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Visualization of latent fingermarks on the surfaces of paper tape

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Abstract: Despite its name, paper tape does not possess the porous characteristics of traditional paper, necessitating alternative approaches for latent fingermark development. In this study, ten commercially available paper tapes were examined to evaluate the effectiveness of various visualization methods on both the non-adhesive and adhesive sides. The non-adhesive side was treated with amino acid-sensitive reagents (ninhydrin, 1,2-indanedione/zinc chloride), a lipid-sensitive dye (Oil Red O), CA fuming followed by Basic Yellow 40 or powdering, and several fingerprint powders including Swedish black, Greenescent, and Dazzle Red magnetic powder. However, none of these methods produced identifiable ridge detail due to the surface's non-porous and textured characteristics, which inhibited fingermark deposition. On the adhesive side, two development methods were tested: an iron oxide-based powder suspension and a carbon-based Wet Powder Black. Both produced comparable performance in visualizing ridge detail. Furthermore, even when tapes adhered to surfaces were separated using an adhesive neutralizer (Un-du), fingermarks on the adhesive side could still be successfully developed. These findings highlight the importance of surface characteristics in fingermark visualization and offer practical recommendations for forensic processing of paper tape evidence.

Key words: latent fingermark, paper tape, non-adhesive side, adhesive side, surface texture

1. Introduction

Adhesive tape is a widely used material in everyday life due to its easy accessibility and low cost; therefore, it is likely to be used in crimes such as kidnapping, murder, improvised explosive device (IED) manufacturing and drug packaging.[1] When handling adhesive tapes, latent fingermarks that can be used for personal identification may be deposited on both the adhesive and non-adhesive sides[2]; therefore, the development and visualization of latent fingermarks on both sides of the adhesive tape is important for criminal investigation.

There have been several studies on the methods of developing latent fingermarks left on tape. For example, Bouzin *et al*.[1] and Ree *et al*.[3] have shown that powder suspension is effective in visualizing latent fingermarks on the adhesive side of tape. Garcia *et al*.[4] tested nine reagents (alternate black powder, cyanoacrylate (CA) fuming followed by Basic Yellow 40, gentian violet, Liqui-Drox, powder in suspension, CA fuming

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followed by rhodamine 6G, Sticky-side Powder, TapeGlo, and Wetwop) on the adhesive side of duct, electrical, and cellophane tape. They concluded that Wetwop, a commercially available carbon-based wet powder suspension, was the most effective reagent. Schiemer *et al.*[5] compared several reagents, including powder suspension, CA fuming followed by fluorescent dye staining, Ardrox, gentian violet, and small particle reagent, for their effectiveness on black electrical tape. They concluded that CA fuming followed by fluorescent dye staining is an effective technique for developing fingermarks on the non-adhesive side. Berg *et al.*[6] demonstrated that CA fuming followed by rhodamine 6G could develop fingermarks on the non-adhesive side of duct tape.

Recently, paper tape has gained widespread use in daily life. As a result, the likelihood of its submission as forensic evidence has increased, highlighting the need to develop effective fingermark visualization techniques for such substrates. However, to the best of the authors' knowledge, no published method currently exists for the development of latent fingermarks on paper tape.

Similar to resin tapes, paper tapes consist of an adhesive layer and a backing material, and are categorized into kraft and masking types based on the backing composition.[7,8] Kraft tape uses kraft paper as the backing material, while masking tape uses materials such as crepe paper, polyester, polyvinyl chloride or polyamide as the backing material.[7,8] One side of the backing material is covered with a layer of release coating (usually silicone), which protects the backing material from moisture and allows the adhesive layer to separate easily.[9] The other side of the backing material is coated with an adhesive such as rubber, acrylic or silicone resin.[10]

Ninhydrin or its analogues are commonly used to develop latent fingermarks on porous surfaces such as paper,[11] so it is reasonable to assume that ninhydrin or its analogues could also be used to develop latent fingermarks on the non-adhesive side of paper tape. However, as mentioned above, paper tape, despite its name, may not have the properties of paper because its surface is coated with a polymeric material.[9,12] Therefore, the authors investigated a method to effectively develop latent fingermarks from both the adhesive side and the non-adhesive side of the paper tape.

