**Article**

# Fingermark Detection on Thermal Papers: Proposition of an Updated Processing Sequence

***Thomas Fitzi***
***Ruth Fischer***
***Sébastien Moret***
***Andy Bécue***

***École des Sciences Criminelles***
***University of Lausanne, Switzerland***

**Abstract**: The detection of latent fingermarks on thermal papers proves to be particularly challenging because the application of conventional detection techniques may turn the sample dark grey or black, thus preventing the observation of fingermarks. Various approaches aiming at avoiding or solving this problem have been suggested. However, in view of the many propositions available in the literature, it gets difficult to choose the most advantageous method and to decide which processing sequence should be followed when dealing with a thermal paper.

In this study, 19 detection techniques adapted to the processing of thermal papers were assessed individually and then were compared to each other. An updated processing sequence, assessed through a pseudo-operational test, is suggested.

## Introduction

The processing of thermal papers for fingermark detection is known to be a challenging task, mostly because of the risk for the substrate to turn dark grey or black during the treatment. This phenomenon is the result of an unwanted activation of the sensitive layer of the thermal paper, which contains

Received February 19, 2014; accepted March 25, 2014

dyes, sensitizers, and stabilizers, by some polar solvents or by the detection protocol (application of heat) [1]. Consequently, various techniques or methods have been developed to solve this issue: modification of the reagent or the solvent composition to avoid the use of chemicals that cause the darkening [1–5], removal of the sensitive layer before the application of a conventional technique [6], chemical reversal of the substrate darkening after having applied a conventional technique [7–9], use of techniques presenting no detrimental effect on thermal papers (e.g., water-based) [10–12], or solvent-free protocols (e.g., chemical fuming [13–15], dry-application [16, 17], or heating [18, 19]). The quite large variety of available techniques inevitably raises questions: (1) Which technique(s) should be chosen when dealing with a thermal paper?, and (2) How should the most efficient techniques be combined into a sequence to which an operator may easily refer? This study attempts to answer these questions.

## Materials and Methods

### *Detection Techniques*

After a literature review, 19 detection techniques were chosen according to their ability to detect fingermarks on thermal papers (Table 1). These techniques were classified into seven different groups, defined as follow:

Group I–Adapted Formulation: These are techniques for which the solvents or the reagents have been specifically modified to avoid the risks of substrate darkening.

Group II–Pre-treatment: This a technique that aims to remove the thermal layer by immersing the sample into a polar solvent (i.e., ethanol) for several seconds. The substrate is subsequently processed with a conventional technique.

Group III–Post-treatment: These are techniques that aim to reverse the substrate darkening that has occurred after the application of a conventional technique (typically 1,2-indanedione or ninhydrin). The "whitening" agents modify the leuco-dye structure, turning it back to its colorless configuration.

Group IV–Vapors and Fumes: These are techniques based on exposing the sample to solvent vapors or chemical fumes (heated solid crystals) to initiate the reaction with the secretion residues.

Group V–Heat: These are techniques based on the application of moderate heat to induce a selective darkening of the sample.

By adjusting the temperature and the heating time, the fingermarks may appear before the paper darkens.

Group VI–Sandwich: The sandwich technique consists of inserting a sample between two filter papers that have been saturated with a conventional reagent solution (e.g., 1,2-indanedione/zinc), then dried. The detection occurs by direct contact between the reagent and the sample for several hours. In absence of solvents, the risk of darkening is avoided.

Group VII–Other: These are techniques that present no particular side effects when applied to thermal papers. This group essentially encompasses techniques based on aqueous solution or solventless ones.

| | Technique | Development/ Application | Remark | Ref. |
|---|---|---|---|---|
| Group I Adapted Formulation | ThermaNin | 24–48 h in dark, at room temperature | Modified ninhydrin structure, soluble in nonpolar solvents | [2] |
| | Ninhydrin (thermal) | 24–48 h in dark, at room temperature | Adapted formulation (HFE-711PA/HFE-7100) | [3] |
| | NinK12 | 24–48 h in dark, at room temperature | With polyvinylpyrrolidones (PVP) as anti-darkening agents | [4] |
| | 1,2-Indanedione (thermal) | 24–48 h in dark, at room temperature | Adapted formulation (no acetic acid) | [1] |
| | 1,2-Indanedione/ Zinc (AFP/thermal) | 24–48 h in dark, at room temperature | Adapted formulation (no acetic acid) | [5] |
| Group II Pre-treatment | Ethanol pre-dip | 5–10 seconds immersion (pre-detection) | Removal of the sensitive layer | [6] |
| Group III Post-treatment | G3 solution | Quick immersion after a conventional technique | Discoloration reversal | [7] |
| | DABCO | Same as for G3 | Discoloration reversal | [8] |
| | Cellophane tape | Sample covering after a conventional technique | Discoloration reversal, mechanism unknown | [9] |
| Group IV Vapors and Fumes | Iodine | Exposition to fumes (heated crystals) | – | [13] |
| | Acetic acid | Exposition to vapors | – | [14] |
| | pDMAC | Exposition to fumes (15 cm, heated crystals) | – | [15] |
| Group V Heat | Oven | 5–10 min at 65–70 °C | – | [18] |
| | Hairdryer | – | Close-range application, monitoring of the detection | [19] |
| Group VI Sandwich | pDMAC | 24 h between 2 impregnated foils | – | [16] |
| | 1,2-Indanedione/ Zinc | 24–48 h between 2 impregnated foils | – | [17] |
| Group VII Other | Oil Red O | According to recipe | – | [12] |
| | Physical developer (PD) | According to recipe | Water-based | [10] |
| | Single metal deposition (SMD) | According to recipe | Water-based; evolution of the MMD | [11] |

