Title page: **The effect of DNA recovery on the subsequent quality of latent fingermarks: a pseudo-operational trial**

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Abstract

The recovery of fingermarks and DNA from the same location at a crime scene can be problematic because of contamination issues associated with powdering or laboratory-based visualisation processes and/or the perceived destructive impact of commonly employed 'swabbing' approaches to DNA recovery. Previous research in a controlled environment demonstrated that it was possible to recover DNA and latent fingermarks from the same location on various substrates when an adhesive approach to DNA recovery was used. The aim of this research was to conduct a pseudo-operational trial into the dual recovery of DNA and fingermarks using gel lifters for DNA recovery. Participants were asked to voluntarily and anonymously donate a wide variety of porous and non-porous substrates post handling. No instruction as to fingermark deposition nor environmental storage was provided. BVDA gel lifters were applied to the substrates to replicate DNA recovery followed by the application of fingermark visualisation processes. The number and quality of the fingermarks was established using a grading approach. Application factors were also investigated to consider the effects of user variation. The results demonstrated that it was possible to recover DNA and fingermarks considered to be capable of supporting an identification. Fingermark quality post lifting was dependant on the substrates used. The weight applied to the gel during its application was a lesser contributing factor than the duration of its contact with the surface. There was a greater chance of leaving the fingermarks unaltered with the application of a low weight and instantaneous retraction.

Keywords: Evidence: DNA: Fingermarks: Crime Scene: Contamination: Innovation

Introduction

The recovery of fingermarks and DNA are widely used and important pieces of forensic evidence as they can assist in the differentiation of individuals and therefore help to identify perpetrators of crime. The recovery of both evidence types from the same location at a crime scene or evidential item can be problematic given that the recovery of either evidence type can affect the recovery of the other. The approach at present often involves the investigator making a choice as to which evidence type to recover, or to recover DNA and fingermarks from alternative areas of the substrate. Fingermark visualisation methods, such as dusting, which is frequently deployed at scenes of crime owing to its simple, portable, and relatively inexpensive nature can easily contaminate or remove potential sources of DNA [1] [2] [3]. Precautions, such as disposable brushes and single use powder samples may alleviate contamination issues, although they do not address DNA source displacement arising from the physical action of brushing. The use of magnetic powders may mitigate DNA displacement, as they have no direct contact with the surface during application [4]. It has been demonstrated however, that some magnetic powders can negatively impact DNA recovery and cause inhibition during DNA extraction for methodologies which utilise paramagnetic beads [5] [6] [7]. Compared to dusting methods, laboratory development of marks offers increased versatility and sensitivity as the approaches target specific components of latent fingermark residue. Problematically, many of these approaches involve immersion of the evidential item into various solutions, which have also demonstrated to result in cross-contamination and DNA destruction, requiring omittance of certain techniques and freshly prepared solutions [3]. The impact of any fingermark visualisation process on DNA recovery is likely to be linked to laboratory practices with respect to DNA decontamination protocols for reagents and environments, should dual recovery be considered. The extent to which these precautions are taken are likely to vary according to the nature of the investigation and police force policy, including the financial and time implications for the user.

It is possible to recover DNA using a variety of mediums. Cotton swabs are routinely deployed for DNA recovery from persons or evidential items given their relatively cost-effective and user friendly approach. Depending on the area for recovery the swab may be moistened with water or solvents, including extraction buffer, which is designed to facilitate effective recovery and subsequent DNA analysis [8]. Alternative swab types are available, such as flocked and foam. Alternative published research by the authors has demonstrated that it is possible to recover DNA from non-porous and porous substrates using gel lifters [9]. This approach has also been reported as effective in research projects by alternative research teams, providing evidence of a proof of concept in its design [5] [10]. Different recovery mediums are used for different substrates and circumstances, such as the use of cotton swabs for the recovery of DNA from humans and DNA recovery from clothing with tape [11]. The effectiveness of these approaches, including complementary extraction has been extensively reviewed in the literature because variance can affect the quality and quantity of DNA recovered [12] [13].

The recovery of DNA and fingermarks from the same location or evidential item may offer clear benefits to an investigation given the increased quantity of evidence available, both of which can potentially support an identification. In this instance there are several possible scenarios. The DNA and the fingermark may be from the same donor where the source of the DNA is the fingermark. Alternatively, the DNA and the fingermark may be from different donors but both evidence types originate from the fingermark. The DNA and fingermark may be from the same donor but the source of the DNA or fingermark are from different biological materials, or the

DNA and the fingermark may be from different donors and the source of the DNA or fingermark are from different biological materials. It may also mean that some of the evidential material may be latent and other material patent. These scenarios may produce complexities for the forensic scientist, but this is typical of casework material.

In some circumstances it may be possible to locate the fingermark prior to any contact of DNA recovery or visualisation process such as powder. Location may be assisted with the use of oblique lighting and high intensity light sources, although in practice there is limited assurance that the use of light sources for fingermark detection effective, given that there is often insufficient material or fluorescent contamination in a fingermark to make them visible [14]. In instances where detection is possible, an assessment of the identification potential of the mark may be considered, which would offer a huge benefit to the investigator in their development of a forensic strategy. The reality for many cases however is that the quality and identification potential of any existing marks is unknown until the visualisation process has been applied, and the quality of any marks are significantly affected by the substrate itself, deposition factors such as force applied [15], the chemical composition of the latent mark residue, and their environment(s) to which there are exposed post-deposition, as summarised by Girod et al [16]. Additionally, the quality of the resultant marks is likely to be related to the competency of the person applying the technique and/or efficacy of the equipment being used. This means that despite best efforts, fingermarks that are recovered from evidential items will not necessarily support an identification, and in routine processing of the item for fingermark evidence there are no further opportunities to recover DNA evidence.

Likewise, the quality and quantity of DNA recovered from a substrate is unknown at the time of recovery and it is logical to assume that the recovery of DNA prior to fingermark recovery using typical dry and wet swabbing would affect the appearance of any fingermarks deposited at the same location, thus removing the opportunity for dual recovery. Earlier research by the research team supports this, but also found that less adhesive approaches to DNA recovery and the use of dry flocked swabs were far less destructive to latent fingermark quality generally than wet or dry cotton swabs or adhesive tape [17]. The effects of DNA recovery and extraction has also been investigated with respect to alternative evidence types, such as fibres when processing clothing, for both biological and trace evidence [18].

This piece of work has provided a useful starting point research in this subject area. In line with the International Fingerprint Research Group Guidelines [19] and guidance from the Centre for Applied Science and Technology [20], a pseudo-operational investigation has been conducted which has significantly enhanced this research area, facilitating an investigation in a less controlled environment, using samples of fingermarks and DNA from a broader range of donors, substrates and environmental exposure.

Method

Collection of Latent Fingermark Samples for the Pseudo operational trial

The pseudo-operational trial was split into two parts. The first part consisted of an uncontrolled element in which amnesty boxes were placed in public spaces to allow for voluntary and anonymous donation of items for people to contribute items consisting of ; 15cm high ball smooth glasses, textured plastic knife handles, white photocopier paper, aluminium drinks cans, and plastic drinks bottles. Glasses and knife handles were provided by the research team as clean, ready to use items, which were left beside the amnesty boxes for participants could use and return. No instruction was given to any participant regarding mark deposition, the quantity of surface contact, the duration

of ownership, or the number of people who were likely to have been in contact with the donated items, although it was explained to the participants that the recovery of fingermark and DNA samples was to be attempted from the substrates. A limit of twenty items of each substrate type were collected over the course of the study, with no prior knowledge of who may have, or how frequently an individual may have donated or handled an item.

