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A preliminary investigation into the feasibility of using UVC reflection to monitor changes in fingermarks in a research context: The effects of fingermark removal methods and time, substrate and type of fingermark

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ABSTRACT

A preliminary study to explore the application of short-wave ultraviolet (UVC) reflection to fingermark visualisation in a research context is reported, consisting of two experiments. The first evaluated the use of UVC reflection in the detection of fingermarks after deliberate attempts to remove them from a glass surface, with subsequent comparison of the results of UVC reflection with those obtained from subsequent chemical/physical processing and an interpretation of microstructure obtained using scanning electron microscopy. The second experiment explored the use of UVC reflection in sequential processing routines to establish whether all originally deposited marks are detected by subsequent physical and chemical processes, and whether chemical/physical enhancement always improves mark quality. It was found that UVC reflection was capable of detecting faint traces of fingermarks following deliberate attempts to remove them, but the quality of mark detected by UVC reflection was generally inferior to that developed by subsequent application of a white powder suspension. Scanning electron microscopy revealed some evidence of fingermark residue after all removal methods but in many cases these could not be detected by UVC reflection, although there was sufficient material to interact with white powder suspension. The experiment exploring sequential processing routines showed that UVC reflection could be effective in visualising marks of higher quality than those developed by subsequent enhancement methods, but results were strongly influenced by the substrate marks were deposited on and the composition of the mark. It was concluded that UVC reflection is a useful analytical method to include in fingermark research activities in addition to its potential benefits in casework.

1. Introduction

Optical methods for fingermark visualisation have been used since the earliest cases involving fingerprint identification. White light at different angles, output powers and levels of diffusion can be used to locate many different kinds of fingermark, and a recent review of the use of light sources in examination of serious crime scenes [1] has shown that a significant proportion of marks found using optical methods may not be subsequently detected by chemical or physical processes. The non-contact, non-destructive and non-contaminating nature of light source examination makes it an important initial stage in a forensic examination, both for detection of fingermarks but also for the location of other types of forensic evidence.

The range of optical methods available extends beyond the visible region of the spectrum, with ultraviolet and infrared wavelengths each having applications in the detection and enhancement of evidence. In relation to fingermarks, near infrared reflection (700 – 1100 nm) can be performed using adapted DSLR cameras and has been used after chemical processing to reduce interference from coloured and patterned backgrounds [2–4], but tends to be less effective for detection of latent fingermarks. Mid-wave IR imaging has also been considered as a means of detecting latent and treated fingermarks by mapping areas where characteristic IR absorption bands occur [5,6]. However, mid-wave IR imaging requires specialist analytical equipment and collection of images of complete fingermarks is time consuming.

Ultraviolet radiation has a wider range of applications. The use of ultraviolet radiation as a means of producing fluorescence in fingermarks and other types of forensic evidence has been considered since the

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1930s [7]. In the original application, long wave ultraviolet (UVA) radiation was used to promote fluorescence in the visible region of the spectrum, with UV fluorescent powders being proposed as a fingermark development process [8]. Because the resultant fluorescence was visible, conventional photographic methods (with appropriate filtration) could be used to capture developed marks.

Direct viewing of fingermarks in the short wave ultraviolet (UVC) region of the spectrum became possible in the early 1970s, with early experiments using video displays being performed by Japanese researchers [9,10]. Experiments were conducted to both characterise the UV absorption and fluorescence characteristics of fingermarks and also to demonstrate the feasibility of directly viewing marks on both porous and non-porous surfaces at both UVC (254 nm) and UVA (365 nm) wavelengths.

Although UV imaging was not initially adopted operationally due to the expense and complexity of the equipment required, as imaging technology advanced UV-intensifier systems became available from the mid-1990s and were utilised for imaging of fingermarks both at crime scenes and in laboratories. A further development was the introduction of back-thinned, UV- sensitive charge-coupled device (CCD) cameras, enabling marks to be viewed and captured directly. The application of UV imaging to casework was reported by several groups conducting research and operational work in the late 1990s/early 2000s [11–17].

Early investigations predominantly concentrated on shorter wavelength UVC radiation. However, significant health and safety concerns were raised regarding the potential adverse effects of exposure to these wavelengths on ocular and dermal tissues. As the importance of DNA as identification evidence increased, there were also concerns about the detrimental effect of UVC irradiation on DNA and this was evaluated by several researchers [18–21]. Consideration has therefore also been given to the development of long wave, UVA imaging systems [22]. Several digital camera manufacturers now produce systems with the UV-IR blocking filter removed from the imaging sensor to give a 'full spectrum' imaging capability which is claimed to be between 340 – 1000 nm. Commercial systems with specialist optics which transmit UV radiation down to at least 254 nm are now available for long and short wave reflected ultraviolet imaging. In contrast to UVC imaging, the principal application reported for UVA imaging systems has been the enhancement of cyanoacrylate fumed fingermarks [23,24], as opposed to the detection of latent fingermarks prior to treatment.

Despite concerns about the detrimental effects of UVC radiation, with appropriate precautions UVC imaging is a valuable examination technique that can detect evidence not found by other methods in both fluorescence and reflection modes.

UVA fluorescence is probably the most widely used and long-established method that utilises UV radiation because the fluorescence occurs in the visible region of the spectrum. However, there are several substrates (such as white paper) where optical brighteners may be added which fluoresce strongly under UVA radiation and may obscure fluorescence from developed fingermarks and limit some applications of this process. When UVC is used as the incident radiation, the fluorescence occurs in the UV region, meaning that specialist imaging equipment is required to view it. UVC-excited fluorescence has been re-evaluated in the past decade and researchers found the technique to be capable of recovering 70–80% of deposited marks on porous surfaces without the requirement for chemical treatment [25]. Using a 266 nm laser as the irradiation source Saitoh and Akiba [26] showed that latent fingermarks exhibit two emission peaks at 330 nm and 440 nm, and the same research group [27] demonstrated using a tunable laser system that the optimum wavelength for promoting fluorescence was 280 nm.

Although UVC fluorescence does have potential operational uses and UVA fluorescence is a well-established process, recent interest has focused on UV radiation used in reflection mode. Few comparative studies have been conducted between the effectiveness of UVA and UVC radiation for the detection of latent fingermarks. Those that have been published [28,29] indicate that short wave UVC is more effective than UVA (and mid wave UVB) for this application, and that both wavelengths can detect marks not found with white light [29]. There are important differences between UVC and UVA reflection, one being that some substrates such as glass appear opaque and dark at UVC wavelengths thus increasing visibility of marks on this type of surface [14], whereas under UVA this effect is not as pronounced. The smaller wavelength of UVC also means that fine surface features such as latent fingermark ridges interact more strongly with the radiation [28], making them more likely to be detected.

The potential of UVC reflection to detect marks not found by other optical processes makes it desirable to further investigate its capability and to understand its benefits and limitations. It should be noted that there are several modes by which UVC reflection can be used to detect fingermarks. On porous surfaces, fingermarks can absorb UVC wavelengths and appear as dark ridges against a lighter background [28] (the absorbed radiation may be emitted as fluorescence at higher wavelengths [25–27]). On smooth non-porous surfaces, fingermarks may be detected due to scattering caused by their topography, and are revealed as lighter ridges against a dark background [28]. This mode of detection can be very dependent on angle of irradiation and finding the optimum angle may not be trivial. Alternatively, UVC irradiation may be used in a diffuse reflection mode, where the UVC source is used to project a pool of radiation onto the surface and the fingermark reflects less UV than the surface, appearing as darker ridges against a lighter background. This is analogous to the ball lighting method that can be used in white light examination [1]. All modes may be useful in detection of latent marks. A new generation of live view UVC sensitive imaging systems are now available, and studies are being conducted to evaluate their capability in detecting latent fingermarks and also in enhancing detection of marks developed using other processes such as cyanoacrylate fuming [30]. In addition to evaluating to operational effectiveness of UVC imaging, such systems can also be used to assist in fundamental research. UVC reflection can be used to evaluate changes in latent fingermarks over time after deposition, and after exposure to different environments. The quality of the fingermark as captured using UVC can also be compared to their quality after subsequent application of chemical and physical enhancement processes.

The objectives of the experimental work were to establish the feasibility of UVC reflection as a tool to monitor the changes in fingermarks exposed different removal methods, and to evaluate the effect of time and substrate type on mark detection at different stages of a sequential processing routine. Although optical methods have been previously used in some of these applications, UVC reflection may offer a complementary method capable of detecting finer detail. A secondary objective was to explore whether UVC reflection could visualise marks of a higher quality than those enhanced by subsequent chemical and physical processes.

This study is considered as a Phase 1 project (pilot study) according to the fingermark research guidelines issued by the IFRG [31].

2. Experimental methods

2.1. Methodology overview and fingermark deposition

The experimental work is divided into two sections. The first explores the use of UVC reflection in monitoring changes in fingermarks during attempts to remove them, and the second investigates incorporation of UVC reflection into fingermark enhancement sequences.

Institutional ethical approval for the study was obtained under application ETH2425–0175. Fingermarks were deposited by a single male donor, previously assessed as being average to good in terms of fingermark deposition quality.

In the experiment to investigate fingermark removal, 'natural' fingermarks [31] were used. The donor had not washed their hands for at least 30 min and rubbed hands together to homogenise material across hands and fingers prior to deposition. Fingermarks were deposited

across the boundary of two slides, so that approximately half the fingermark was deposited on each slide. One slide was kept as a control (not exposed to any removal method) and the other exposed to the selected method of fingermark removal.

The effect of depletions was also explored in this study. Because of the size of the slides, it was not possible to place a full depletion series on the slide so marks 1,5 and 10 in the depletion series were deposited on the slide, and marks 2–4 and 6–9 on a piece of paper (not treated). It is recognised that using paper as a sacrificial substrate may deplete the fingermark residues more quickly than a deposition on glass, but using glass (a non-porous surface) may result in material being transferred back to the fingertip as the number of marks placed on the sacrificial substrate builds up.

In the experiment to investigate UVC in enhancement sequences, four different types of mark were deposited:

Natural marks - the donor had not washed their hands for at least 30 min and rubbed hands together to homogenise material across hands and fingers prior to deposition

Sebaceous marks – the donor washed their hands with water and hand soap and allowed them to dry, before rubbing the finger against the base of their nose. Marks were then deposited using the 'loaded' finger.

Vaseline® – the donor dipped their finger into the pot of Vaseline® and dabbed it several times on a tissue to remove excess material before deposition.

Blood – the donor wiped their finger on a tissue saturated with defibrinated horse blood (TCS Biosciences Ltd) and dabbed it on the tissue to remove any excess before deposition.

Marks were deposited as depletion series, the number being determined by the size of the sample available.

'Natural' and sebaceous marks were used because they are representative of the types of marks that may typically be encountered at crime scenes. Blood is a contaminant that may be associated with fingermarks at serious crime scenes. Vaseline® was used because it represents a contaminant that may be found on fingers because it is applied by hand, and because it is a greasy contaminant that is chemically very different from sebaceous material. As a such it represents a contaminant that may be detected by white light and fluorescence examination methods, but may not be subsequently detected by chemical reagents.

