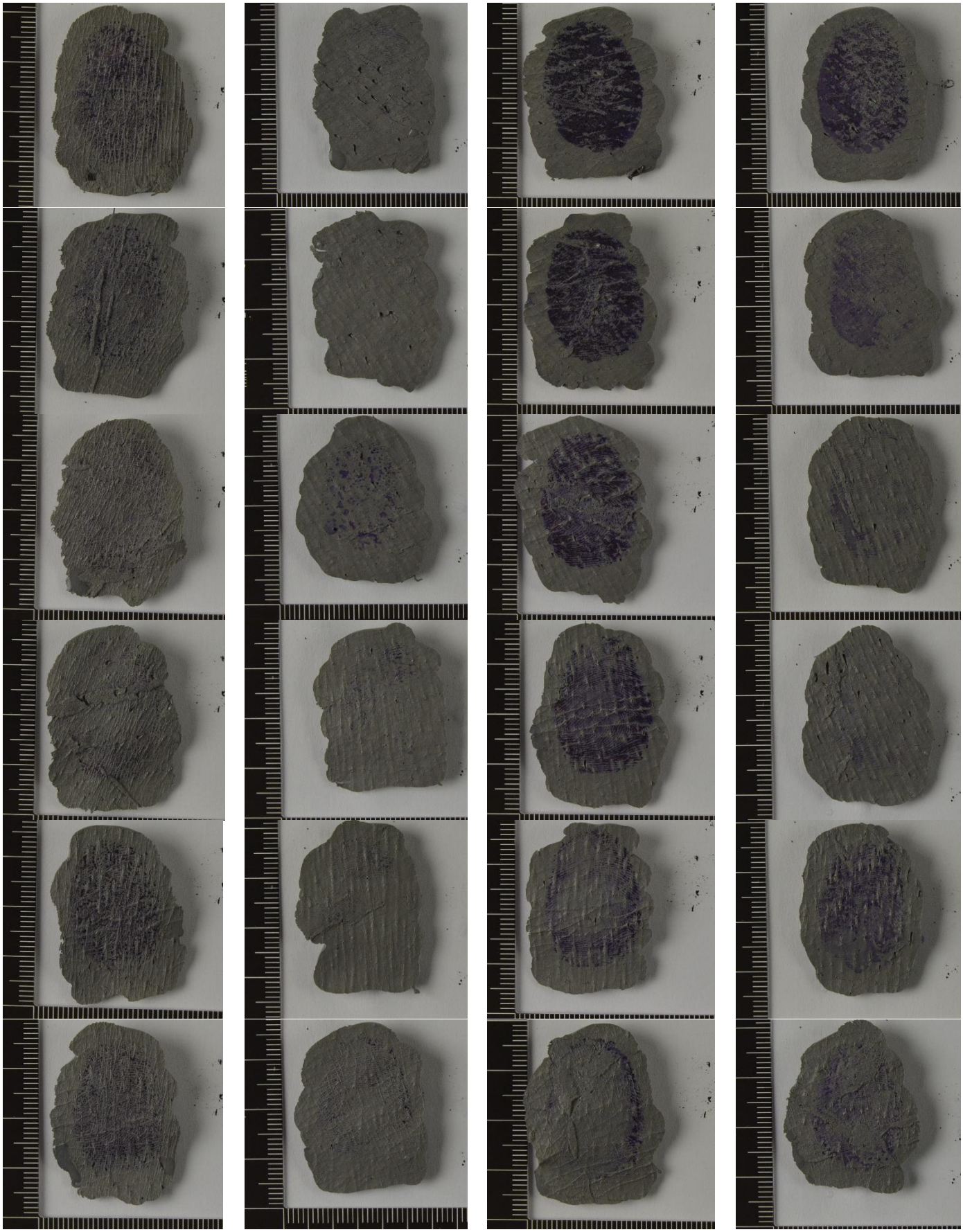


Washed skin (green soap)
20 minutes

2 hours

Washed skin (ethanol)
20 minutes

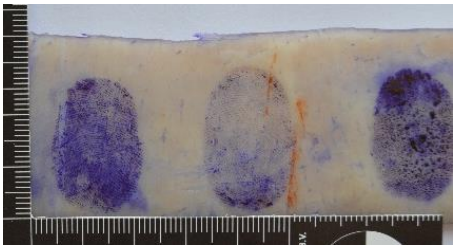
2 hours

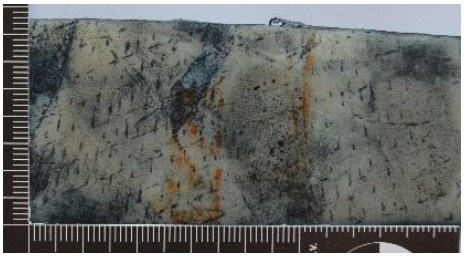


Blood enhancement on directly applied to skin

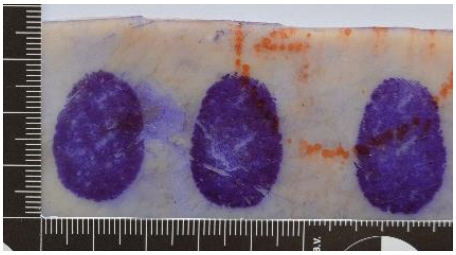
ALCV | **Hungarian Red** | **Amido Black**

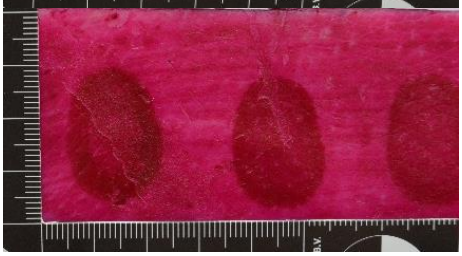
Not washed

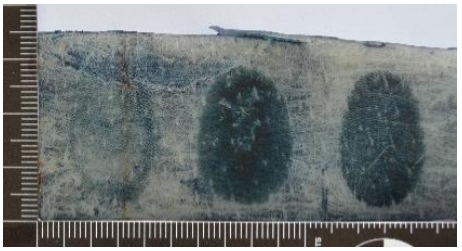




Washed (GS + ethanol)