One of the difficulties with conducting a pseudo-operational trial is the researcher's assurance that a sample of fingermarks representative of those encountered in casework has been acquired. In traditional, laboratory-based trials, a common approach is to recruit donors according to their observed ability to deposit fingermarks of a respective mass [13]. In response to this, six participants, consisting of 2 x 'heavy' latent fingermark donors, 2 x 'medium' latent fingermark donors, and 2 x 'light' latent fingermark donors were recruited for participation, a strategy designed to strengthen the experimental approach by providing some assurance of sample representativeness. Donor type was established as part of a pilot study, where consistency of latent fingermark depositions was accepted as far as practically possible (fingermarks were donated on three previous occasions, and the marks were visually examined to determine the consistency of the donor's marks). Each participant was provided with 3 of each of the previously described items in a clean condition following washing with mild detergent and warm water and was asked to handle and/or use the items and to return them once finished, as with the instruction to the anonymous donors.

Once retuned, items from both the controlled and uncontrolled elements were stored openly in a laboratory at 20 degrees Celsius for 24 hours prior to further treatment.

All items from the pseudo operational trial were subjected to DNA recovery using BVDA gel lifters per the following method. Using nitrile gloved hands, the acetate covering of 30 x 40 mm sections of gel was removed and the adhesive layer of the gel was applied to the donated items and consecutively applied, in overlapping sections until the entirety of the substrate had been exposed to a single gel. This method was employed to mimic the application of tape for the recovery of DNA [21] [22]. The authors recognise that DNA decontamination of the gel would be required prior to usage in an operational setting. Although this was not implemented in this study, ideas for decontamination using ethylene oxide and UV irradiation have been discussed and may form part of the team's future research.

Post DNA recovery the donated items were processed for latent fingermark development, using recommended practice from the Fingermark Visualisation Manual [2014]. White photocopier paper was submerged in a 0.5% solution of ninhydrin, containing acetic acid, ethyl acetate, ethanol and HFE7100. The paper was air dried in a fume cupboard and transferred to a humidity cabinet at 80ºC and 65% relative humidity for 5 minutes. Fingermarks on glass were enhanced by aluminium powder, which was applied with a Zephyr fibre glass brush until any fingermarks were visible. Aluminium cans, smooth and textured plastic items were developed using cyanoacrylate fuming in a Mason Vactron, MVC 3000 cabinet using 2 g of liquid cyanoacrylate as part of an autocycle. Once fumed, the items were submerged in Basic Yellow 40 (2 g in 1 L ethanol) for 1 minute, rinsed under slow running tap water and allowed to air dry in the laboratory. All fingermarks were photographed using a Foster and Freeman DCS5 system.

All fingermarks were graded using the following four criteria; 1). The estimated quantity of the fingermark available for analysis, 2). The quantity of the fingermark that was occupied by friction ridges, 3). Friction ridge

continuity within the fingermark, 4). The level of contrast between the ridges and the background. Each criterion was graded out of 5, with a total score being out of 20 [23]. This is summarised in Figure 1.
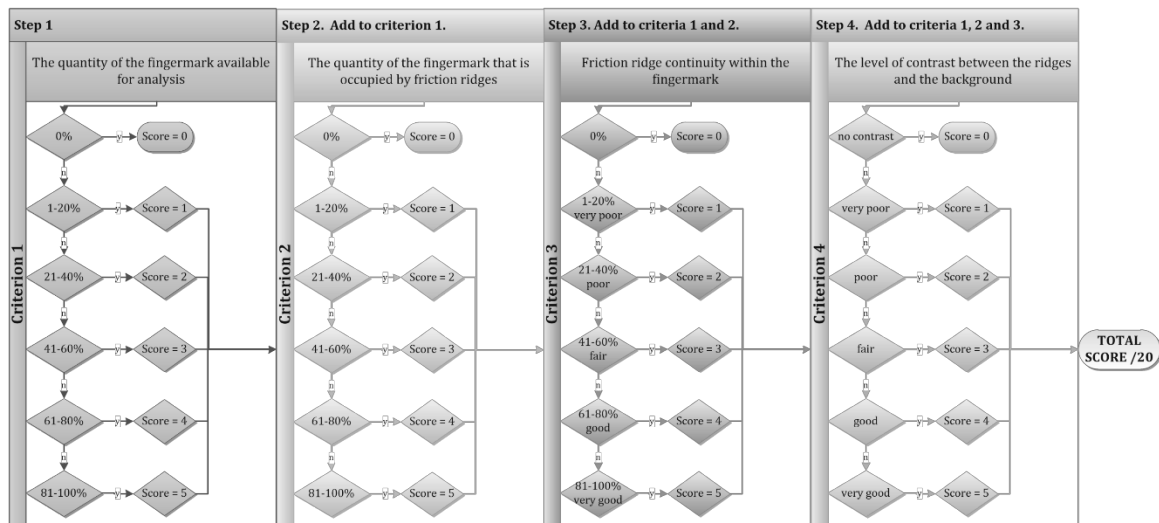

Fig 1 The grading methodology used for the pseudo operational trial

Areas of palm were graded as a 5 for surface area. The grading system used was specific to each technique used to take account of visualisation effects. For example, the Ninhydrin grading scale took into account marks affected by ridge 'dotting' (discontinuous development primarily concentrated around the pore openings), as expected within marks visualised using this process, and therefore the authors feel that this helped to normalise the assessment.

The total number of fingermarks recovered from each of the substrates was calculated.

Simulated user variation in the application of force to gel and its effects on latent fingermarks

Latent fingermarks were deposited on to each of the substrate types used for the pseudo-operational trial with acetate sheets being used to represent smooth plastic. Ten consecutively deposited split fingermarks were placed on to two adjacent substrates of the same type as a depletion series. One of the two split marks was subjected to DNA recovery using gel lifters applied at 400 g, 700 g, and 1200 g weights, referred to as 'low', 'medium' and 'high'. Conical flasks were filled with water until the above weights were reached. These were then applied over the gel lifters. The first, fifth and tenth marks of the depletion series were used to provide fingermarks of sufficient mass variation, with a total of 540 fingermarks. The split fingermarks were graded as described in figure 2 [24] [19].

Score	Definition
+2	Half control impression exhibits far greater ridge detail and or/contrast than the corresponding half-impression exposed to the gelatine lifter
+1	Half control impression exhibits slightly greater ridge detail and/or contrast than the corresponding half impression exposed to the gelatine lifter
0	No significant difference between the corresponding half impression
-1	Half-impression exposed to the gelatine lifter exhibits slightly greater ridge detail and/or contrast than the control half-impression
-2	Half-impression exposed to the gelatine lifter exhibits far greater ridge detail and/or contrast than the control half-impression

Fig 2 Grading system used in the user variation [24].

