Article

Oil Red O Versus Physical Developer on Wet Papers: A Comparative Study

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Abstract: Amino acids dissolve in water, and, therefore, fingerprints on porous surfaces that have been exposed to aqueous environments cannot be tested with traditional methods such as ninhydrin or DFO. Traditionally, the physical developer method has been used. Tests were conducted to compare Oil Red O and physical developer on three types of paper surfaces: thermal paper, white standard paper, and brown kraft paper. Oil Red O was consistently superior to physical developer in terms of the mean fingerprint quality produced on thermal paper. Oil Red O was also shown to be superior for recovering fingerprints on standard white paper. On brown paper, the mean fingerprint quality was not significantly different between the two methods. This research supports the use of Oil Red O in laboratories for the treatment of wet porous surfaces.

Introduction

"Fingerprints found at crime scenes lead to more suspects and generate more evidence in court than all other forensic techniques combined." [1] Paper evidence is commonly encountered at crime scenes. Several methods have been developed for fingerprint development on this type of surface, including ninhydrin and 1,8 diazafluoren-9-one (DFO). These methods are excellent when paper and cardboard products are dry. But recovering fingerprints from evidence that has been found in garbage cans, exposed to the weather, discarded outside, or wet presents a problem that has meant resorting to the traditional cumbersome method: physical developer (PD).

Received May 2, 2005; accepted September 19, 2005

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In 2004, Beaudoin [2] developed a method that made the recovery of fingerprints on wet porous surfaces simple and easy. Specifically, surfaces such as paper and cardboard that had been exposed to water or high humidity were ideal for Oil Red O (ORO). His three-step method displayed simplicity and differed from the multistep PD used in laboratories across Quebec (Appendix I). The purpose of this study was to compare ORO and PD. Three porous surfaces were tested: white standard paper, kraft brown paper, and thermal paper.

Current Methods of Lifting Prints on Porous Surfaces That Have Been Wet

Few methods have proven successful in developing latent fingerprints on wet surfaces. The standardized method that is used in forensic laboratories to successfully develop these particular prints is physical developer [2]. The first characteristic of PD is that it reacts with the water-insoluble component of the latent fingerprint, working as an oxidation-reduction reaction. In the PD working solution, silver ions come from the silver nitrate, and ferrous ions come from ferrous ammonium sulfate. Here is a simple overview of this complex reaction. The silver ions (Ag^+) are reduced to solid silver (Ag) and the ferrous ions (Fe^{2+}) are oxidized to ferric ions (Fe^{3+}) [3]. Although the reaction between solid silver and the water-insoluble components of the latent fingerprint is unclear, it has been suggested that an electrostatic force contributes to the development of the fingerprint [4]. The end result is a black print exposed on a light gray surface [5].

One of many problems with the method includes the large quantity of glassware needed for the treatment of evidence. This glassware should be reserved exclusively for use in this method to prevent contamination with other solutions. Cleanliness, of the glassware as well as of the working station, is necessary to achieve good results [5, 6]. Even with the necessary cleanliness, Beaudoin reports that results using PD are uneven and poor, even on high-quality test samples [2]. The authors noticed that the method itself is dirty; the counter tops, linen, appliances, and glassware become stained if they are in contact with the working solution.

The PD that was used in this comparative study requires a number of basins to wash and treat evidence. The acid wash at the beginning of the treatment renders the paper weak and easy to damage. It serves to wash soiled surfaces [5] and is necessary to neutralize the alkaline binders and fillers found in most common papers [3, 7]. It is also destructive; it becomes impossible to reuse the sample with another method to find fingerprints if the PD proves unfruitful. It is thus imperative to use it last, if a series of different methods is required [5].

Despite the disadvantages listed above, PD is still the primary method used to develop soiled fingerprints or latent fingerprints that have been exposed to water or high humidity. Physical developer can always be used as a last resort after unsuccessfully treating the surface in question with DFO or ninhydrin. It leaves a stable print after development, and the print does not fade or disappear after it has been retrieved. Furthermore, on colored paper, which is sometimes hard to photograph, this method produces a clear visible black print [5].

The fact that PD is one of the primary methods for developing fingerprints on surfaces that have been exposed to water has led many investigators to try to modify the traditional version, making it less expensive, for example, in an effort to improve the method [8, 9]. However, the complexity of PD discourages its use, and the newly proposed method, which uses ORO [2], is a simpler alternative to the traditional PD.

