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# Evaluation of Five Methods to Develop Latent Prints on Thermal Paper

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**ABSTRACT**

Forensic latent fingerprint laboratories determine the proper techniques for fingerprint visualization based on the substrates upon which they are deposited. Typical forensic analysis of thermal paper evidence involves the application of ninhydrin and/or 1,2-indanedione dissolved in a polar solvent. However, polar solvents create an undesirable reaction with the thermal paper's internal properties and often lead to discoloration of the evidence. When this occurs, not only are the fingerprints less likely to be visible due to the loss of contrast, but the evidentiary print on the receipt may be lost entirely. This research sought to compare five development methods to determine their effectiveness at developing latent fingerprints on thermal paper.

This experiment had two main components including analysis of fingerprints experimentally deposited on receipts and fingerprints naturally occurring on receipts. In the first part of the experiment, 10 receipts from Kroger and 10 receipts from Costco Wholesale were subjected to each of five development methods: sequential application of 1,2-Indanedione and ninhydrin, heat methods (oven, hot water immersion, and hairdryer), and p-Dimethylaminocinnamaldehyde (PDMAC) paper. The receipts were photographed following these treatments and rated by three individual examiners on a five-point quality scale, which categorizes the visualized prints according to their utility for individual identification. Statistical analyses suggested PDMAC paper as an effective substitute for current methods since, unlike the effects of ninhydrin, there was no background darkening of the receipt paper. The process itself was simple, although the receipts remained sandwiched between the impregnated paper for three hours; this time requirement, while significant, was comparable to the current 1,2-Indanedione and ninhydrin time commitment. The resulting fingerprints were also comparable in quality to those visualized with 1,2-Indanedione. In contrast, fingerprints developed from the other methods were of poor quality, if visualized at all.

Based on these preliminary results, fingerprints naturally occurring on receipts from various businesses were developed with PDMAC paper sandwiching to determine how long after processing photographs should be taken. Photographs were taken at 40 mins, 1 hr, 3 hrs, 5 hrs, 27 hrs, 1 wk, and 2 wks. Photographs taken between 27 hrs and 2 wks after processing were found to have the highest fluorescence. Future research is needed to determine what length of time receipts should be sandwiched between PDMAC paper in order to best visualize the fingerprints. Once confirmed, this protocol could improve the overall ease and effectiveness of developing latent prints on thermal paper, thus leading to more accurate comparisons.

**Key words: Latent prints, PDMAC, Thermal paper**

**INTRODUCTION**

Thermal paper, a type of paper that produces black or colored print in reaction to the application of heat, is commonly used for receipts, bus tickets, ATM receipts, and other applications. The paper is made up of multiple layers, each with its own purpose; these layers include the back coat, base-paper, precoat, thermal/active coat, and topcoat (glossy side of the paper). The most forensically relevant layer is the thermal coat which includes an initially-colorless leuco dye, a developer, sensitizers, and stabilizers. When heat is applied, the matrix that separates the leuco dye from the developer melts and causes these two components to react and form a polar complex that appears as black or colored print (Jonas, Rubner, & Oetken, 2019; Stimac 2003a, 2003b; Yadav 2019; USEPA 2015).

Thermal papers often contain latent fingerprints, which can connect a perpetrator to a scene or link an individual to an item(s) purchased and used to commit a crime. Within the latent print division of forensic science laboratories, thermal paper proves especially difficult to analyze due to its complex makeup. Typical analysis of paper evidence involves ninhydrin and/or 1,2-indanedione dissolved in a polar solvent such as acetone or ethyl acetate, respectively; this poses a problem with thermal paper, however, because polar solvents dissolve the developer and allow it to react with the leuco dye to turn the paper black (Stimac 2003b; Jonas et al. 2019). If thermal paper turns black from this undesirable reaction, not only is the information on the receipt lost due to the loss of contrast, but any evidentiary prints may be lost as well.

A few methods, which can be grouped into seven main categories, have been proposed to visualize latent prints: adapted formulation, pre-treatment, post-treatment, vapors and fumes, heat, sandwich, and other. Adapted formulation refers to the adaptation of current methods involving chemicals (e.g. ninhydrin and 1,2-indanedione) to better mitigate the darkening effect, while post-treatment methods assume discoloration and aim to reverse it after the fact. Pre-treatment methods are those that deactivate the thermosensitive layer before processing in order to prevent the paper from turning black. The vapors and fumes methods expose the thermal paper to these substances in a controlled environment. Although heat can cause darkening of the thermal paper, research has shown that the application of low heat may deliver better contrast. Sandwich methods, usually involving p-dimethylaminocinnamaldehyde (DMAC, also known as PDMAC) or 1,2-indanedione/zinc require time for the sample to process while in the middle of two impregnated foils. Finally, other methods included Oil Red O, physical developer (PD), and single metal deposition (SMD) (Fitzi, Fischer, Moret, & Bécue, 2014).