User variation in DNA recovery according to gel contact time with substrate during DNA recovery

Latent fingermarks were deposited on to each of the substrate types used for the pseudo-operational trial. Ten consecutively deposited split fingermarks were placed on to two adjacent substrates of the same type as a depletion series, again with the first, fifth and tenth depletion being targeted. One of the two split marks for each depletion was subjected to DNA recovery using gel lifters with an instant gel retraction. This was repeated but with the gel left to contact the substrate for two minutes prior to recovery.

The weight variations and contact time were combined to replicate real life application as far as possible.

Results and discussion

The total number of fingermarks recovered from each of the substrates post DNA recovery can be viewed in table 1.

Substrate	Total number of fingermarks recovered
Smooth plastic	1147
Aluminium	1245
Textured plastic	319
Paper	1528
Glass	1357

Table 1 The total number of fingermarks recovered from each substrate

These results demonstrate that it was possible to visualise friction ridge skin marks on each of the substrates post DNA recovery. The number of fingermarks on the surfaces encountered depended on the number of contacts made by the person handling the item, and the quality and quantity of the residue transferred during deposition, which was not controlled given the pseudo-operational approach.

This project has not focussed on the quantification of DNA from the samples but has examined the effects of this DNA recovery approach on the quality and quantity of the latent fingermark samples. This is because alternative research has provided evidence of a proof of concept of the use of gel lifters for DNA recovery, therefore

demonstrating its potential and how it could be applied in this context. Conversely, the literature has yet to report upon the effects of adhesive gel DNA recovery on the subsequent visualisation of latent fingermarks in a pseudo-operational context, which is equally part of the dual approach.

There was a significant variation in the number of marks recovered between some of the substrates. For example, 1528 marks were recovered from the paper samples, yet only 319 were recovered from the textured plastic knife handles. This was attributed to differences in surface area, as it was logical to expect fewer marks to be recovered from the smaller knife handle. Increased numbers of overlapping marks on the knife handles compared to larger surface areas such as paper were also expected, where the opportunity for handling the item was increased, and large sections of the area were often untouched. Textured substrates are notoriously more difficult to obtain friction ridge skin marks from, which may have contributed to the reduced frequency of marks, which will be considered later in the discussion.

The application of grading systems to assess the quality of fingermarks is common, owing to their ability to quantify qualitative descriptions of the fingermark in a reasonably succinct, time efficient manner, which frequently facilitates simple data analysis. The grading system used to assess the marks utilised four criteria, designed as part of a proficiency test for assessors of fingermark quality, to provide evidence of ability and consistency between users. Fingermark grades from table 1 along with the associated variance is illustrated in figure 3. Median values were used as the central measure to reflect the non-parametric data.
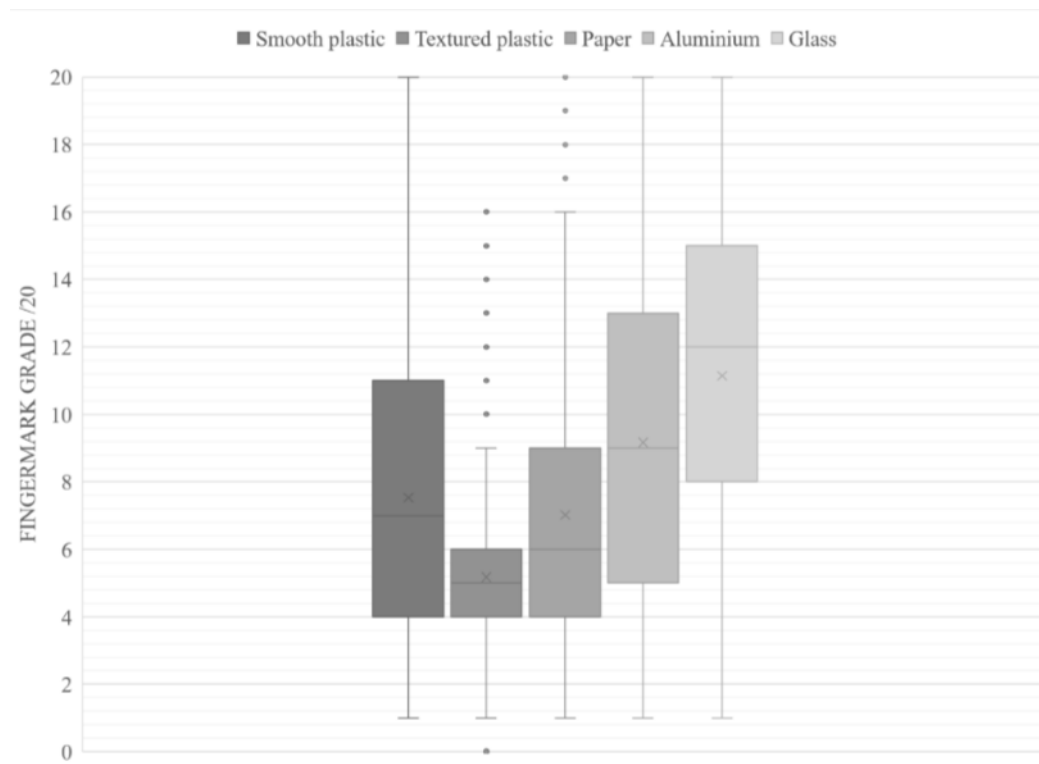

Fig 3 The quality of the marks according to the total grade /20 on each substrate (combined data from the uncontrolled and controlled pseudo-operational trials).

The results show that fingermarks recovered from the glass surface produced marks with the highest median values than the remaining substrates, followed by aluminium, smooth plastic, paper and textured plastic. When the upper and lower quartile range of values was considered, there was considerable overlap between grades, although the relative proportion of grades in the quartiles suggested a trend for quality, which aligned with the median values. Smoother surfaces are likely to produce marks of an increased quality to rougher substrates given that there is less substrate interference on the latent ridge structure. To summarise, if fingermarks of identical composition and structure were deposited on to a textured plastic and smooth glass substrate, one would expect the smooth substrate to produce a mark of better quality.

The visualisation techniques applied to each of the substrates were considered appropriate for use according to the porosity and colour of the substrate. The authors accept that the quality and number of the marks may have been different had additional treatments have been used because of the opportunity for the techniques to react with different constituents within the mark.

Most grades were below a grade of 15. The significance of this finding is difficult to quantify because we have no way of establishing how these results might compare to operational trial data. Fingermarks are exceptionally variable sample types and are affected by numerous physical and chemical factors which makes consistency and reproducibility in sampling and therefore accurate study of them very difficult. Compared to a controlled study, pseudo-operational samples are subjected to additional factors, such as overlapping marks, heterogenous samples and surface contaminants, which will be discussed in due course.