*Table 1*

*List of the tested techniques, classified into seven general groups.*

*Thermal Papers*

For Steps I through III (described on following page), thermal papers from three sources were used: gas station receipts (i.e., BP–Switzerland), mobile phone credit receipts (i.e., Lycamobile–Switzerland), and lottery tickets (i.e., EuroMillions). For the pseudo-operational test, a random selection of used thermal papers was gathered during several weeks. From these specimens, the following 100 samples were processed: shop receipts (59), ground transportation tickets (26), waiting line tickets (4), ATM receipts (4), airline tickets (3), parking receipts (3), and a national lottery ticket (1).

*Fingermarks*

Except for the pseudo-operational test, only natural secretions were considered in this study. Four donors (donorship level: one good, two average, and one poor) were asked to wash their hands, then to act normally for 30 minutes before leaving fingermarks on the substrates of interest. The fingermarks were then allowed to age during 1 week or 1 month before being processed. Split marks were used for steps II and III, as described hereafter. Because the fingermarks were not intentionally placed, the nature of the fingermarks and the number of donors in the pseudo-operational test are unknown. The only information available was the printing date of the document, if indicated (e.g., date of purchase).

*Detection Techniques*

All the techniques were applied by following the recommendations given in the literature (Table 1). The marks were observed and recorded under the optimal observation conditions. For luminescent marks, a Mini-Crimescope 400 and a Coherent TracER Compact laser (532 nm) were used in combination with interferential filters.

*Sample Management*

The samples were managed as follows:

Step I: At this stage, the intrinsic ability of each technique to detect fingermarks was assessed. For this purpose, the donors were asked to leave two depletion series of four marks (using two different fingers) on each sample. Taking into account the various three sources of thermal papers, the two aging times (i.e., 1 week and 1 month), and four donors, 24 samples with 8 fingermarks each (hence, a total of 192 fingermarks per technique) were consequently used to assess the quality of the 19 techniques.

Step II: From the remaining techniques, those with a similar reaction mechanism (but differing in their formulations) were compared to each other to determine the most suitable ones. For this purpose, the donors were asked to leave on each sample two depletion series of eight marks (using two different fingers). These samples were then cut in half to allow a side-by-side comparison of two techniques.

Step III: The selected techniques were put into two sequences, which were then compared by following the same approach as in Step II (i.e., use of split marks).

Pseudo-operational test: Each sample was cut into two portions of equal size, considering as far as possible how these samples would have been handled prior to collection. Therefore, one may reasonably assume to find the same amount of marks on each portion.

*Assessment of the Quality of Fingermarks*

Two quality assessment scales were used in this study (Table 2). The first scale was an "absolute" one based on the clarity of Level 2 characteristics (i.e., minutiae) observed on the analyzed (half-) marks [11]. For this, (1) all half-marks were converted into grey scales, (2) one half-mark was presented at a time (nonpaired, randomly selected among all the half-marks) to the assessor(s), (3) a score from 0 to 3 was allocated according to the ridge quality and the easiness to report minutiae, and (4) the evaluation stopped when all half-marks were ranked. The second scale was a "comparative" one; the half-mark processed with the technique under test was compared to its corresponding half-mark processed with another technique [20]. For this, (1) each half-mark was converted into grey scale and paired with

its complementary half, and (2) the reconstructed marks were graded by the assessor(s) on the basis of relative efficiency: a score from -2 to +2 was allocated according to the improvement (+) or the decrease (−) in quality compared to the other technique. The individual comparative scores were then added to give an overall trend about the efficiency of one technique over another. In this study, the absolute scale was used in Steps I and II (one assessor), as well as in Step III (four assessors). The comparative scale was used in Steps II (one assessor) and III (four assessors). In addition to the obtained quality scores, some operational aspects (e.g., solution stability, cost, easiness of preparation and application) were also considered to reach a conclusion, especially if two techniques were quite similar in terms of quality and sensitivity. For the pseudo-operational test, the quality criterion was defined as the total number of marks presenting at least six minutiae (on each processed half-sample).