Adaptation of ninhydrin processes is one of the most common techniques studied, as the marks it produces are of high quality on porous materials. In a comparison of the efficacy of ThermaNin, ninhydrin (thermal), and NinK12, ninhydrin (thermal) was more practical due to the stability of the treatment, even though the performance of ThermaNin was slightly better (Fitzi et al. 2014). Another simple adjustment to the ninhydrin technique involves the use of water-based glue. Eksinitkun, Pansiw, and Phutdhawong (2019) found reduced background blackness with a 0.20-0.50 g/mL ratio of glue to ninhydrin working solution. Fitzi et al. (2014) also suggested a sequence of cyanoacrylate fuming → 1,2-Indanedione/zinc → ninhydrin → SMD.

1,8-Diazafluoren-9-one is a ninhydrin analog known for its fluorescent properties under green light. Luo, Zhao, and Liu (2013) concluded the combination of polyvinylpyrrolidone (PVP), which mitigates darkening of the paper, and DFO leads to a better background contrast than ninhydrin by itself. One adaptation universal to ninhydrin, 1,2-Indanedione, and DFO is the addition of 1-methoxy-nonafluorobutane (HFE-7100) solvent (Stimac 2003a). While, for example, 1,2-Indanedione in ethyl acetate typically leads to the paper's darkening, the HFE-7100 acts to mitigate this damage by adjusting the solution's polar properties (Stimac 2003b). Other benefits of HFE-7100 include its low toxicity, low environmental impact, and nonflammability (Stimac 2003a). The positive outcomes of Stimac's studies are promising, however, future research should compare these results to other methods that have developed in the 17 years since the paper was published. One study by Levin-Elad, Liptz, Bar-Or, and Almog (2017) briefly compared 1,2-Indanedione to both ninhydrin and DFO and concluded 1,2-Indanedione to be superior of the three.

Fitzi et al. (2014) studied post-treatment techniques including use of cellophane tape, G3, and 1,4-Diazabicyclo[2.2.2] octane (DABCO). In addition to not properly whitening the background of the thermal paper, cellophane tape also prevented subsequent processing. G3 is a chemical mixture whose formulation was created by Schwarz and Klenke (2007). Both G3 and DABCO whiten the background of the thermal paper by altering the leuco-dye structure in the thermosensitive layer through a Lewis acid/base reaction. G3 and DABCO performed well, although neither were effective on lottery tickets.

Fitzi et al. (2014) researched the use of ethanol to deactivate the paper's thermosensitive layer before analysis with ninhydrin; while the purpose--deactivation--was achieved, the method resulted in blurred fingerprints and therefore will not be considered in this study.

Ovens, hairdryers, and hot water have all been studied as sources of heat to develop prints on thermal paper. The basis of a latent fingerprint is the deposition of oils and perspiration on a surface, which makes the latent fingerprint characteristically hydrophobic. When these hydrophobic components interact with the components in the thermosensitive layer, the temperature at which the solvent dissolves is lowered, thus allowing the fingerprint's color change to occur at a lower temperature as well. By immersing the evidence briefly in hot water tailored to the specific type of thermal paper, the print can be developed before the entire paper is darkened. While this process is logical in theory, Jonas et al. (2019) found that it works best for prints deposited less than a week prior to processing; this limitation poses a problem in forensic science, as evidence may not be processed in the laboratory immediately after the scene investigation (and scene investigations do not always occur immediately after the crime took place). A follow-up study by Ruedy (2020) was conducted at the Virginia Department of Forensic Science (VA-DFS), which did not identify any fingerprints until the water temperature reached at least 90 °C. Bissonnette, Knaap, and Forbes (2010) conducted a study using steam instead of hot water, and the usefulness was again limited by the freshness of the prints. Wakefield and Armitage (2005) found that the use of a hairdryer can develop prints when set to 30 °C below the temperature at which the thermal paper is activated.