It was very encouraging to see that all of the substrates had retained marks that were capable of achieving the highest of all grades, although the authors recognise that for the textured plastic substrate, these values were listed as outliers. This was encouraging because it supported the idea that for some marks the application of a low adhesive DNA recovery method, such as gelatine had still permitted the recovery of a high quality fingermark, that could support an identification. The textured plastic substrate displayed more consistent grades, albeit lower, which was attributed to the substrate topography and the associated issues encountered within fingermark visualisation on this substrate type, and the likely presence of more overlapping marks. Marks on this surface type were frequently absent, incomplete (displaying an outline mark), or with limited and generally fragmented ridge detail. This was attributed to the fact that the friction ridges may only have contacted the topmost 'peaks' of the surface texture and therefore latent material only transferred at these points. To help establish whether the grades were attributable to the substrate or the DNA recovery, additional handles were subjected to fingermark visualisation using the same approaches, but without any prior DNA recovery. Analysis of these results suggested that the resulting marks displayed similar characteristics to those subjected to DNA recovery using gelatine lifters, suggesting that the substrate was contributing to the quality of the marks, and that the gelatine lifting process was having a minimal effect on fingermark quality.

When the data was compared to the results from a previously published controlled laboratory study it was found that fingermarks deposited on the smoother glass and metal substrates were more affected by adhesive DNA recovery methods than rougher substrates [17]. This was attributed to the fragility of the marks. It could be that despite their exposure on smoother substrates, the substrates themselves initially retain higher quantities of higher quality fingermarks, but the DNA recovery process can very destructive to weaker marks where most of the

material present is removed by the adhesive lifter. On marks of an increased mass the resilience of the samples are significantly increased, offering greater scope for dual recovery. It is essential to consider the pre and post design of the laboratory study, which examined the effects of recovery on mark quality. In controlled studies, useful strategies for effective comparative analysis are also possible, such as the use of split marks. In the pseudo-operational study only post DNA recovered substrates were examined. The team did consider 'controlled' non-DNA recovered items but felt that on account of the experimental design of anonymous donation, the allocation of a truly representative independent samples design to the experimental groups would have been exceptionally difficult to establish, and that this approach would also reflect operational work.

Also, in the previous laboratory study [17], fingermarks that were 'eccrine rich', 'sebaceous rich', and 'natural' were used. The former two strategies had the intention of biasing the residue composition and consisted of strategies commonly reported in fingermark related studies, and yet it is likely (and was commented in the publication) that this alteration to the natural composition of friction ridge residue will have affected the fragility of the marks. Eccrine rich marks may be more prone to degradation with or without DNA recovery on non-porous surfaces because of the reduction in water insoluble constituents, which may provide a resilient layer and increased mass to the marks. If we consider sebaceous contamination to increase mark mass and to incubate alternative reactive components then it would be logical to assume that any attempt to remove part of the mark would affect the mark to a lesser extent, which would also support observations recorded in the laboratory study. On this basis the authors would stress the need to review strategies to obtain representative samples of fingermarks for research, particularly those generated through strategies used to bias the composition because of the possibility of distorting the data, supporting the recommendations of International Fingerprint Research Group [20].

In addition to the chemical composition of the fingermark, the substrate itself was highly likely to have affected mark quality. This is because the substrates utilised as part of controlled experimental trials are intentionally likely to be mark and contaminant free, and isolated in terms of their deposition. In this trial the substrates were frequently saturated with marks, many of which overlapped. Contaminants and environmental exposure were unknown but considered likely to contribute to mark quality and certainly affected the visualisation processes by inhibiting or negatively enhancing some of the visualisation techniques such as excessive superglue polymerisation. In future work, it might be of interest to take multiple lifts from the same substrate to see whether it is possible to remove successive layers of fingermark deposits, which might infer something about the order of deposition. The researcher had no prior knowledge of the history of the aluminium and smooth plastic surfaces. Participants would have purchased them from a variety of sources, and these items are likely to have been stored and handled by various individuals prior to donation. This was a huge benefit to the study, given that it was considered that such samples were more likely to align with samples encountered in casework. The authors do recognise that sub-types of these materials may well behave in a different manner to those encountered in this study with the gel lifter, evidence of which was found in this study. For example, the number of different plastic materials which might be encountered in casework undoubtedly exceeds these samples, and of those encountered in this study it was apparent that the level of adhesion between the gelatine and the plastic varied from highly adhesive to limited adhesion, causing slippage during application. This action may have affected the quality of any underlying marks. The composition of the residue of the mark is likely to simultaneously affect its retention

and DNA recovery. For example, difficulties in gel adhesion may have been similarly indicative of poor interaction between the residue and the substrate.

All substrates also produced marks with poor quality grades after development. Numerous factors are known to contribute to the quality of friction ridge skin marks, including physical deposition, substrate contamination and residue composition, which contribute to mark resilience. The authors also accept that in some instances the recovery of DNA prior to fingermark visualisation is highly likely to have contributed to the poorer quality of the marks by removing part of the mark.
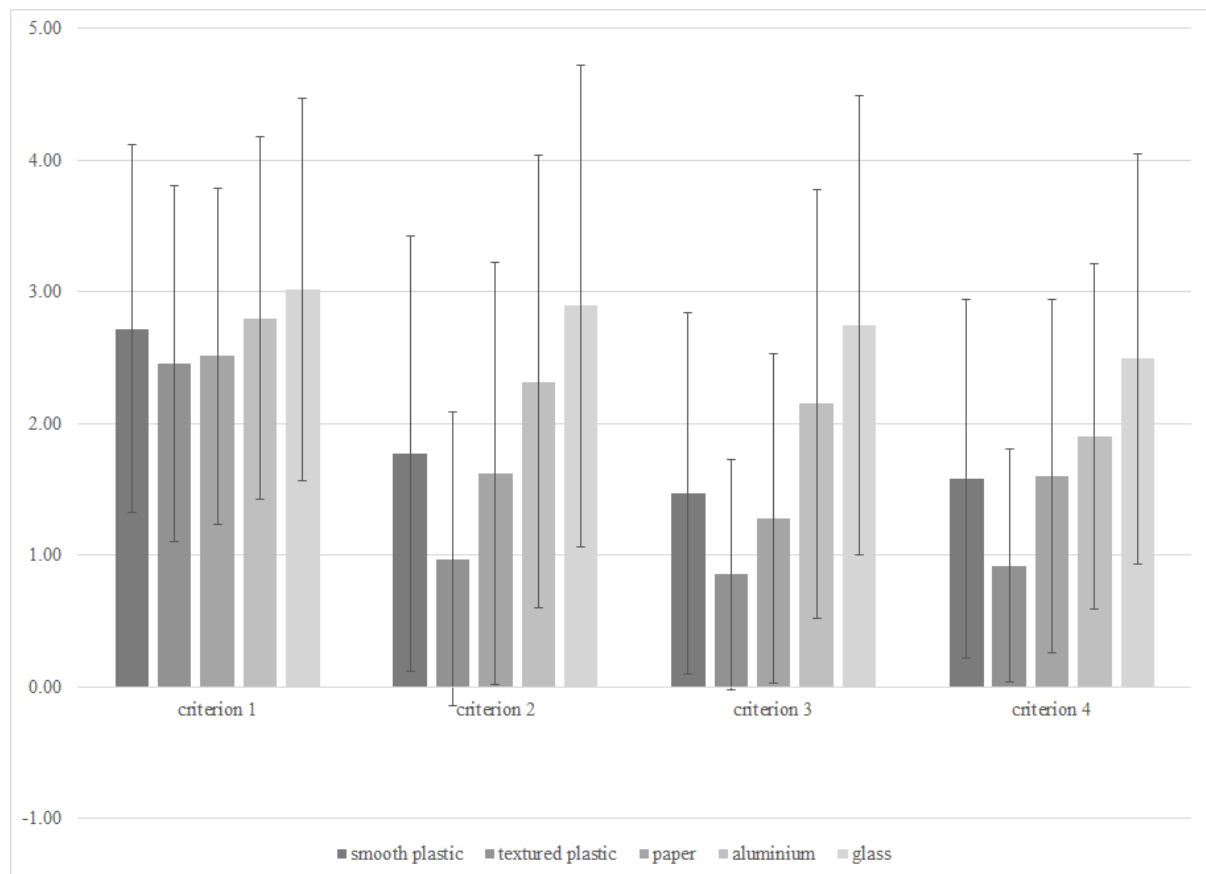

Fig 4 The quality of the marks according to each criterion of the grading approach /5 for each substrate (combined data from the uncontrolled and controlled pseudo-operational trials).