| | Score | Qualitative Equivalent |
|---|---|---|
| **Absolute Scale** (based on [11]) | 0 | No ridge, no fingermark visible |
| | 1 | Ridges are visible over a small area (or over the whole mark), but it is extremely difficult to retrieve Level 2 characteristics (such as minutiae) because of extremely poor ridge details. |
| | 2 | Ridges are visible on almost the whole mark; Level 2 characteristics can be retrieved. Nevertheless, the quality is not optimal because of a low contrast, strong background staining, or faint ridges. |
| | 3 | Ridges are very well defined on the whole mark. Level 2 characteristics can easily be retrieved. The contrast is optimal with no (or extremely faint) background staining. |

| | Score | Qualitative Equivalent |
|---|---|---|
| **Comparative Scale** [20] | -2 | Significant decrease in enhancement of the assessed technique when compared to the other technique |
| | -1 | Slight decrease in enhancement of the assessed technique when compared to the other technique |
| | 0 | No enhancement of the assessed technique when compared to the other technique |
| | +1 | Slight increase in enhancement of the assessed technique when compared to the other technique |
| | +2 | Significant increase in enhancement of the assessed technique when compared to the other technique |

*Table 2*

*Description of the two quality assessment scales: the absolute scale (top) and the comparative scale (bottom).*

## Results

*Step I*

The first step of the experiment aimed at selecting the techniques that are actually efficient in detecting fingermarks on thermal papers (in terms of good general quality and ridge clarity). For this purpose, the samples were processed as a whole and the quality of the detected marks was assessed by one individual using an absolute scale. At the completion of Step I, the following techniques were retained: Group I (all), Group III (G3 and DABCO), and Group VII (Oil Red O and SMD). Several techniques (or groups of techniques) were discarded for the following reasons:

Group II–Ethanol pre-dip: The darkening of the substrate was indeed avoided, but blurred marks were obtained after treatment with ninhydrin. Given that other methods gave better results with ninhydrin, the pre-dip process was not retained.

Group III–Cellophane tape: In addition to poor results (regarding the whitening of the darkened substrate), the decision not to retain this post-treatment mainly relied on the fact that this procedure prevented the application of any subsequent technique.

Group IV–Vapors and Fumes: Even though the chemical vapors allowed visualization of latent fingermarks, processing the sample homogeneously proved to be particularly difficult. Moreover, the monitoring of the fingermark enhancement was demanding because some vapors can darken the substrate (e.g., acetic acid). Furthermore, the quality of the marks detected with pDMAC and iodine fumes was considered as insufficient.

Group V–Heat: It was difficult to apply the appropriate amount of heat (enough to allow the visualization of ridges but not too much to avoid the darkening of the thermal paper). Moreover, the quality of the obtained marks was insufficient. One additional drawback of this technique was its limitation to the thermosensitive side of the sample, whereas other techniques allowed the processing of both sides at the same time.

Group VI–Sandwich: The "dry" application of reagents led to luminescent marks and no background darkening, but the detection was not homogeneous and was considered as inferior to what could be obtained with the other processes.

Group VII–Physical developer: Because this method did not visualize any marks, it was not selected for the next steps (see Discussion).

*Step II*

Given that some techniques had very similar reaction mechanisms (e.g., three modified ninhydrin formulations, two modified 1,2-indanedione formulations, and G3 and DABCO as "whitening agents"), we decided to examine closely their respective efficiency to select the most suitable ones. The comparisons were done using extended depletion series and half-marks. The following conclusions were reached:

ThermaNin vs ninhydrin (thermal) vs NinK12: Ninhydrin (thermal) was retained because it led to the detection of more marks of slightly higher quality compared to NinK12 and ThermaNin (Figure 1). On the absolute scale, ThermaNin scored slightly better, but because the working solution was particularly unstable, it was discarded.

1,2-Indanedione (thermal) vs 1,2-indanedione/zinc (AFP/thermal): The AFP formulation was retained for its higher quality scores (Figure 2).

G3 vs DABCO (subsequent to conventional ninhydrin and 1,2-indanedione/zinc formulations): Both reagents follow the same reaction mechanism (i.e., Lewis base(s) modifying the leuco-dye structure). Therefore, it was not surprising to obtain similar results in terms of efficiency. G3 developed marks of slightly higher quality compared to DABCO (Figure 3). However, we decided to keep DABCO because of its ease of preparation, its lower price, and its lower toxicity compared to G3. This choice is further discussed in the next section. It should be stressed that both solutions were ineffective on the EuroMillions tickets, which remained dark-stained.

Oil Red O and SMD were not compared to each other at this stage because their detection mechanisms are fundamentally different. Both techniques were consequently kept for Step III.