Oil Red O Background

Oil Red O is a lysochrome used in biology to stain lipoproteins recovered after electrophoresis separation, and it is also used in electron microscopy. It is lipid-specific, and no lipid in latent fingerprints is spared. It has also been used in forensics to stain lip prints on porous surfaces [10]. The principle applied to fingerprints applies to lip prints: the lipids left behind are simply stained with the compound [10]. The result, for both lip and fingerprints, is a red print on a pink background, creating a nice contrast, visible in daylight.

Test Procedures

For each of the three thermal paper trial runs, three point-of-sale receipts from each of seven participating companies (Zellers, Bureau en Gros, Canadian Tire, Wal-Mart, Future Shop, National Bank of Canada, and Petro-Canada) were used. Each sheet of paper was divided into 3 sections where fingerprints were deposited.

Test subjects wiped their foreheads with their fingers and then placed them in the appropriate areas on the test papers. For each paper, at least two test subjects were used. An hour after deposition, the thermal papers were then placed in tap water at room temperature for two hours before being tested. Each paper was then cut down the middle, separating the fingerprint in half (allowing one half to be tested in ORO and the other half in PD). This ensured a comparison of the same fingerprint in both methods (Figures 1 and 2). No drying time was allowed between the cutting and treatment phases.

For standard white paper and brown kraft paper, a similar procedure was used. Papers were divided into five sections and fingerprints were deposited in the same manner as they were with the thermal paper runs. Sheets were then immediately placed in water for 2, 16, or 24 hours. An additional sheet of paper was soaked for two hours before having prints deposited on it. After drying, papers were stored for 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25, or 30 days. After the predetermined number of days stored, papers were cut down the middle and were subsequently processed in each method.

Materials and Methods

The ORO method as well as the stain solution concentrations and pH 7 buffers were the same as previously published [2]. The PD solutions [5] and method outlined in this reference were influenced by Kent's procedure [6] with the addition of an acetic acid solution pretreatment, inspired by the vinegar solution outlined by Ramotowski [3]. Following internal testing and studies, it was established that better results were obtained with both the acetic acid solution pretreatment at 25% and the strong maleic acid pretreatment (twice the concentration of reference 6). The degree of purity of N-dodecylamine acetate varies according to

1a *1b*

Figure 1

Example of latent fingerprint soaked in water for two hours and developed with ORO (1a) and physical developer (1b) three days after deposition on white paper.

2a *2b*

Figure 2

Example of latent fingerprint developed on thermal paper with physical developer (2a) and ORO (2b).

company and batch number. Depending of this purity, the weight of N-dodecylamine acetate needed for the solution changes considerably. However, the calculation of weight must be precise to get an ideal working concentration. A concentration that is too weak induces precipitation of the silver, and a concentration that is too strong prevents the working solution from reacting [5]. In Appendix 1, the N-dodecylamine acetate concentration has been adjusted to the purity of the batch used to one twice as strong as the one found in reference 6. Furthermore, the synperonic-N concentration has been increased as well, in accordance to the N-dodecylamine acetate concentration changes. These PD modifications are applied throughout Quebec. The working solution for the PD was prepared the day of treatment to ensure that the solution was fresh.

After treatment, two qualified senior crime scene technicians evaluated the fingerprints. Both technicians were conscious of the quality scale and systematically compared the fingerprints and gave their expert opinions regarding the quality of the print produced by the two different methods. All fingerprints in all treatments for all three types of papers were scored on a scale ranging from 0 to 2 (Table 1).

Quality rating	Description
0	Print is either invisible or useless to a comparison.
1	Print has a few distinguishing characteristics, with visible ridges, but there is too little information to make an accurate comparison.
2	Print is of sufficient quality, in terms of ridge characteristics, to make an accurate comparison.

Table 1

Description of the scale used to score fingerprint quality.

Results

Thermal Paper

The mean fingerprint quality (MFQ) was tabulated from the fingerprints for each sample of thermal paper. A direct comparison between ORO and PD for seven different types of thermal paper revealed that, for all types of thermal papers tested, the MFQ was superior for ORO. There were only two instances where the mean qualities between PD and ORO were close to each other: the Canadian Tire (MFQ for PD was 1.07 versus ORO at 1.15) and Petro-Canada (MFQ for PD was 0.96 versus ORO at 1.22) receipts.