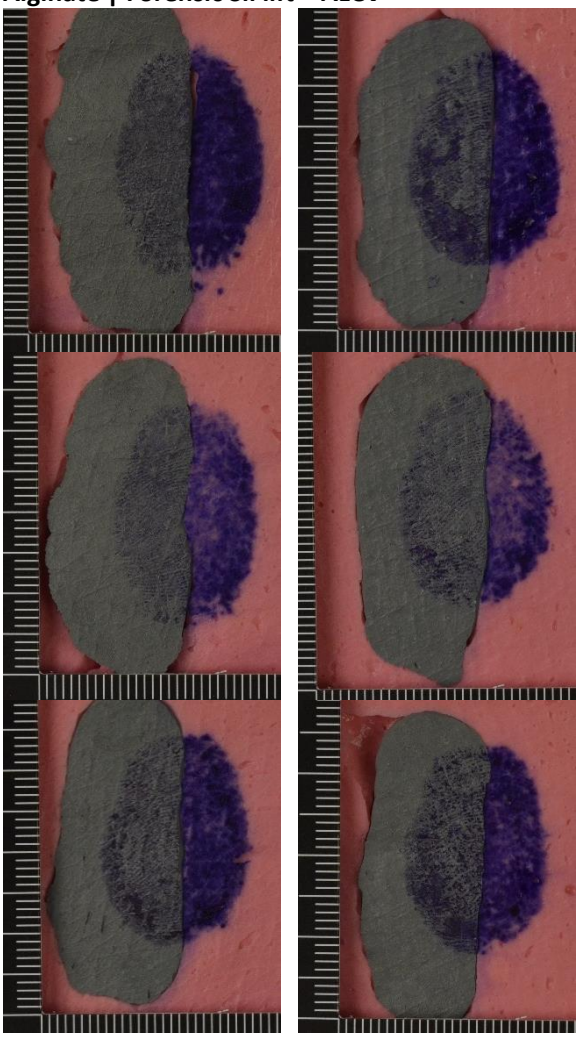




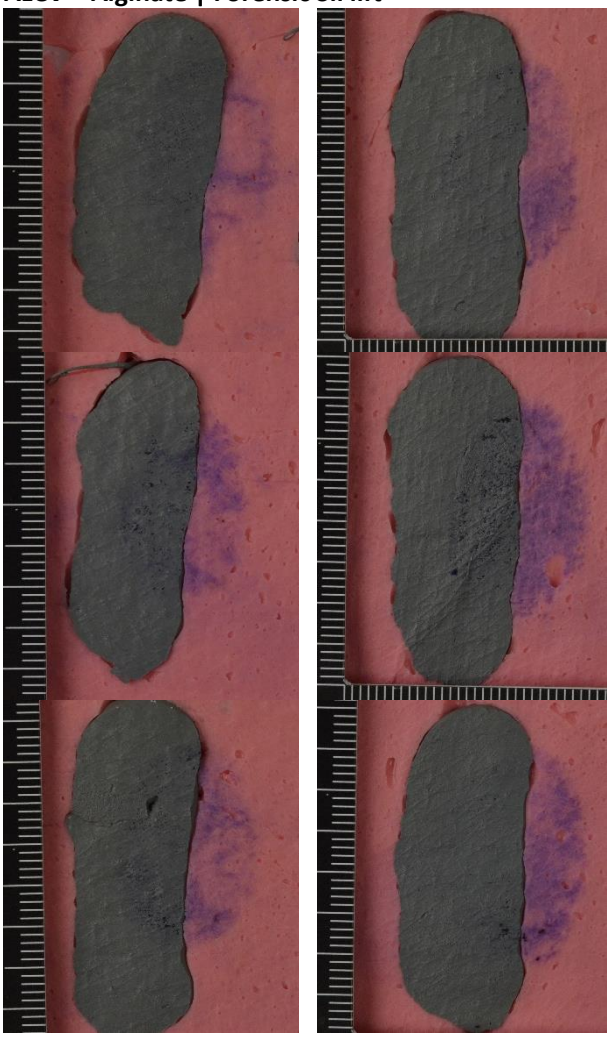


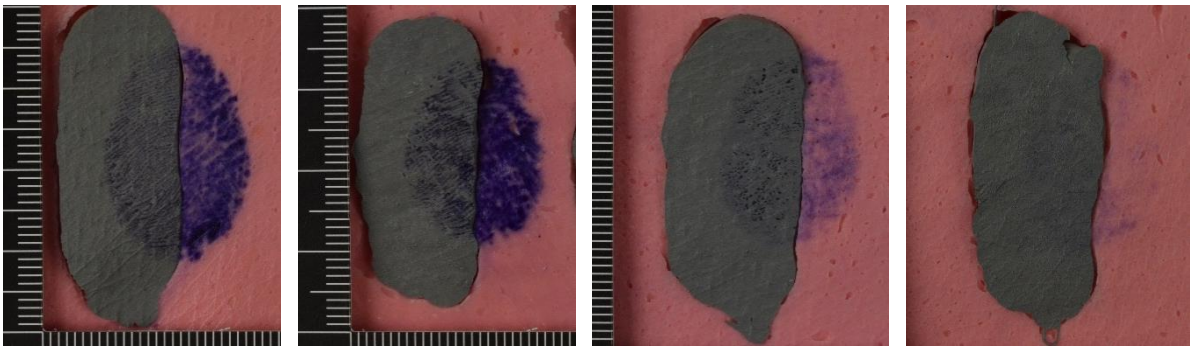
Sequence of lift and enhancement

Alginate | Forensic Sil lift > ALCV



ALCV > Alginate | Forensic Sil lift

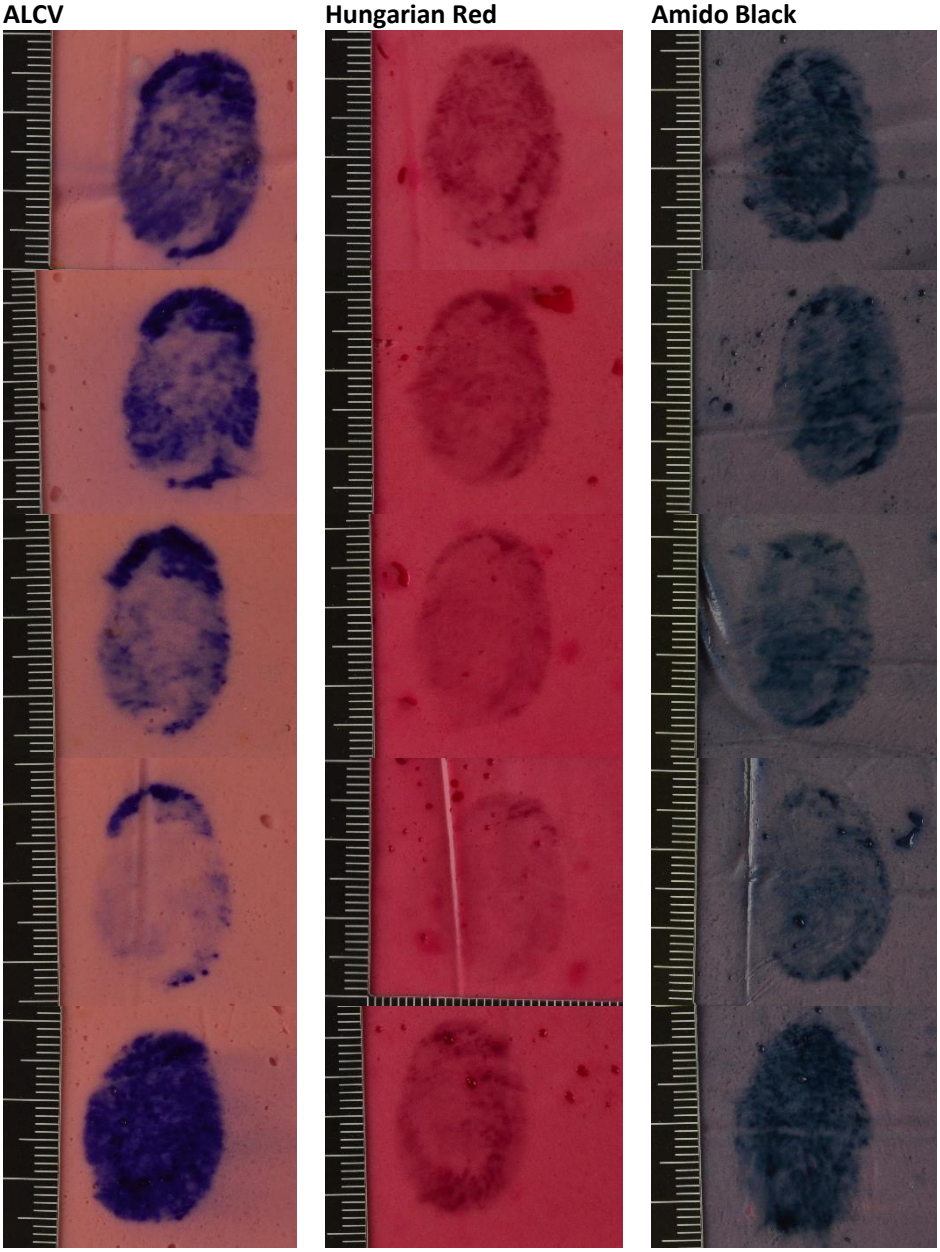


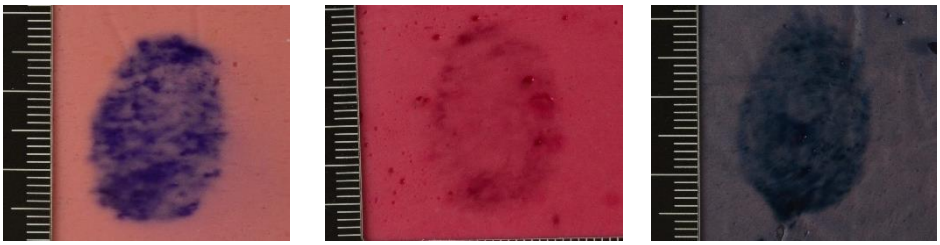


Lifting with alginate

Lift followed by enhancement

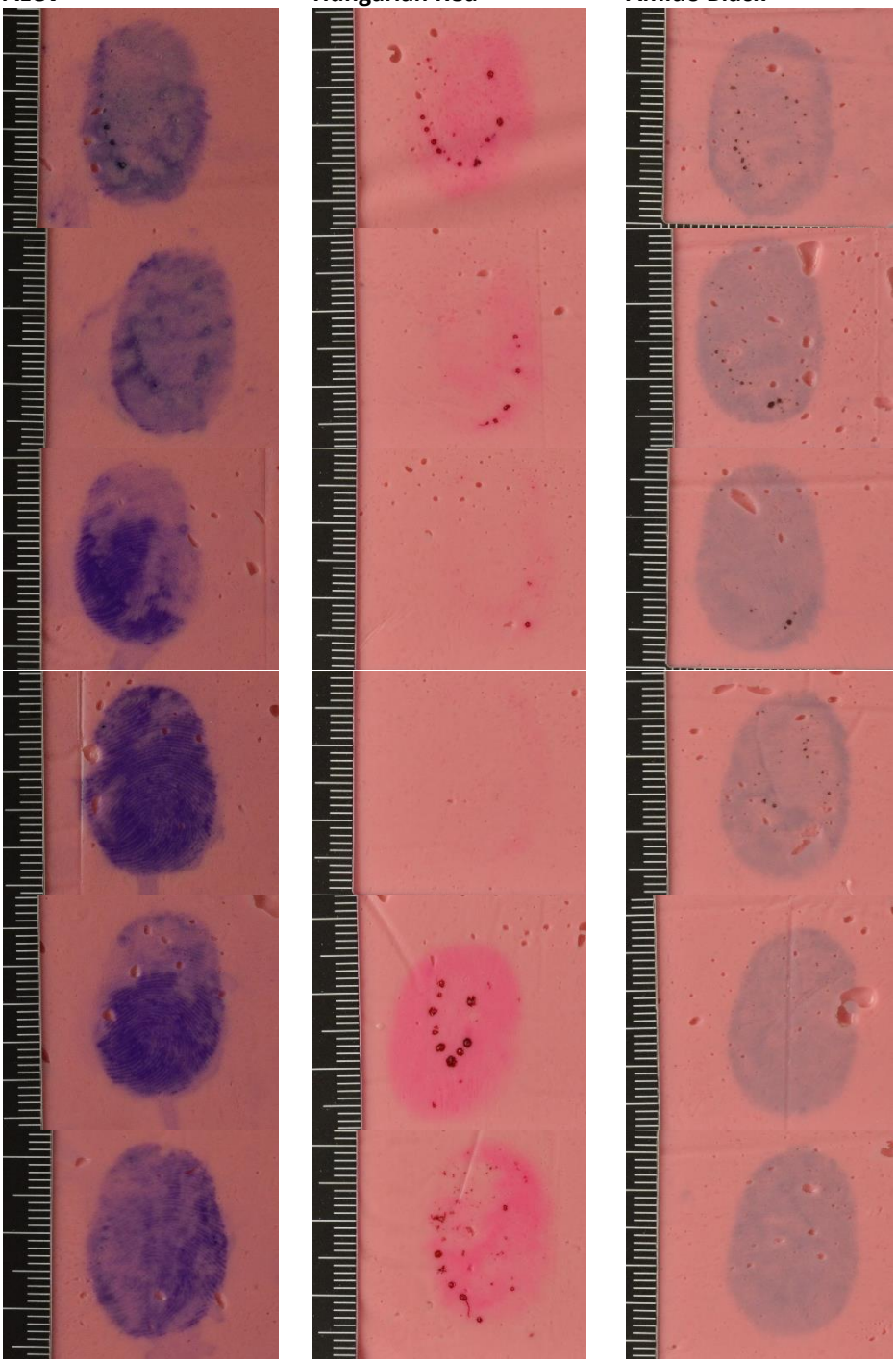
ALCV **Hungarian Red** **Amido Black**



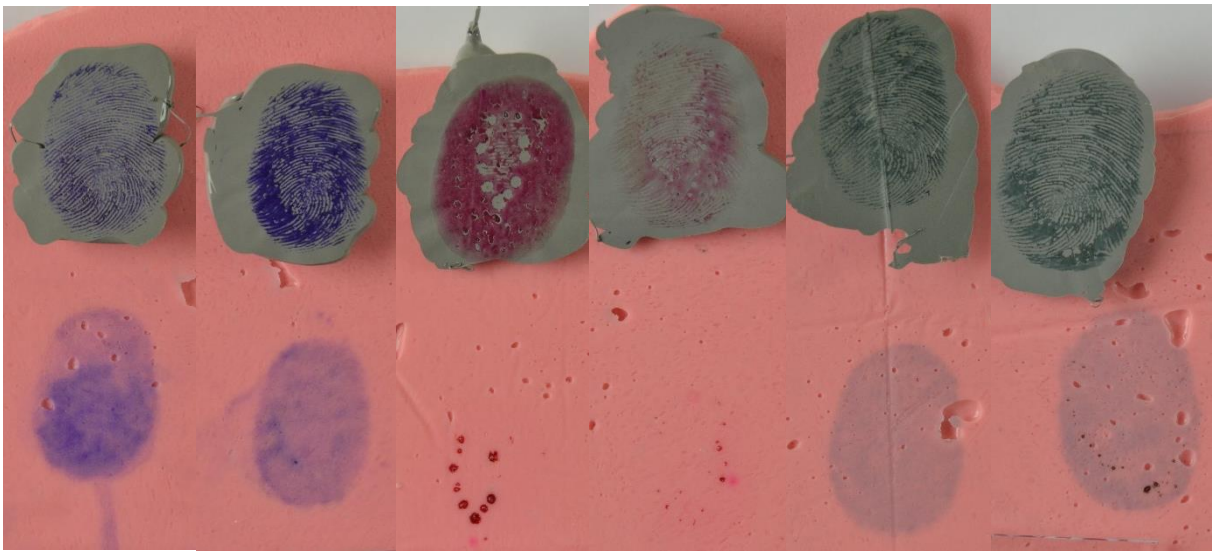


Enhancement followed by lift

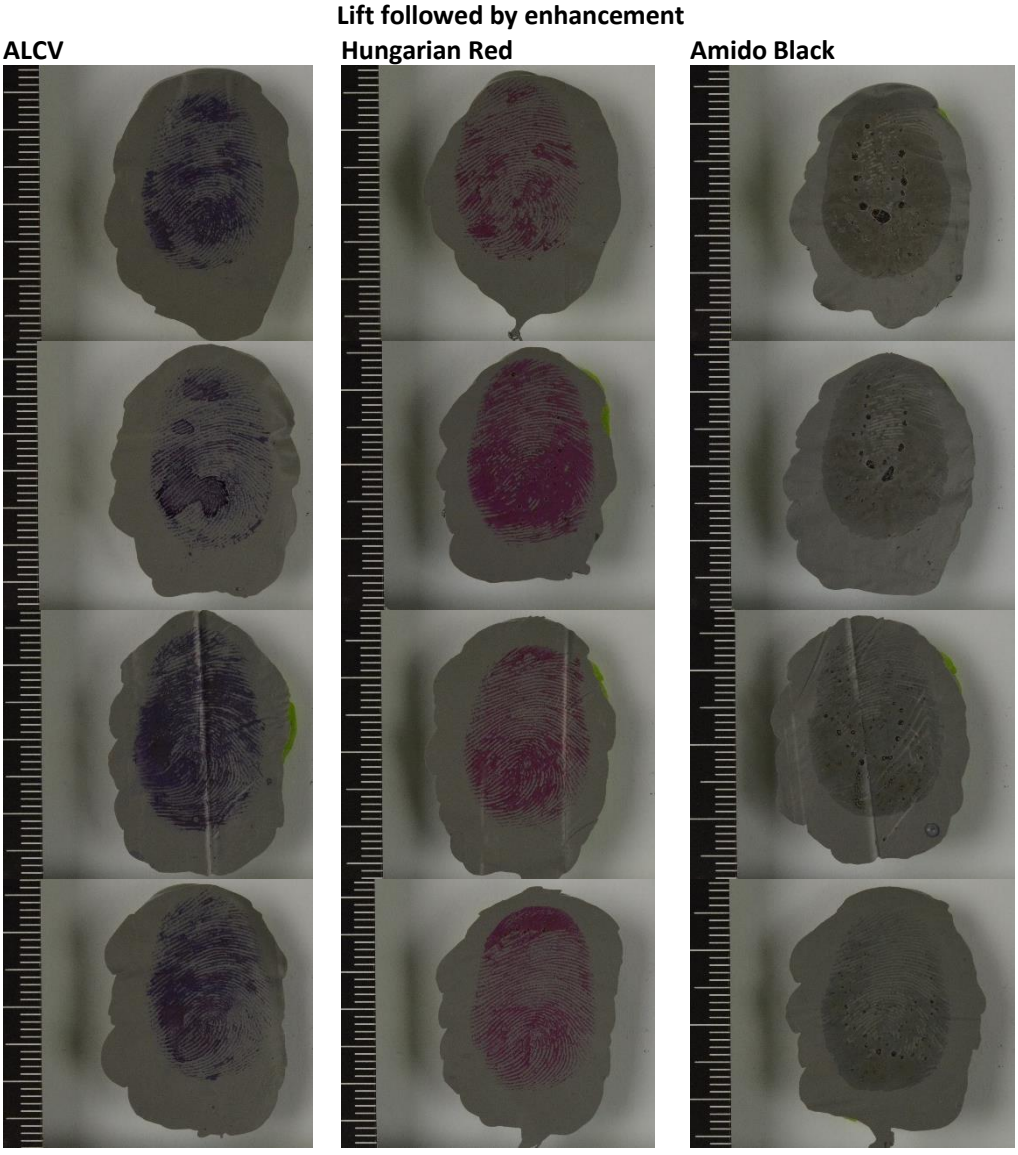
ALCV **Hungarian Red** **Amido Black**

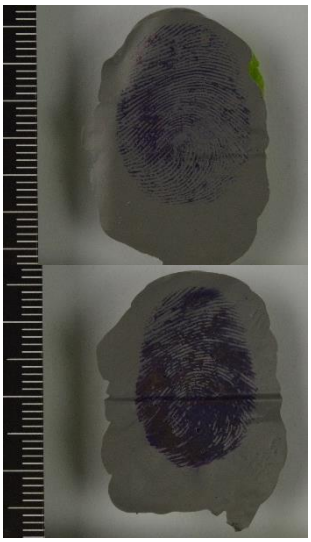


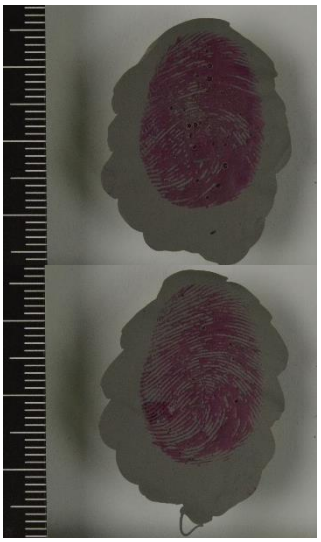
Additional: Forensic Sil lift versus alginate lift (enhancement > lift)