2. Experimental

2.1. Materials

The paper tapes were purchased from a local market. *Table* 1 lists these tapes along with the adhesive components disclosed by the manufacturers. In cases where the manufacturer did not disclose the adhesive components, 'unknown' is indicated.

Ninhydrin was purchased from Samchun Chemicals

Table 1. A list of the paper tapes used in the experiment and the ingredients of the adhesive

Item No.	Type	Source (Product)	Origin	Comp.
1	"K"	Asintnf (More10A)	Korea	Natural rubber
2		Kumsung K&T	Korea	Unknown
3		Ecoand	Korea	Unknown
4		Youngdae	Germany	Natural rubber
5		Tesa	Korea	Natural rubber
6		09 Tape	Korea	Water-based acrylics
7		Okong	Korea	Unknown
8		Tapex	Korea	Rubber
9	"M"	Asintnf (More10W)	Korea	Natural rubber
10		Osung	Korea	Unknown

*"K" : Kraft tape
**"M" : Masking tape
***Comp. : Adhesive composition

(Korea), and Oil Red O was obtained from Daejung (Korea). The chemicals 1,2-indanedione (1,2-IND), Dazzle Red magnetic powder, and Greenescent powder were supplied by Sirchie (USA). Swedish black powder, Wet Powder Black, and Basic Yellow 40 (BY40) were sourced from BVDA (Netherlands). Instant adhesive used in the study was Loctite 401 (Henkel, Germany), while Iron (II, III) oxide powder and Tween 20 were acquired from Sigma-Aldrich (USA). The adhesive neutralizer was obtained from Un-du (USA).

The CA fuming chamber used in this study was the Megafume M61 (Attestor Forensics, Germany), and the heat press employed was the Dreame 81 (Designdream, China). The 505 nm and 450 nm light sources used for illumination were Polilight Flare Plus 2 (Rofin, Australia), paired with an orange filter from Altlight (Korea). Microscopic examination was conducted using a Leica M80 stereo microscope (Leica, Germany). Samples were photographed with a 62 mm ultra-macro lens (Laowa, China) mounted on a Nikon D5500 DSLR camera (Nikon, Japan).

2.2. Fingermark deposition

Eccrine and natural fingermarks were obtained from two female donors in their 20s. To obtain eccrine fingermarks, each donor washed their hands with soap, allowed them to dry naturally, wore latex gloves, and then engaged in normal daily activities for 30 minutes before depositing their fingermarks. To obtain natural fingermarks, the donors washed their hands and carried out daily activities for 30 minutes without touching their forehead or nose prior to deposition.

For each development method, one fingermark from each of the two donors was deposited on separate surfaces to form a test set, representing two replicates. All donors were instructed to deposit their fingermarks with natural pressure, approximately equivalent to the force used when picking up a small object, and to maintain contact for about two seconds to minimize donor variability, in accordance with the IFRG (2014) guidelines. For other development methods, the same preparatory procedure (eccrine or natural) was repeated for each donor, and a new test set was created by collecting one fingermark from each donor.

All fingermarks were stored indoors for one day prior to development (IRB number:202403-SB-010).

2.3. Fingermark visualizing reagents preparation and application

The ninhydrin working solution was prepared by dissolving 6 g of ninhydrin in 50 mL of ethanol and 950 mL of petroleum ether.[13] Each fingermark-bearing strip of paper tape (hereafter referred to as a *sample*) was immersed in the ninhydrin working solution for 10 seconds and then completely air-dried. Once dry, the samples were heated at 80 °C for 10 seconds using a heating press to develop the fingermarks, which were then observed and photographed under white light.