The mean difference in the MFQ between the two treatments was 0.73, almost three-fourths of a full score of quality. The highest MFQ recovered by ORO was 1.78 for samples from the National Bank of Canada (NBC), Bureau en Gros, and Future Shop. The highest MFQ recovered from PD was 1.11 (from the Zellers sample), which is lower than the lowest ORO samples (Figure 3).

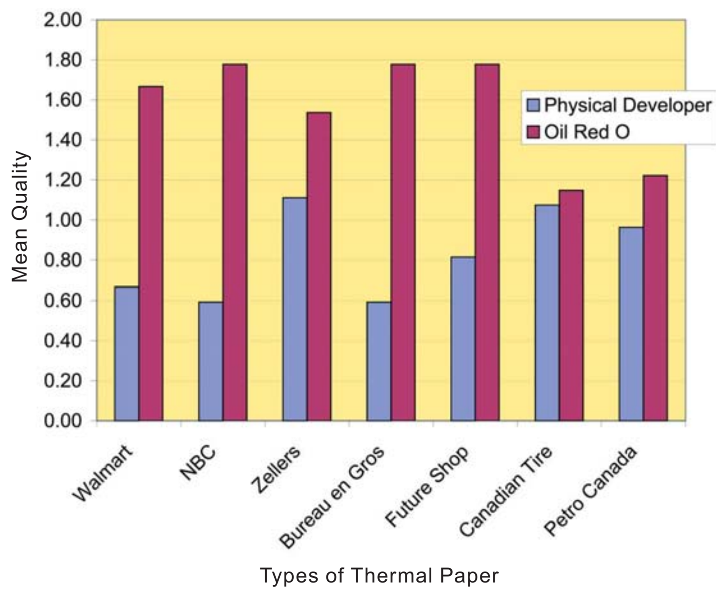

Figure 3

Thermal paper results. This graph represents the mean fingerprint quality for seven types of thermal paper tested in both Oil Red O and physical developer.

White Standard Paper and Kraft Brown Paper

It should be noted that for all method and paper combinations used, ORO/W had the highest percentage of Quality 2 prints (Table 2). (WP was excluded from these calculations, because it was noted earlier that this treatment would skew the percentages.)

Figure 4 compares brown kraft paper and standard white paper tested with both methods. During the research, the percentage of quality prints for white paper with the ORO method was consistently higher than the percentage for the ORO method with brown kraft paper.

At nine different time periods, no prints were visible with ORO on brown paper (days 4, 5, 7, 8, 9, 15, 20, 25, and 30). These days represent the time stored after water treatments for the papers before being processed. The mean percentage of prints per day for the brown paper was lower for both methods, compared to the white paper tested in both methods. The mean percentage for brown kraft paper tested with ORO was 6.4% and with PD it was 17.1%. The mean percentage for white paper tested with ORO was 38.6% and with PD it was 15.4%. On all days tested, except one day (day 15), the standard white paper tested with ORO rendered equivalent or superior results than the rest of the paper and method combinations. On eight of the fourteen days of testing, the brown paper rendered a higher percentage of Quality 2 prints per day than did the white paper, using PD.

		Score of fingerprints		
		0	**1**	**2**
Method/paper used	**PD/W**	58.1%	24.8%	17.1%
	ORO/W	27.1%	24.3%	48.6%
	PD/B	51%	28.6%	20.5%
	ORO/B	74.8%	17.6%	7.6%

Table 2

Mean percentage of fingerprints recovered for each score category over the entire thirty-day period. Results presented are for treatments P1, P2, and P3.