Figure 4 presents the mean grade data for each criterion on each substrate and error bars illustrating the standard deviation. When the data was considered by criterion, a similar trend was found in that glass and aluminium substrates retained fingermarks that were more complete, had increased quantities of ridge detail and improved ridge continuity and contrast compared to smooth plastic, textured plastic and paper.

Differences in the quantity of ridge detail was less apparent between substrates (criterion 1), which simply confirmed the presence of latent residue post DNA recovery. When this criterion was compared to the remaining criteria, it suggested that the substrate itself was significantly contributing to the quality of fingermark ridge detail retained post DNA recovery. For instance, the relatively poor overall grades for textured plastic are clearly attributable to the proportionately and consistently low grades for the criteria relating to ridge detail, continuity and contrast (criteria 2-4), with a standard deviation rarely exceeding a grade of 2. The mean grades for glass

were also consistent but proportionately higher, and the standard deviation suggested that the highest of all grades were awarded to this substrate.

The effects of DNA recovery on the identification potential of the fingermarks

The grading method used multiple criteria, which helped to consider how different properties of the fingermarks had contributed to their overall quality. However, this grading system focused upon the quality of the fingermarks rather than their value for identification, which is an obvious consideration for casework. It is common practise for fingerprint examiners working within numeric and non-numeric standards to use ridge detail to estimate the mark's value for identification, and therefore to investigate the proportion of marks suitable for casework identification the percentage scores for criterion 2 (the quantity of the fingermark occupied by usable ridge detail) were examined. Grades of 3-5 were classed as 'suitable for identification', as they represented marks with an estimated 41% or above of the surface area of the mark occupied by usable ridge detail. The results of this analysis can be seen in figure 5. From the earlier analysis it was evident that the results obtained were linked to substrate types therefore the results were similarly examined according to substrate.
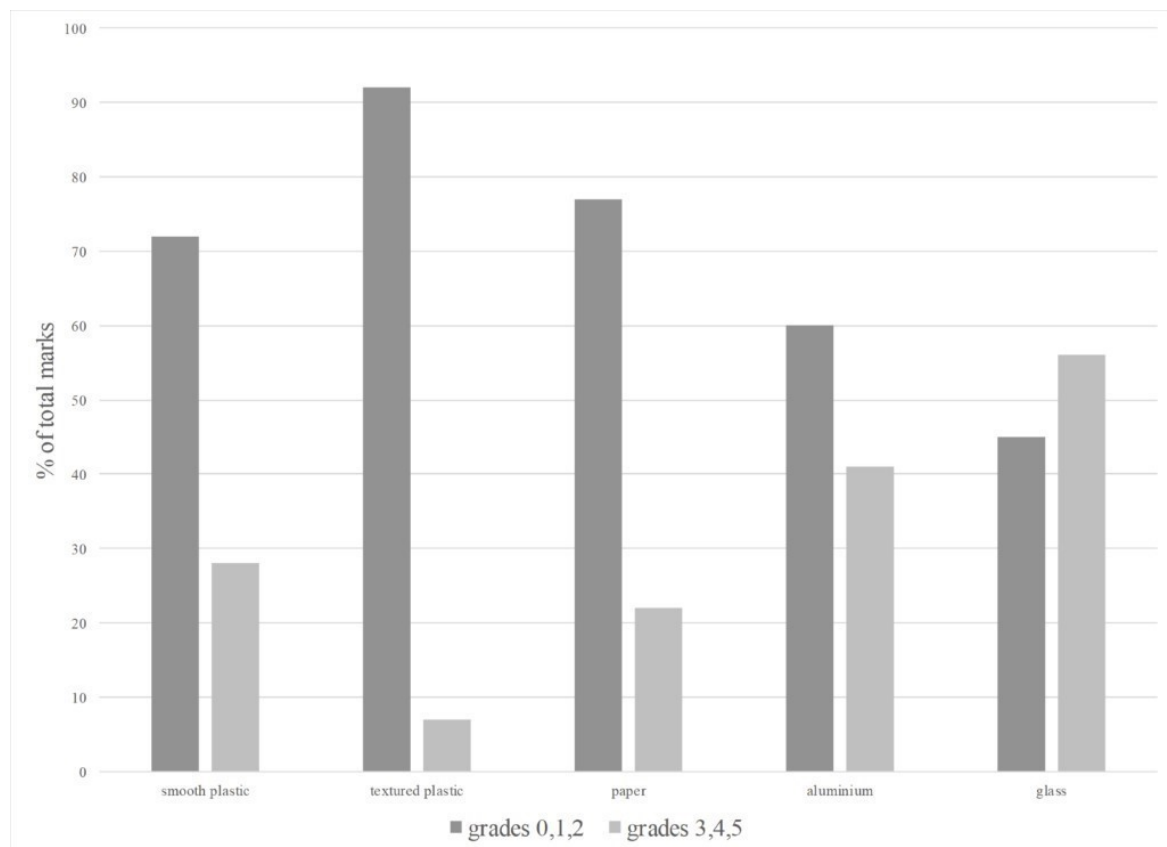

Fig 5 Percentage distribution of fingermarks 'suitable for identification' according to substrate for pseudo - operational trial marks

As far as the authors are aware there is no accepted data available to suggest the likely proportion of usable fingermarks retrieved from these substrates as part of casework, and therefore it is not possible to state if this data falls within an accepted casework standard. An accepted casework standard would be extremely difficult to