Instead of using one of the easily available heat methods listed above, Bond and Phil (2013) created their own heating apparatus made of brass and a hotplate. They found optimal results when the brass rectangle was heated to 44 °C and the resulting prints were viewed with a blue LED light source with a peak wavelength of 465 nm. Unlike previous studies, this method did not cause fading of the developed prints until 12 wks post-analysis; this, along with other differences among findings, may be due to differences in the chemical composition of the thermal papers used. Recently, a Hot Print System (HPS) has become available that works similarly to the apparatus described by both Bond and Phil (2013) and Robb, Deacon, Fordyce, Fennesy, and Farrugia (2020). When compared to UV, ninhydrin, and ThermaNIN, however, HPS was found to be inferior; furthermore, *contra* to the findings of Fitz et al. (2014), an acetone pre-wash followed by ninhydrin proved to be the most effective. Bond and Phil (2014), on the other hand, found that the application of heat was superior, requiring less time and producing better ridge detail than chemical treatment.

Of the other methods tested by Fitzi et al. (2014), PD was not tested thoroughly as it did not visualize any marks in the initial trial. However, like SMD, PD could be used as the last step in a development sequence if the laboratory is comfortable with its use. Because of Oil Red O's ability to destroy already-developed prints when used in sequence with other methods, Fitzi et al. (2014) warns this method should only be considered when the thermal paper in question is wetted.

Iodine fuming is another technique commonly used to analyze porous materials that is now being tested on thermal paper. When sublimation of iodine crystals occurs, the vapors stick to the oil and perspiration in the latent print, turning the friction ridges an orange color. As opposed to previously discussed methods, iodine fuming is effective for prints up to a year after their deposition. Although, of older prints, sebaceous prints are better preserved than eccrine-based prints (Jasuja and Singh 2009). Methods involving $NO_2$ gas similarly are more effective for sebaceous prints (Stojkovikj, Oklevski, Jasuja, & Najdoski, 2020). Ninhydrin can also be sublimated to remove the need for polar solvents with optimal conditions at 150 °C for 30 mins with 50 mg ninhydrin (Schwarz, Nat, & Frerichs, 2002).

Other less common fuming techniques involve the use of ruthenium dioxide or muriatic acid. Ruthenium dioxide fuming can easily be made portable and develops fingerprints with sharp detail on thermal paper. Its use does not interfere with further processing and the prints developed with this method do not fade easily (Mashiko & Miyamoto, 1998). The toxicity of the compound and its explosive nature limit its use in forensic laboratories, however (Sodhi & Kaur 2019). Bronnick and Knapp (2002) showed that muriatic acid fuming developed prints of excellent quality on thermal paper, although only on the emulsion side. While this method is quick, it cannot be used with any other developing methods and also poses a hazard due to its corrosive nature.

Some solvents, namely PDMAC can be used in both fuming and sandwich forms. Previous research has shown that fuming is relatively effective, if difficult to apply homogeneously, while dry contact DMAC paper is inferior to current ninhydrin and DFO techniques (Brennan, Bramble, Crabtree, & Wright, 1995.; Lee, Bleay, Sears, Mehmet, & Croxton 2009; Fitzi et al. 2014). Pre-packaged PDMAC paper has recently been added to the market. This research investigated the usefulness of this new technique and further compared the results to current methods used.

As discussed, this research aimed to compare five current methods for developing latent prints on thermal paper: 1,2-Indanedione and ninhydrin, heat methods (oven, hot water immersion, and hairdryer), and PDMAC paper. A comparison between the Kroger and Costco receipt paper was also considered. These comparisons were conducted by having three researchers rate each print on a numerical scale as outlined by Fairley, Bleay, Sears, and NicDaeid (2012) then further performing comparison of means statistical analyses on these ratings. The pros and cons of each method, including processing time, safety, and ease, were considered in a conclusion recommending a superior method to those currently used in forensic science laboratories. Additionally, the rater agreement was taken into account concerning consistency of results and was analyzed statistically to explore the perceived subjective nature of fingerprint analysis.

## MATERIALS AND METHODS

This experiment had two main components, the analysis of fingerprints experimentally deposited on receipts and fingerprints naturally occurring on receipts. Hundreds of receipts were collected from a variety of businesses in the months prior to the research, although only 120 were analyzed. Each receipt analyzed was cut to a standard size (approximately 9 x 7.75 cm) to maximize the number of receipts that could be processed at once. All experimentally deposited fingerprints in the first component of the study were from a single donor (JP). Prior to placement of the fingerprints, the subject rubbed her index finger behind her ear for approximately five seconds to collect sebaceous oil. The print was placed in an area of the receipt with no ink markings and a light pencil mark was drawn roughly above where the fingerprint was deposited. As is protocol at the VA-DFS, all receipts were photocopied and viewed under a Full Spectrum Imaging System (FSIS) prior to processing. Once fingerprints were deposited, the receipts were stored in plastic bags according to standard evidence protocol for at least one week before processing. After processing, each receipt was photographed with a Nikon D800 camera and viewed under an alternate light source (ALS).