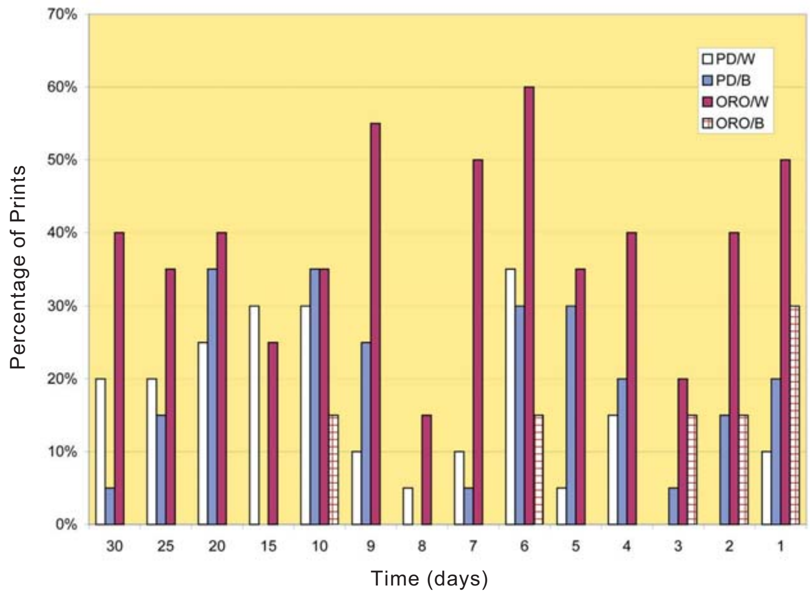

Figure 4

Percentage of Quality 2 prints for the combination of methods and papers during a 30-day period. PD/W = physical developer on standard white paper; PD/B = physical developer on brown kraft paper; ORO/W = Oil Red O on standard white paper; ORO/B = Oil Red O on brown kraft paper.

Figure 5 compares white and brown paper using the Oil Red O treatment. Treatments P1, P2, and P3 refer to the water treatments, where fingerprints were soaked for 2, 16, or 24 hours, respectively. WP refers to water treatment where papers were soaked before fingerprints were deposited. The mean fingerprint quality was tabulated. For treatments P1, P2, and P3 on standard white paper, Oil Red O showed a top mean quality of 1.329.

Even with standard deviations for the kraft brown paper, in the first three treatments, the results still showed that ORO provided a greater mean fingerprint quality on white than on brown paper for all treatments where papers were wet after the deposition of fingerprints.

On brown paper, there were no significant differences in terms of mean fingerprint quality. Even though some samples were clearer with physical developer on this surface, the margin of error was too large to show a significant difference between the two methods.

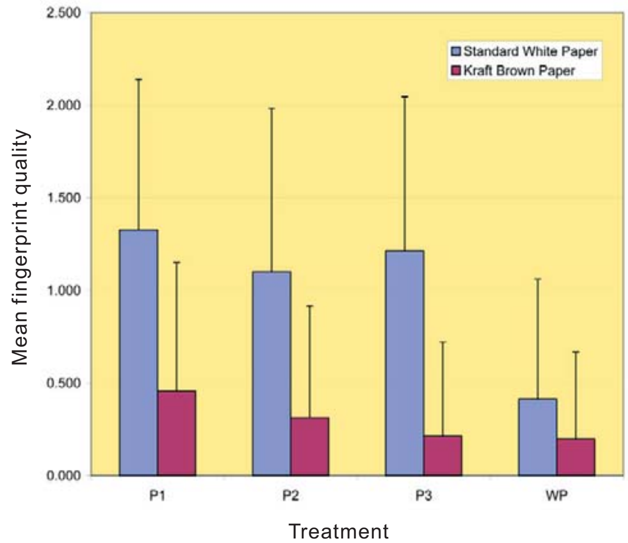

Figure 5

Comparison of standard white paper and kraft brown paper for ORO by measure of the mean quality of fingerprints in different treatments.

Figure 6 shows the difference in the overall MFQ between ORO and PD on standard white paper. The MFQ was calculated for treatments where fingerprints were exposed to water after their deposition on the surface. The MFQ was slightly more than double for ORO on standard white paper (MFQ = 1.21 for ORO, MFQ = 0.6 for PD).

Comparison of Water Treatments: Oil Red O Versus Physical Developer

Figure 7 demonstrates a few trends, the first being that the WP was poorer than the rest of the treatments for all the methods and paper combinations used. Furthermore, this graph confirms previous results: for all the treatments, the ORO/W combination rendered superior results compared to other combinations of methods and paper, with the percentage of Quality 2 prints recovered above 40% for treatments P1, P2, and P3.