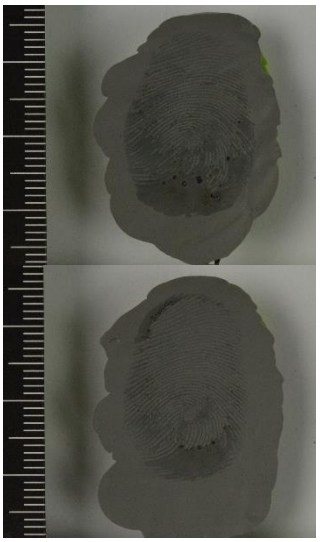


Lifting with Forensic Sil



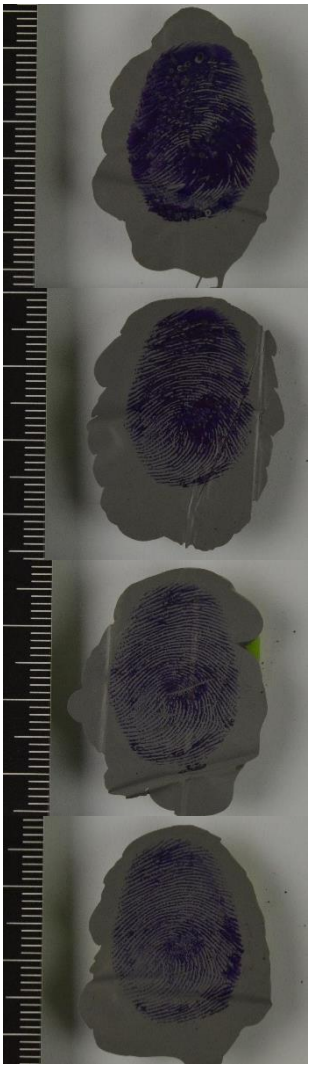


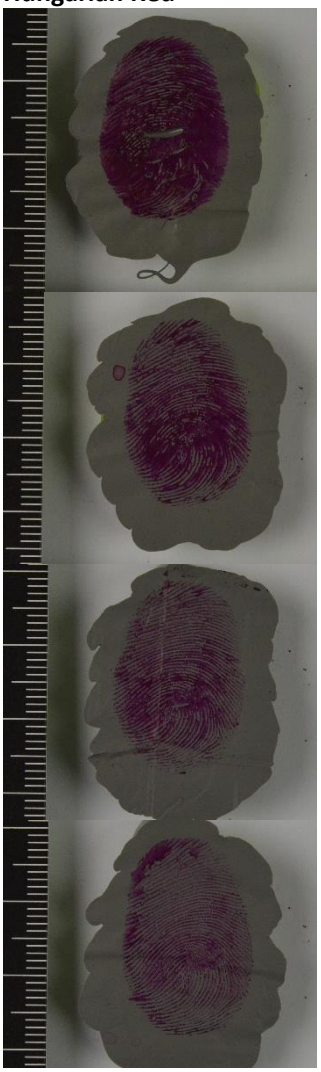


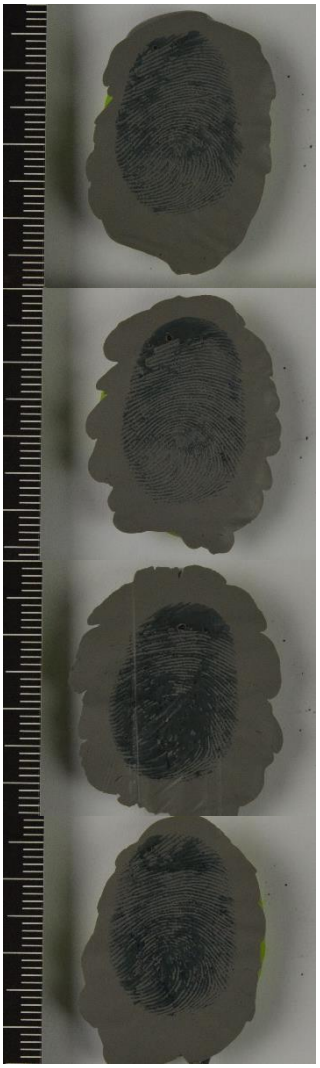


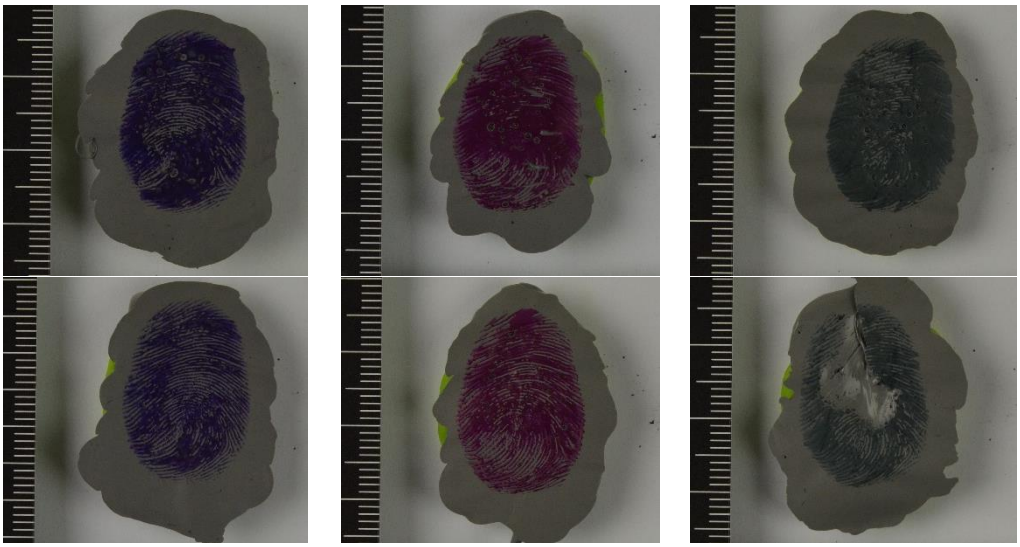
Enhancement followed by lift

ALCV **Hungarian Red** **Amido Black**





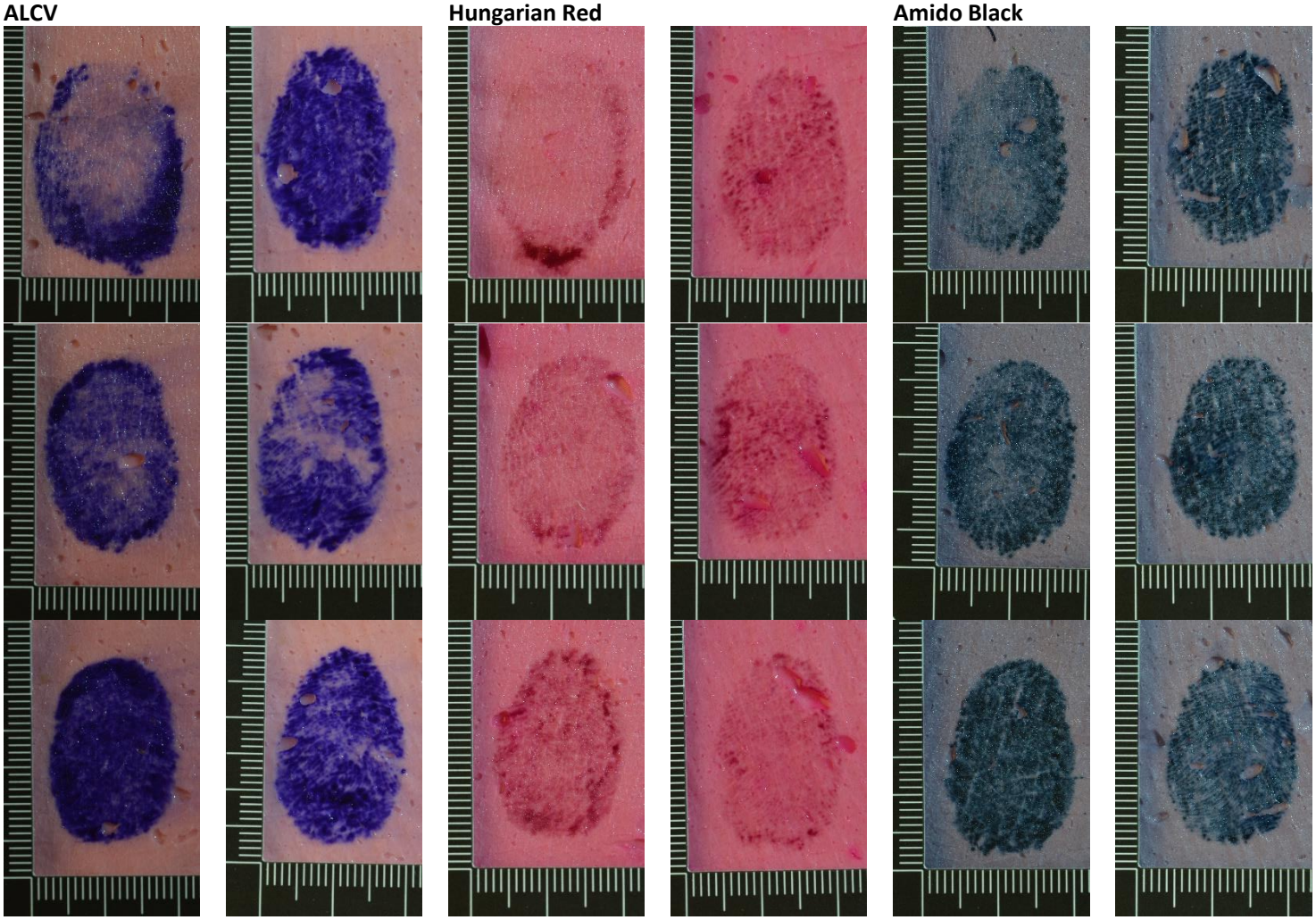


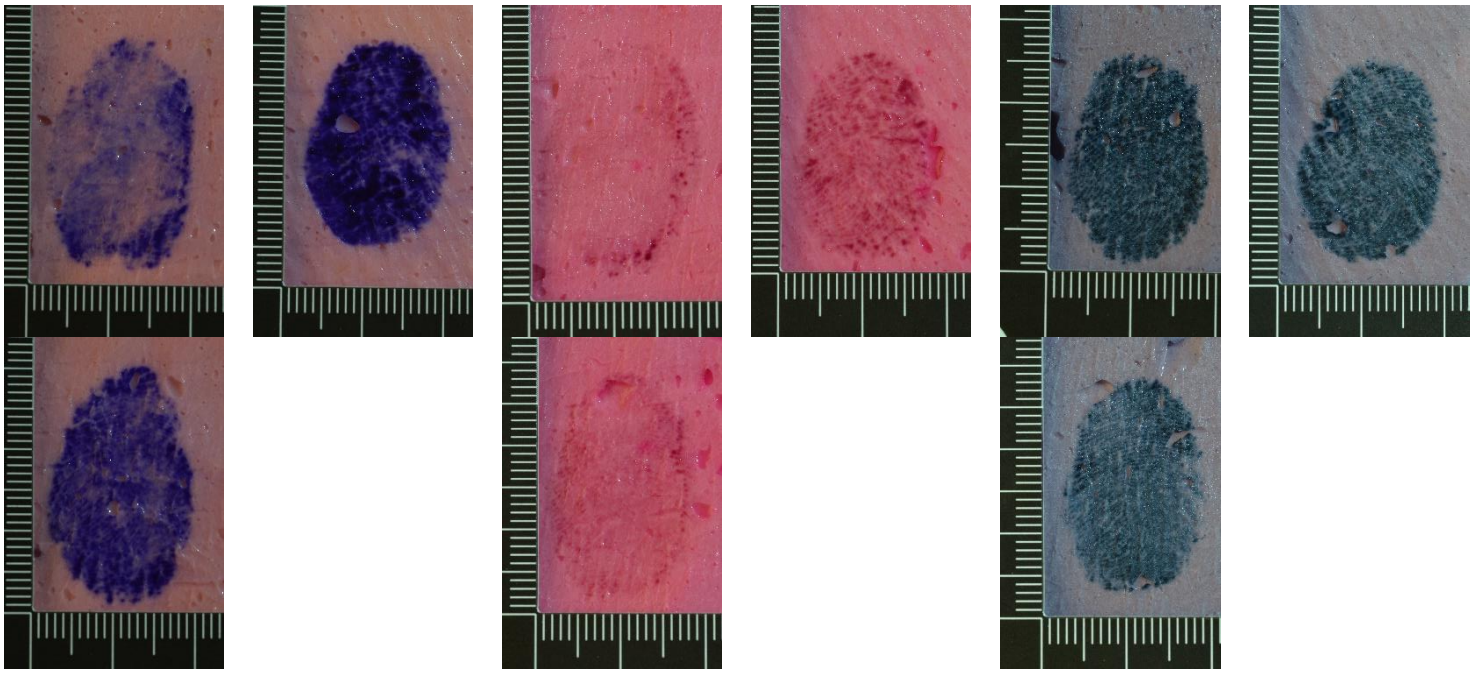


Main research

Donor 1 - alginate

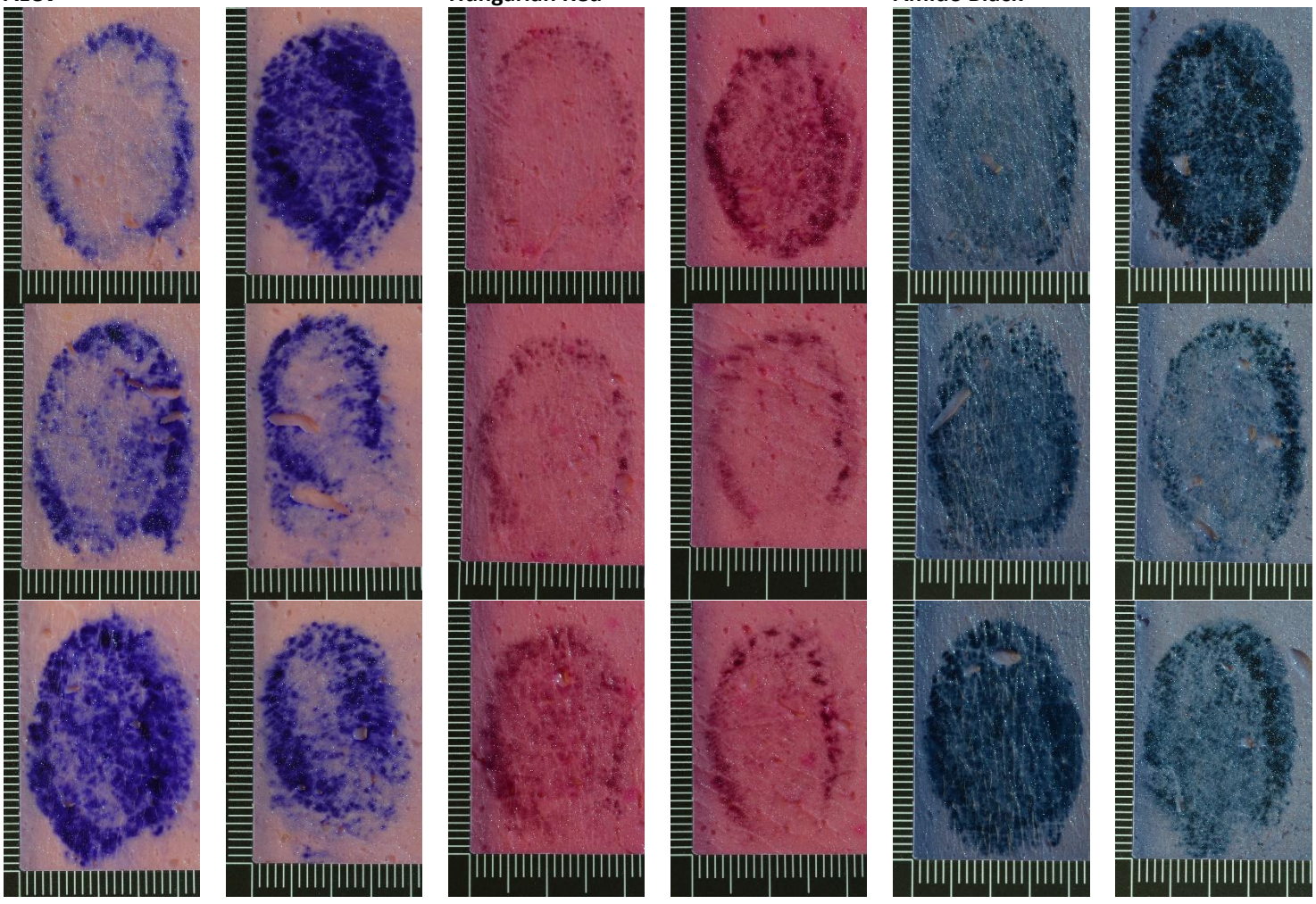
ALCV **Hungarian Red** **Amido Black**

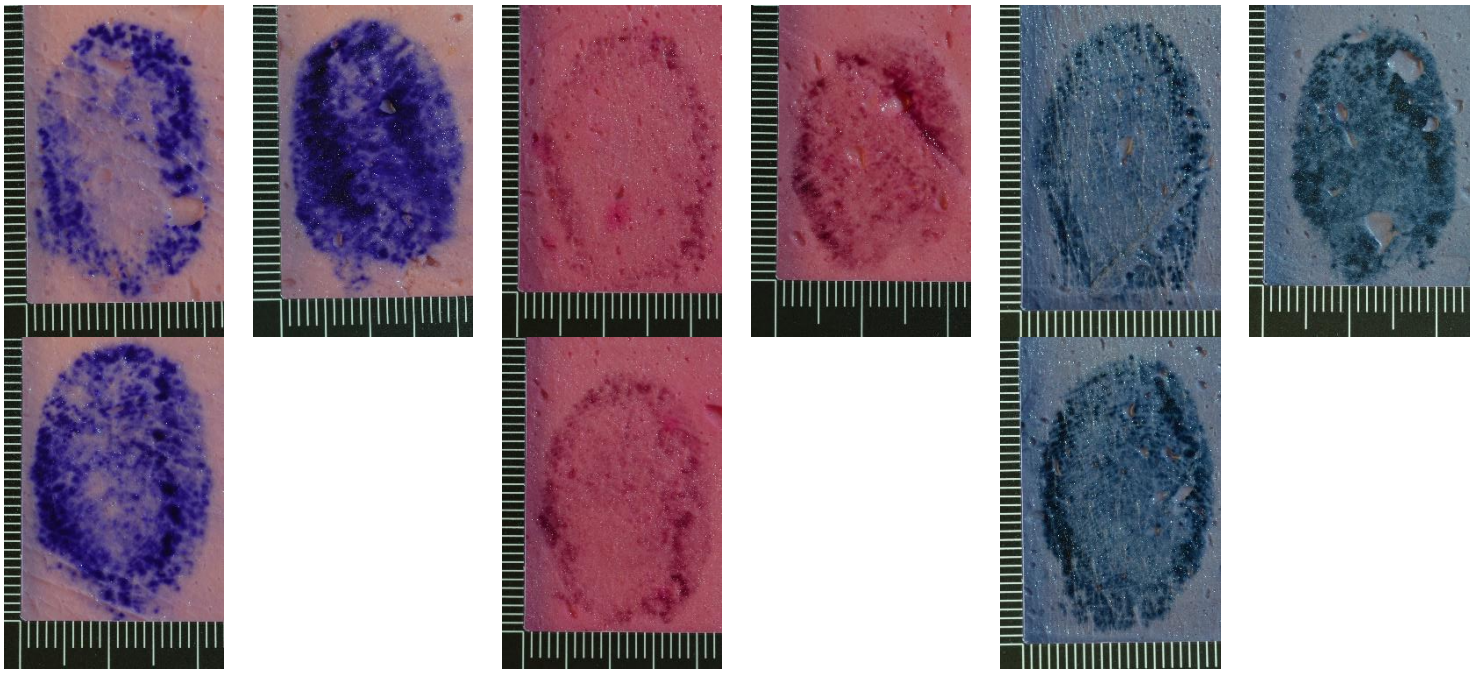




Donor 2 - alginate