2.2. Evaluation of the effectiveness of different fingermark removal methods

The purpose of the experiment was to utilise UVC reflection to determine the effectiveness of different approaches in removing fingermark residues from a surface. UVC reflection has previously been shown to be highly effective in detecting latent fingermarks on glass surfaces, therefore glass microscope slides (Jaytec MCG00810) were used in this study. The use of microscope slides also enabled provision of complementary information to recent research evaluating the effect of high concentration corrosive substances on fingermark recovery [32].

14 sample sets were prepared in all, using the deposition conditions described above. A baseline image set was collected using the UVC reflection system, all images being captured on the same day as mark deposition. The samples were then left overnight before further treatment.

One day after deposition, the microscope slides were separated. The 'control' side was retained and stored at room temperature in dry conditions. The 'test' sides of each sample were exposed to different conditions with the potential to remove fingermarks. The first 9 samples were exposed to a range of high concentration acids and alkalis, as used in a previous study [32]. The remaining 5 'test' samples were subjected to different approaches for attempting to remove fingermark residues. Four samples were wiped with a tissue, with 10 repeat wipes being applied with a similar pressure to that used when drying dishes, 5 in each direction. For one sample the tissue was kept dry, in other cases the tissue was wetted with a different liquid (acetone, ethanol and a water/hand soap mix). The final sample was placed in a dry oven at 300°C for 1 h. A summary of the samples prepared is given in Table 1.

After all samples were dry, the control and test sides of each sample were recombined and all 14 samples were imaged again using UVC reflection, enabling visualisation of any fingermark residue remaining on the test side and a direct comparison with the control side of the mark.

After 1 week, both sides of each sample were powdered using black magnetic powder (Black magna, Tetra Scene of Crime, Wickford, UK) and a magnetic applicator. They were then photographed. Black magnetic powder was selected because it has previously been found to be effective on fingermarks exposed to adverse conditions [32], although the 1-week aging condition is longer than would usually be experienced in operational conditions.

After a further 3 weeks the samples were retreated with white powder suspension (Wet Powder White, Kjell Carlsson Innovations), in accordance with the processing sequence recommended in the Fingermark Visualisation Manual [33]. White powder suspension was selected because it had been found previously to be a highly effective process for recovering fingermarks after exposure to corrosive substances [32]. The samples were then rephotographed.

The experiment is illustrated schematically in Fig. 1.

2.3. Evaluation of the effect of time and substrate on mark detection

The purpose of this study was to evaluate the effect of time since deposition and substrate type on the detection of fingermarks of different compositions using UVC reflection, and also to compare the quality of marks imaged using UVC to marks subsequently enhanced using chemical and physical processes.

The four substrates used were cut samples of soda-lime-silica glass (80 ×100 mm), polymethyl methacrylate (70 ×70 mm), polyethylene and polypropylene (95 ×95 mm). These were chosen to represent large, rigid surfaces and objects that may be encountered at crime scenes (e.g. glass and polymethyl methacrylate – glazing, polyethylene – wheelie bins, polypropylene – garden furniture). The size of the sample allowed a depletion of 12 marks to be deposited on glass, and 9 mark depletions on other substrates.

After deposition, the samples were then stored in a laboratory on an open bench at room temperature, under room (fluorescent tube) lighting. Although some marks were visible with a cursory examination under room lighting, due to the limited range of white lights available marks were not captured using white light. All samples were imaged using UVC reflection 1 day after deposition, then re-imaged after 12 days and again after 20 days. Following collection of the final set of UVC reflection images, each set of samples was processed with a chemical treatment deemed appropriate to the type of fingermark deposit.

Natural and sebaceous marks were processed using cyanoacrylate

Table 1
Summary of the methods used to attempt to remove fingermarks from microscope slides.

Sample number	Removal/exposure method
1	Drain cleaner (11 M sodium hydroxide)
2	Ammonia (5 M ammonium hydroxide)
3	Cleaner (8 M nitric acid)
4	Brick Cleaner (5 M hydrochloric acid)
5	Cleaner (13 M phosphoric acid)
6	Drain cleaner brand 1 (18 M sulfuric acid)
7	HCl Cleaner (10 M hydrochloric acid)
8	Drain cleaner brand 2 (18 M sulfuric acid)
9	Rust Remover (8 M phosphoric acid)
10	Acetone on tissue – 10 wipes
11	Ethanol on tissue – 10 wipes
12	Water/detergent – 10 wipes
13	300°C oven, 1 h
14	Dry tissue – 10 wipes

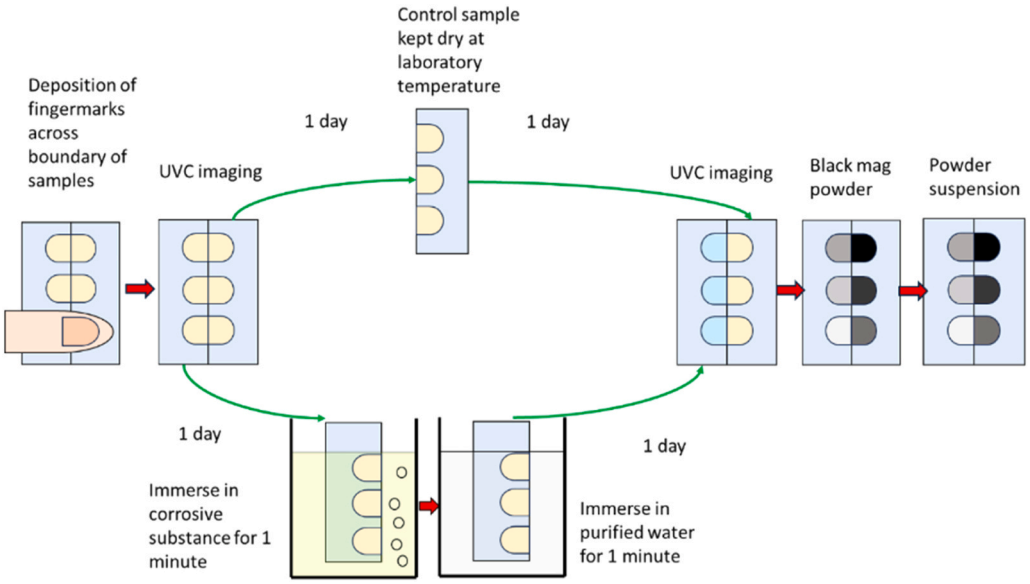

Fig. 1. Schematic diagram showing the processing sequence used for samples exposed to concentrated acids and alkalis.

fuming in an MVC5000 cabinet using Cyanobloom (Foster + Freeman, Evesham, UK). Because UVC reflection is known to be effective on marks processed with cyanoacrylate fuming due to the raised poly-cyanoacrylate structures developed on the ridges, the marks were then re-imaged using UVC before progressing to a final dye stage using ethanol-based Basic Yellow 40 dye [33] followed by photography.

Vaseline® contaminated marks were developed using black magnetic powder (Black Magna, Tetra Scene of Crime, Wickford, UK) using a magnetic applicator, then photographed.

Blood contaminated marks were developed using Acid Violet 17 [33] before photography using a Canon EOS 800D DSLR camera with EF-S 18–55 mm lens under white light from a Crimelite 82S. The samples were finally treated with iron oxide-based powder suspension [34] and rephotographed using the same conditions.

The experiment is illustrated schematically in Fig. 2.

2.4. Imaging

Imaging of fingermarks was carried out at several points during both studies, using imaging techniques appropriate to the stage in the processing sequence. The imaging conditions used were those appropriate to the type of mark being captured, there was no deliberate attempt to use the same aperture and ISO settings for UVC reflection and visible light/fluorescence photography.

UVC reflection imaging was conducted using an Arrowhead Forensics FSIS-II system, with 20 megapixel Digital FSIS-II camera and 50 mm UV lens. A 254 nm bandpass filter was used in front of the lens, with UVC radiation provided by a hand-held lamp with two mercury tubes with spectral output at 254 nm. The FSIS-II operating software includes an option for image integration, and imaging was conducted in integration mode by moving the UVC lamp through different angles so that appropriate reflection conditions could be obtained in real time across all areas of the sample being examined. The final image captured represented what was considered as optimum contrast between fingermark

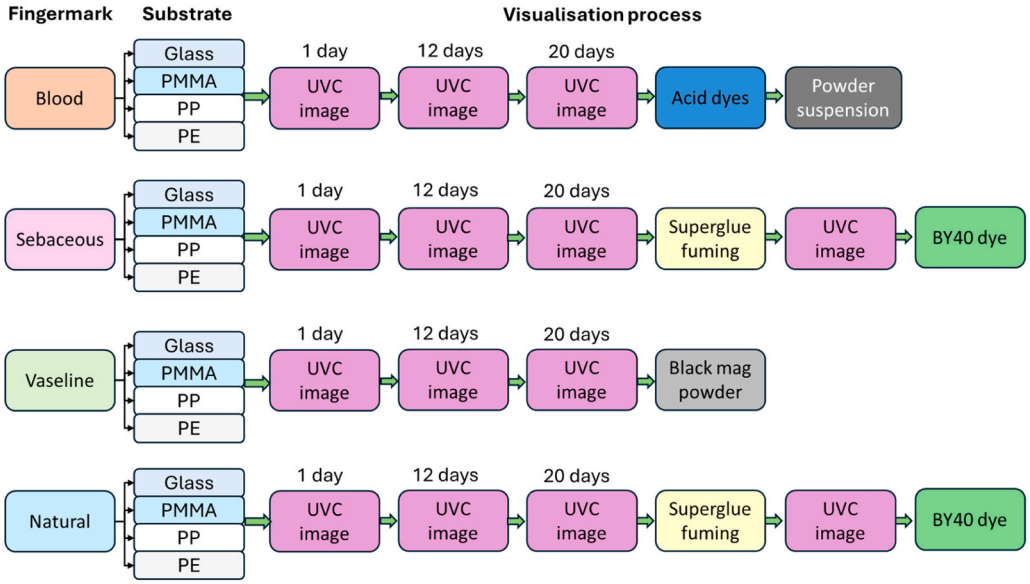

Fig. 2. Schematic diagram showing the sequence of processes used for fingermark visualisation for each scenario.

and substrate across the sample, with integration typically over 100 – 200 frames in this study. It is noted that skilled operators may be able to achieve similar results in a single exposure using other imaging modes.

Fingermarks developed using processes producing visible marks were photographed using a Canon EOS 800D DSLR camera with EF-S 18–55 mm lens (set to 55 mm) under white light from a Crimelite 82S (Foster + Freeman, Evesham, UK). Fingermarks on clear substrates (glass, Perspex) were photographed against a background of contrasting colour to the developed mark.

Photography of fingermarks enhanced using the fluorescent dye Basic Yellow 40 was carried out using the same camera and lens fitted with a Schott glass GG495 filter, using illumination from a blue (420 – 470 nm) Crimelite 82S.