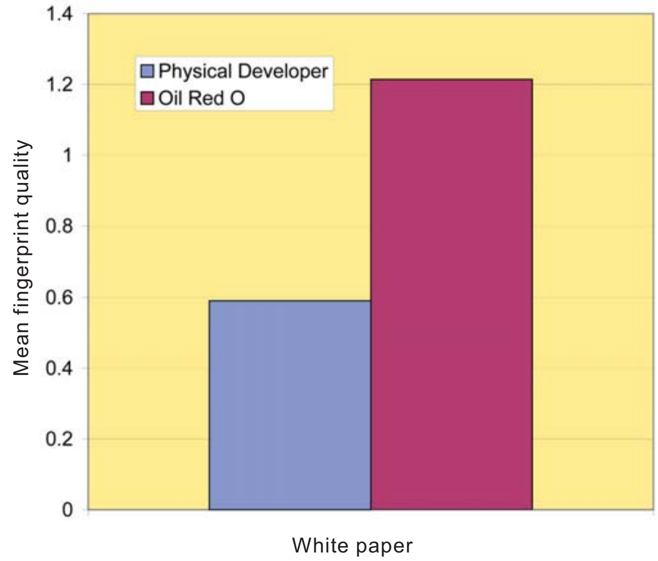

Figure 6

Difference between physical developer and ORO for overall MFQ over the entire 30-day period in treatments P1, P2, P3 for

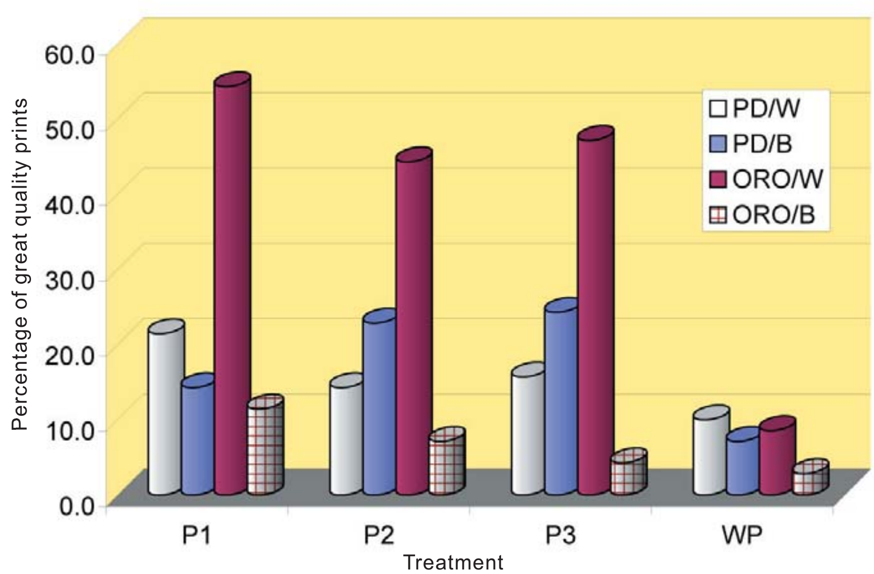

Figure 7

Percentage of Quality 2 prints in different method and paper combinations compared with different treatments over the 30-day period.

Discussion

Thermal Paper

The MFQ was tabulated, and the results indicated that Oil Red O was superior to PD for all types of paper tested. Differences in the mean quality between the papers in the two methods were apparent because the composition of the papers is known to vary slightly from one paper manufacturer to the other. The same coating is not used on every type of thermal paper [11]. The quality of the samples was noticeable to the touch, and some samples were lighter and less resistant to water than others. The mean difference in quality between the two methods for all seven samples of paper was 0.73. This is almost a full score of quality, and this result shows the superiority of ORO on thermal paper.

Observations during the experiment showed that when in ORO, thermal papers would lose the writing or information that was on them; this was not the case in PD. This observation could be both an advantage and a disadvantage, depending on how an investigator looks at the situation. The obvious disadvantage is the loss of information on the evidence. One simple way of rectifying this is to photocopy or photograph the evidence before treating with ORO. However, the elimination of the information on the evidence makes for a clearer identification of the print, because there is no background writing to obscure details in the fingerprint. The loss of the information on thermal papers may be attributed to the methanol in ORO's working solution reacting with the active layer of the paper. In fact, alcohol-based stock solutions might not react appropriately with the physical and chemical properties of thermal paper [12]. On standard white paper and on kraft brown paper, this phenomenon does not appear to be as dramatic, because information written in ballpoint pens changes color or gets lighter, but it is still visible after being processed.