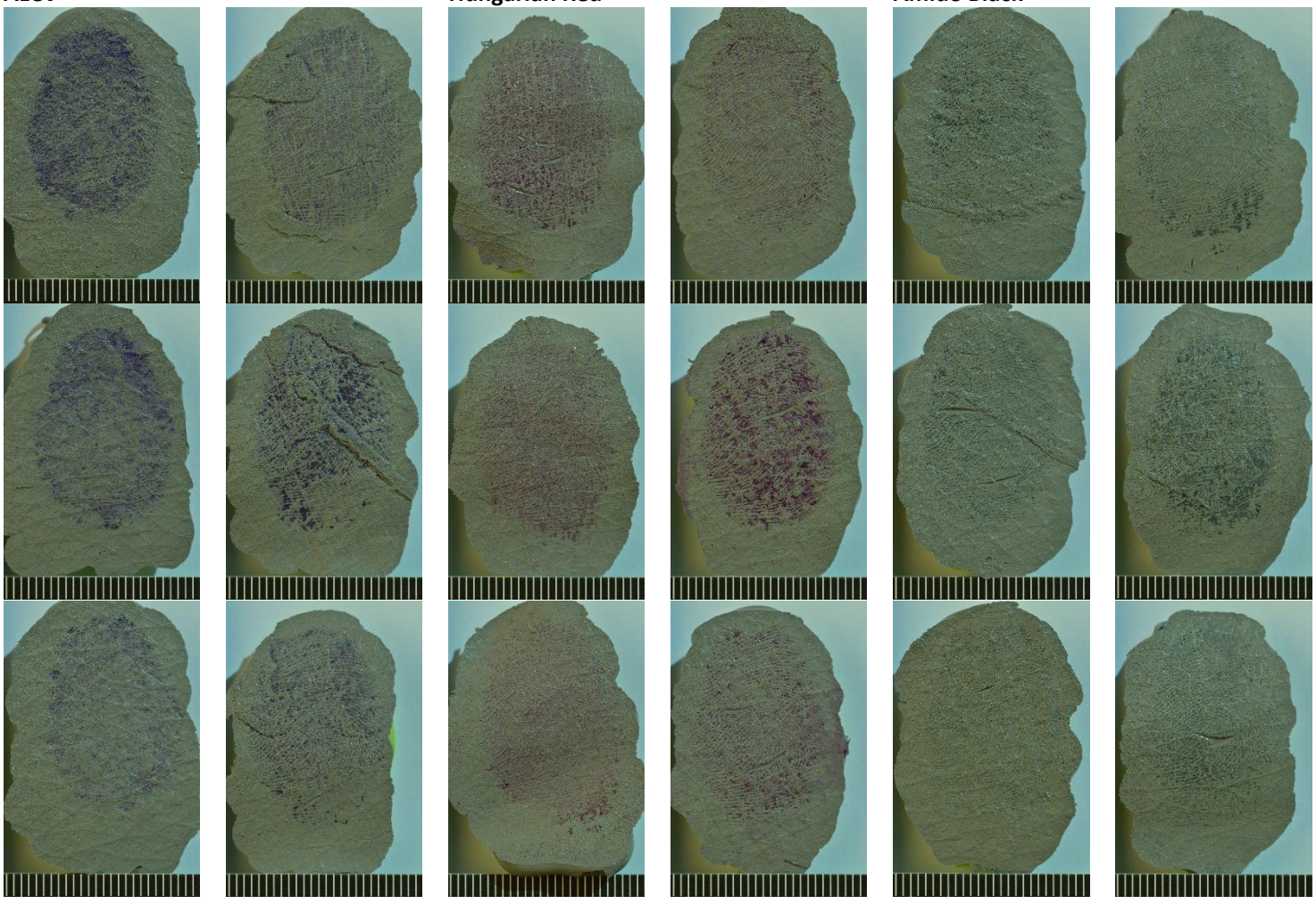
ALCV **Hungarian Red** **Amido Black**

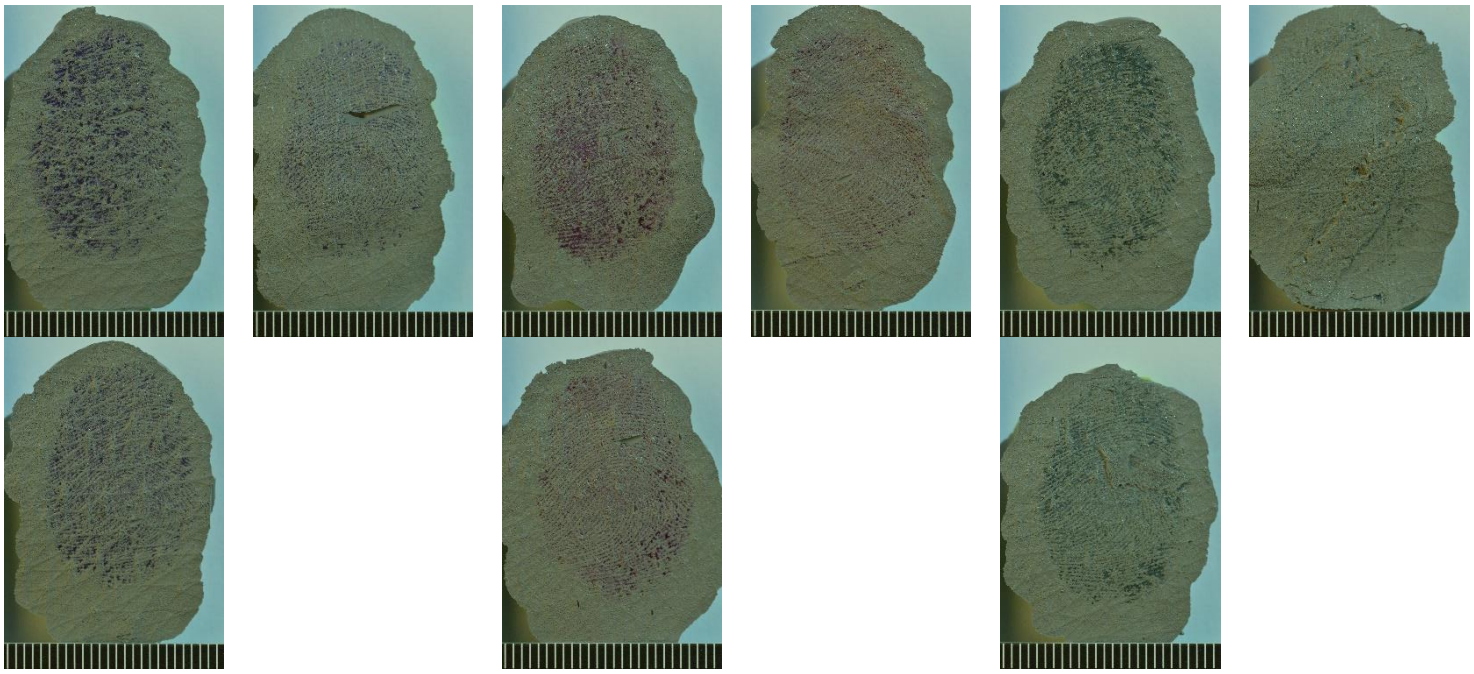




Donor 1 – Forensic Sil

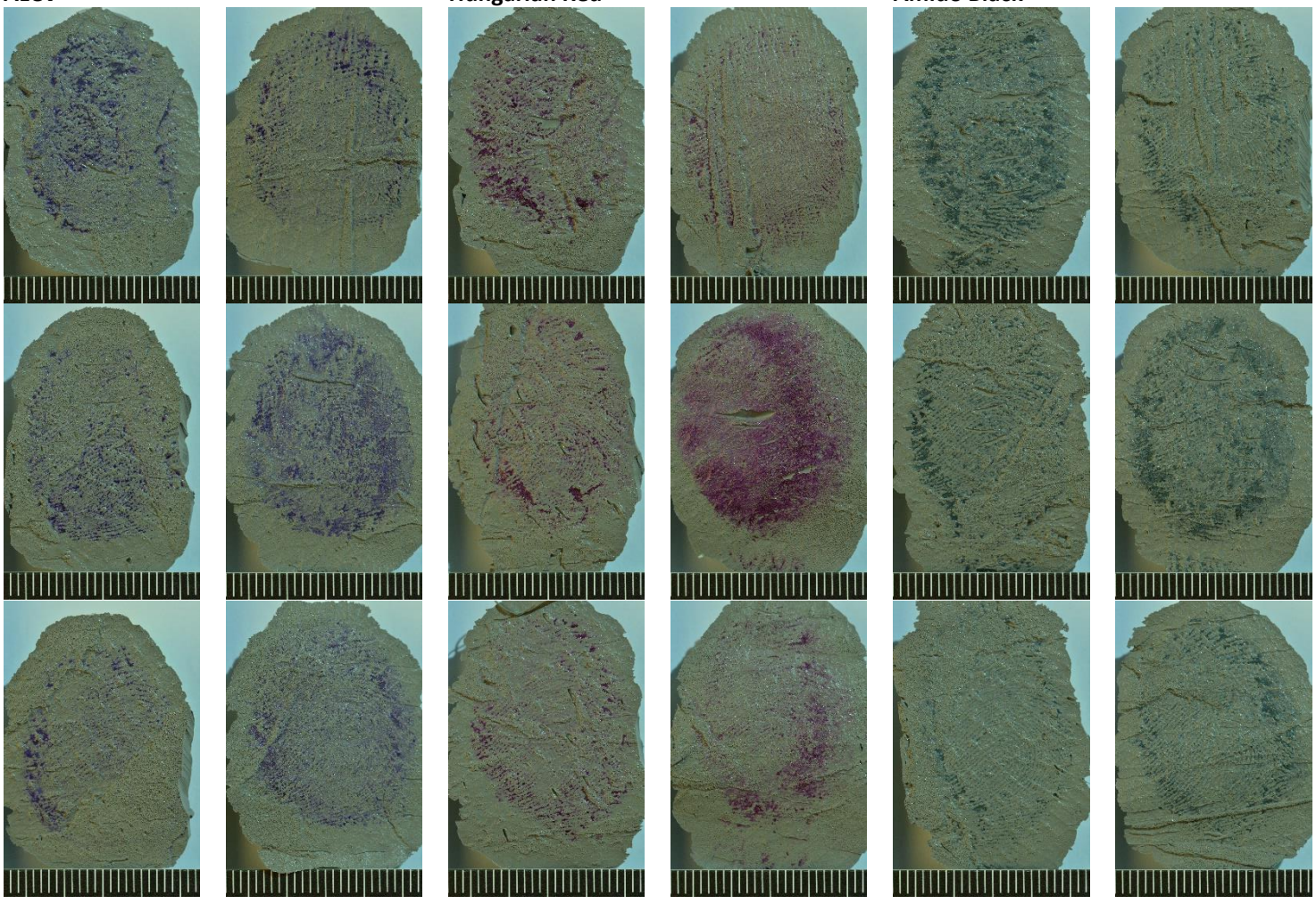
ALCV **Hungarian Red** **Amido Black**

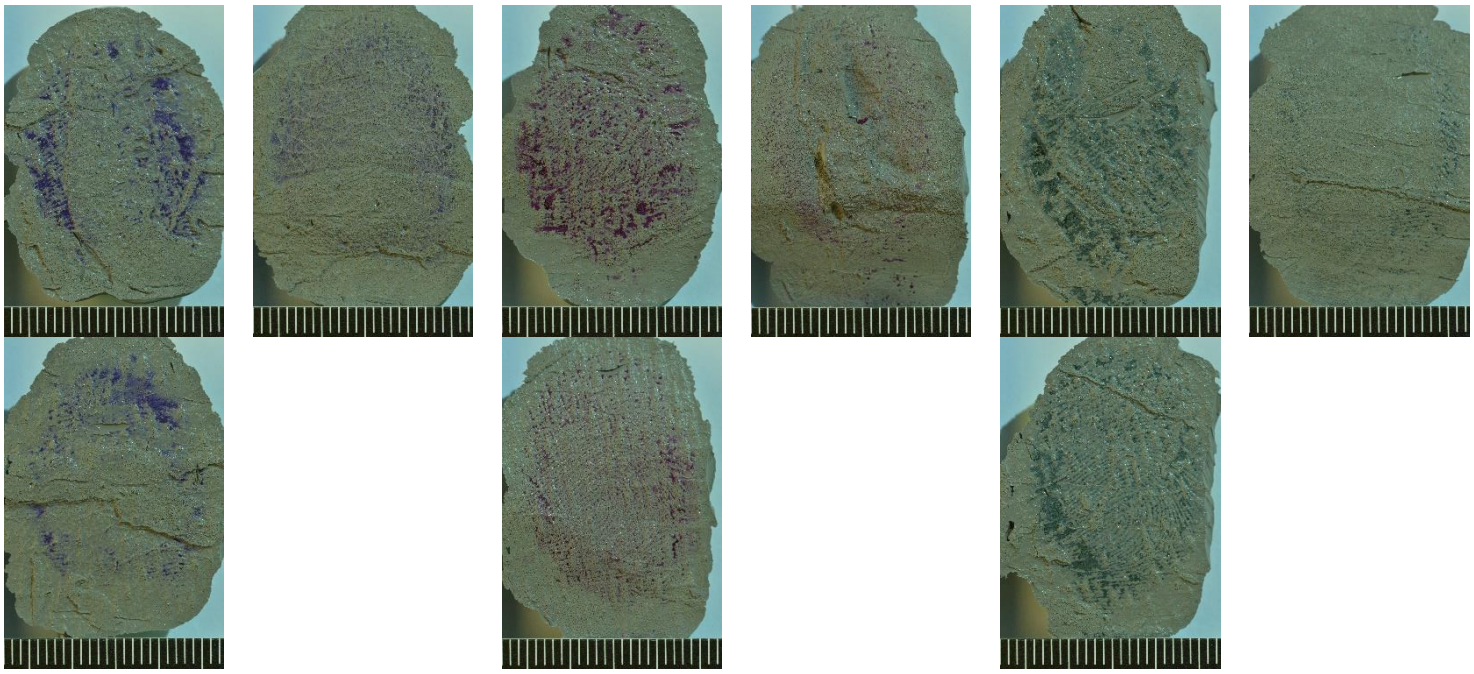




Donor 2 – Forensic Sil

ALCV **Hungarian Red** **Amido Black**





Donor 3 & 4

A selection of results obtained from donor 3 and 4 are presented in this appendix. Other photographs are stored externally and can be requested.

Donor 3
Alginate

Forensic Sil

Donor 4
Forensic Sil

Appendix III