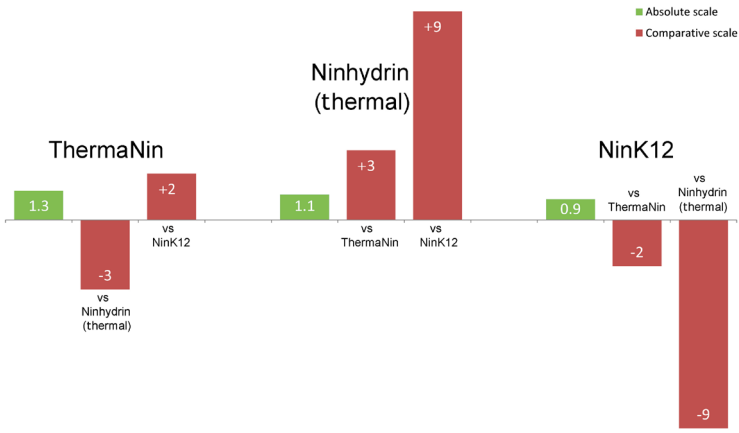



*Figure 1*

*Absolute scores (green) and comparative scores (red) resulting from the comparison of ThermaNin, ninhydrin (thermal), and NinK12.*

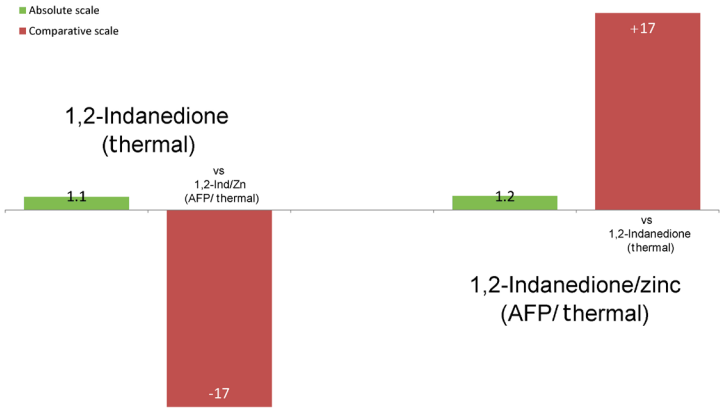



*Figure 2*

*Absolute scores (green) and comparative scores (red) resulting from the comparison of 1,2-indanedione (thermal) and 1,2-indanedione/zinc (AFP/ thermal).*

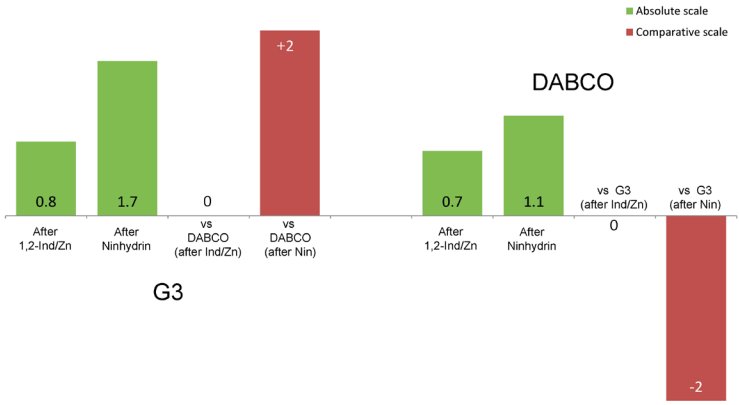



*Figure 3*

*Absolute scores (green) and comparative scores (red) resulting from the comparison of G3 and DABCO as whitening agents. Conventional ninhydrin and 1,2-indanedione/zinc formulations were used (see Appendix B).*

### *Step III and Pseudo-Operational Test*

At this stage, the remaining techniques were inserted into detection sequences. The sequences were established according to the following principles: "from less to more destructive" and "from solvent-based to aqueous-based". This led to the following two sequences: "Sequence I" containing techniques with formulations specifically adapted for thermal papers and presenting no risk of substrate darkening, and "Sequence II" containing conventional techniques (i.e., petroleum ether-based ones, processed according to the conventional protocols) used in combination with DABCO as the whitening agent (Figure 4). Regarding the amino acid reagents, both sequences had virtually the same efficiency, though the thermal version of 1,2-indanedione/zinc performed better than the conventional one combined with DABCO (Figure 5). This observation was further confirmed during the pseudo-operational test, because the thermal formulations led to the detection of more marks overall (Figure 6). Oil Red O was included only in Sequence I (using HFE-7100 as the solvent), because it cannot be used after the application of petroleum ether-based techniques [21]. However, no additional marks were obtained when applying Oil Red O after the amino acid reagents. It even removed already developed marks, which

is a considerable disadvantage if further techniques are to be applied (SMD in this case). Oil Red O was therefore removed from Sequence I, although it could still be used in specific situations (e.g., wetted substrate).

The recommended detection sequence is illustrated in Appendix A, with the corresponding recipes and protocols in Appendix B. Both sequences (Sequence I and Sequence II) were retained and merged into a single one. The reasons for this choice are explained in the Discussion section.