The 1,2-IND/Zn working solution was prepared by adding 0.8 g of 1,2-IND to 90 mL of ethyl acetate, 10 mL of glacial acetic acid, 820 mL of petroleum ether, and 80 mL of the zinc chloride stock solution.[13] The zinc chloride stock solution was prepared by dissolving 0.4 g of zinc chloride in 10 mL of ethanol, 1 mL of ethyl acetate, and 190 mL of petroleum ether.[13] The samples were immersed in the 1,2-IND/Zn working solution for 10 seconds, then completely air-dried. Once dry, the samples were heated at 165 °C for 10 seconds[14] using a heating press to develop the fingermarks, which were then photographed through an orange filter under a 505 nm light source illumination.

The Oil Red O staining solution was prepared by dissolving 1.54 g of Oil Red O in 770 mL of methanol and mixing it with a solution prepared by dissolving 9.2 g of sodium hydroxide in 230 mL of deionized water.[15] This mixture was then filtered twice through filter paper. After immersion in the Oil Red O staining solution, the samples were neutralized by immersion in a buffer solution (pH 7). The buffer solution was prepared by dissolving 26.5 g of sodium carbonate in 2 L of deionized water and slowly adding 18.3 mL of 70 % nitric acid, and then diluting with deionized water to a final volume of 2.5 L.[15] The fingermarks developed in this way were observed under a 505 nm light source illumination.

For CA fuming, the samples were placed in a CA fuming chamber along with cyanoacrylate monomer, and fumed at 120 °C with 80 % relative humidity for 25 min to develop the fingermarks.[16] After development, a BY40 solution was sprayed onto the fingermarks for staining. Any unreacted BY40 was rinsed off with running tap water, and the samples were thoroughly dried. Once completely dry, the samples were viewed and photographed through an orange filter under a 450 nm light source illumination.

Swedish black powder and Greenescent powder were applied to the fingermarks on the surface using a brush, while Dazzle Red magnetic powder was applied using a magnetic applicator. The samples treated with Greenescent powder or Dazzle Red magnetic powder were then viewed and photographed through an orange filter under a 505 nm light source illumination.

The iron oxide-based powder suspension was prepared by mixing 3 g of Iron (II, III) oxide powder and 7 mL of Tween 20 in 500 mL of deionized water.[17,18] The samples were immersed in this solution for 1 minute, then rinsed with deionized water and allowed to air dry completely at room temperature before being photographed under white light.

Wet Powder Black was used as purchased. It was applied to the fingermark on the adhesive side of the tape with a brush. After 15 seconds, the samples were rinsed with deionized water and allowed to air dry completely at room temperature before being photographed under white light.

3. Results and Discussion

Fingermarks can be deposited on both sides of a paper tape. Therefore, when such tape is submitted as evidence, law enforcement agencies must process both the non-adhesive and adhesive sides in an effort to develop fingermarks suitable for forensic examination. Accordingly, the authors of this study investigated the most effective methods for visualizing latent fingermarks on both sides of the paper tape.

3.1. Non-adhesive side

3.1.1. Water drop absorption test

It is well known that the method of developing latent fingermarks should vary according to the porosity of the surface.[19] Paper is a typical porous material, and the surface of paper absorbs moisture well. However, as mentioned in the introduction section, the non-adhesive side of paper tape is made by applying a release coating over the backing material,[10,12] so it is not a porous surface and may not absorb moisture. To see the porosity of the surface and its ability to absorb moisture, a drop of water was placed on the non-adhesive side of the paper tapes (kraft and masking) and observed after 30 minutes to see if the drop had been absorbed. For comparison, a piece of kraft paper taken from a regular cardboard packing box was treated in the same way.

The results are shown in *Fig*. 1, where it can be seen that on the kraft paper surface, the water droplets were smeared onto the surface (see arrow), whereas

Fig. 1. Comparison of water droplet absorption on the non-adhesive sides of paper tapes (kraft and masking) and kraft paper.

on the non-adhesive side of all the paper tapes used in this study, the water droplets were not absorbed. This experiment demonstrates that the non-adhesive side of the paper tapes does not maintain the porosity of the paper.