Thermal paper is composed of five layers (from top to bottom): top coat, active layer or active coat, base coat, base paper, and back coat. Specific thermal print heads react with the active layer of the paper. This layer contains dyes, co-reactants, sensitizers, and stabilizers. When heat is applied, solid sensitizers melt, reacting to join the colorless dyes and coreactants together. Stabilizers work to keep the image in the layer more or less permanent. Above the active layer, one finds a topcoat, which works to seal and protect the active layer. Because it is the uppermost coat of the paper, it is here that latent fingerprints are likely to be recovered [11].

Another indication of different manufacturing processes, and thus chemically different papers, is related to the final product after processing with both methods. Three of the seven types of papers tested produced a “grainy background” when processed with either ORO or PD, making it slightly more difficult to identify fingerprints.

Standard White Paper and Kraft Brown Paper

From the results tabulated above, it is clear that ORO performs best on white standard paper and that PD works better with brown kraft paper. A brief discussion on these different papers will help explain these results.

All papers are made, essentially, from cellulose fibers originating from trees. In a nutshell, usually softwood is converted to pulp, which is subsequently transformed into paper. Pulping ruptures the wood fibers and releases the cellulose from the cell walls, essential to the papermaking process. This process can be mechanical, chemical, or semichemical. Bleaching is a step that is not necessarily essential to all papers and consists mainly of whitening the paper pulp. Finally, the papermaking process starts and different treatments are given to different papers. The water is removed from the pulp and the resulting cellulose fibers are worked into sheets. The resulting sheets are then pressed, dried, sized, and sometimes coated [13].

Cellulose is a key ingredient that maintains the paper’s strength. Gloss, brightness, opacity, and ink receptivity are, in part, improved or in some cases provided by mineral fillers and pigments [13].

Brown kraft paper is unbleached paper that is made entirely from wood pulp by the alkaline sodium sulphide process (a chemical process) [14]. It is a strong paper, and the average percentage of fiber retained from the original wood product in the pulp is estimated to be approximately 45-50%. It is used particularly in packaging and for wrapping material. A common example of the use of this type of paper is in the manufacture of paper grocery bags [13].

The porosity of a paper is related to the density of the paper and the amount of coating and fillers that will be absorbed by the paper [14]. Kraft paper contains minimal fillers, because these types of papers are used primarily for their strength. Because this paper is not treated as much as other papers, pores are likely to be uneven and unevenly spaced throughout the sheet, simply as a biproduct of manufacturing [13].

Because of the uneven surface and different size of pores, fingerprint residue on kraft paper could leach into deeper pores, as well as stay on the surface of the paper. Because ORO is lipid-specific, all of the lipids were stained. Therefore, once the print became visible in the treatment, furrow and ridges were not detectable. The result is a blotch of lipids detected by ORO. Physical developer renders slightly better quality results on this paper. The authors suggest that mainly the water-insoluble components of the latent fingerprint at the surface of the paper are targeted by the physical developer's working solution. Mong et al. [4] explain that silver particles are deposited at the surface of the paper and interact with the fatty residues in the ridge details of latent fingerprints. The authors therefore considered the idea that the paper surface could act as a barrier to limit silver deposition to nonwater-soluble components in the deeper areas of the paper. Further research must be done on this topic.

The unevenness of the pores could also explain why some prints were still visible with ORO at different stages during the experiment. These fingerprints might have been deposited on an area that was tighter and therefore had less open pores than other areas in the paper.

In a final effort to recover fingerprints on the brown kraft paper's uneven surface, the authors combined both the ORO and physical developer treatments. A few fingerprints on wetted brown paper were first processed in ORO. This treatment helped in finding where the fingerprints were on the evidence paper despite showing poor ridge resolution. The evidence was then processed in physical developer to recover potential surface water-insoluble components. From the preliminary tests, black fingerprint ridges on a pink background seem to show promising quality.

The white paper used in this study was standard white paper that is used in photocopy machines and printers. This type of paper, produced with chemical processes as well, is uncoated, but it is treated with fillers to improve paper quality. Ink receptivity, opacity, and brightness are properties that are enhanced with the use of these mineral fillers. The most common mineral filler is known as china clay or kaolin. In combination with other fillers, such as talc, titanium dioxide, or calcium carbonate, papers of different quality are produced for different purposes [13]. The use of fillers reduces the porosity of the paper and slows down the leeching of ink or other materials in the paper.