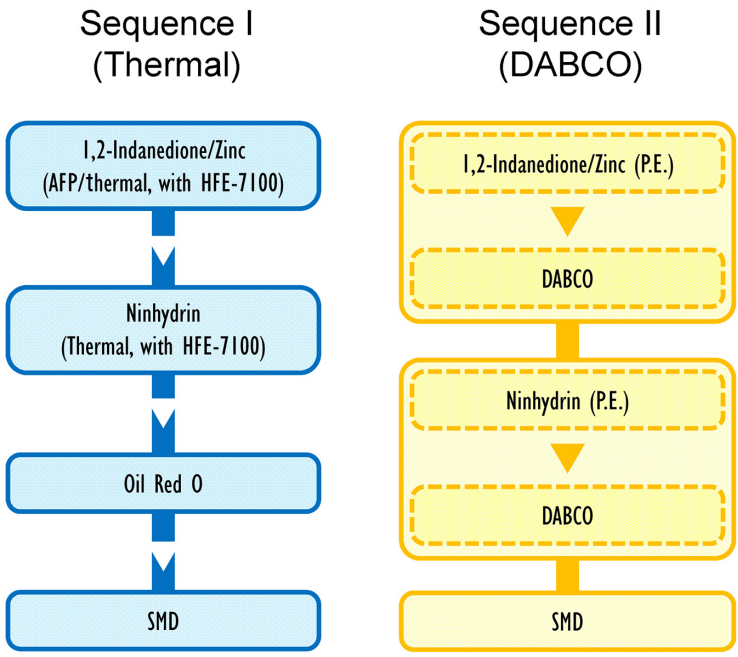



*Figure 4*

*Illustration of the thermal and DABCO sequences. Note: P.E. = petroleum ether.*

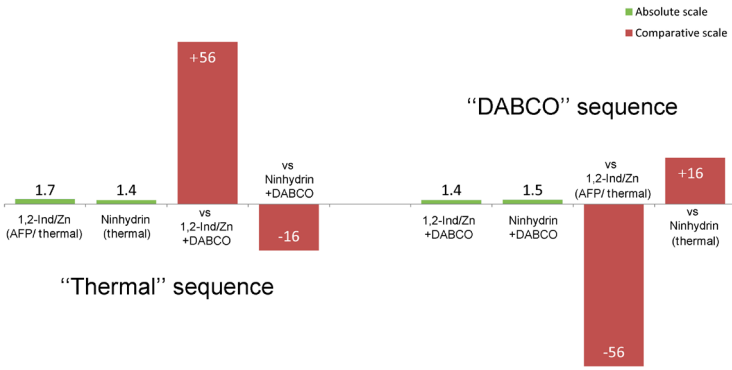



*Figure 5*

*Absolute scores (green) and comparative scores (red) resulting from the comparison of the thermal and DABCO sequences.*

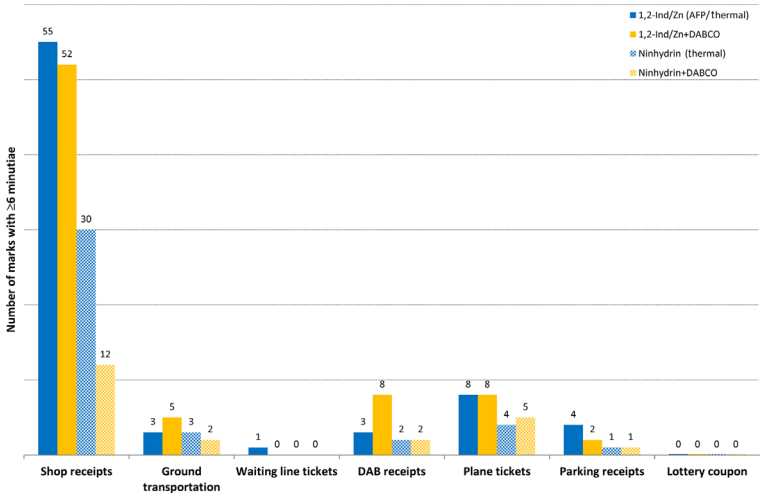



*Figure 6*

*Results of the pseudo-operational test in terms of the total number of marks observed after 1,2-indanedione and ninhydrin, applied in sequence using adapted formulations (thermal) or a whitening agent (DABCO). A mark was counted if it presented at least six minutiae.*

## Discussion

### *About the Study*

#### The Selection of the Donors

The four donors were chosen from a group of nine. To determine the donorship level of each donor (i.e., ability to leave secretions whose composition and quantity result in a fingermark rated as "good" or "poor" when processed with a detection technique), two depletion series of eight marks on white paper were assessed considering natural secretions only. One depletion series was processed with ninhydrin (for the eccrine fraction) and the other with Oil Red O (for the sebaceous fraction). On this basis, four donors were selected: one rated as "good", two as "average", and one as "poor". This selection protocol allowed us to consider a reduced number of donors, while trying to keep a pool of donors as representative as possible.