3.1.2. Performance of amino acid sensitive reagents

As shown in the results of Section 3.1.1, the surface of the paper tape was found to be non-porous, contrary to what might be expected from the term "paper tape". Therefore, amino acid-sensitive reagents may not be suitable for developing latent fingermarks on this surface. Nevertheless, to prevent potential errors in reagent selection, the authors deposited eccrine fingermarks on the non-adhesive side of the paper tapes, left them at room temperature for 24 hours, and then treated them with ninhydrin and 1,2-IND/Zn. As a result, no ridge detail was observed on any of the tape samples. On the contrary, as shown in *Fig.* 2, some samples exhibited heavy background

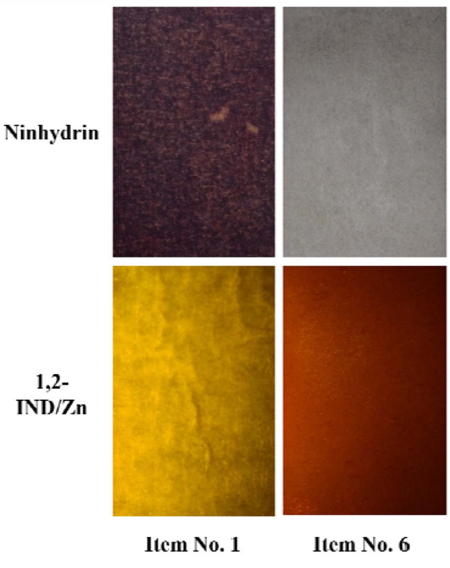

Fig. 2. Results of treating the non-adhesive side of paper tape bearing eccrine fingermarks with amino acid-sensitive reagents. Item No. 1 represents an example of severe background staining, while Item No. 6 shows an example without staining. The ninhydrin-treated sample was observed under ambient light, whereas the 1,2-IND/Zn-treated sample was visualized using 505 nm illumination with an orange filter.

staining. This phenomenon is presumed to have occurred due to a reaction between the amino acid-sensitive reagents and amine groups present in the polyamide material used to manufacture the non-adhesive side of the paper tape. These findings clearly reaffirm that amino acid-sensitive reagents are not suitable for visualizing latent fingermarks on the non-adhesive side of paper tapes.

3.1.3. Performance of fingermark development reagents on non-porous surfaces

Amino acid-sensitive reagents commonly used for porous surfaces were found to be ineffective on the non-adhesive side of paper tape. Therefore, this portion of the study evaluated the suitability of reagents designed for non-porous surfaces. Natural fingermarks were deposited on the non-adhesive side of ten different types of paper tape and aged for one day at room temperature. The samples were then processed using CA fuming followed by post-treatment, Oil Red O, Swedish black powder, Greenescent powder, and Dazzle Red magnetic powder. The results are summarized below.

CA fuming followed by post-treatment: After CA fuming followed by staining with BY40 (CA/BY40) on paper tape surfaces bearing natural fingermarks, a weak indication of a fingermark was observed only on Item No. 8, while no fingermarks were detected on the remaining tapes. Although fluorescence intensity varied among the tapes, strong background fluorescence was consistently observed on all surfaces. *Fig.* 3 illustrates several examples of this surface fluorescence. The authors hypothesize that this fluorescence resulted from the solution-based BY40 dye remaining on the surface without being washed off. To address this, the CA-fumed surfaces were post-treated with fingerprint powders—namely, Swedish black powder, Greenescent powder, and Dazzle Red magnetic powder—instead of the BY40 dye. However, regardless of the powder type used for post-treatment following CA fuming, only the approximate locations of fingermarks were observed on Item Nos. 1, 5, and 10, and no fingermarks were developed on the remaining items. *Fig.* 4 presents