Receipts with experimentally placed fingerprints were derived solely from either Kroger supermarkets (labeled K 1-50) or Costco wholesale (Labeled C 1-50). The final analysis of these naturally deposited fingerprints was conducted on receipts randomly selected from all the receipts collected. Table 1 displays which receipts from each business were analyzed by each method for experimentally deposited fingerprints on thermal paper receipts.

*1,2-Indanedione and Ninhydrin*

The 1,2-Indanedione (Lot #: 080620, Exp: 02/06/2021) and ninhydrin (Lot #: 030420, Exp: 03/04/2021) were solutions prepared by DFS, according to the VA-DFS Latent Print

Procedures Manual; specifically, the preparation of ninhydrin used the acetone standard operating procedure (SOP). The receipts were heated with a heat press at 170 °C for 60 s following 1,2-Indanedione application per protocol. After application of 1,2-Indanedione, receipts were left in a drying chamber overnight then viewed and photographed under 520 nm with an orange filter. Ninhydrin was subsequently applied but heat was not used to speed up processing. Receipts were again left in a drying chamber overnight then viewed and photographed. A control print was also included on a separate piece of paper to ensure the solutions were in working order.

*Heat Application – Hairdryer*

The settings among hairdryers differ; therefore, a receipt not included in the study was first tested to determine if Wakefield and Armitage's (2005) suggested technique would visualize prints with the hairdryer used here. Heat was applied via a Sutra beauty 1000 W hairdryer (model #: 20BDT-B37) by turning the hairdryer to the highest setting and briefly (10 – 40 s) holding it approximately one centimeter away from the receipt until the print began to develop.

*Heat Application – Hot Water Immersion*

Based on the research conducted recently by Ruedy (2020), a 90 °C Biotage TurboVap water bath was prepared and the respective samples were immersed individually for approximately 1 s then allowed to dry. Once dry, they were photographed immediately.

*Heat Application – Oven*

While Bond et al. (2013) found that the optimum temperature for the HPS is 44 °C, not every laboratory has access to such a system. Ovens are often more accessible and therefore a 120 V Cuisinart convection toaster oven (model #: TOB-195) was used in this study. The oven was set to 65.5 °C, as this was the lowest possible setting. Receipts were laid on the grating and left in the oven until prints began to develop or two minutes had been reached, whichever came first.

*PDMAC Paper – Experimentally Placed Prints*

The Pioneer Forensics PDMAC paper was employed as directed on its packaging. This involved placing the receipt evidence between two pieces of PDMAC paper (Lot #PF30038) for three hours then removing, viewing, and photographing it under ALS at 480 nm. In this photography process, the camera was additionally suited with an orange filter. While the fingerprints were situated between the PDMAC paper, the paper was held down with a large plastic tray that weighed roughly three pounds.

*PDMAC Paper – Naturally Occurring Prints*

The final component of this study involved developing fingerprints on 10 randomly selected receipts from those collected prior to the research study. These receipts had naturally occurring fingerprints on them along with one intentionally placed fingerprint at the top that acted as a control. As fingerprints are usually not planted by suspects at a crime scene, the purpose of this was to ensure PDMAC paper was effective for receipts that were both from sources other than Kroger and Costco and naturally handled. The main purpose of this component of the study, however, was to determine the ideal time after PDMAC processing to photograph results. After being removed, receipts were photographed at 40 mins, 1 hr, 3 hrs, 5 hrs, 27 hrs, 1 wk, and 2 wks. The camera was again suited with an orange filter and used in conjunction with an ALS set to 480 nm.

All resulting fingerprints were analyzed using the scale comparison outlined by Fairley et al. (2012). Three researchers independently, and in their own time, rated each fingerprint according to the scale and a reliability analysis was conducted to determine if differences occurred in the way each grader rated fingerprints. Specifically, a one-way random intra-class correlation coefficient (ICC) was calculated on the Statistical Package for Social Sciences (SPSS) where a value between 0.75 and 1.00 is reflective of excellent agreement (Cicchetti, 1994; Tritella et al., 2020; de Boer et al., 2012).

Since each method was initially tested on 20 receipts, and those 20 receipts each had 3 ratings, there were a total of 60 ratings per development method. These 60 ratings for each development method were used to again conduct a difference of means analysis. Statistical comparison of means was conducted with an Analysis of Variance (ANOVA) test in conjunction with Tukey's pairwise post hoc test. A qualitative comparison of the safety, time required, and ease of each method was also taken into consideration.