estimate given that internationally and nationally different laboratories are likely to encounter a different mix of exhibits depending on the crimes committed in that region. Different laboratories may work towards different submission policies, which will also influence success rates. As described in the methods section, a difficulty associated with the design of a pseudo-operational trial is the assumption that a representative sample (i.e. of casework marks) has been obtained. In response to this issue, the control group was used, containing items handled by fingermark donors considered to donate 'heavy', 'medium' and 'light' fingermarks. Figure 6 illustrates the percentage distribution of fingermarks classed as 'suitable for identification' for the control group marks.
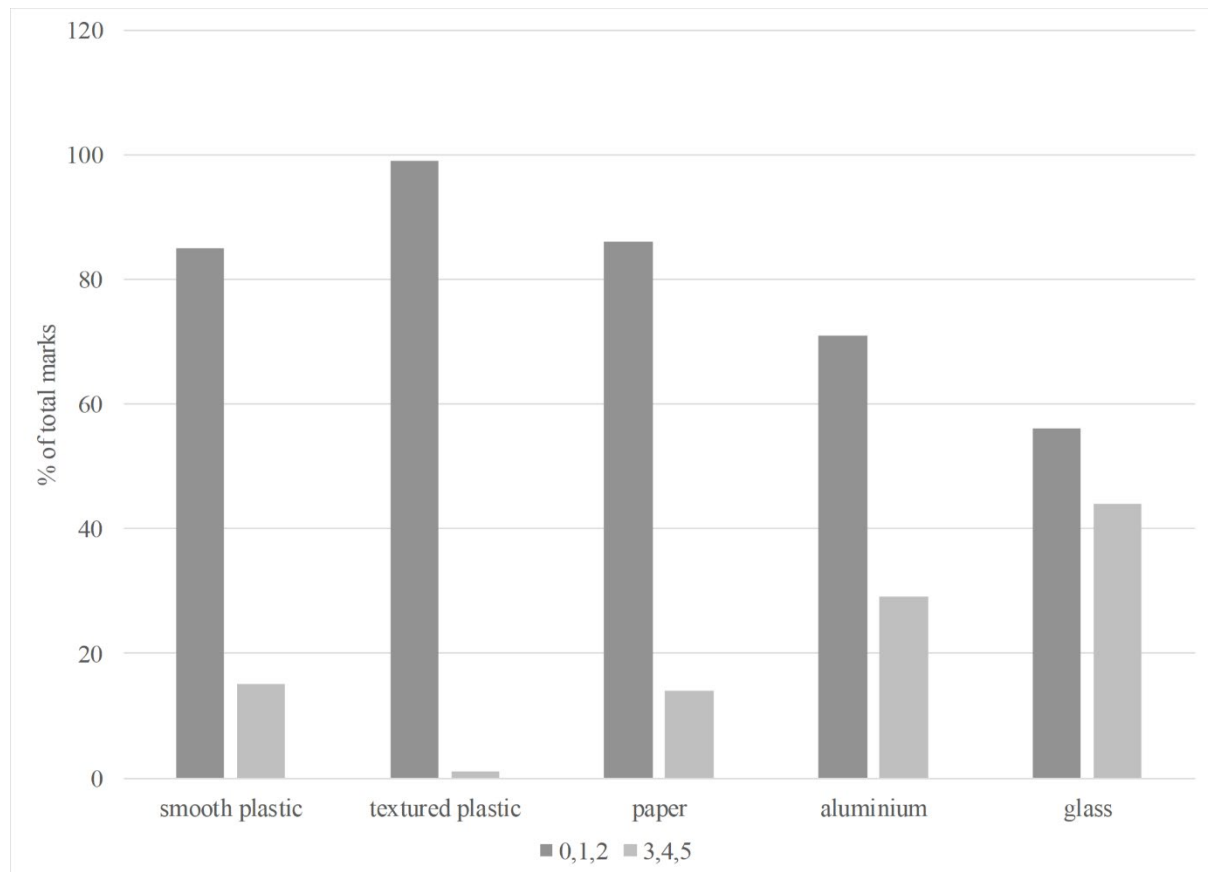

Fig 6 Percentage distribution of fingermarks 'suitable for identification' according to substrate for the control group marks

The trend for the pseudo-operational group and the control group were very similar, suggesting that a good range of fingermarks had been deposited within the pseudo-operational sample group. The strategy used to recruit donors in the control group is routinely used within fingermark research projects to obtain marks that are representative of casework.

The data demonstrated that it was possible to recover fingermarks that were 'suitable for identification' post DNA recovery using gel lifters for DNA recovery prior to mark visualisation on those substrates utilised as part of the study and on smoother substrates the user is seemingly more likely to retrieve a mark that could support an identification. If we consider these results in combination with the earlier controlled study, smoother substrates were those where the quality of the fingermarks was most affected, so these results could imply that where the fingermark is of sufficient initial quality, these substrates receive and retain the residue in such an effective manner

as to permit partial removal and post visualisation. It also highlights the sensitivity of the reagents used to visualise the marks. Recovery of the marks was attempted following 24 hours of storage. In the future the team would like to examine the effects of a longer pre DNA recovery period. The team are also considering alternative, novel DNA recovery techniques that continue to facilitate the recovery of DNA and fingermarks with minimal destructive impact on either evidence type. Included in this work is consideration of the requirement for sterility of the DNA recovery process. During examination of the items, it was sometimes apparent where the gelatine lifter had been used due to an outline of residue being observed post development. This has been reported with alternative research [25]. This reduced as the number of DNA recovery applications increased and was attributed to a reduction in the adhesiveness of the gel. Within this outline fingermarks were still present, yet in some instances the gelatine lifter was only laid over some of the ridge detail and not all. The difference between the two parts of the fingermark varied in quality, with occasional observations of lower contrast but clearer ridge detail being in the parts exposed to the gelatine lifter. An example of this can be seen in figure 6.

This was beneficial to those marks with a heavy mass residue due to reducing film thickness whilst also removing potential interferences from the surface resulting in more defined ridge detail [26]. A similar effect has been reported by Hemmell *et al*, who used gelatine lifters as a way of pre-treatment before chemically enhancing 2-dimensional footwear impressions, as they removed contaminates [27].

Fig 7 Fingermarks from a drinking glass illustrating the area where the gelatine lifter was applied.

One of the perceived benefits of using an adhesive medium to recover DNA is the increased uniformity in application between users and the interaction with the surface. The application of other recovery methods such as swabs, can be difficult to standardise between users when ensuring consistency, due to inter-user variation being demonstrated [28]. However, as far as the authors are aware the extent of this variation has not been fully explored. The perceived benefit of the gelatine layer is that it allows for even distribution of weight over a small area minimising the usage variations.