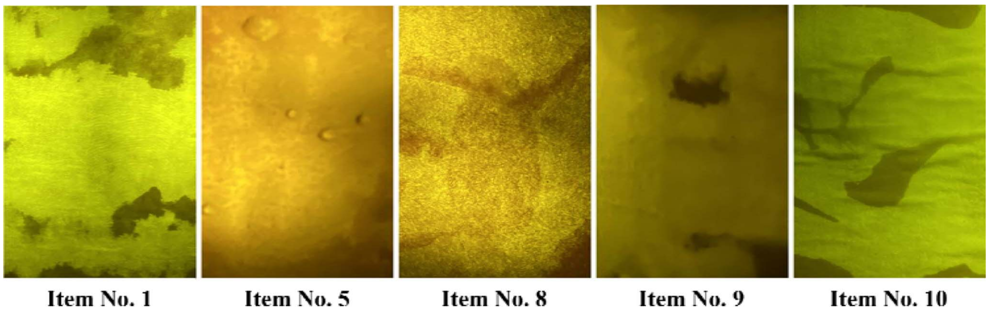

Fig. 3. Results of CA fuming followed by BY40 staining on natural fingermarks deposited on the non-adhesive side of paper tape. The photographs were taken under 450 nm illumination using an orange filter.

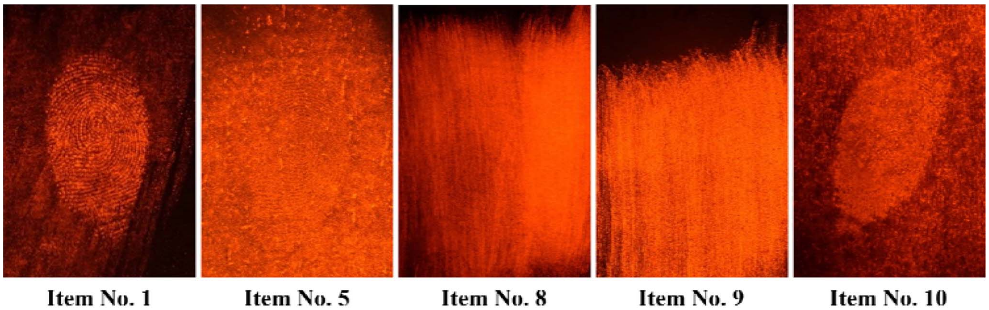

Fig. 4. Results of CA fuming followed by treatment with Dazzle Red magnetic powder on natural fingermarks deposited on the non-adhesive side of paper tapes. The photographs were taken under 505 nm illumination using an orange filter.

part of the results obtained after CA fuming followed by treatment with Dazzle Red magnetic powder. Similar results were observed when Swedish black powder or Greenescent powder was used instead of Dazzle Red magnetic powder.

Powder: When using powder alone for enhancement, ridge detail was observable only on Item Nos. 1, 5, 9, and 10. On the other tapes, only faint impressions indicating the possible locations of fingermark deposition were visible, or no identifiable ridge detail was observed. *Fig*. 5 presents examples of both successful and unsuccessful fingermark development across several types of tape.

Oil Red O: Fingermarks were treated with Oil Red O; however, no ridge detail was observed in any case.

3.1.4. Reasons for the failure to visualize fingermarks

Although the methods used in the experiment described in Section 3.1.3 have been proven effective for visualizing fingermarks deposited on non-porous surfaces, none of them yielded satisfactory visualization in this study. This led the authors to suspect that the reagents failed not because they were ineffective, but because the fingermarks had not adhered to the surface in the first place. To investigate this, the authors examined fingermarks in which ridge details were observed in *Fig*. 5 under a microscope at 10× magnification to assess the state of ridge attachment. *Fig*. 6 shows microscopic images of the core areas of Items No. 1, 9, and 10 treated with Swedish black powder, revealing that the ridges were not fully intact. Additionally, when touched by hand, all non-adhesive sides of the paper tapes used in the experiment were found to be textured rather than smooth. It is obvious that if the surface is not smooth, fingermarks cannot adhere properly upon contact with fingers. Therefore, it is concluded that the reason no fingermarks were observed regardless of the method used is that the fingermarks had not been fully deposited on the surface.