## RESULTS AND DISCUSSION

### Component 1

#### *1,2-Indanedione and Ninhydrin*

Application of ninhydrin caused the receipts to immediately turn white then blue or black within two to three seconds. Since the fingerprints visualized by 1,2-Indanedione were ruined once ninhydrin was applied and no additional fingerprints were visualized with ninhydrin, only fingerprints photographed prior to 1,2-Indanedione application were included in the analysis. Since the text itself could be used as evidence, it would be ideal to avoid ruining the text on the receipt. While photocopying the receipt prior to processing would ensure the text is preserved, having the original receipt would be better. The mean grade given to a fingerprint developed by this method was 2.40 (Table 2).

While the process of spraying receipts with these solutions was simple, it took approximately 48 hrs to complete due to the drying time required.

*Heat Application – Hairdryer*

While Wakefield and Armitage's (2005) study concluded the hairdryer's lowest setting for five seconds was the ideal visualization technique, the technique was altered in this study because the hairdryer settings differed and no change was visualized with the test receipt. Like with the other heat application methods, the time required to visualize fingerprints varies receipt to receipt which does not allow for a standard operating procedure and increases the chance of overdeveloping or even burning the receipt completely. Of the fingerprints that did develop in this study, most appeared as white ridges atop a darkened background. The mean grade given to a fingerprint developed by this method was 0.52 (Table 2).

*Heat Application – Hot Water Immersion*

When briefly submerged in the hot water tank, the print on the front of the receipts immediately disappeared. The colorful advertisements on the back of the Kroger receipts remained in their original condition, however. The mean grade given to a fingerprint developed by this method was 0.00 (Table 2).

*Heat Application – Oven*

As with the hairdryer method, the time necessary to develop fingerprints varied widely. Fingerprints were visualized on two receipts within 25 s, while the remaining 18 receipts did not develop any fingerprints within the 2 m cutoff time. While text on the receipt remained after processing, burn marks developed which slightly altered the appearance of the receipt and could impact future processing. The mean grade given to a fingerprint developed by this method was 0.15 (Table 2).

*PDMAC – Experimentally Placed Prints*

Prior to processing, only receipts C42, C43, C44, and C48 contained fingerprints visible under FSIS; of these, only C42 contained a fingerprint of high enough quality to capture (Figure 1).

Processing itself caused the receipts to develop a light yellow tinge but all text remained in its original condition. Photographs were taken both immediately after processing ceased and one week later. It was observed that fingerprints appeared brighter when photographed one week after processing; this observation led to the second aim of the study. The mean grade given to a fingerprint developed by this method was 3.30 (Table 2).

*Statistics*

The intra-class correlation between all 3 graders was 0.928 with a 95% confidence interval from 0.902-0.949. Considering the previously-set 0.75 value cutoff, this result suggests high correlation between ratings for each fingerprint and therefore insignificant differences between graders.

The two-factor ANOVA analysis with method and location as factors assumed a full factorial model and included Tukey's pairwise test for the methods. Table 3 describes, among other analyses, the ratio between between-group and within-group differences, known as the F-ratio. A high F ratio indicates a greater proportion of between-group differences relative to within-group differences. A low F ratio, on the other hand, indicates a greater proportion of within-group differences than between-group differences. Based on these F ratios, there are more differences between methods than between origin location of the receipts (Kroger and Costco).

The only two methods that do not produce significantly different results at the 0.05 significance level are methods three and four: hot water immersion and oven method, respectively (Table 4). This result is also observed in Table 2 where methods three and four are placed in the same subset while all other methods are separated. Additionally, while still significant at the 0.05 level, the difference between the hair dryer and oven methods were not as significant as other differences. The current 1,2-Indanedione and ninhydrin method, while significantly different from all other methods, is only inferior to the newest method—PDMAC. Between those two methods, placing a receipt between PDMAC paper produced fingerprints rated on average almost a whole point higher.

Component 2

As was seen in the study's first component, PDMAC processing slightly tinged the receipts yellow and all text remained in its original condition. In addition to the control fingerprints, PDMAC processing developed six naturally occurring fingerprints distributed among three receipts. Visually, the ideal time to photograph receipt paper is 27 hrs after and no later than 14 days after processing with PDMAC paper (Figure 2). During this time range, the fluorescence appears brightest. This time frame applies to naturally occurring fingerprints as well. In general, the naturally occurring fingerprints appeared clearer than those placed intentionally.