The photography conditions used represented equipment available in the laboratory rather than being optimised for the particular type of marks present. Different illumination modes of white light were not used in this study. Their benefit has been described elsewhere [1] and the primary focus of this study was to explore applications of UVC reflection.

2.5. Grading of fingermarks

Marks were assessed using recognised grading schemes used in fingermark research [31]. The quality of each developed mark was assessed by a single assessor with 22 years of experience in fingermark research, using the Home Office grading system of 0 – 4, Table 2.

The marks visualised by UVC reflection cannot be viewed directly on the surface, and therefore all marks were graded from the computer screen for consistency.

2.6. Scanning electron microscopy

The effect of removal techniques on the appearance of fingermark deposits was explored using scanning electron microscopy. A separate set of fingermarks was deposited by the same donor on glass cover slips, and one half of each cover slip was exposed to each fingermark removal method while the other half remained untreated as a control reference. The exception was the sample exposed to 300°C, where the entire sample was heated. Samples were sputter coated with gold for 3 min before examination in a Pemtron PS−230 scanning electron microscope.

3. Results and discussion

3.1. Evaluation of the effectiveness of different fingermark removal methods

The effect of the corrosive substance/cleaning method on the appearance of each mark was assessed by assigning grades to each half mark and monitoring the change in grade at each stage in the sequence (pre-test, post-test, after black magnetic powder and after white powder suspension). The full results of this assessment are provided in supplementary information file S1, and bar charts showing results obtained for a representative set of removal conditions including acids, alkalis, heating and physical removal methods are shown in Fig. 3. These charts show results for depletions 1, 5 and 10 on test and control sides of the sample at each stage in the experiment.

Table 2
The Home Office grading system used to grade controls and equivalent half-marks exposed to liquid.

Grade	Level of detail
0	No evidence of mark
1	Weak development; evidence of contact but no ridge detail visible
2	Limited development; up to 1/3 of original contact area developed with ridge detail but probably cannot be used for identification purposes
3	Strong development; between 1/3 and 2/3 of original contact area developed with ridge detail
4	Very strong development; between 2/3 and all of original contact area developed with ridge detail

In general, UVC reflection post-testing showed almost all methods of deliberate removal of the fingermarks resulted in a reduction of the quality of the marks exposed to test conditions compared to the control. In most cases some evidence of a fingermark was detected using UVC reflection after application of the removal process, examples being shown in Fig. 4. The quality of the mark decreased as the number of depletions increased, as expected.

In almost all cases, black magnetic powder developed marks of a lower quality than those initially observed using UVC imaging, examples being shown in Fig. 5. This observation was true for both control and test sides of the sample, demonstrating that physical/chemical treatments may not always enhance the quality of marks compared to detail revealed by optical methods alone. It should be noted that the 1-week period between mark deposition and powdering is longer than standard operational practice and the water component of the mark (one factor promoting particle adhesion) may have been lost during this period.

The subsequent application of white powder suspension showed a restoration in mark quality, in many cases to a level equivalent to the mark initially observed by UVC reflection. This improvement was observed even for samples where no mark was visible by UVC reflection post-treatment, suggesting that even if the topography of the mark has been reduced to a level where it can no longer be detected by UVC reflection, there are still small quantities of the chemical constituents remaining to initiate deposition of titanium dioxide particles. Examples are shown in Fig. 6.

Heating of the fingermark gave anomalous results, Fig. 7.

In this case there is still evidence of fingermark residue on the test side after heating using UVC reflection, but this residue gives reversed contrast development to the control side when treated with black magnetic powder and white powder suspensions. The ‘reversed development’ by black magnetic powder has previously been observed in other studies investigating the effect of fire on fingermark recovery [35]. The heating process appears to have caused changes to the fingermark, the surface (or both) which has altered the relative affinity of the powder to the ridge and background regions.

SEM analysis enabled the effect of the different removal methods on the fingermark residue to be visualised. Fig. 8 shows a typical image of fingermark ridges in the control side of the samples, which shows a dispersion of droplets of fingermark residue along the line of the ridges, with pores and the occasional skin cell visible.

The changes in appearance of the residue after a selection of different removal conditions can be seen in Fig. 9.

After immersion in the alkali sodium hydroxide there are no clearly defined fingermark ridges, with a faint indication of a dendritic pattern formed uniformly over the surface. The samples immersed in acids both have an indication of ridges are still present, but there is a reduction in number and size of droplets present. The more concentrated sulfuric acid has a greater effect, with the surface after immersion being mostly clean and featureless, with some isolated circular features which may be remnants of fingermark residue.

For the dry tissue wiped sample SEM imaging shows smearing of the constituents in ridges along the direction of the wiping action, but the general direction of the ridges can still be seen. When a solvent (acetone) is used in combination with the tissue wipe there is still evidence of the fingermark ridges, but the original droplets of residue are reduced in number and appear to have diffused and coalesced.

After heating the ridge direction is still visible, although the droplets of original constituents are no longer visible and replaced by a flat, ‘dried out’ region. There is evidence of formation of crystals within the ridges, which may be sodium chloride.

In general UVC reflection has proved to be an effective method for monitoring changes in fingermarks exposed to various methods of attempted removal.

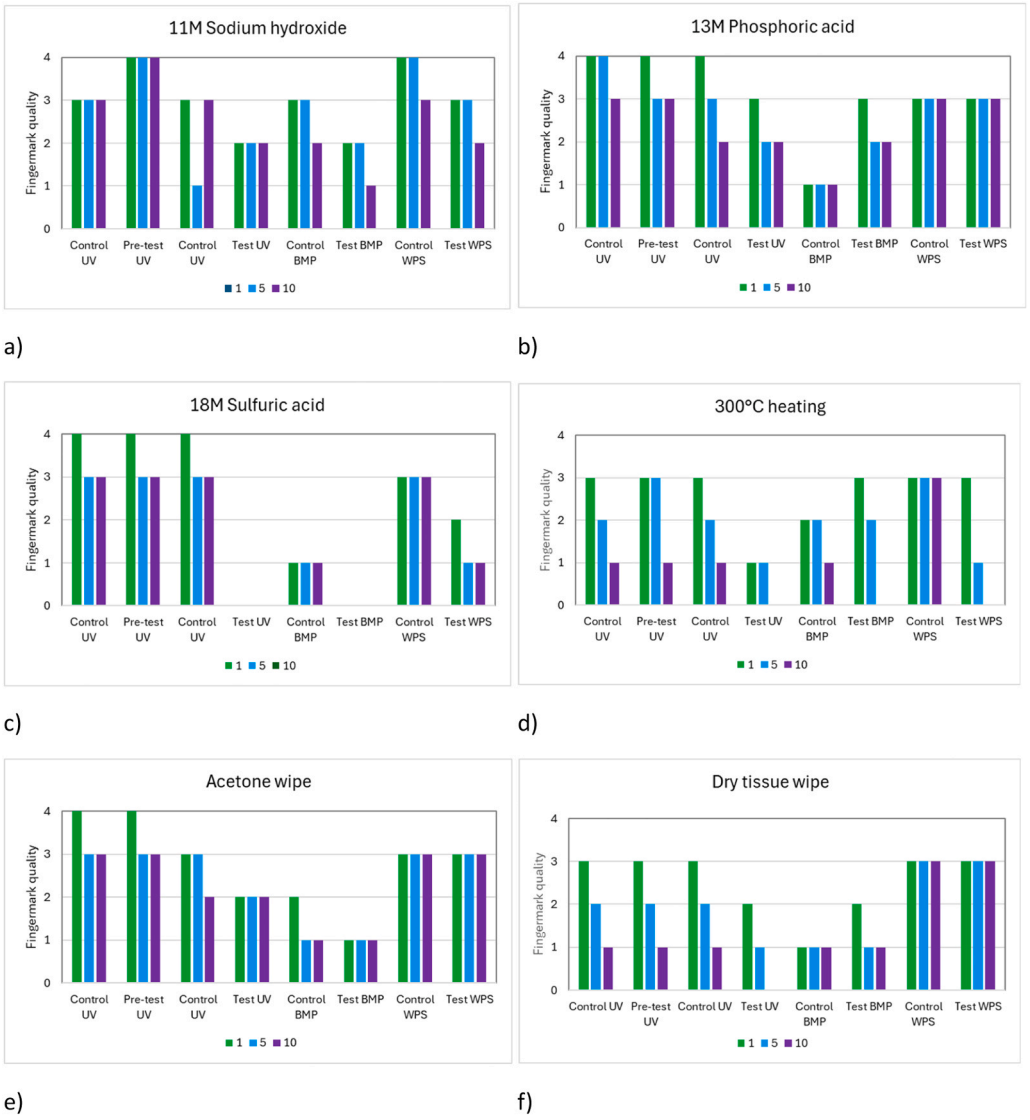

Fig. 3. Bar charts showing fingermark quality scores for depletions 1, 5 and 10 after exposure to different removal conditions using different visualisation methods: a) 11 M sodium hydroxide, b) 13 M phosphoric acid, c) 18 M sulfuric acid, d) 300°C heating, e) acetone wipe and f) dry wipe.

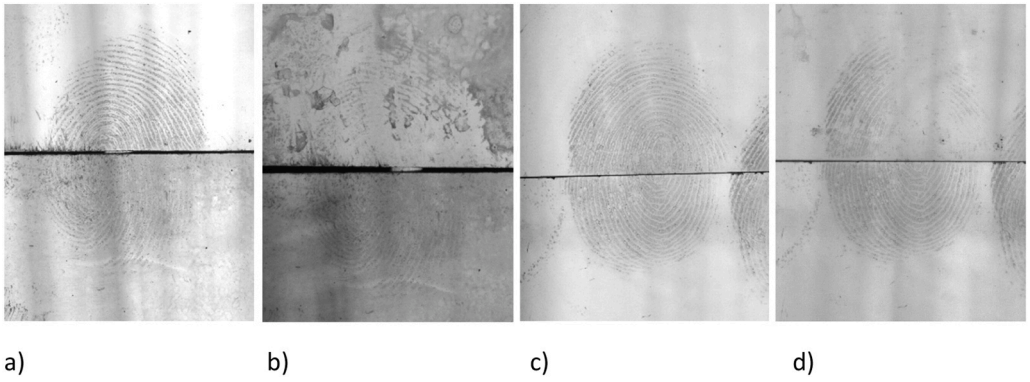

Fig. 4. Effect of fingermark removal on visualisation of fingermarks by UVC reflection: a) fingermark prior to immersion in 11 M sodium hydroxide, b) fingermark after immersion in 11 M sodium hydroxide, c) fingermark prior to immersion in 13 M phosphoric acid, d) fingermark after immersion in 13 M phosphoric acid. (top half of mark = immersed, bottom = control).