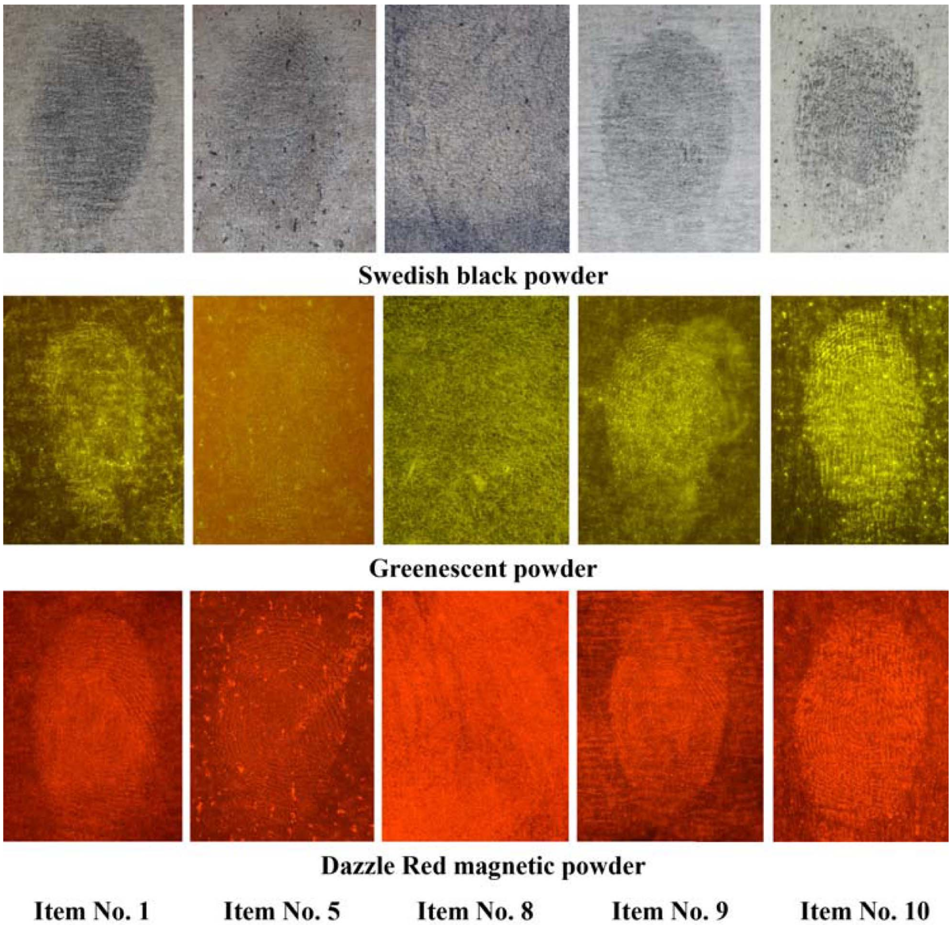

Fig. 5. Results of treating natural fingermarks deposited on the non-adhesive sides of paper tapes with Swedish Black powder, Greenescent powder, and Dazzle Red magnetic powder. Images of Swedish Black powder treatment were captured under natural light, while those of Greenescent powder and Dazzle Red magnetic powder treatments were taken under 505 nm illumination with an orange filter.

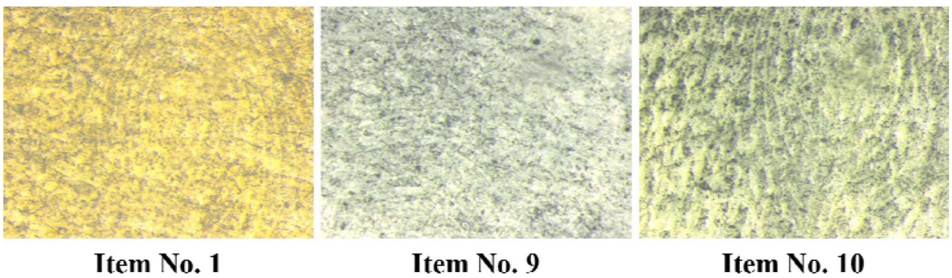

Fig. 6. Microscopic (×10) images of the core areas of fingermarks developed with powders on the non-adhesive sides of paper tapes.