## CONCLUSION

While the process of spraying receipts with 1,2-Indanedione and ninhydrin was simple, it took about 48 hrs to complete due to the drying time required. This was comparable to the ease and time required for PDMAC paper processing. All three heat application methods took less than two minutes per receipt and were generally simple, although many receipts did not develop latent fingerprints in this time. Whether this outcome was due to the properties of the receipt, fingerprint, or processing method is unknown; however, if each receipt had been processed for a different length of time depending on development, this would have made the process less routine and more susceptible to over processing.

Both 1,2-Indanedione and ninhydrin are classified as irritants, although if used as directed in a fume hood with proper protective equipment, this risk is low. As PDMAC paper is relatively new, there is limited data on its safety. However, much like 1,2-Indanedione and ninhydrin, p-dimethylaminocinnamaldehyde is also an irritant as well as harmful if ingested. Again, these hazards are easy to mitigate with proper personal protective gear and safety equipment. Additionally, the risk of ingesting or coming into direct contact with the reagent is much lower in its solid paper form than if it were in a liquid form. Heat application techniques do not require fume hoods as irritating solvents are not involved; however, these methods could cause dermal burns.

Significant differences were not found among ratings given by each of the three independent researchers even though the researchers were at different experience levels. While the subjectivity of fingerprint analysis as a whole is not relevant to this study, fingerprint rating using the Fairley et al. (2012) system is adequately objective and may be helpful to future research of fingerprint visualization techniques.

Overall, PDMAC paper proved promising as a new method of developing latent fingerprints on thermal paper. Each paper set can process hundreds of receipts, although the exact number of repetitions has not been quantified in this research. Because only 20 receipts were tested for each method in the first component of the study, a larger and more variable sample size is needed to make any conclusive changes to laboratory SOPs. Forensic laboratories considering adopting this new technique should also consider how many receipts are received as evidence at any given time since the shelf life is approximately six months when stored in its protective metallic sleeve. According to the manufacturer, PDMAC paper is effective at developing latent fingerprints on other porous items of evidence as well, although thermal paper receipts were the only substrate tested here.

While time until photography did not play a large role in obtaining fingerprints, between 27 hrs and 2 wks was found to be the most ideal in terms of fluorescence quality. Future research should focus on determining the ideal length of time receipts should stay sandwiched between the PDMAC paper in order to maximize fingerprint visualization.

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## CRITICAL DATA

**Table 1. Methods for analysis of experimentally placed fingerprints on thermal paper receipts**

| | 1,2-Indanedione and Ninhydrin (Group 1) | Hairdryer (Group 2) | Hot Water Immersion (Group 3) | Oven (Group 4) | PDMAC Paper (Group 5) |
|---|---|---|---|---|---|
| Kroger | K 1-10 | K 11-20 | K 21-30 | K 31-40 | K 41-50 |
| Costco | C 1-10 | C 11-20 | C 21-30 | C 31-40 | C 41-50 |