The smaller pores in the standard white paper could explain why more prints were visible with ORO on this surface. Lipids were less likely to leech into the pores of the paper, because the pores were smaller. Because more pores were filled in with mineral fillers, the white paper's surface was more even and fewer, smaller pores were present for the lipids to seep into.

Traditional methods that are used to treat other paper surfaces (e.g., standard white paper and brown kraft paper) are ineffective on thermal paper because exposure of the active layer to ninhydrin and DFO causes the exhibit to turn black and obliterates the latent fingerprints. Some of the polar solvents used in ninhydrin react with the active layer of the thermal paper, causing the sensitizers to dissolve and allowing the co-reactants and dyes to mix. The result is the blackening of the paper [12].

Other methods have been developed to counter the darkening problem of thermal paper. In 2002, the further development of an interesting observation by St. Thomas Police Services led to the refinement and creation of muriatic acid vapors to develop latent prints on the emulsion side (the side of the top coat/active layer) of thermal paper [15].

As a University of Toronto at Mississauga student, Merk [16] showed that modified solutions of ninhydrin or DFO cleared the darkening of the thermal paper. The modified solution had a higher content of ethanol, and it was suggested that this modification was responsible for clearing the darkened thermal papers. Merk therefore recommended that the modified solutions be used as a standard operating procedure for thermal paper.

In 2003, Stimac [17] tested 1,2 indanedione (IND) on thermal paper. This amino acid specific technique revealed latent fingerprints on this specialty paper. Visualization was done with an alternate light source at 530 nm wavelengths, using orange filter goggles. His method also prevents discoloration, and minimal damage is reported to the surface of the paper.

Particular advantages of ORO compared to the methods listed above include the fact that ORO does not involve the use of an alternate light source, and the results will not fade after development.

Time and Mean Fingerprint Quality

On standard white paper, the results show that there is no statistical relationship to aging time. That is, the percentage number of prints in each score of the measuring scale is not affected by the time the fingerprints were aged, within the 1- to 30-day time frame of the experiment. For example, one would have expected the mean fingerprint quality to be inversely proportional to the time the fingerprints were left to age. No such trend was established in three of the four treatment and paper combinations, and, therefore, it can be concluded that another variable is probably influencing the quality of fingerprints. The data was fit to a linear regression model, comparing time and mean fingerprint quality.

The ORO and kraft brown paper combination was the only one where a significant statistical trend was measured by a simple linear regression. Time was therefore determined to have had a detrimental effect on the mean fingerprint quality on this type of surface, using that recovery method ($t=2.02$, $p<0.010$, two-tailed) [18]. Perhaps a larger sample size might have produced more salient results in terms of time effect on the MFQ.

A hypothesized reason for these results might lie in the porosity of the kraft brown paper. The uneven porosity of the kraft brown paper might imply that old prints are even less likely to be detected over time if we assume a greater loss of residue to the pores as time increases. Some absorption would be expected, even on more even-pored paper, but an uneven porous surface such as that of kraft paper, coupled with time, can only forecast deteriorating fingerprint quality.

The Effect of Water

Water treatment before the deposition of fingerprints demonstrates poorer results compared to water treatment after deposition of fingerprints, with the percentage of Quality 2 prints scoring below 10% for all paper and method combinations.

The effect of water on paper could be simply one of clogging the pores. In both methods, when the papers came out of the water treatment, fingerprints were immediately rolled on the wet surface, and then the papers were hung to dry before being processed. As the water fills the pores, the lipid residues are left with fewer spaces to cling to. Lipids are hydrophobic and are not able to bind to the paper; water molecules are lost or moved and, therefore, distort the resulting fingerprint. The few lipids that do bind to the papers can be recovered with both methods. The results are faint and poor, implying that fewer lipids are present to react to the methods.

General Observations

The senior crime scene technicians who evaluated the fingerprints pointed out that the contrast might have appeared better with the PD at first glance, but that under the magnifying glass, the ORO results were more impressive and clear. If the concentration of the ORO powder in the staining solution were increased, we might find the contrast to be clearer to the naked eye.