The scores for all weight variations were averaged over all surfaces used. The scores resulted in +0.16, +0.32 and +0.36 for the low medium and heavy weight respectively. As all the average scores were positive it indicated that there was some alteration to the fingermark when compared to the control half, with the lower weight having a lesser effect than the medium and heavy weight. As expected, the heavy weight had a greater impact due to the higher level of force, facilitating more of an interaction of the of the adhesive forces with the fingermark residue, although the difference with the medium weight was minimal. It should be noted that there was a total of 25 fingermarks which displayed no ridge detail on either side of the split surface resulting possibly from deposition variables that were left uncontrolled. These were spread evenly across depletion series and surfaces and were not considered further. There were instances where -2 grades were awarded due to the lack of a control half, possibly resulting from deposition variables such as uneven distribution of force and residue across the friction ridge skin during contact and were usually evident within a depletion series. The overall percentage of grades awarded over all surfaces are displayed in figure 7.
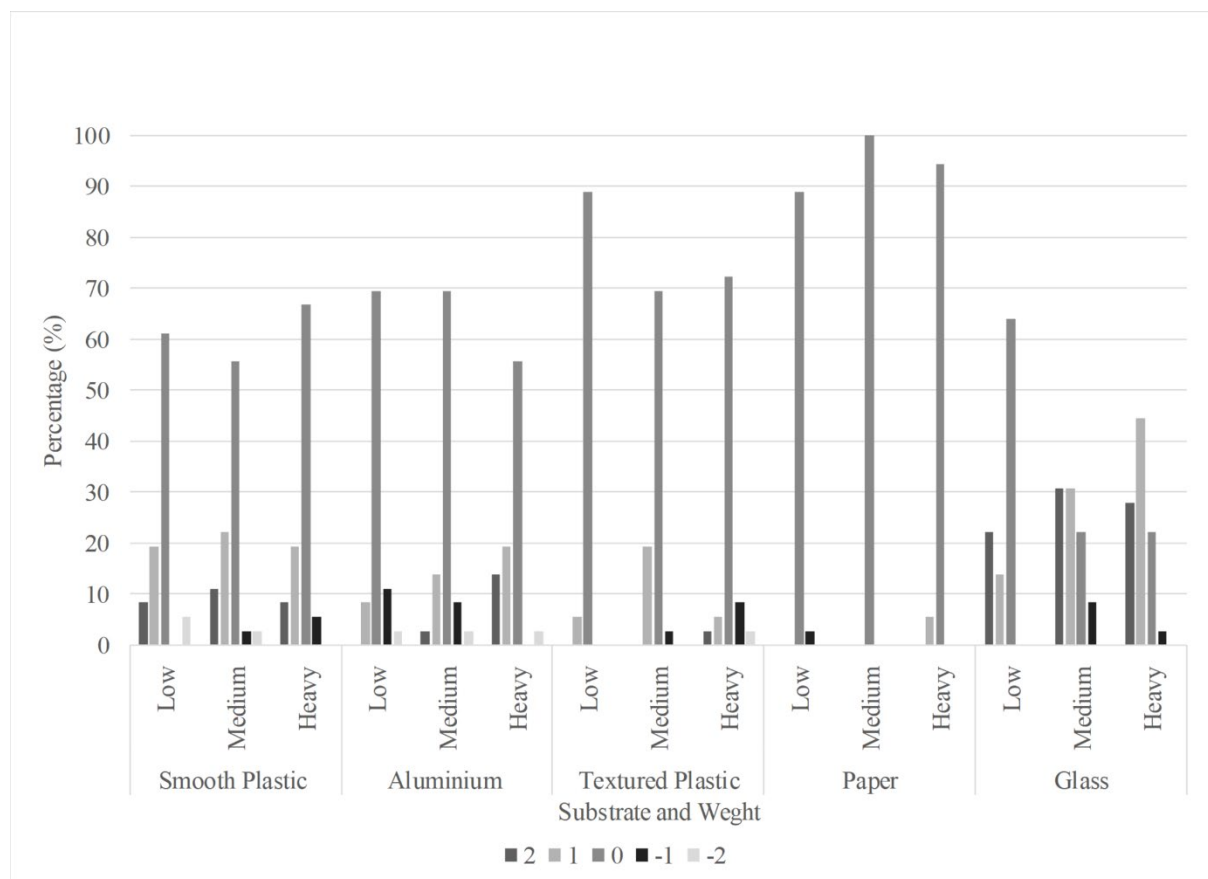

Fig 8 Percentages scores for weight distributions over all surfaces.

Most of the scores for surfaces were graded as 0 indicating there was no noticeable difference between the control half and that which was exposed to the gelatine lifter, with the exception of the glass surface. When comparing the percentage grade allocations with the combined means for each surface, variation was apparent as the usage of the gelatine lifter displayed some benefit for enhancement as seen in figure 8. Negative averages were seen for the low weight on paper and aluminium, and for the heavy weight on textured plastic indicating that the quality of the half exposed to the gelatine lifter was usually better. Due to the inconsistency with the results for the weight variations, it suggested that the type of substrate had a greater effect than the weight applied.
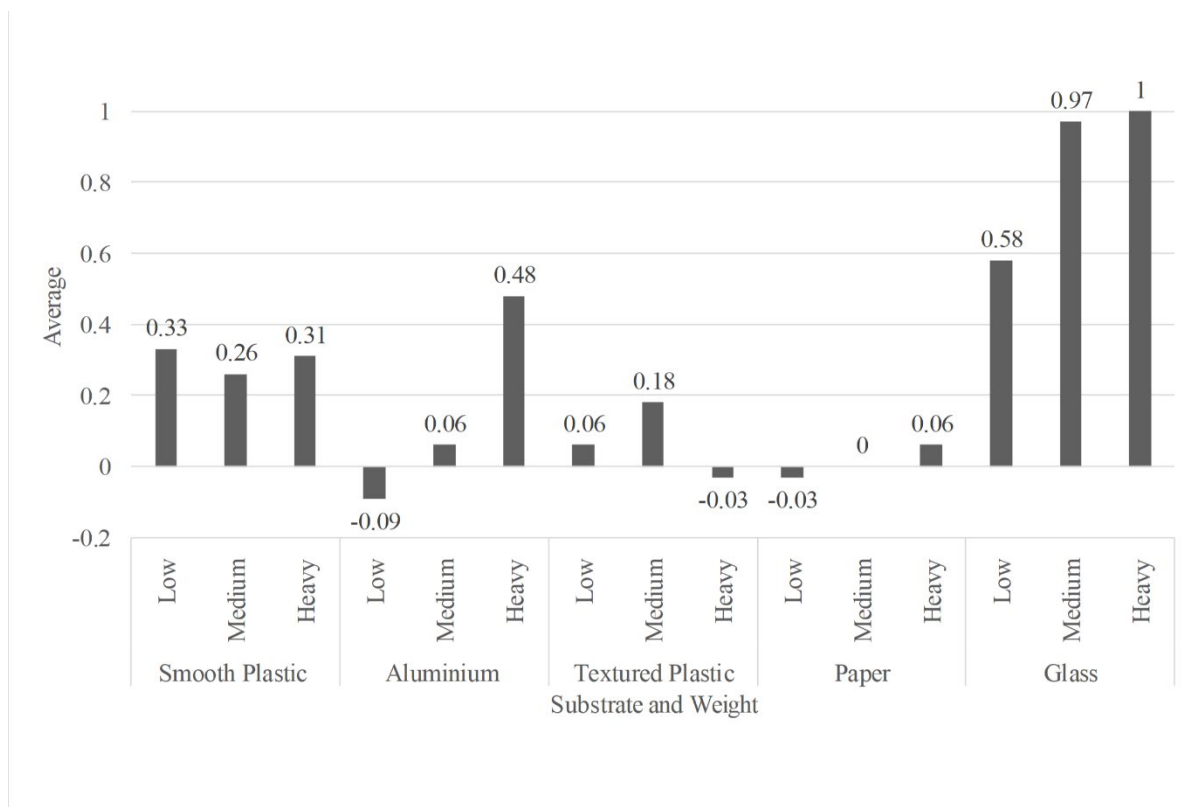
Fig 9 Average scores for each weight variation over all surfaces.

The glass surface displayed a clear trend with the low weight having comparable scores with other surfaces and may account for why fingermarks were still observable during the pseudo- operational trial. The medium and heavy weight applications displaying more positive scores, indicating more effect on the ridge detail, which is also demonstrated in the score averages which increases as heavier weight are applied. This could have been due to the glass surface itself, which extremely smooth and has a proclivity for fingermarks yet, leaves them more vulnerable to alteration from extrinsic factors. It is interesting to note that -1 scores were awarded with the medium and heavy applications. This could be attributed to a transference of adhesive residue, or slight rehydration of the fingermark residue [29] allowing for greater uptake of the aluminium powder increasing contrast and ridge definition, due instances where the enhancement was greater for that half exposed to the gelatine lifter.