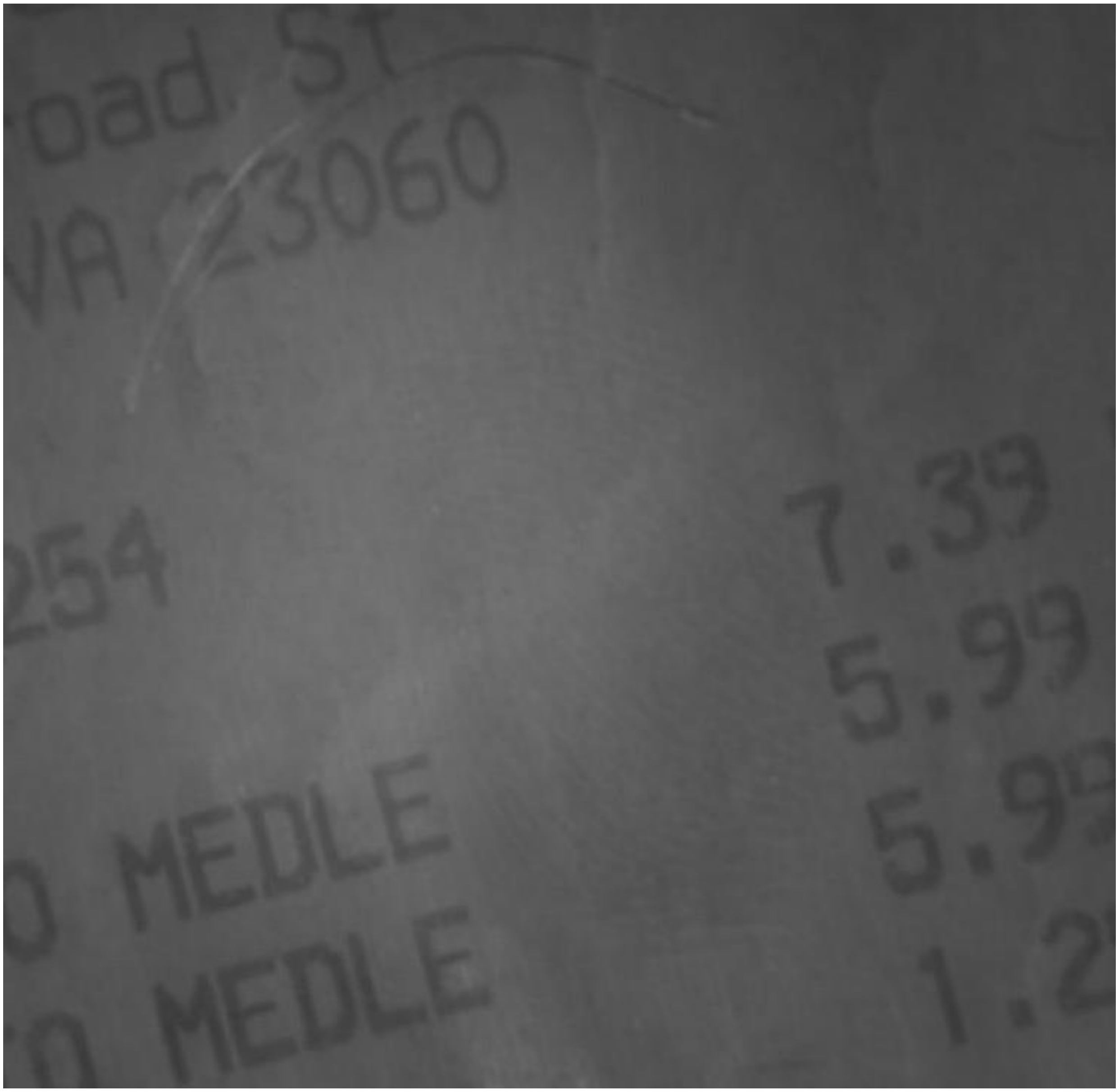


**Figure 1. C42 FSIS-captured fingerprint**

**Table 2. Grade**

| Tukey | | | | | | |
|---|---|---|---|---|---|---|
| Method | N | Subset | | | | |
| | | 1 | 2 | 3 | 4 |
| Hot Water Immersion | 60 | .00 | | | |
| Oven | 60 | .15 | | | |
| Hairdryer | 60 | | .52 | | |
| 1,2-Indanedione | 60 | | | 2.40 | |
| PDMAC | 60 | | | | 3.33 |
| Sig. | | .758 | 1.000 | 1.000 | 1.000 |

Alpha = 0.05.

**Table 3. Tests of Between-Subjects Effects**

| Dependent Variable: Grade | | | | | |
|---|---|---|---|---|---|
| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
| Corrected Model | 539.816 | 9 | 59.980 | 125.440 | <.001 |
| Intercept | 491.562 | 1 | 491.562 | 1028.046 | <.001 |
| Location | .118 | 1 | .118 | .247 | .620 |
| Method | 537.227 | 4 | 134.307 | 280.887 | <.001 |
| Location * Method | 1.582 | 4 | .396 | .827 | .509 |
| Error | 138.664 | 290 | .478 | | |
| Total | 1170.000 | 300 | | | |
| Corrected Total | 678.480 | 299 | | | |