On the 'test' side of samples the residual material detected by UV reflection after fingermark removal was closely equivalent to the areas of mark developed by black magnetic powder. It was observed that the use of a tissue wipe in combination with a solvent tended to be more detrimental to subsequent development of marks with powder than immersion in acids and alkalis. This may be because the solvent can

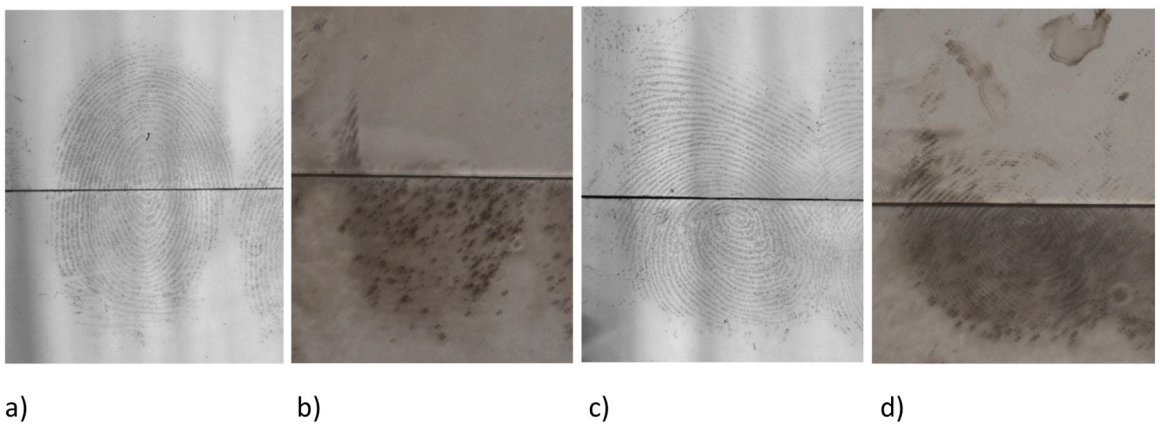

Fig. 5. Comparison of marks initially visualised using UVC reflection with equivalent mark after development with black magnetic powder: a) fingermark prior to immersion in 18 M sulfuric acid, b) fingermark after immersion in 18 M sulfuric acid, developed using black magnetic powder, c) fingermark prior to wiping with acetone soaked tissue, d) fingermark after wiping with acetone soaked tissue, developed using black magnetic powder. (top half of mark = immersed, bottom = control).

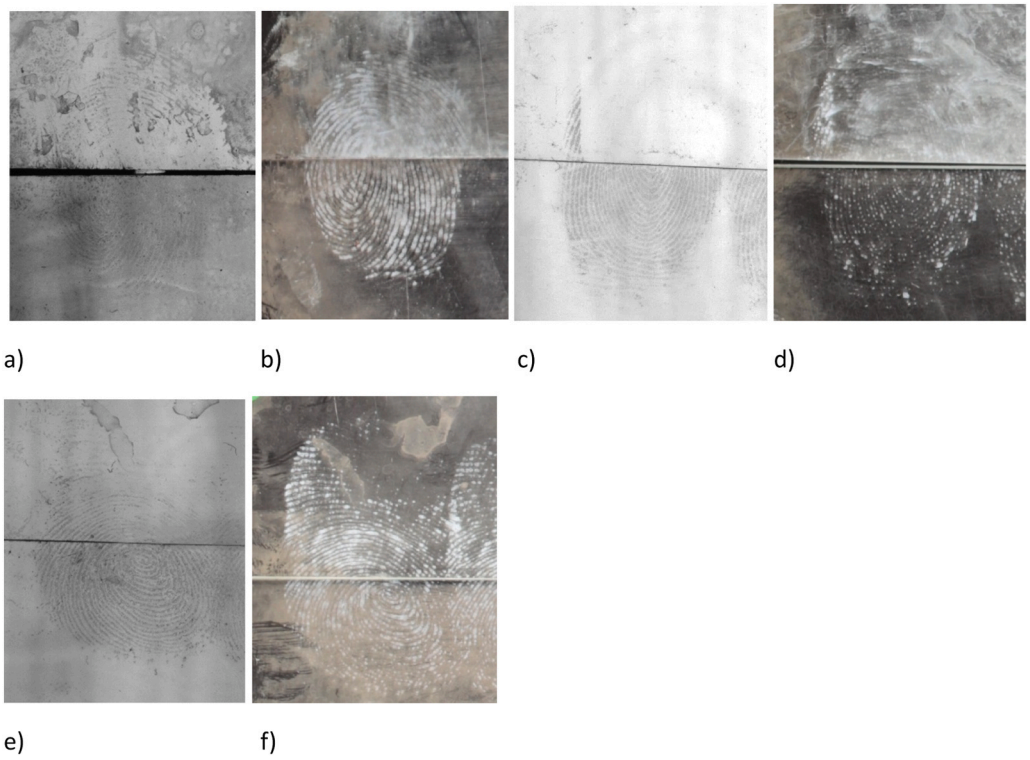

Fig. 6. Comparison of marks visualised using UVC reflection after removal with equivalent mark after development with white powder suspension: a) fingermark after immersion in 11 M sodium hydroxide, visualised using UVC reflection b) fingermark after immersion in 11 M sodium hydroxide, developed using white powder suspension, c) fingermark after immersion in 18 M sulfuric acid, visualised using UVC reflection b) fingermark after immersion in 18 M sulfuric acid, developed using white powder suspension, e) fingermark after wiping with acetone soaked tissue, visualised using UVC reflection, f) fingermark after wiping with acetone soaked tissue, developed using white powder suspension. (top half of mark = immersed, bottom = control).

dissolve certain constituents of the fingermark and the mechanical action may then remove or redistribute them, in addition to smearing any constituents that do not dissolve. In contrast, static immersion in a strong acid or alkali may initiate localised changes in the fingermark chemistry but will not necessarily remove all constituents present.

On the 'control' sides, the quality of marks detected by initial examination using UVC reflection was almost always superior to the mark subsequently developed using black magnetic powder, with the caveat that black magnetic powder would usually be applied 1–2 days after deposition in an operational scenario whereas in this study the period between deposition and development was 1 week. Despite this, the results support previous observations using white light [1], showing that non-contact, non-destructive optical techniques can detect more ridge detail than may be subsequently developed using chemical or physical methods.

The application of white powder suspension significantly improves the quality of marks after attempts have been made to remove them. In several cases where few, if any ridges are visible under UVC reflection and there is little development using powder, white powder suspension can still reveal significant detail. This indicates that some material

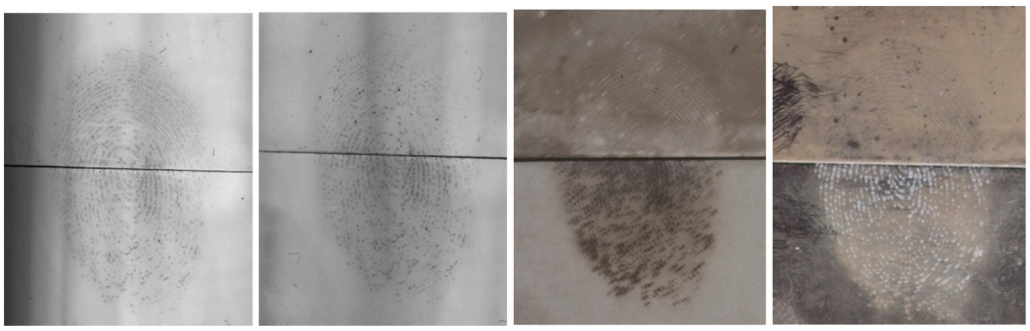

Fig. 7. Results for fingermarks heated to 300°C for 1 h, a) UVC reflection, prior to immersion, b) UVC reflection, after immersion, c) after black magnetic powder, d) after white powder suspension (top half of mark = immersed, bottom = control).

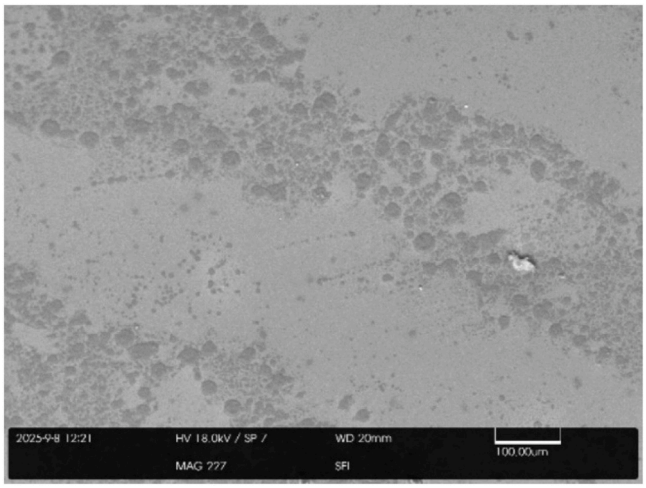

Fig. 8. SEM micrograph of fingermark ridges in control section of mark.

capable of initiating powder suspension deposition is still present, but either it is in too thin a layer to be detected by UVC reflection or has a similar UV reflectivity to the glass surface and therefore does not provide contrast. It is also possible that the fingermark has interacted with the glass surface to leave a residual reaction/etching product that can be developed by powder suspension.

SEM analysis supports the proposition that some material remains after the different removal methods, and although the nature of the deposit may be significantly altered in most cases the modified residue was still developed to some extent by white powder suspension. No evidence of reaction or etching of the glass surface was seen in this study.

3.2. Evaluation of the effect of time and substrate on mark detection

The results of the experiments investigating the effect of time and substrate on different types of marks are summarised below. For each scenario, a series of images were captured showing the progressive change in appearance of a representative mark through the processing sequence. Full sets of these images are included as supplementary data file S2. The proportion of marks at each grade category was also recorded as a stacked bar chart, enabling general trends in fingermark quality to be observed. The bar charts incorporate results from all fingermarks in the depletion series (12 or 9 marks, depending on substrate).

Fig. 10 shows the depletion series deposited in blood on the glass substrate on day 1 of the study.

It can be seen that the integration mode of the UVC imaging system has enabled all marks in the depletion series to be captured, and that as expected the quality of the fingermark decreases as the number of depletions increases. On some of the images of depletion series some marks were slightly overlapping and others had interfering features. In subsequent figures where sequences are shown, a depletion number has been chosen where there were clear images at each stage of the sequence. This is not necessarily the same depletion number for each example used.

3.2.1. Marks in blood

The proportions of the marks in each depletion series developed at each quality grade are illustrated for all 4 substrates in Fig. 11. The image taken on polyethylene using UVC reflection after 12 days became corrupted and is omitted from analysis.

Using UVC reflection, very little change in the appearance of the mark was observed over time on all substrates. Enhancement with Acid Violet 17 produced mixed results, on glass and PMMA the marks lower down the depletion series treated with Acid Violet 17 were of lower quality that those imaged using UVC reflection, whereas on polyethylene and polypropylene Acid Violet 17 did improve quality of marks over UVC reflection. Subsequent application of iron oxide-based powder suspension produces an improvement in quality of marks above that seen with UVC reflection and Acid Violet 17 on all substrates, Fig. 12 showing the sequence of results on polypropylene.