3.2. Adhesive side

Powder suspension is known to be effective for developing latent fingermarks on the adhesive side of tapes.[3,18] Therefore, the authors visualized fingermarks on the adhesive side using an iron oxide-based powder suspension and a commercially available carbon-

Fig. 7. Visualization results of natural fingermarks on the adhesive side of Item No. 6.
Left: processed with Wet Powder Black.
Right: processed with the iron oxide-based powder suspension.

Fig. 8. The result of splitting latent fingermarks on the adhesive side of paper tape, stored in different ways, and visualized with an iron oxide-based powder suspension.
Left: Attach to a cardboard packing box and stored indoors for 7 days, then removed with Un-du.
Right: Stored indoors for 7 days without attaching to any surface.

based powder suspension, Wet Powder Black. To compare their performances, natural fingermarks were deposited on the adhesive side of ten different tapes, stored at room temperature for one day. Each fingermark was then split in half. The left half was developed using Wet Powder Black, and the right half with an iron oxide-based powder suspension.

Fig. 7 presents the results for Item No. 6, showing that both the iron oxide-based powder suspension and the carbon-based powder suspension developed comparable and well-defined fingermarks. Similar outcomes were observed with the other adhesive tapes tested.

3.3. The effect of adhesive neutralizer

Since most paper tapes submitted as evidence are attached to other surfaces (especially cardboard packing boxes) with an adhesive side, a separation process is required before visualizing the latent fingermarks. However, if the paper tape is pulled forcibly to remove it, it may tear, causing irreparable damage to the fingermark. Therefore, the authors decided to use Un-du (an adhesive neutralizer) for separation.[20,21]

To ensure that the Un-du helped to successfully separate the paper tapes but did not interfere with the subsequent visualization of the fingermarks, the authors prepared natural fingermarks on the adhesive side of the paper tapes. The fingermarks were then split into two halves and one half was stored at room temperature for 7 days without adhering to a cardboard packing box and then treated with an iron oxide-based powder suspension. The other half was adhered to a cardboard packing box and stored at room temperature for 7 days, then the tape was separated with Un-du and treated with an iron oxide-based powder suspension. The results are shown in *Fig*. 8, and it can be seen that Un-du successfully separated the tapes, and the subsequent visualization of the fingermarks was not affected. Studies have shown that removing synthetic resin tapes with Un-du can cause blurring of ridge details,[20,21] but in *Fig*. 8, no blurring of ridges was observed.

3.4. Discussion

The non-adhesive sides of the paper tapes tested in this study had rough surfaces and did not absorb the sweat components present in fingertips. As a result, secretions from the fingertips were unable to adhere while maintaining ridge structure. Furthermore, when treated with amino acid–sensitive or fluorescent staining reagents, background staining was observed. Consequently, none of the conventional techniques used for either porous or non-porous surfaces were effective in visualizing latent fingermarks on these paper tapes. Therefore, when attempting to recover identification evidence from paper tape surfaces, greater emphasis should be placed on collecting alternative forms of evidence, such as touch DNA, rather than fingermarks.

These results indicate that the failure to visualize fingermarks is primarily attributable to the non-porous and textured nature of the paper tape surface, which prevents consistent ridge deposition. This finding demonstrates that the limitation lies in the substrate's physical characteristics rather than donor-related variability, reinforcing the conclusion that traditional fingermark reagents are not suitable for this material.

This study was conducted using only ten types of paper tapes. If tapes with smoother surface textures than those used in the present experiment become commercially available in the future, further research will be necessary to determine appropriate visualization methods for those tapes.

4. Conclusions

Testing conducted on ten commercially available paper tapes revealed that fingermark residues did not adhere sufficiently to the non-adhesive sides to preserve ridge detail. Furthermore, even when partial residues were present, the non-adhesive sides reacted with fingermark development reagents, resulting in background staining that hindered successful visualization. Accordingly, when paper tapes are submitted as evidence, efforts to obtain identification information should prioritize alternative forms of evidence, such as touch DNA, rather than fingermarks. Once such evidence collection is complete, it is recommended that the tapes be removed from the surface using an adhesive neutralizer, and the adhesive side be treated with a powder suspension to develop any latent fingermarks.

Acknowledgements

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