The reference fingerprints taken and photographed from all donors (4) are presented. These photographs have been used by the fingerprint examiner for professional fingerprint identification. Additional results of fingerprint identification to the results shown in chapter 5 ‘Results’ are also given.

Reference fingerprints

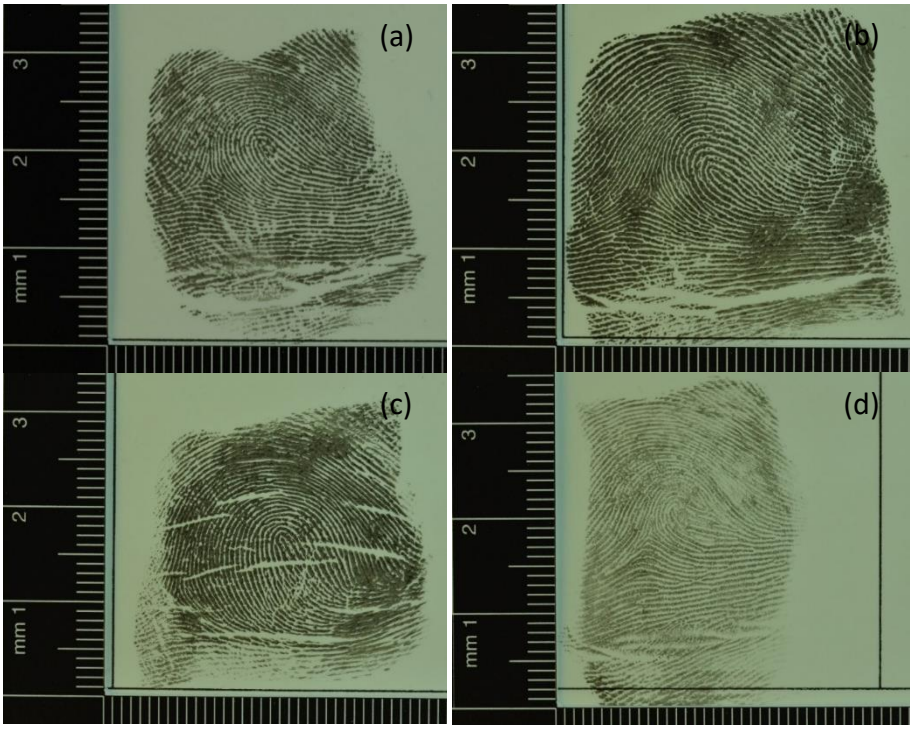


Figure 32 *Reference fingerprints (a) donor 1 (b) donor 2 (c) donor 3 (d) donor 4.*

Fingerprint identification results

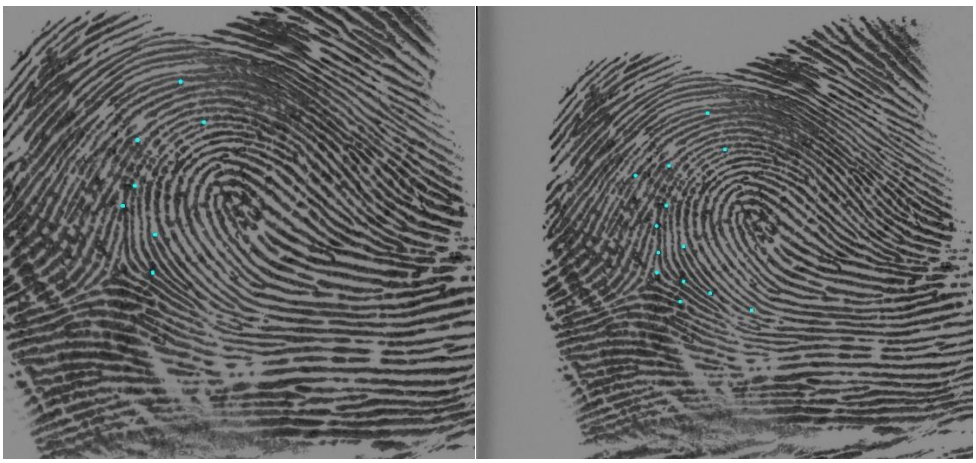


Figure 33 *Reference print 1 (left, corresponding to alginate lift) and 2 (right, corresponding to Forensic Sil lift).*