A similar trend was also seen with the smooth plastic and the aluminium, both of which are smooth substrates. Despite over 50% of the fingermarks displaying no alteration, positive grades were still allocated, possibly due the removal of residue and initiators for the fuming process. This may also have prevented overdevelopment of such areas as these surfaces also have negatively scores and a negative average for the low weight application on aluminium. This suggests that the use of a gelatine lifter may have limited beneficial effects supporting the observations reported in the pseudo-operational trial. A similar observation was also displayed on the textured plastic with some areas of the control half having limited ridge definition whilst the half exposed to the gelatine lifter were clearer, although this was more prevalent with the heavy weight. The least affected surface was the paper as over 85% of the fingermarks were awarded a score of 0 for all weight variations, whilst also having the lowest averages for all weights used. This may be due to the amino acids within the fingermark residue having an

affinity for the cellulose in paper and remaining unaltered due to the gelatine lifters adhesion being unable to penetrate into the paper's matrix [16].

Regarding contact time, the average grade for the instantaneous use was +0.11 (Standard Deviation (SD) 0.59), of the -2 to +2 range, and a grade of +0.46 (SD 0.81) for the 2-minute application period, indicating that contact time had an impact on fingermark quality and is displayed in figure 10. As there is overlap between the standard deviations, it suggests that the difference may not be statistically significant.
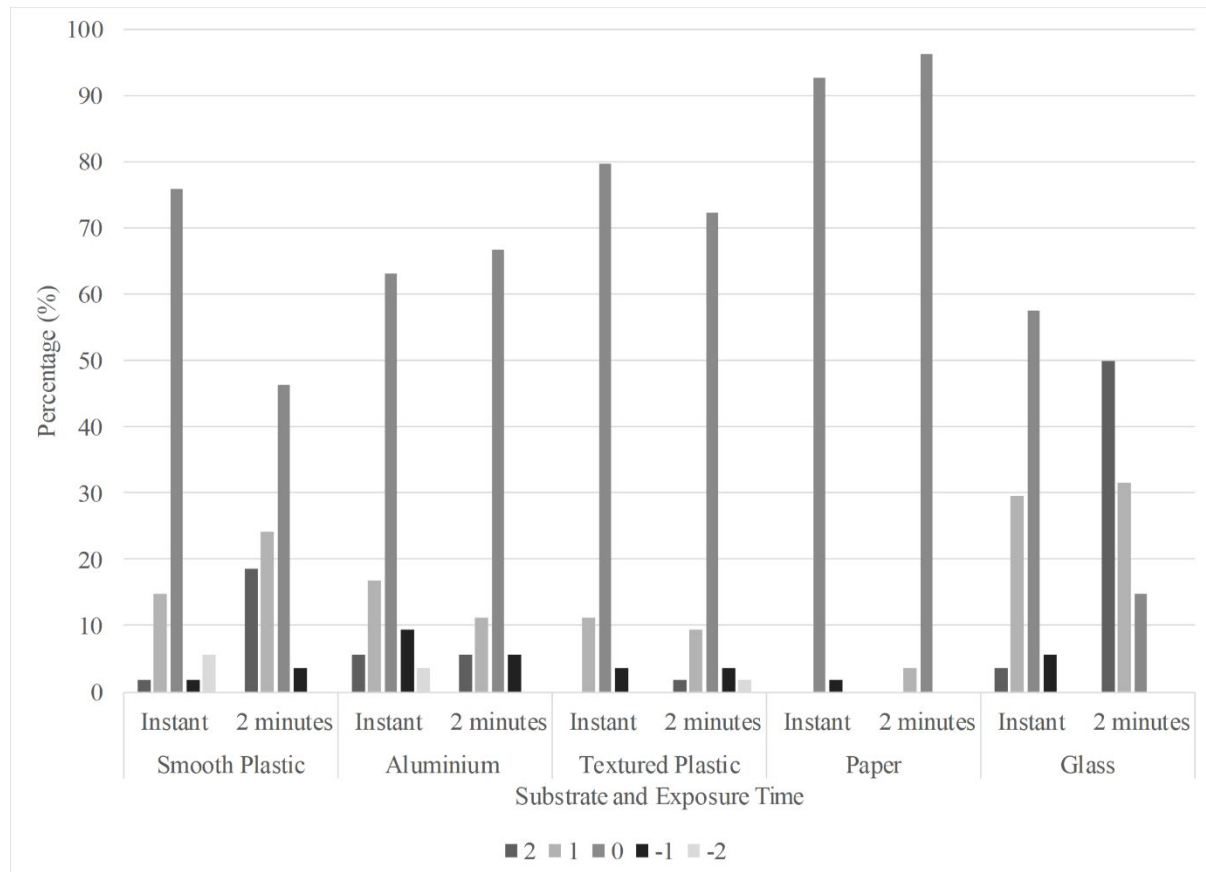

Fig 10 Percentage score for contact time over all surfaces.

Similar to the weight variation there were a substantial amount of 0 grades awarded, with over 45% of fingermarks over all surface displaying not alteration, again, with the exception of glass. For the 2-minute application, there was an increase in positive scores mainly +2 due to the partial/complete removal of the ridge detail from the surface via the gelatine lifter. This was sometimes apparent before enhancement as the ridge detail was clearly visible on the gelatine lifter upon removal. This was unsurprising due to the 2-minute period being a recommendation to rehydrate residue to facilitate uptake to recover and visualise the fingermark.

Contradictory to weight, contact time appears to be a greater variable to fingermark quality, although the substrate was still a contributing factor, as the fingermarks on smoother surfaces were affected more. Positive grades were still awarded and were mainly seen with the instantaneous retraction of the gel. There was still a beneficial aspect with the 2-minute contact period over the smooth and textured plastic, and the aluminium.

It should be noted that the identifiability of the fingermarks was not considered during the user variation aspect. Some of the +1 grades were given due to there being greater ridge continuity and/or contrast with the substrate rather than the removal of ridges or minutiae. As with the pseudo-operational trial, it is unclear how this would translate in conjunction with fingermark quality observed within casework.

Conclusion

The purpose of the study was to investigate the effect of gelatine lifters as a means of DNA recovery on the quality of latent fingermarks via pseudo-operational use and user variation during application. From the pseudo-operational trial, many friction ridge skin marks could still be visualised post DNA recovery. The quality of the fingermark scores were substrate dependant, with smoother surfaces resulting in higher grades deemed to be 'suitable for identification' in accordance with the used grading system. In regard to usage variation, the weight applied during application was a lesser contributing factor than the amount of time the gelatine lifter was left in contact with the surface. There is a greater chance of leaving the friction ridge skin marks unaltered with the application of a low weight instantaneous usage. Again, the fingermark quality post lifting was dependant on the substrates used. In both trials there also appeared to be some limited beneficial use to a pre-treatment before enhancing and was mostly evident for surfaces enhanced with cyanoacrylate fuming.

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study.

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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