3.2.2. Natural fingermarks

The proportions of the marks in each depletion series developed at each quality grade are illustrated for all 4 substrates in Fig. 13.

In contrast to marks in blood, there is a clear time and substrate dependence on the quality of marks visualised using UVC reflection. On all substrates there is a clear reduction in quality of marks over time, with the exception of polyethylene where none of the deposited marks are visible using UVC reflection, even on day 1. The initial quality and rate of degradation of marks visualised using UVC reflection is also determined by substrate, with mark quality being highest and rate of degradation being slowest in the order glass (best), PMMA, polypropylene, polyethylene (worst). The full sequence for glass is shown in Fig. 14.

On glass, marks lower in the depletion series were enhanced by application of cyanoacrylate fuming followed by UVC viewing. Application of Basic Yellow 40 did not always result in increased quality, with the lower marks in the depletion series being of lower quality than the equivalent mark viewed under UVC reflection. On the polymer substrates the effectiveness of cyanoacrylate fuming followed by UVC reflection was variable, with little or no benefit on PMMA and polyethylene and a more positive effect on polypropylene. For polyethylene and polypropylene, subsequent treatment with BY40 enhanced marks

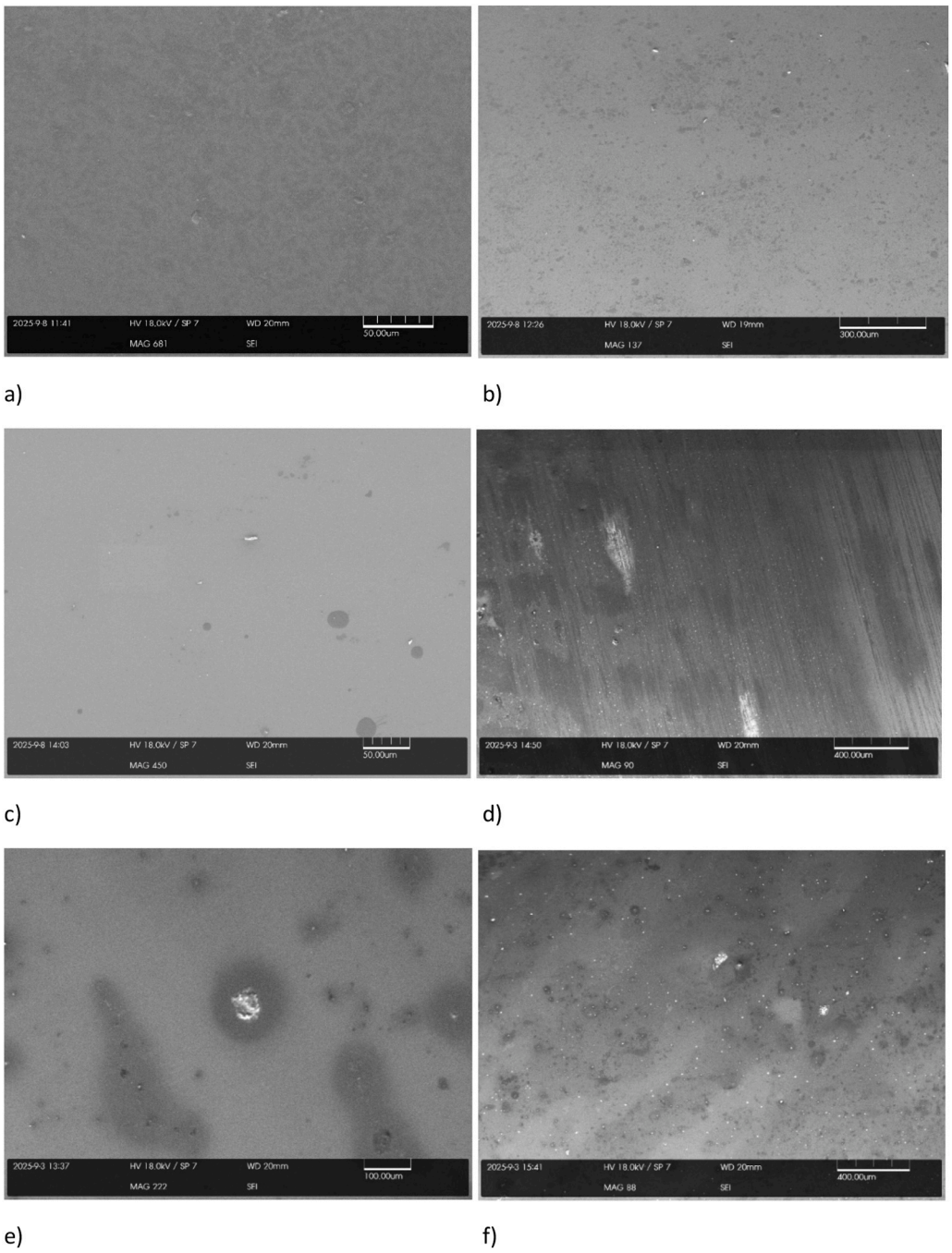

Fig. 9. SEM micrograph of fingermark ridges in test sections of marks, a) 11 M sodium hydroxide, b) 13 M phosphoric acid, c) 18 M sulfuric acid, d) dry tissue wipe, e) acetone wipe, f) 300°C heating.

superior to any visualised using UVC reflection, Fig. 15.

3.2.3. *Sebaceous marks*

The proportions of the marks in each depletion series developed at each quality grade are illustrated for all 4 substrates in Fig. 16. The image taken using UVC reflection after cyanoacrylate fuming became corrupted and is omitted from analysis.

Sebaceous marks behaved slightly differently to natural marks on all substrates but show the same time and substrate dependence when visualised using UVC reflection.

On glass a gradual degradation in mark quality over time was observed using UVC reflection, particularly for later marks in the depletion series. The quality was further reduced by application of cyanoacrylate fuming, and after treatment with BY40, marks were inferior to their equivalent directly viewed under UVC reflection, Fig. 17. Under UV reflection, untreated marks appear as dark ridges against a light background whereas those developed using cyanoacrylate appear as light ridges against a dark background. This suggests that the mode of UV reflection changes from diffuse reflection to scattering as the structure and topography of the fingermark are modified by the enhancement process.

On the polymer substrates different trends are observed. On PMMA there is also a degradation in the quality of marks over time when viewed under UVC reflection, with progressive spreading of ridge detail across the surface and loss of definition. On polyethylene marks are poorly defined immediately after deposition and further degradation

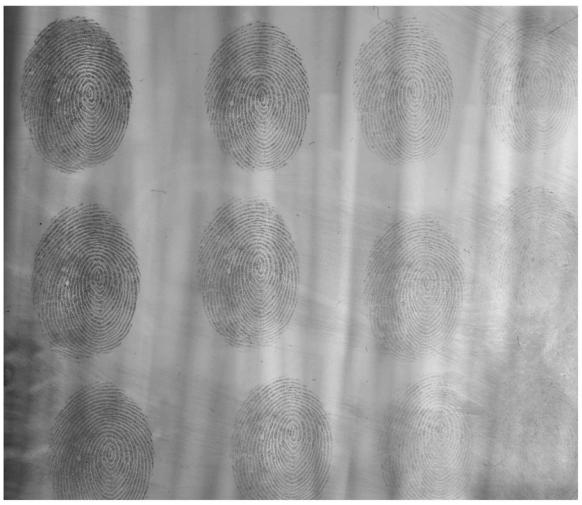

Fig. 10. Depletion series of natural fingermarks deposited on a glass substrate and imaged using UVC reflection after 1 day.

occurs during monitoring using UVC reflection until no marks are visible. Sebaceous marks on polypropylene are more easily detected than on polyethylene and although degradation of marks does over time, over 50% remain visible and of a reasonable quality. Some marks towards the beginning of the depletion series initially appear lighter than the background but this reverses as marks age. Some of these trends can be seen in Fig. 18.

Treatment with cyanoacrylate fuming and BY40 produces enhancement in quality for marks on all polymers compared to the marks visualised using UVC reflection after 12 and 20 days, but it is only for the polyethylene substrate that the quality is enhanced above that seen on initial examination using UVC reflection.

3.2.4. *Marks in Vaseline®*

The behaviour of marks in Vaseline® is much more consistent across all surfaces studied. In the case of glass, all marks are of high quality and there is no change in the appearance of marks viewed using UVC reflection over time. The marks developed by black magnetic powder are of the same quality as the UVC images, Fig. 19.

The trends obtained on PMMA were very similar to those seen on glass.

On polyethylene a slightly different phenomenon was observed. There was no significant change in mark quality over time, but a 'halo' was observed to form around the edges of mark as time progressed. Application of black magnetic powder caused degradation of the marks due to smearing of the Vaseline® deposits, and the region of the 'halo' was also seen to be developed by the powder in addition to the ridges, Fig. 20. On polypropylene there was no formation of a halo around the mark but smearing of marks was also observed to occur during application of black magnetic powder.

In this part of the study UVC reflection again proved to be an effective method for monitoring changes in fingermarks over time and on different substrates.

In summary, the results for fingermarks deposited using contaminants appear relatively independent of surface type. Fingermarks in blood and Vaseline® appear to be dimensionally stable on most surfaces, the exception being the formation of a halo around the mark deposited on polyethylene. This is believed to be associated with migration of some of the constituents of the Vaseline® across the surface. The formation of halos around marks of polymer surfaces has also been observed by other researchers. De De De Alcaraz-Fossoul et al. [36] observed the formation of halos around sebaceous marks deposited on polystyrene and developed using white powder, Popov et al. [37] used a variety of microscopy techniques to observe migration of a thin film of constituents away from the fingermark ridge on silicon wafers and Formica polymer, and Dorakumbura et al. [38] recorded the migration of constituents from a fingermark ridge on a glass slide in real time using atomic force microscopy. Although in these cases the marks were all

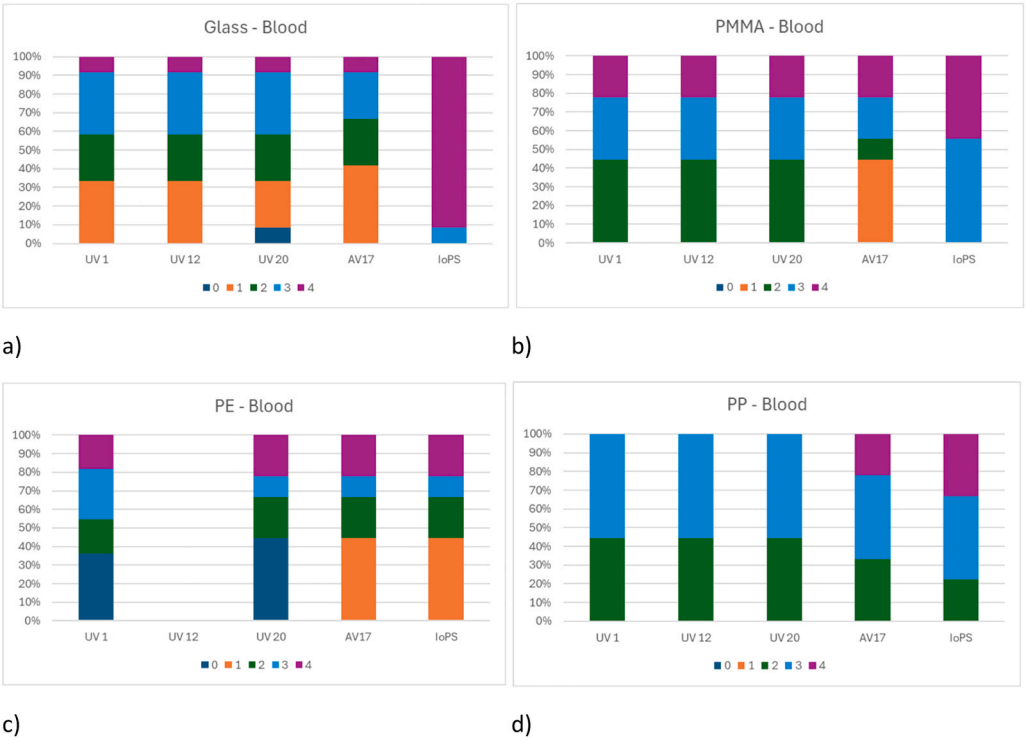

Fig. 11. Stacked bar charts showing changes in mark quality at different stages of the processing sequence for marks in blood on a) glass, b) PMMA, c) polyethylene, d) polypropylene.