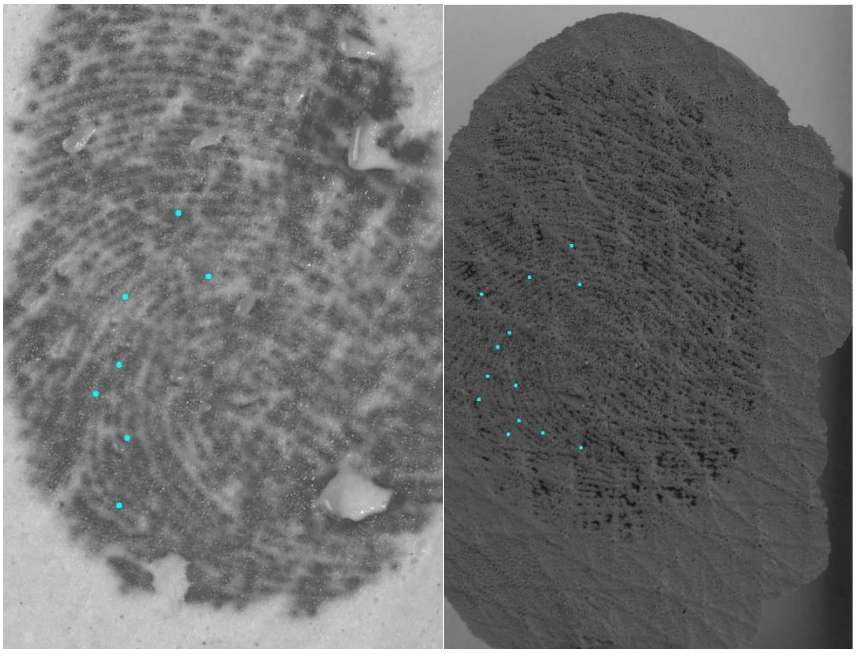
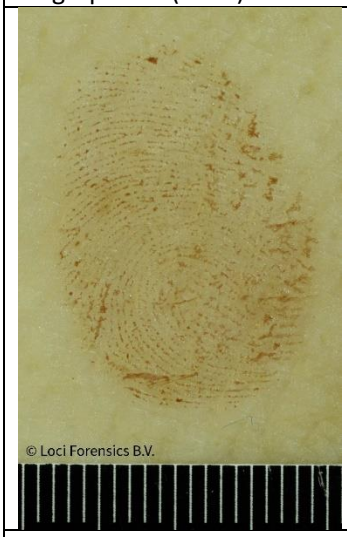
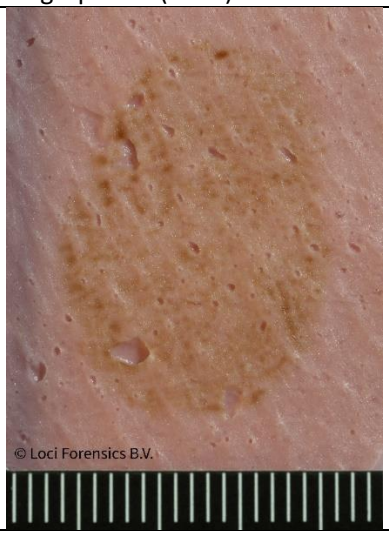
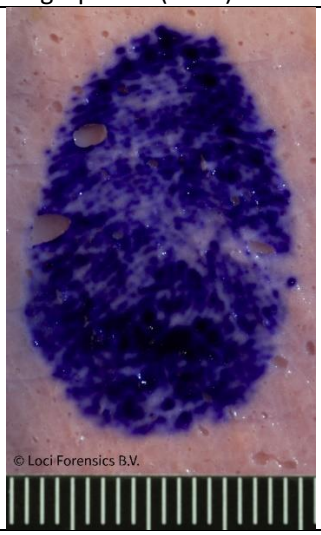
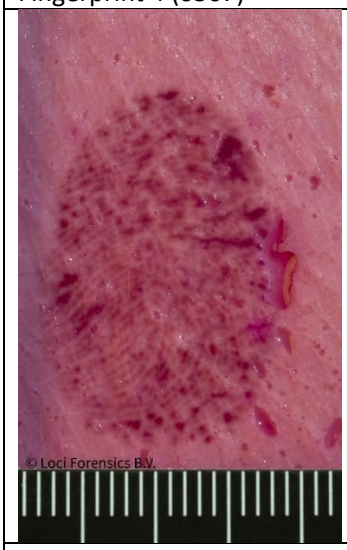


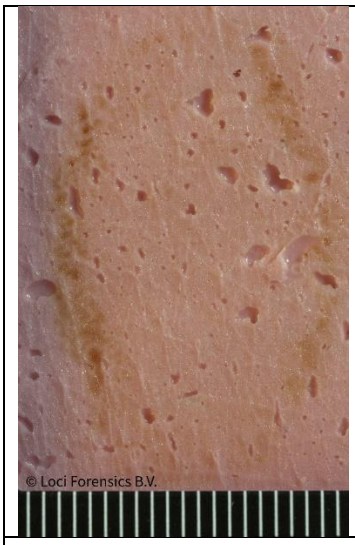
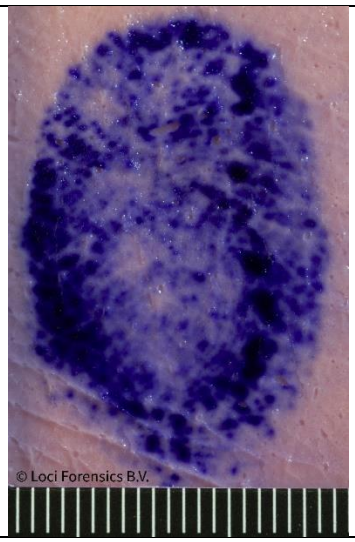
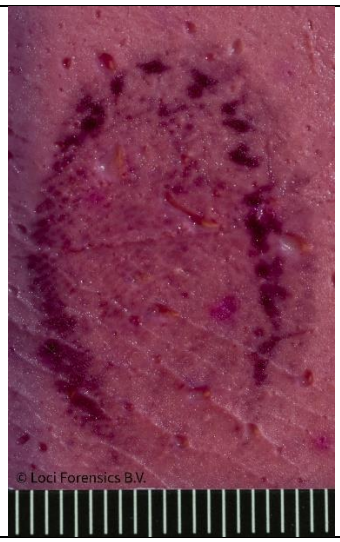
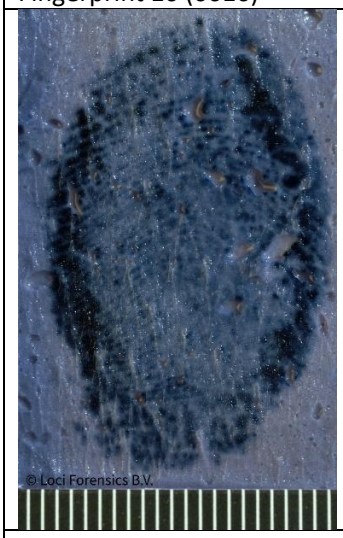
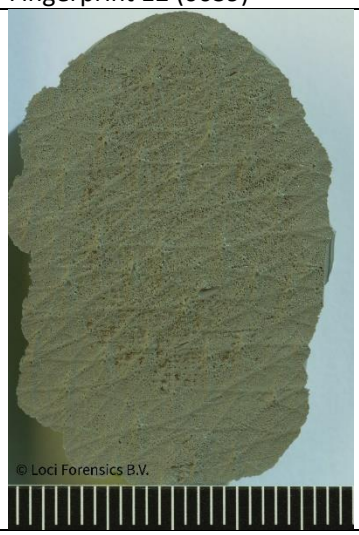
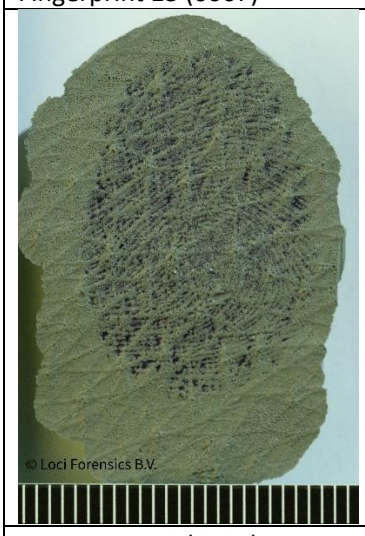
Figure 34 *Comparison fingerprint 1 (left, corresponding to reference print 1) and fingerprint 2 (right, corresponding to reference print 2).*

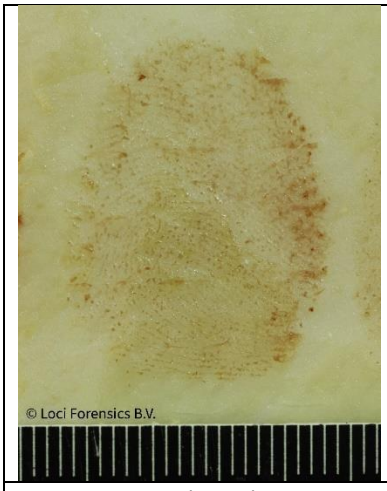
Appendix IV

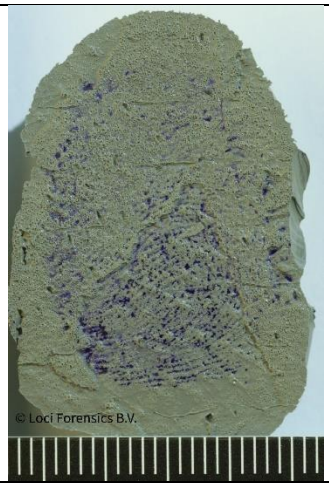
This appendix includes all results (photos, data) obtained from fingerprint grading, including the results that have been omitted in chapter 5 ‘Results’.

Photos fingerprint grading form

Fingerprint 1 (0445)	Fingerprint 2 (0516)	Fingerprint 3 (0477)
		
Fingerprint 4 (0507)	Fingerprint 5 (0531)	Fingerprint 6 (0558)
		
Fingerprint 7 (0606)	Fingerprint 8 (0578)	Fingerprint 9 (0600)

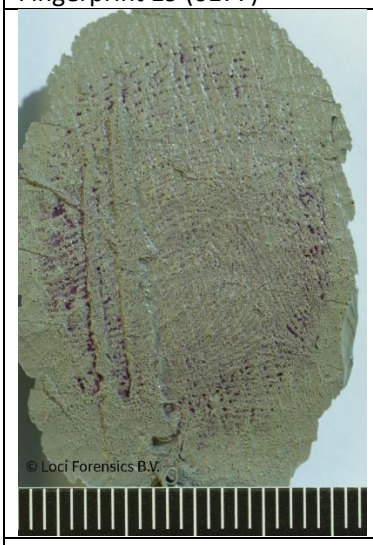
		
Fingerprint 10 (0616)	Fingerprint 11 (0005)	Fingerprint 12 (0039)
		
Fingerprint 13 (0067)	Fingerprint 14 (0076)	Fingerprint 15 (0084)
		
Fingerprint 16 (0105)	Fingerprint 17 (0134)	Fingerprint 18 (0163)



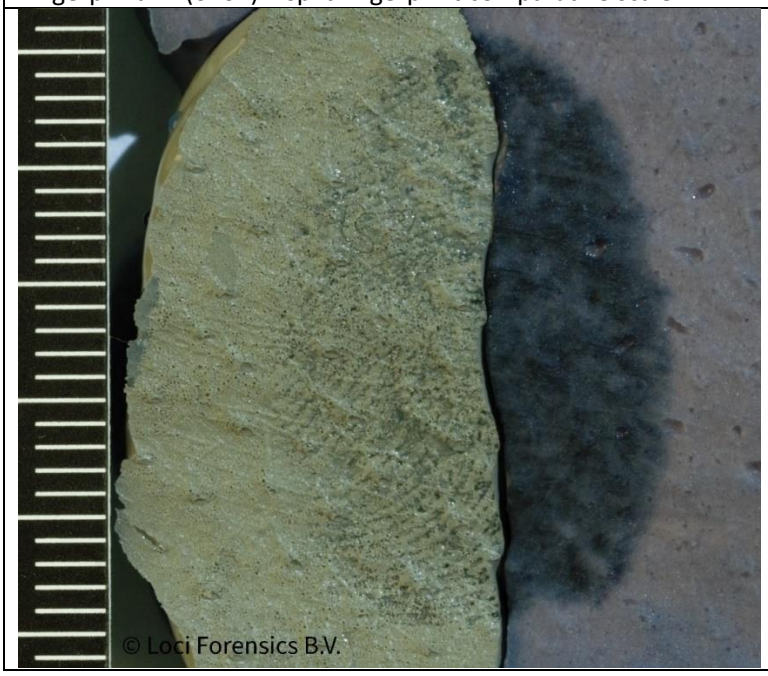


Fingerprint 19 (0177)