#### The Use of Plain (Nondivided) Marks in Step I

The use of plain marks is generally to be avoided when comparing the efficiency of different fingermark detection methods. In this study, 19 techniques were to be assessed in Step I. Comparing each technique to the others by using split marks (for each donor, age, and substrate) would have resulted in a practical impossibility at this stage. Considering that the aim of Step I was a preliminary selection (discarding the inefficient techniques or those presenting major operational drawbacks), the use of plain marks was justified in this case, especially because the sample size was large (i.e., four donors who left two depletive series of four marks on each sample). For all the other steps, half-marks were used, which is in accordance with the current recommendations on fingermark detection research [22].

#### The Use of Two Quality Assessment Scales

The main difference between the two quality assessment scales was that the absolute scale focused on the quality of detection for identification purposes (contrast, ridge detail, minutiae reporting), whereas the comparative scale expressed the relative efficiency of a technique compared to another. However, this scale did not give specific information on the intrinsic quality of the ridges. In our opinion, both scales can be seen as complementary. Both scales gave concordant trends in general, as illustrated in the Results section.

The decision to use one assessor for Steps I and II was made for practical reasons, considering that a large number of marks and substrates had to be evaluated. When considering four assessors (Step III), their scores were highly consistent. This could be explained by understandable guidelines (Table 2) and similar education regarding the evaluation of the quality of fingermarks.

IFRG Guidelines

This research was performed in accordance with the recently published recommendations of the International Fingerprint Research Group (IFRG) on the assessment of fingermark detection techniques [22]. In regards to the different phases described in this report, this study encompassed Phase 2 (Optimization and Comparison) and Phase 3 (Validation) aspects and can consequently be followed by an actual operational testing. All major recommendations were followed (e.g., number of substrates, natural marks, depletion series, split marks, realistic aging times, combination of quantitative and comparative scales), with the exception of the number of donors (i.e., 4 compared to 5 to 15 recommended for Phase 2). In view of the large number of techniques and samples to process, only four donors were considered, this decision being strengthened by considering a preliminary selection of the donors based on their donorship level.

*About the Obtained Sequence*

Merging Two Sequences into One

The two sequences compared in Step III were both efficient to detect marks on thermal papers (Figure 5). Thus, we decided to merge them into one single sequence. The "thermal" sequence (which led to higher quality scores) was based on the use of adapted formulations using HFE-7100 as the carrier solvent. Because HFE-7100 is very expensive, some forensic services may not use it. In such a case, the DABCO sequence is an appropriate alternative because conventional formulations are used (e.g., based on petroleum ether) followed by the application of DABCO to reverse the substrate darkening. Operators should be aware that some thermal papers may be insensitive to the whitening reagent (G3 or DABCO). This was observed with the EuroMillions tickets, for example.

G3 and DABCO

The idea of using a Lewis base to change the leuco-dye back into its colorless structure originated from Schwarz who proposed the G3 formulation in 2007 [7]. DABCO has been designed as an alternative to G3 in order to have a less expensive, easier to prepare, and less toxic reagent [8]. As seen in the Results section, G3 gave slightly better results than DABCO. However, we recommend the use of DABCO for the operational reasons that have been previously explained. It should be kept in mind that such a post-treatment will result in an overall whitening of the sample (i.e., any printed text will be erased). It is therefore recommended to record an image of the thermal paper prior to any treatment, in particular if relevant text is imprinted.

A Sequence Based on Amino Acid Reagents

1,2-Indanedione/zinc, ninhydrin, and SMD target amino acids and proteins contained in secretion residues. Their presence in the finally proposed sequence is not surprising given that they are currently among the methods of choice for detecting fingermarks on porous substrates. Considering the lack of any lipid-sensitive reagent, it has been observed that the presence of Oil Red O after ninhydrin prior to SMD offered no advantage (no additional marks and a risk of deterioration of the existing ones). However, when facing a wetted thermal paper, it is conceivable to discard the amino acid reagents for the benefit of Oil Red O.

Introduction of Cyanoacrylate Fuming at the Beginning of the Sequence

After the completion of this study, discussions among peers led to the proposition of introducing cyanoacrylate fuming as a first step of the sequence. Indeed, thermal paper can be seen as a semiporous substrate for which the cyanoacrylate → ninhydrin sequence is known to be effective. Therefore, we would propose the following sequence: cyanoacrylate fuming → 1,2-indanedione/zinc → ninhydrin → SMD. Inserting cyanoacrylate as a processing step may equilibrate the current amino acid-driven sequence. Nevertheless, because the use of cyanoacrylate at the beginning of the proposed sequence has not been tested yet, it should be further reviewed.

Physical Developer (PD) or Single-Metal Deposition (SMD)

Physical developer did not pass Step I, because it is currently ineffective in our institution (or it results in marks of lower quality than expected) for unexplained reasons (e.g., water quality or surfactants). This does not mean that PD should not be applied on thermal papers. Because both PD and SMD are end-of-sequence techniques, SMD could be replaced with PD in the proposed sequence if a forensic service is at ease with it.