Research by Dikshitulu et al. [19] has shown that some components of fingerprints disappear over time. Though it is not specified in their article which components disappear, based on the observations from the current study, light could be shed on the subject. Fingerprints that were stored for 20, 25, or 30 days and then processed in ORO and in PD were fainter in color than fresher, day-old fingerprints. Because both of these methods, and especially ORO, target lipid components of fingerprints, a fainter color would suggest a lesser amount of lipids. Therefore, it is proposed that the disappearing components from the fingerprints in the research by Diskhitulu et al. [19] were lipids.

Conclusion

Beaudoin's method [2] did not involve the use of alternate light sources. He focused on nonfluorescent methods and targeted the solid lipid components in latent fingerprints. Used primarily for wet surfaces, ORO was compared to the standardized method (physical developer) currently used at the Sûreté du Québec to develop fingerprints on wet surfaces. The two methods were compared on three different types of wet paper: thermal paper, white paper, and brown kraft paper. Thermal paper involved the use of fresh fingerprints, while the white paper and the brown paper tested aged fingerprints, from 1 to 30 days. All papers were exposed to tap water. Results show that for thermal paper, for all seven manufacturers tested, ORO provided better fingerprint quality than did PD. For standard white paper, ORO worked optimally, producing the greatest amount of prints. Finally, searching for optimal results, the authors preliminarily tested fingerprints with both methods sequentially, using ORO first and completing the test with the PD to recover damaged or old fingerprints. Results are promising and plans are underway to test several other recovery methods in a sequential order in the hopes of finding the most favorable series for the recovery of these fingerprints. Preliminary unpublished results with ORO on dry paper previously treated with DFO and ninhydrin also render optimistic results.

Acknowledgments

The authors would like to thank Bureau en Gros, Future Shop, Canadian Tire, National Bank of Canada, Walmart, Petro-Canada, and Zellers for donating samples of their thermal paper; the University of Toronto at Mississauga Forensic Science Program for giving the opportunity of an internship; Bruno Caron from the University of Waterloo for statistical discussions; the Services de l'Identité Judiciaire at the Sûreté du Québec, in Montréal, Canada; and the senior crime scene investigators, Sergeants Marc Bessette and Daniel Trudeau, for their evaluations of the fingerprints, comments, and support.

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Appendix
Technical Specifications

Oil Red O

Preparation of Solutions:

1) Stain Solution:

- Weigh out 1.54 g of Oil Red O and dissolve it in 770 mL of methanol.

- Dissolve 9.2 g of NaOH (sodium hydroxide) in 230 mL of water and add it to the above solution.

- Mix and filter, then store in a brown bottle away from light.

2) pH 7 Buffer Solution:

- Add 26.5 g of Na_2CO_3 (sodium carbonate) to 2 L of water and shake until it is dissolved.

- Carefully add 18.3 mL of concentrated HNO_3 (nitric acid), shaking constantly.

- Add enough water to increase volume to 2.5 L.

Procedure:

1. The document is first immersed in the stain solution and shaken for 60 to 90 minutes.
2. It is then removed and drained, then immersed in the buffer solution to adjust the pH of the document.
3. The document is then rinsed in a container of distilled water and dried.

Drying can take place in the open air or in an oven at 50 ºC to accelerate the process.

Physical Developer

Preparation of Solutions:

1) Acetic acid solution:

    - 250 mL glacial acetic acid in 750 mL distilled water

2) Maleic acid solution:

    - 25g of Maleic acid in 500 mL of distilled water

3) REDOX Solution:

    - 30 g of ferric nitrate nonahydrate in 900 mL distilled water
    - Add 80 g of ferrous ammonium sulphate hexahydrate
    - Add 20 g of citric acid

4) Silver nitrate solution:

    - 5 g silver nitrate in 25 mL of distilled water

5) Detergent solution:

    - Add 2.7 g of N-dodecylamine acetate in 500 mL of distilled water
    - Add 4.0 g of Synperonic-N

6) Physical Developer Working solution:

    - Add 20 mL of detergent solution to 480 mL REDOX solution
    - Add silver nitrate solution

Procedure

1. Tray 1 Acetic acid pre-treatment
2. Tray 2 Maleic acid treatment
3. Tray 3 Working solution
4. Tray 4 Washing with distilled water