Fingerprint 20 (0185)



Fingerprint 21 (0404) – split fingerprint comparative scale



Raw data fingerprint grading

Fingerprint grading: granted scores to fingerprints per student						
Photo nr.	FP number	Student 1 (C)	Student 2 (M)	Student 3 (L)	Student 4 (H)	Student 5 (K)
445	FP 1	3	3	2	4	3
516	FP 2	1	1	1	0	0
477	FP 3	1	1	1	1	1
507	FP 4	2	2	2	3	2
531	FP 5	2	3	2	3	3
558	FP 6	1	2	2	2	2
606	FP 7	0	0	0	0	0
578	FP 8	1	0	1	1	0
600	FP 9	1	1	1	2	2
616	FP 10	1	2	1	3	3
5	FP 11	2	3	2	2	4
39	FP 12	0	2	1	1	1
67	FP 13	2	3	3	4	3
76	FP 14	3	4	3	4	4
84	FP 15	2	3	3	3	3
105	FP 16	2	2	2	2	2
134	FP 17	0	0	0	0	0
163	FP 18	1	1	1	2	2
177	FP 19	1	3	2	3	2
185	FP 20	2	2	2	2	3
404	FP 21	+2	+2	+2	+2	+2

Frequency table

	Data fingerprint grading		*Frequency table (amount of times the score is granted per fingerprint)*				
FP nr.	*Phase*	Photo	**Score 0**	**Score 1**	**Score 2**	**Score 3**	**Score 4**
1	*original*	445	0	0	1	3	1
2	*alginate*	516	2	3	0	0	0
3	*alginate e*	477	0	5	0	0	0
4	*alginate e*	507	0	0	4	1	0
5	*alginate e*	531	0	0	2	3	0
6	*original*	558	0	1	4	0	0
7	*alginate*	606	5	0	0	0	0
8	*alginate e*	578	2	3	0	0	0
9	*alginate e*	600	1	2	2	0	0
10	*alginate e*	616	0	2	1	2	0
11	*original*	5	0	0	3	1	1
12	*FS*	39	1	3	1	0	0
13	*FS e*	67	0	0	1	3	1
14	*FS e*	76	0	0	0	2	3
15	*FS e*	84	0	0	1	4	0
16	*original*	105	0	0	5	0	0
17	*FS*	134	5	0	0	0	0
18	*FS e*	163	0	3	2	0	0
19	*FS e*	177	0	1	2	2	0
20	*FS e*	185	0	0	4	1	0
			Score -2	**Score -1**	**Score 0**	**Score +1**	**Score +2**
21	*Alg | FS*	404	0	0	0	0	5

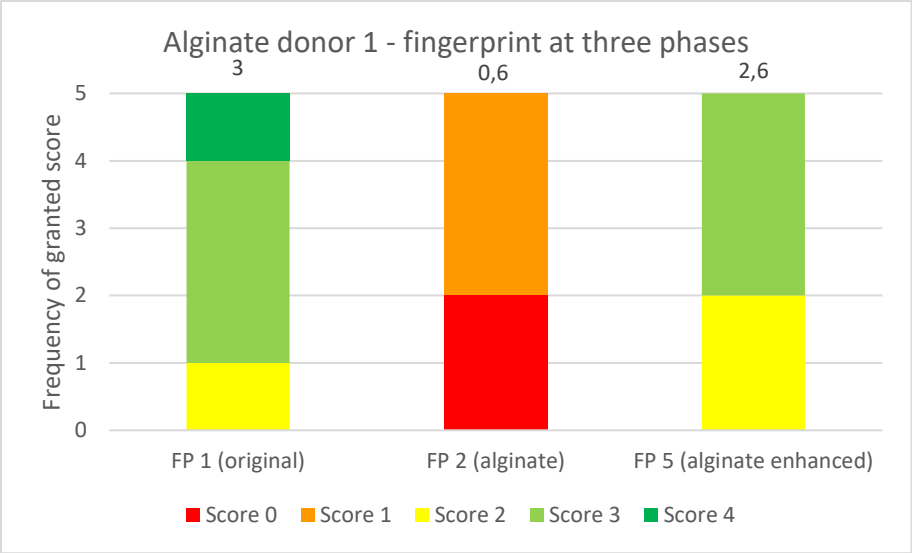
Data processing Excel

Frequency table of alginate grading for donor 1 and 2

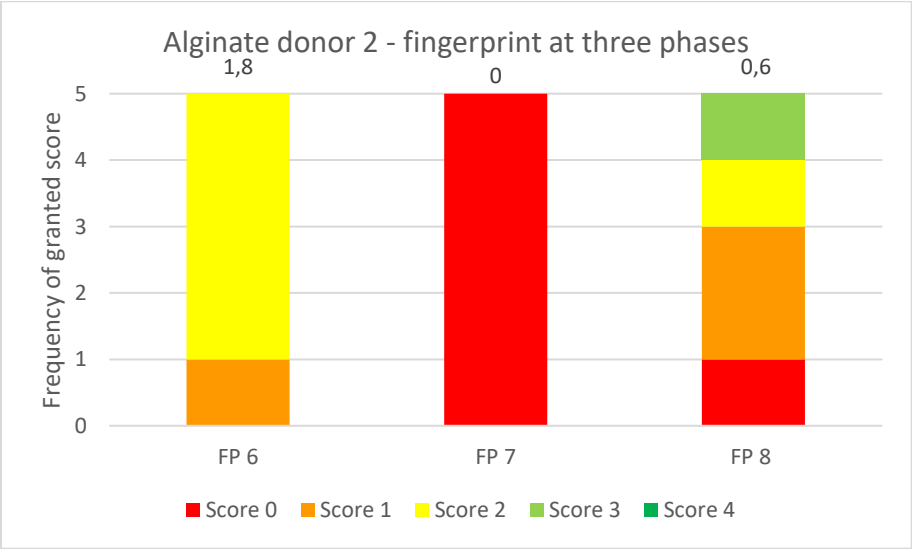
Table 19 Alginate *Frequency table of fingerprint grading data: frequencies of granted scores per fingerprint and phase of 2 donors.*

	Alginate					
		Score 0	Score 1	Score 2	Score 3	Score 4
Donor 1	FP 1 (original)	0	0	1	3	1
	FP 2 (alginate)	2	3	0	0	0
	FP 5 (alginate enhanced)	0	0	2	3	0
Donor 2	FP 6 (original)	0	1	4	0	0
	FP 7 (alginate)	5	0	0	0	0
	FP 8 (alginate enhanced)	1	2	1	1	0

Graphs of score frequency per fingerprint and phase



Graph 5 *Fingerprint grading data donor 1: comparison of an original fingerprint (FP1) to the fingerprint lifted with alginate (FP2) and the enhanced alginate lift (FP5) (average score above bars).*



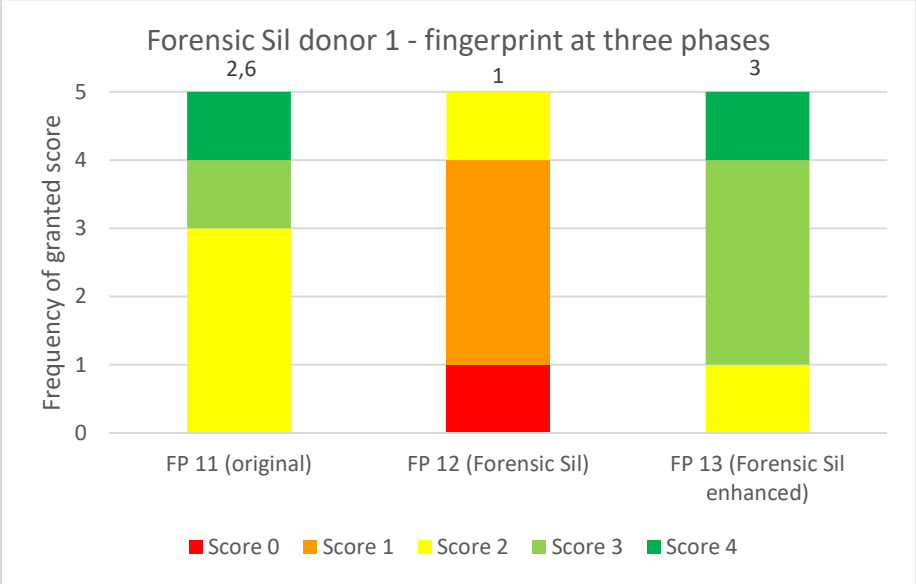
Graph 6 *Fingerprint grading data donor 2: comparison of an original fingerprint (FP6) to the fingerprint lifted with alginate (FP7) and the enhanced alginate lift (FP8) (average score above bars).*

Frequency table of Forensic Sil grading for donor 1 and 2

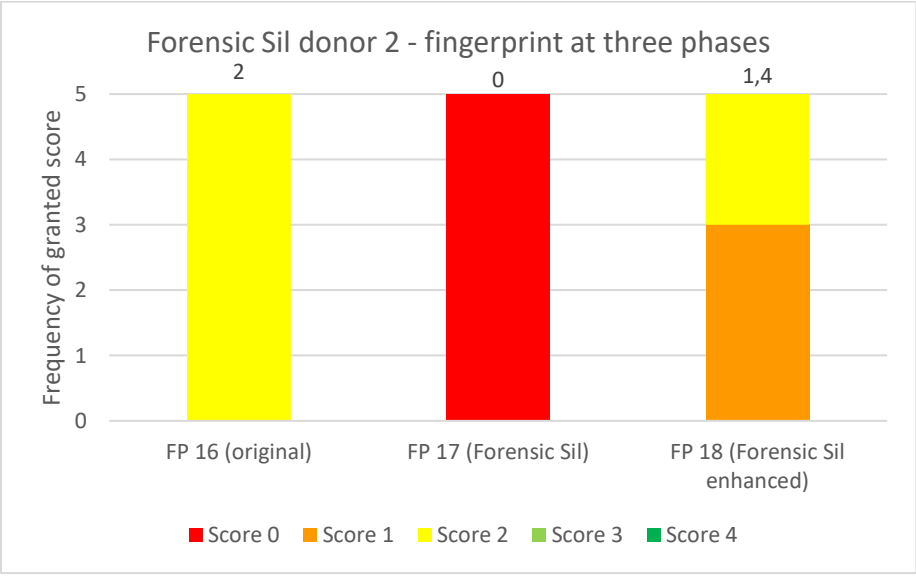
Table 20 Forensic Sil *Frequency table of fingerprint grading data: frequencies of granted scores per fingerprint and phase of 2 donors.*

	Forensic Sil					
		Score 0	Score 1	Score 2	Score 3	Score 4
Donor 1	FP 11 (original)	0	0	3	1	1
	FP 12 (Forensic Sil)	1	3	1	0	0
	FP 13 (Forensic Sil enhanced)	0	0	1	3	1
Donor 2	FP 16 (original)	0	0	5	0	0
	FP 17 (Forensic Sil)	5	0	0	0	0
	FP 18 (Forensic Sil enhanced)	0	3	2	0	0

Graphs of score frequency per fingerprint and phase



Graph 7 *Fingerprint grading data donor 1: comparison of an original fingerprint (FP11) to the fingerprint lifted with Forensic Sil (FP12) and the enhanced alginate lift (FP13) (average score above bars).*

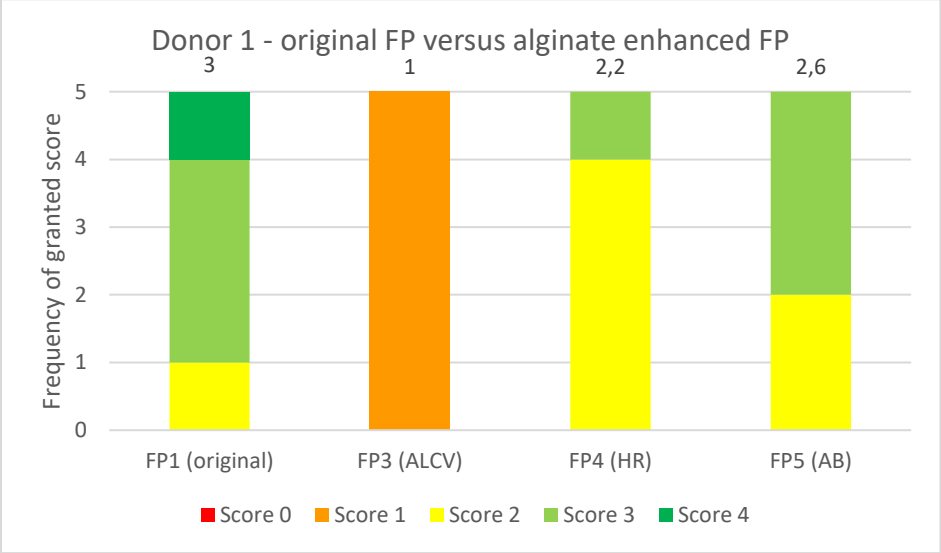


Graph 8 *Fingerprint grading data donor 2: comparison of an original fingerprint (FP16) to the fingerprint lifted with Forensic Sil (FP17) and the enhanced alginate lift (FP18) (average score above bars).*