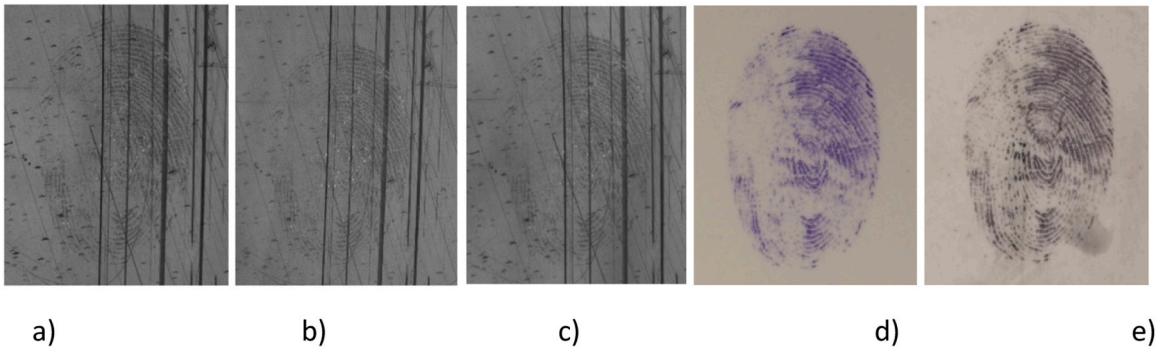

Fig. 12. Results for fingermarks (depletion 5) in blood deposited on polypropylene, a) UVC reflection, day 1, b) UVC reflection, day 12, c) UVC reflection, day 20, d) Acid Violet 17, e) iron oxide-based powder suspension.

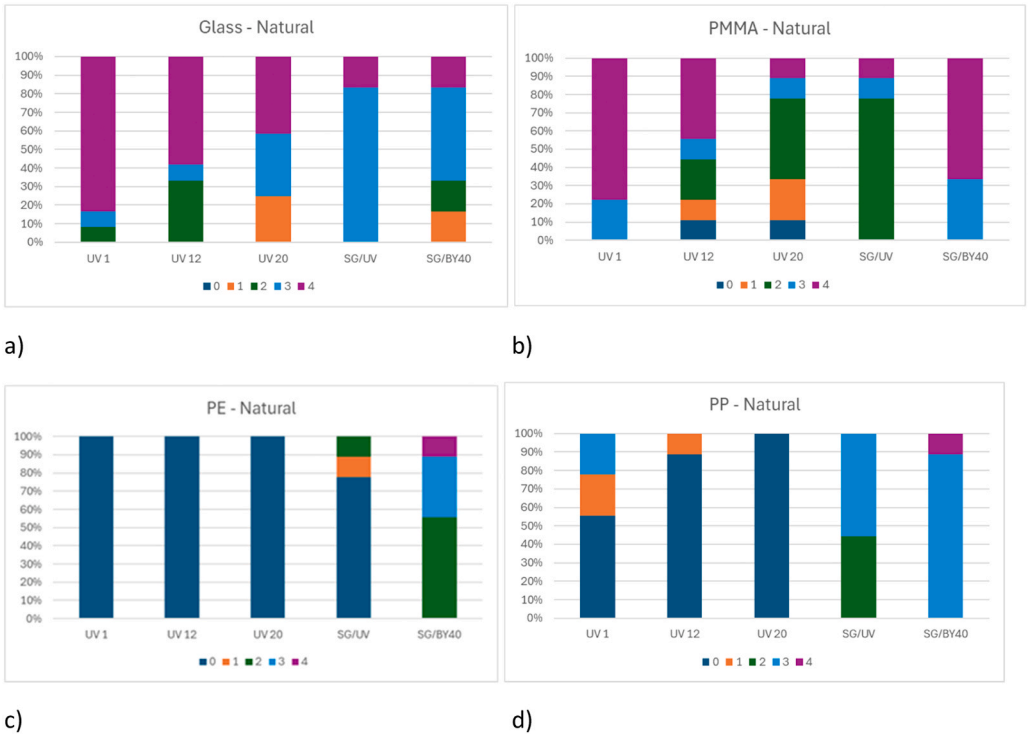

Fig. 13. Stacked bar charts showing changes in mark quality at different stages of the processing sequence for natural marks on a) glass, b) PMMA, c) polyethylene, d) polypropylene.

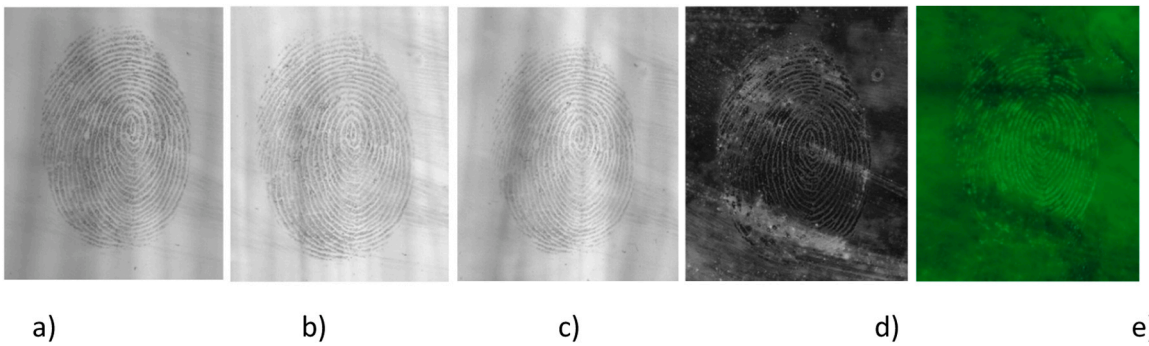

Fig. 14. Results for natural fingermarks (depletion 5) deposited on glass, a) UVC reflection, day 1, b) UVC reflection, day 12, c) UVC reflection, day 20, d) UVC reflection after cyanoacrylate fuming, e) Basic Yellow 40.

sebaceous in nature, Vaseline® also contains oils and wax constituents that may behave in a similar way to sebaceous constituents of fingermarks. The effect of the surface on the level of migration observed has also been previously noted. Popov et al. [37] observed more

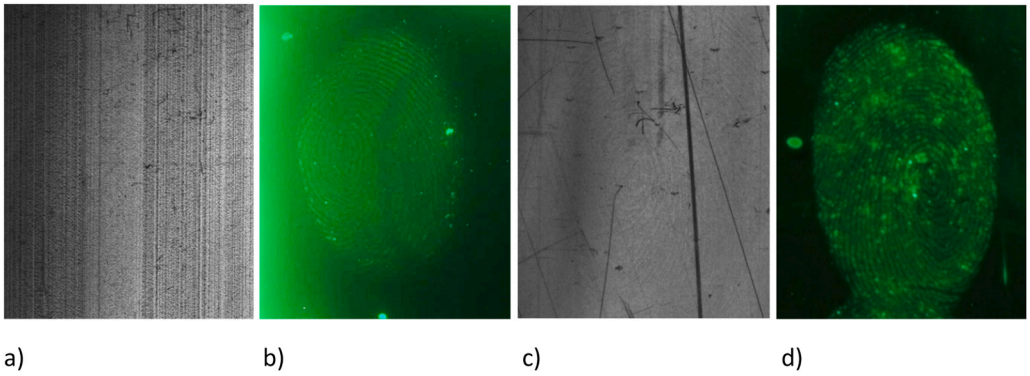

Fig. 15. Results for natural fingermarks (depletion 1) visualised with a) UVC reflection on polyethylene, day 1, b) mark a) following cyanoacrylate fuming and BY40, c) UVC reflection on polypropylene, day 1, d) mark c) following cyanoacrylate fuming and BY40.

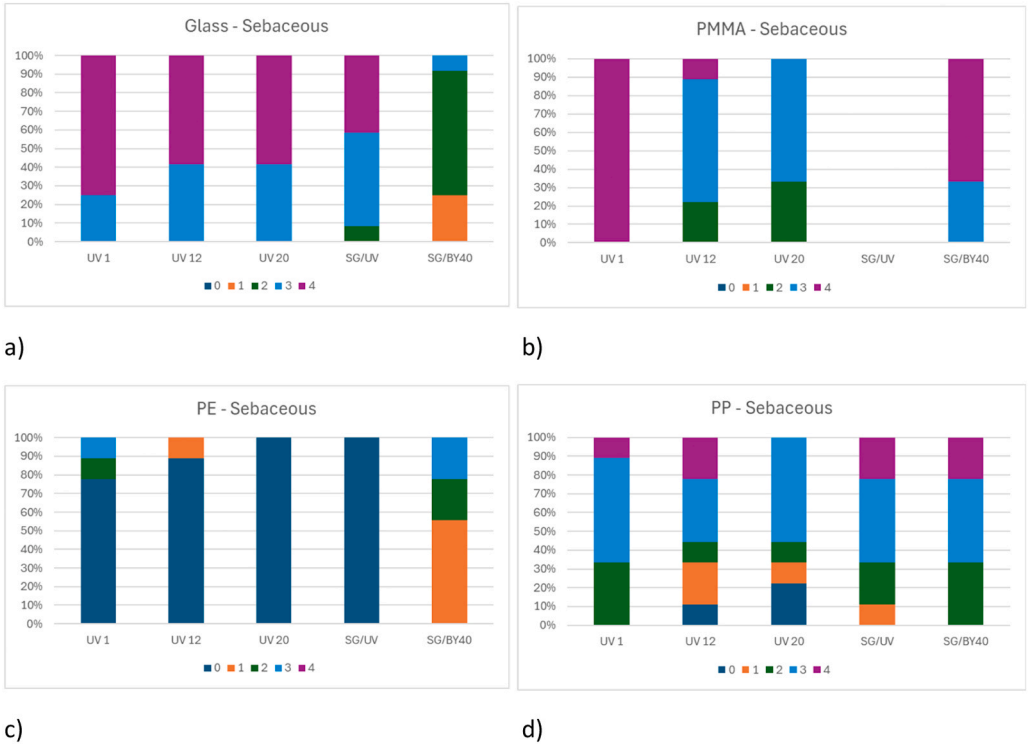

Fig. 16. Stacked bar charts showing changes in mark quality at different stages of the processing sequence for sebaceous marks on a) glass, b) PMMA, c) polyethylene, d) polypropylene.