## Conclusion

This study aimed at evaluating various fingermark detection techniques currently proposed to detect marks on thermal papers and to combine the most efficient ones into a single detection sequence. At the completion of the study, we reached a consensus on a sequence presenting two pathways: one based on adapted formulations to avoid any darkening of the samples (with HFE-7100 as the carrier solvent) and an alternative based on conventional formulations followed by a post-processing step to reverse the darkening of the substrate. The use of adapted formulations resulted in slightly higher quality scores but the choice for one sequence or another will be influenced by different considerations (mainly financial aspects because HFE-7100 is expensive). Considering that the proposed sequence is driven by amino acid reagents, further adaptions of the sequence (e.g., regarding lipid-sensitive reagents) were also discussed in this paper.

For further information, please contact:

Andy Bécue
École des Sciences Criminelles, Institut de Police Scientifique
University of Lausanne–Building Batochime
CH-1015 Lausanne
Switzerland
andy.becue@unil.ch

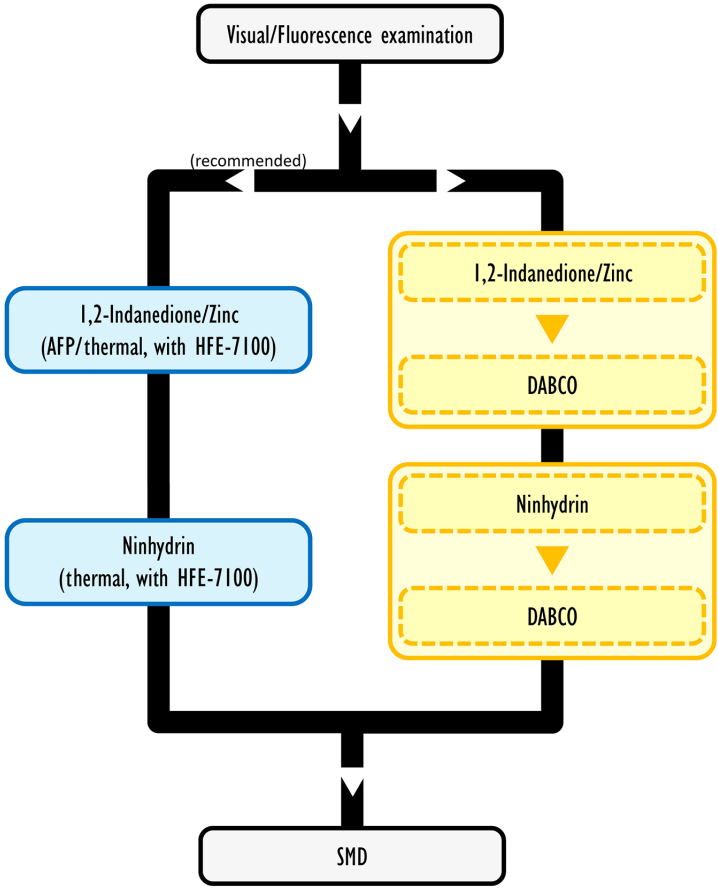
## References


1. Stimac, J. T. Thermal Paper: Latent Friction Ridge Development via 1,2-Indanedione. *J. For. Ident*. **2003**, *53* (3), 265–271.
2. BVDA. Manual of Use for ThermaNin. http://www.bvda.com/en/prdctinf/en_thermanin.html. (Accessed February 6, 2014).
3. Stimac, J. T. Thermal & Carbonless Papers: A Fundamental Understanding for Latent Friction Ridge Development. *J. For. Ident*. **2003**, *53* (2), 185–197.
4. Schwarz, L.; Klenke, I. Improvement in Latent Fingerprint Detection on Thermal Paper Using a One-Step Ninhydrin Treatment with Polyvinylpyrrolidones (PVP). *J. For. Sci*. **2010**, *55* (4), 1076–1079.
5. Stoilovic, M.; Lennard, C. *Fingermark Detection & Enhancement,* 6th ed.; National Centre for Forensic Studies: Canberra, Australia, 2012.
6. *Use of DMAC on Thermal Papers*. H.O.S.D.B Fingerprint and Footwear Forensics Newsletter. October 2006, Publication Number 58/06.
7. Schwarz, L.; Klenke, I. Enhancement of Ninhydrin- or DFO-Treated Latent Fingerprints on Thermal Paper. *J. For. Sci*. **2007**, *52* (3), 649–655.
8. Fischer, R. Whitening of Thermal Paper: Development of an Alternative to the G3 Solution of the BKA. Master of Science Thesis, Ecole des Sciences Criminelles, University of Lausanne, 2009.
9. Siegel, S. D. The Use of Cellophane Tape to Overcome the Background Discoloration on Thermal Paper. *J. For. Ident*. **2007**, *57* (2), 240–243.
10. Ramotowski, R. S. Metal Deposition Methods. In *Lee and Gaensslen's Advances in Fingerprint Technology,* 3rd ed.; Ramotowski, R. S., Ed.; CRC Press LLC: Boca Raton, FL, 2012; pp 55–81.
11. Bécue, A.; Scoundrianos, A.; Moret, S. Detection of Fingermarks by Colloidal Gold (MMD/SMD)–Beyond the pH 3 Limit. *For. Sci. Int*. **2012**, *219* (1), 39–49.
12. Beaudoin, A. New Technique for Revealing Latent Fingerprints on Wet, Porous Surfaces: Oil Red O. *J. For. Ident*. **2004**, *54* (4), 413–421.
13. Jasuja, O. P.; Singh, G. D. Development of Latent Fingermarks on Thermal Paper: Preliminary Investigation into Use of Iodine Fuming. *For. Sci. Int*. **2009**, *192* (1–3), e11– e16.
14. Ma, R.; Wei, Q. Chemical Fuming: A Practical Method for Fingerprint Development on Thermal Paper. *J. For. Ident*. **2006**, *56* (3), 364–373.