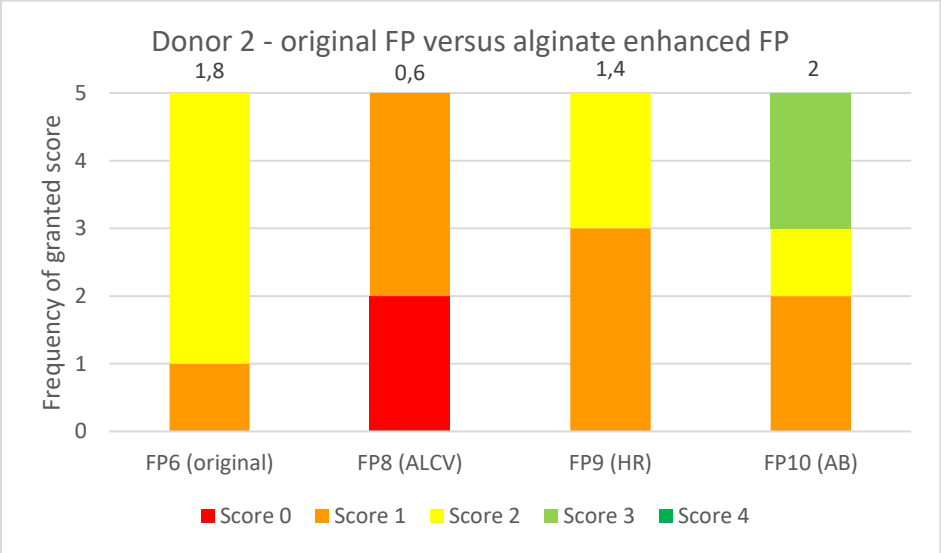
Comparison of an original fingerprint to three enhanced fingerprints lifted with alginate

Table 21 Alginate *Frequency table of fingerprint grading data: frequencies of granted scores per fingerprint (original and lifted, enhanced fingerprints) of 2 donors.*

	Original fingerprint vs 3 enhanced fingerprints - ALGINATE					
		Score 0	Score 1	Score 2	Score 3	Score 4
Donor 1	FP1 (original)	0	0	1	3	1
	FP3 (ALCV)	0	5	0	0	0
	FP4 (HR)	0	0	4	1	0
	FP5 (AB)	0	0	2	3	0
Donor 2	FP6 (original)	0	1	4	0	0
	FP8 (ALCV)	2	3	0	0	0
	FP9 (HR)	0	3	2	0	0
	FP10 (AB)	0	2	1	2	0



Graph 9 *Fingerprint grading data donor 1: comparison of an original fingerprint (FP1) to three fingerprints lifted with alginate and enhanced (FP3, FP4, FP5) (average score above bars).*

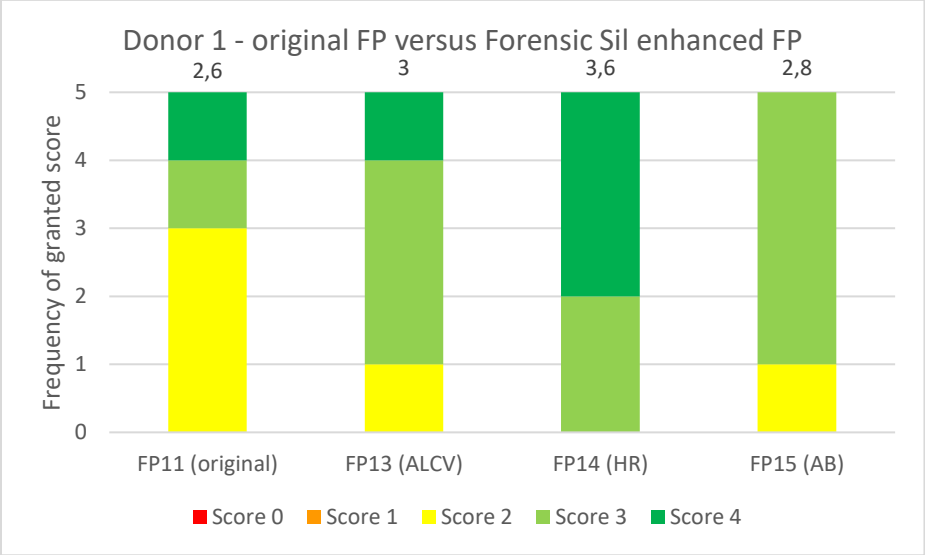


Graph 10 *Fingerprint grading data donor 2: comparison of an original fingerprint (FP6) to three fingerprints lifted with alginate and enhanced (FP8, FP9, FP10) (average score above bars).*

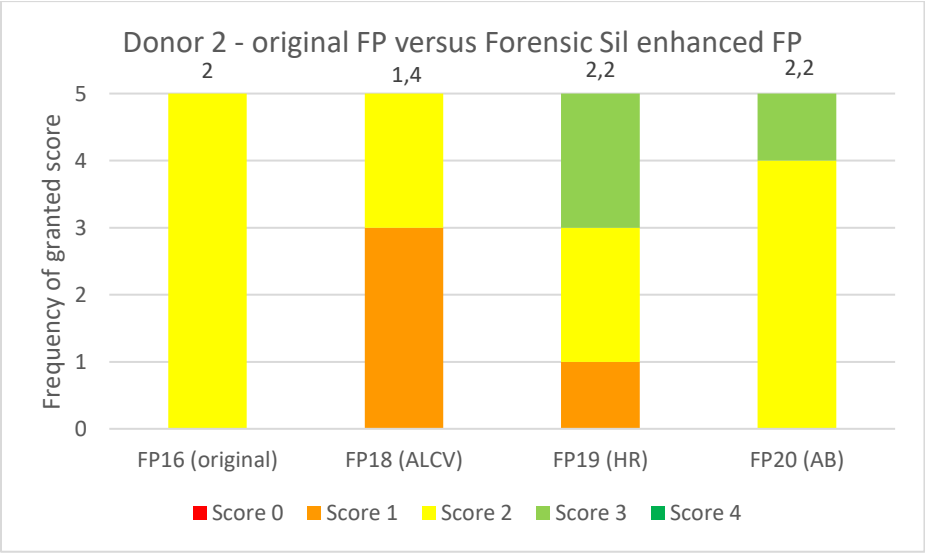
Comparison of an original fingerprint to three enhanced fingerprints lifted with Forensic Sil

Table 22 Forensic Sil *Frequency table of fingerprint grading data: frequencies of granted scores per fingerprint (original and lifted, enhanced fingerprints) of 2 donors.*

	Original fingerprint vs 3 enhanced fingerprints - FORENSIC SIL					
		Score 0	Score 1	Score 2	Score 3	Score 4
Donor 1	FP11 (original)	0	0	3	1	1
	FP13 (ALCV)	0	0	1	3	1
	FP14 (HR)	0	0	0	2	3
	FP15 (AB)	0	0	1	4	0
Donor 2	FP16 (original)	0	0	5	0	0
	FP18 (ALCV)	0	3	2	0	0
	FP19 (HR)	0	1	2	2	0
	FP20 (AB)	0	0	4	1	0



Graph 11 *Fingerprint grading data donor 1: comparison of an original fingerprint (FP11) to three fingerprints lifted with Forensic Sil and enhanced (FP13, FP14, FP15) (average score above bars).*



Graph 12 *Fingerprint grading data donor 2: comparison of an original fingerprint (FP16) to three fingerprints lifted with Forensic Sil and enhanced (FP18, FP19, FP20) (average score above bars).*

Appendix V

This appendix includes the statistical calculation of the ICC-value in SPSS with detailed methodology and results.

Intraclass Correlation Coefficient

Calculating the ICC in SPSS:

1. Import the data in the SPSS data editor.
2. Go to Analyse > Scale > Reliability analysis.
3. Move the variables to the box 'items'.
4. Go to 'Statistics', select the box 'Intraclass Correlation Coefficient', select the model (two-way mixed or random) and select the type (consistency or absolute agreement). Fill in a 95% confidence interval (95% CI).
5. Click on continue > OK.
6. The output is shown on a new screen. The table shows the ICC value, lower and upper bound of the 95% CI and results of the F-test.

Input SPSS:

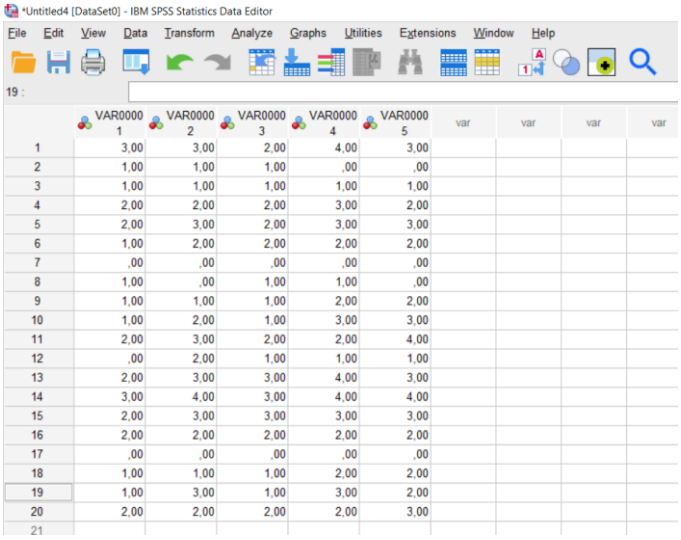


Figure 35 *Input SPSS dataset yielded from fingerprint grading data, used to calculate the ICC-value.*

Output SPSS:

Table 23 *Output of the SPSS reliability analysis based on the fingerprint grading data. The table contains the corresponding two-way random intraclass correlation coefficient with absolute agreement for multiple raters, for single and average measures, with corresponding 95% confidence interval and F-test.*

	Intraclass correlation coefficient						
	Intraclass correlation	95% CI		F-test with true value 0			
		Lower bound	Upper bound	Value	df1	df2	Sig
Single measures	0,741	0,568	0,873	19,448	19	76	<0,001
Average measures	0,935	0,868	0,972	19,448	19	76	<0,001

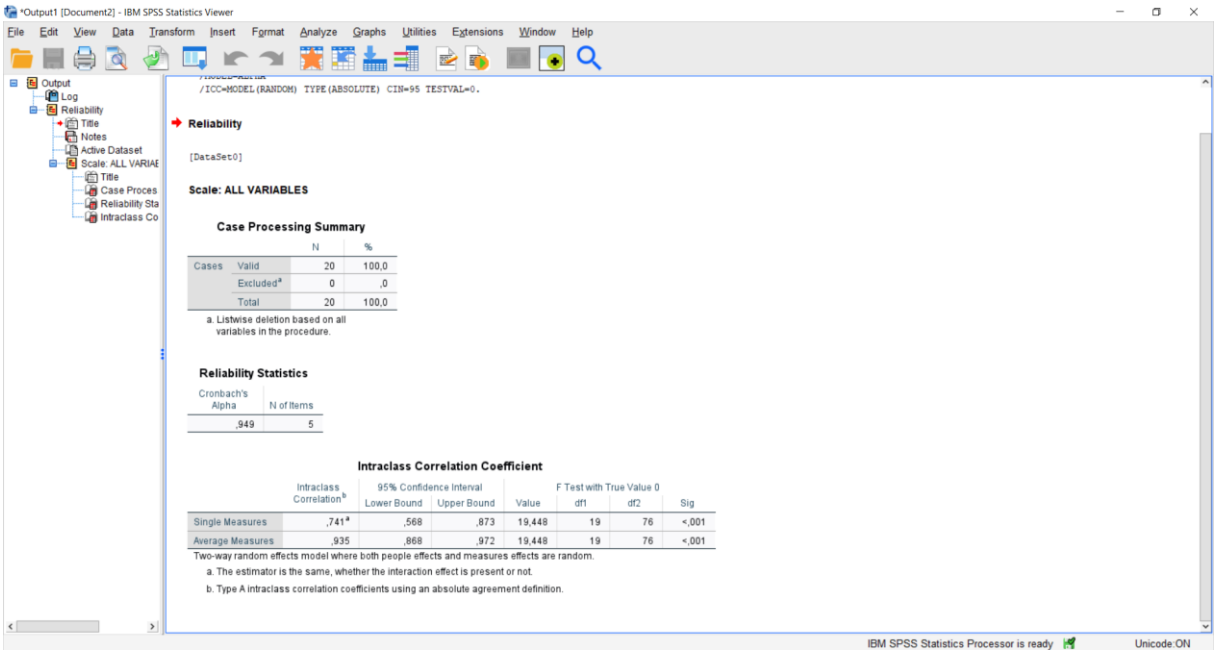


Figure 36 *SPSS output viewer yielded from the input data: intraclass correlation coefficient calculated.*