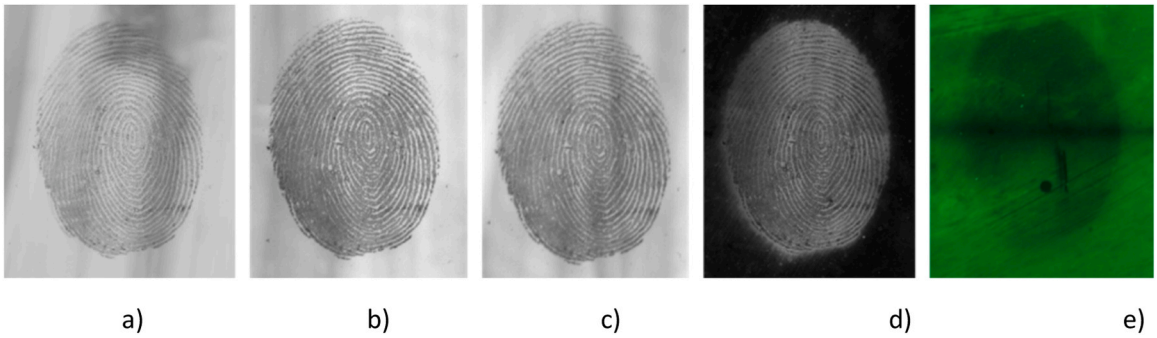

Fig. 17. Results for sebaceous fingermarks (depletion 5) deposited on glass, a) UV reflection, day 1, b) UV reflection, day 12, c) UV reflection, day 20, d) UV reflection after cyanoacrylate fuming, e) Basic Yellow 40.

migration on Formica as opposed to silicon and considered migration to be affected by fingermark components and the substrate texture and

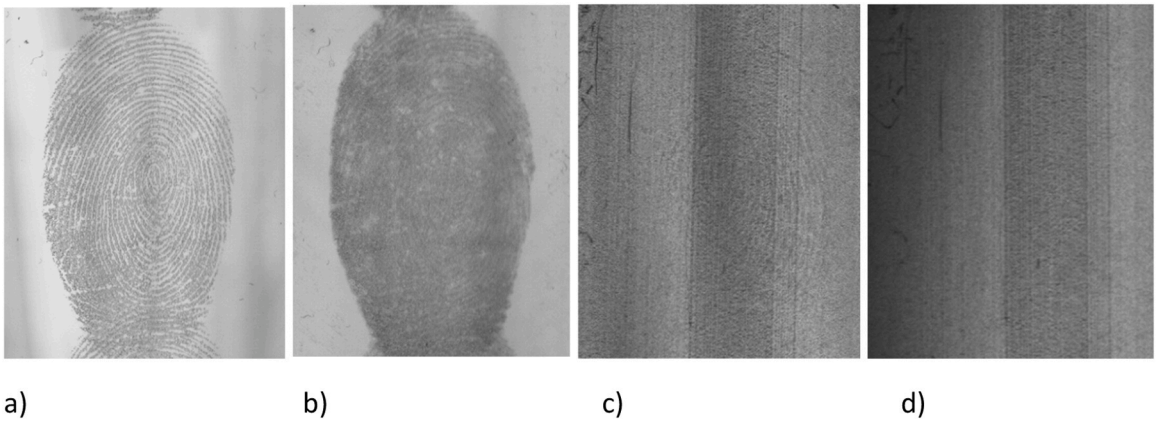

Fig. 18. Results for sebaceous fingermarks, a) depletion 5 on PMMA, UVC reflection, day 1, b) depletion 5 on PMMA, UVC reflection, day 12, c) depletion 1 on polyethylene, UVC reflection, day 1, b) depletion 1 on polyethylene, UVC reflection, day 12.

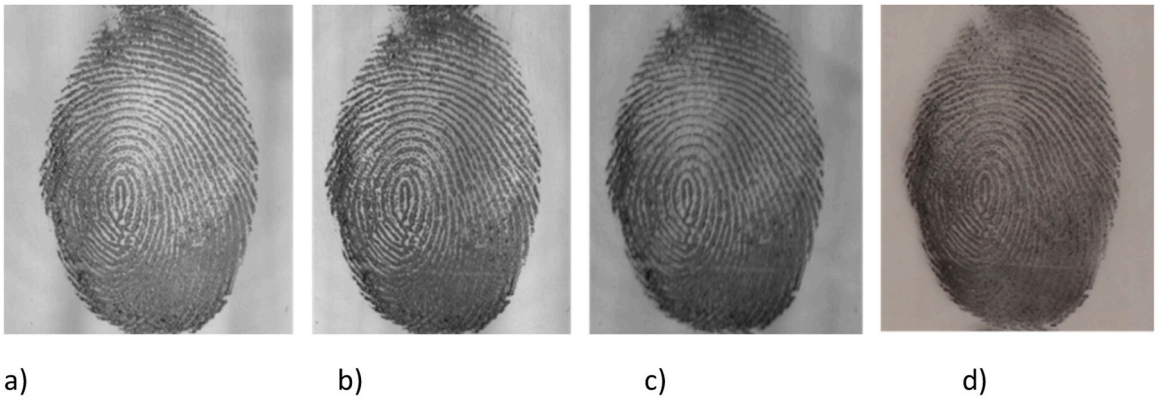

Fig. 19. Results for marks in Vaseline® (depletion 5) deposited on glass, a) UV reflection, day 1, b) UV reflection, day 12, c) UV reflection, day 20, d) after black magnetic powder.

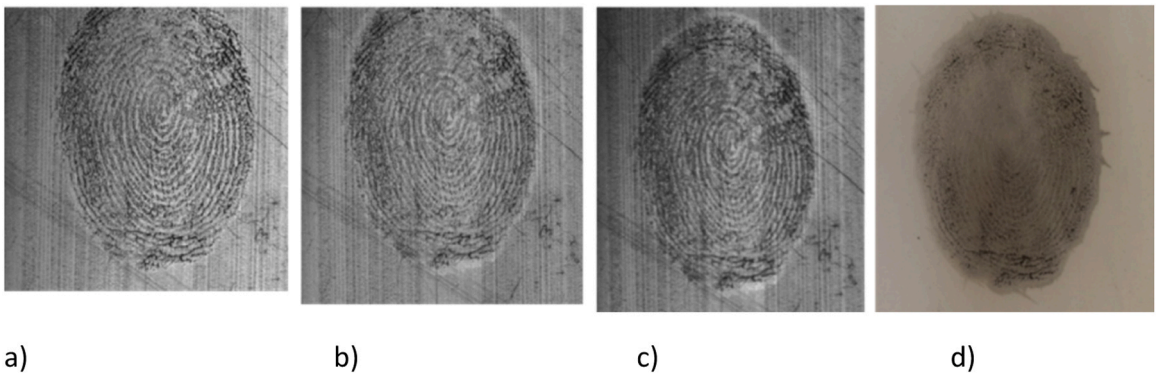

Fig. 20. Results for marks in Vaseline® (depletion 2) deposited on polyethylene, a) UV reflection, day 1, b) UV reflection, day 12, c) UV reflection, day 20, d) after black magnetic powder.

surface energy.

In contrast, the natural and sebaceous fingermarks exhibited more time-dependent behaviour, which is consistent with observations by previous researchers. Moret et al. [39] used various optical and scanning electron microscopy methods to analyse fingermark ridges deposited on glass, polyvinyl chloride (PVC), PP and PE substrates. For sebaceous marks they demonstrated that the distribution and droplet size observed in marks immediately after deposition varied across the different substrates and this was attributed to surface tension. On ageing marks on glass, PP and PVC over a period of 2 months it was seen that on glass any changes in morphology occurred relatively slowly, whereas on PP marks had disappeared in less than 4 days and this degradation occurred more quickly on PVC. This was attributed to constituents dissolving into the substrate or into surface contaminants or coatings.

In this study, UVC reflection was found ineffective in detecting natural marks on the polyethylene substrate used. Possible reasons may be that the polyethylene surface is rougher than the other materials used at a nanometre scale, resulting in more scattering from the surface and reduced contrast with the mark, or possible that the UVC radiation penetrates further into the polyethylene than the other higher density

substrates, making it more difficult to discriminate marks on the surface.

De De De Alcaraz-Fossoul et al. [36] aged eccrine and sebaceous marks on glass and polystyrene over 6 months and also observed marks to be more stable on glass than polystyrene. The current study shows similar trends in the stability of natural and sebaceous marks on different surfaces, with marks persisting longest on glass followed by PMMA, PP, and disappearing quickest on PE. Natural marks disappear more quickly than sebaceous marks, although sebaceous marks can exhibit more diffusion of the ridge detail than natural marks. The diffusion effect has been previously observed [36,37], and the magnitude of diffusion has also been proposed as a method for dating fingermarks [40]. In this study the diffusion of sebaceous marks was shown to be substrate dependent (consistent with [37]) and most pronounced on PMMA. The ridges of some sebaceous marks on polypropylene and viewed by UVC reflection were seen to change from lighter than the background to darker over time. Possible reasons for this include drying of the mark, an associated change in topography, or possibly a change in UV reflectivity as chemical composition is modified by oxidation.

The limited number of results obtained reinforce previous findings that show the use of non-contact optical techniques such as UVC reflection may detect marks of high quality than chemical or physical processes applied subsequently. This is because these methods are visualising the mark in its 'as deposited' state, rather than after interaction with chemicals or physical contact between the developing medium and the fingermark ridges. Previous research [1] showed that white lighting methods (especially a ball light) were also highly effective in this application, but this comparison was not part of the current study so it is not possible to comment on the relative effectiveness of UVC reflection with white light.

Although the results obtained indicate there may be operational benefit in using UVC reflection on casework before chemical and physical processes, it must be emphasised that the current study is limited in scope. The main limitation is that fingermarks were confined to a single donor and a single set of fingermarks (repetitions were not possible due to equipment availability), but the objective of this work was to evaluate the potential use of UVC reflection to complement other methods used in fundamental research, not to conduct a full evaluation of its operational effectiveness relative to other processes

4. Conclusions

In this study UVC reflection was found to be an effective process for monitoring the quality of fingermarks at different stages in processing sequences, both when exploring the impact of methods that may be used to remove them, and for indicating situations where chemical and physical enhancement processes fail to enhance the quality of the material deposited.