**Table 4. Multiple Comparisons**

| Tukey HSD | | | Dependent Variable: Grade | | | |
|---|---|---|---|---|---|---|
| (I) Method | (J) Method | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
| | | | | | Lower Bound | Upper Bound |
| 1 (1,2-Indanedione) | 2 | 1.88* | .126 | .000 | 1.54 | 2.23 |
| | 3 | 2.40* | .126 | .000 | 2.05 | 2.75 |
| | 4 | 2.25* | .126 | .000 | 1.90 | 2.60 |
| | 5 | -.93* | .126 | .000 | -1.28 | -.59 |
| 2 (Hairdryer) | 1 | -1.88* | .126 | .000 | -2.23 | -1.54 |
| | 3 | .52* | .126 | .001 | .17 | .86 |
| | 4 | .37* | .126 | .032 | .02 | .71 |
| | 5 | -2.82* | .126 | .000 | -3.16 | -2.47 |
| 3 (Hot Water Immersion) | 1 | -2.40* | .126 | .000 | -2.75 | -2.05 |
| | 2 | -.52* | .126 | .001 | -.86 | -.17 |
| | 4 | -.15 | .126 | .758 | -.50 | .20 |
| | 5 | -3.33* | .126 | .000 | -3.68 | -2.99 |
| 4 (Oven) | 1 | -2.25* | .126 | .000 | -2.60 | -1.90 |
| | 2 | -.37* | .126 | .032 | -.71 | -.02 |
| | 3 | .15 | .126 | .758 | -.20 | .50 |
| | 5 | -3.18* | .126 | .000 | -3.53 | -2.84 |
| 5 (PDMAC) | 1 | .93* | .126 | .000 | .59 | 1.28 |
| | 2 | 2.82* | .126 | .000 | 2.47 | 3.16 |
| | 3 | 3.33* | .126 | .000 | 2.99 | 3.68 |
| | 4 | 3.18* | .126 | .000 | 2.84 | 3.53 |

*. The mean difference is significant at the 0.05 level.

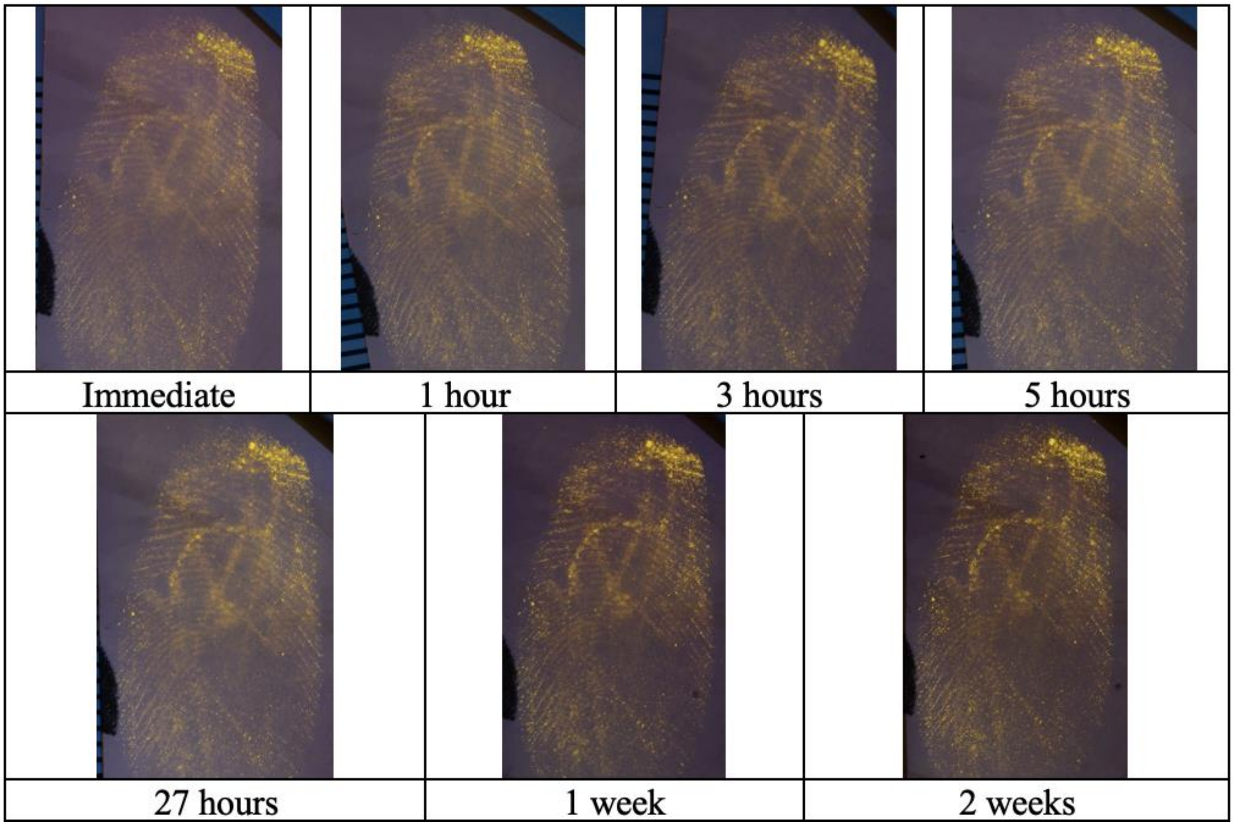


**Figure 2. Photographs of SC6 at various time intervals post-PDMAC processing**

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