The age of the fingermark, its composition and the type of surface it has been deposited on all play a role in the quality of the mark visualised by UVC reflection, and the process can be useful in monitoring these changes over time.

In this respect UVC reflection has been found to be a useful method in a research context, but a larger study with multiple donors and more broadly representative surfaces/items would be required to form opinions on operational effectiveness. It should also be noted that obtaining optimum results requires training and practice, and a skilled practitioner would need to conduct UVC reflection aspects of such a comparison to fully explore the potential of the process. At present, UVC reflection should still be a regarded as a specialist capability. The equipment used in this study is commercially available, but it is recognised that affordability may be a current barrier to widespread adoption in research and operational laboratories.

CRediT authorship contribution statement

S.M. Bleay: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **N.P. Marsh:** Conceptualization, Investigation, Methodology, Writing – review & editing.

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Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Stephen Bleay reports equipment was provided on loan by Arrowhead Forensics and ForenteQ.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.forsciint.2026.113044.

References

[1] N. Marsh, K. Marsh, L. Hall, R. Buckley, S. Bleay, Technical Report: A light touch; Reviewing the relative effectiveness of light sources and physical/chemical techniques for fingermark retrieval in casework, Forensic Science International Reports 10 (2024) 100391.
[2] P. Maynard, J. Jenkins, C. Edey, G. Payne, C. Lennard, A. McDonagh, C. Roux, Near infrared imaging for the improved detection of fingermarks on difficult surfaces, Aust. J. Forensic Sci. 41 (1) (2009) 43–62, https://doi.org/10.1080/00450610802172248.
[3] R.P. Downham, E.R. Brewer, R.S.P. King, A.M. Luscombe, V.G. Sears, Fingermark visualisation on uncirculated £5 (Bank of England) polymer notes: Initial process comparison studies, Forensic Sci. Int. 275 (2017) 30–43, https://doi.org/10.1016/j.forsciint.2017.02.026.
[4] R.P. Downham, E.R. Brewer, R.S.P. King, V.G. Sears, Sequential processing strategies for fingermark visualisation on uncirculated £10 (Bank of England) polymer banknotes, Forensic Sci. Int. 288 (2018) 140–158, https://doi.org/10.1016/j.forsciint.2018.04.018.
[5] M. Tahtouh, P. Despland, R. Shimmon, J.R. Kalman, B.J. Reedy, The Application of Infrared Chemical Imaging to the Detection and Enhancement of Latent Fingerprints: Method Optimization and Further Findings, J. Forensic Sci. 52 (2007) 1089–1096, https://doi.org/10.1111/j.1556-4029.2007.00517.x.
[6] M. Tahtouh, S.A. Scott, J.R. Kalman, B.J. Reedy, Four novel alkyl 2-cyanoacylate monomers and their use in latent fingermark detection by mid-infrared spectral imaging, Forensic Sci. Int. 207 (1–3) (2011) 223–238, https://doi.org/10.1016/j.forsciint.2010.10.012.
[7] J.A. Radley, J. Grant, Fluorescence Analysis in Ultra-Violet Light, 1st edition, D Chapman & Hall, London, 1933.
[8] H.L. Brose, Finger-print Detection, Analyst 59 (1934) 25–27.
[9] H. Ohki, Physio-chemical Study of Latent Fingerprint. 1 Ultraviolet Absorption and Fluorescence of Human Epidermal Secretion, Reports National Research Institute Police Science (Japanese) 23 (1) (1970) 33–40.
[10] N. Saito, S. Arai, The Detection of Fingerprint by Ultraviolet Ray Television, Reports National Research Institute Police Science (Japan) 25 (1) (1972) 57–58.
[11] K.E. Creer, The Detection and Enhancement of Latent Marks Using Specialised Lighting and Imaging Techniques, Proc. Int. Symp Fingerpr. Detect. Identif. (1995). Ne'urim, Israel.
[12] H. Fraval, A. Bennett, E. Springer, UV Detection of Untreated Latent Fingerprints, Proc. Int. Symp Fingerpr. Detect. Identif. (1995). Ne'urim, Israel.
[13] E.R. German, Reflected Ultraviolet Imaging System Applications, Proc. Int. Symp Fingerpr. Detect. Identif. (1995). Ne'urim, Israel.
[14] W.G. Qiang, Detecting and Enhancing Latent Fingerprints with Short Wave UV Reflection Photography, Proc. Int. Symp Fingerpr. Detect. Identif. (1995). Ne'urim, Israel.
[15] L.V. Keith, W. Runion, Short-wave UV imaging casework applications, J. Forens. Ident. 48 (5) (1998) 563–569.
[16] B.Y. Nissim, J. Almog, A. Frank, E. Springer, A. Cantu, Short UV luminescence for forensic applications: Design of a real time observation system for detection of latent fingerprints and body fluids, J. Forens. Sci. 43 (2) (1998) 299–304.

[17] R. Saferstein, S. Graf, Evaluation of a reflected UV imaging system for fingerprint detection, J. Forens. Ident. 51 (4) (2001) 385–393.
[18] J. Anderson, S. Bramble, The effects of fingermark enhancement light sources on subsequent PCR-STR DNA analysis of fresh bloodstains, J. Forens. Sci. 42 (2) (1997) 303–306.
[19] P. Grubwieser, A. Thaler, S. Köchl, l R. Teiss, W. Rabl, W. Parson, Systematic study on STR profiling on blood and saliva traces after visualization of fingerprint marks, J. Forens. Sci. 48 (4) (2003) 733–741.
[20] J. Raymond, C. Roux, E. Du Pasquier, J. Sutton, C. Lennard, The effect of common fingerprint detection techniques on the DNA typing of fingerprints deposited on different surfaces, J. Forens. Ident. 54 (1) (2004) 22–44.
[21] A. Hall, L. Sims, A. Foster, J. Ballantyne, Chapter 10: DNA Damage and Repair in Forensic Science, in: E. Katz, J. Halámek (Eds.), Forensic Science: A Multidisciplinary Approach, Wiley, 2016, https://doi.org/10.1002/9783527693535.ch10.
[22] E. Springer, Two Techniques for Improving Fingerprint Yield, Proc. Int. Symp Fingerpr. Detect. Identif. (1995), 1995. Israel: Ne'urim.
[23] R.S.P. King, L.W.L. Davis, D.A. Skros, The use of longwave reflected UV imaging for the enhancement of cyanoacrylate developed fingermarks: A simple, safe and effective imaging tool, Forensic Sci. Int. 289 (2018) 329–336.
[24] G. Illston-Baggs, P. Deacon, J. Ivanova, L. Nichols-Drew, K.J. Farrugia, A pseudo-operational trial: An investigation into the use of longwave reflected UV imaging of cyanoacrylate developed fingermarks, Forensic Sci. Int. 325 (2021) 110871.
[25] N. Cai, Y. Zou, J. Almog, G. Wang, Z. Mi, Inherent Fluorescence Detection of Latent Fingermarks by Homemade Shortwave Ultraviolet Laser†, J. Forensic Sci. 62 (2017) 209–212, https://doi.org/10.1111/1556-4029.13239.
[26] N. Saitoh, N. Akiba, Ultraviolet Fluorescence Spectra of Fingerprints, Sci. World 5 (1) (2005) 355–366, https://doi.org/10.1100/tsw.2005.43.
[27] N. Akiba, N. Saitoh, K. Kuroki, Fluorescence Spectra and Images of Latent Fingerprints Excited with a Tunable Laser in the Ultraviolet Region, J. Forensic Sci. 52 (5) (2007) 1103–1106, https://doi.org/10.1111/j.1556-4029.2007.00532.x.
[28] A.P. Gibson, M. Bannister, S.M. Bleay, Comparison of Three Ultraviolet Searching and Imaging Systems for the Recovery of Fingerprint, J. Forens. Ident. 62 (4) (2012) 349–367.
[29] Fingermark Visualisation Source Book v3.0, ISBN: 978-1-3999-3393-3 DSTL/PUB143443, September 2022, 2.UV.9 – 2.UV.12.
[30] W. Stoddart, K. Georgiou, P. Deacon, L. Nichols-Drew, K.J. Farrugia, Technical note: A preliminary assessment of UV-C imaging using the Full Spectrum Imaging System (FSIS-II) for the detection of latent fingermarks, Forensic Sci. Int. 355 (2024) 111945.
[31] IFRG, Guidelines for the Assessment of Fingermark Detection Techniques, J. Forensic Identif. 64 (2014) 174–200.
[32] S. Bleay, H. Smart, J. Sorensen, P. Sears, The effect of products containing high concentration corrosive substances on the recovery of fingermarks from non-porous surfaces, Sci. & Justice 64 (5) (2024) 521–532, https://doi.org/10.1016/j.scijus.2024.08.003.
[33] Bandey, H. (ed) Fingermark Visualisation Manual (2ed), Home Office and Dstl, 2022 ISBN: 978–1-3999–0976-1
[34] R.P. Downham, V.G. Sears, L. Hussey, B.-S. Chu, B.J. Jones, Fingermark visualisation with iron oxide powder suspension: The variable effectiveness of iron (II/III) oxide powders, and Tween® 20 as an alternative to Triton™ X-100, Forensic Sci. Int. 292 (2018) 190–203, https://doi.org/10.1016/j.forsciint.2018.09.012.
[35] G. Bradshaw, S. Bleay, J. Deans, N. NicDaeid, Recovery of Fingerprints from Arson Scenes: Part 1 – Latent Fingerprints, J. Forensic Identif. 58 (1) (2008) 54–82.
[36] J. De Alcaraz-Fossoul, C. Mestres Patris, A. Balaciart Muntaner, et al., Determination of latent fingerprint degradation patterns—a real fieldwork study, Int. J. Leg. Med. 127 (2013) 857–870, https://doi.org/10.1007/s00414-012-0797-0.
[37] K.T. Popov, V.G. Sears, B.J. Jones, Migration of latent fingermarks on non-porous surfaces: Observation technique and nanoscale variations, Forensic Sci. Int. 275 (2017) 44–45, https://doi.org/10.1016/j.forsciint.2017.02.015.
[38] B.N. Dorakumbura, T. Becker, S.W. Lewis, Nanomechanical mapping of latent fingermarks: A preliminary investigation into the changes in surface interactions and topography over time, Forensic Sci. Int. 267 (2016) 16–24, https://doi.org/10.1016/j.forsciint.2016.07.024.
[39] S. Moret, X. Spindler, C. Lennard, C. Roux, Microscopic examination of fingermark residues: Opportunities for fundamental studies, Forensic Sci. Int. 255 (2015) 28–37.
[40] S. Muramoto, E. Sisco, Strategies for potential age dating of fingerprints through the diffusion of sebum molecules on a nonporous surface analyzed using time-of-flight secondary ion mass spectrometry, Anal. Chem. 87 (16) (2015) 8035–8038.