15. Brennan, J.; Bramble, S.; Crabtree, S.; Wright, G. Fuming of Latent Fingerprint Using Dimethylaminocinnamaldehyde. *J. For. Ident*. **1995**, *45* (4), 373–380.
16. Lee, J. L.; Bleay, S. M.; Sears, V. G.; Mehmet, S.; Croxton, R. Evaluation of the Dimethylaminocinnemaldehyde Contact Transfer Process and its Application to Fingerprint Development on Thermal Papers. *J. For. Ident*. **2009**, *59* (5), 545–568.
17. Patton, E. L. T.; Brown, D. H.; Lewis, S. W. Detection of Latent Fingermarks on Thermal Printer Paper by Dry Contact with 1,2-Indanedione. *Analytical Methods* **2010**, *2* (6), 631–637.
18. Carrier, J. M. Heat, MMD, RTX and VMD to Detect Fingermarks on Thermal Papers. Bachelor of Science Thesis, Ecole des Sciences Criminelles, University of Lausanne, 2002.
19. Wakefield, M.; Armitage, S. The Development of Latent Fingerprints on Thermal Paper Using a Novel, Solvent-Free Method. *J. For. Ident*. **2005**, *55* (2), 202–213.
20. Chadwick, S.; Maynard, P.; Kirkbride, P.; Lennard, C.; Spindler, X.; Roux, C. Use of Styryl 11 and STaR 11 for the Luminescence Enhancement of Cyanoacrylate-Developed Fingermarks in the Visible and Near-Infrared Regions. *J. For. Sci*. **2011**, *56* (6), 1505– 1513.
21. Guigui, K.; Beaudoin, A. The Use of Oil Red O in Sequence with Other Methods of Fingerprint Development. *J. For. Ident*. **2007**, *57* (4), 550–581.
22. International Fingerprint Research Group (IFRG). Guidelines for the Assessment of Fingermark Detection Techniques. *J. For. Ident*. **2014**, *64* (2), 174–200.
23. Wallace-Kunkel, C.; Lennard, C.; Stoilovic, M.; Roux, C. Optimisation and Evaluation of 1,2-indanedione for Use as a Fingermark Reagent and Its Application to Real Samples. *For. Sci. Int*. **2007**, *168* (1), 14–26.
24. Champod, C.; Lennard, C.; Margot, P.; Stoilovic, M. *Fingerprints and Other Ridge Skin Impressions*. CRC Press LLC: Boca Raton, FL, 2004.
25. Stauffer, E.; Bécue, A.; Singh, K. V.; Thampi, K. R.; Champod, C.; Margot, P. Single-metal Deposition (SMD) as a Latent Fingermark Enhancement Technique: An Alternative to Multimetal Deposition (MMD). *For. Sci. Int*. **2007**, *168* (1), e5–e9.

# Appendix A

## Recommended Detection Sequence



# Appendix B

## Recipes for the Proposed Sequence in Appendix A

### 1,2-Indanedione/Zinc (AFP/Thermal) [5]

*Solution(s):*

Zinc chloride (stock): 8 g zinc chloride in 200 mL absolute ethanol

Working solution: 0.35 g 1,2-indanedione dissolved in 40 mL ethyl acetate, then diluted with 960 mL HFE-7100; 4 mL zinc chloride stock solution is finally added

*Application:*

Short immersion into the working solution, long enough to soak through, then air dried

Development in the dark, at least for 24 hours, at room temperature

Observation in luminescence (exc. 505 nm, obs. 590 nm)

### Ninhydrin (Thermal) [3]

*Solution(s):*

Ninhydrin (stock): 1.5 g ninhydrin dissolved under reflux in 100 mL HFE-71IPA

Working solution: 15 mL ninhydrin stock solution diluted in 100 mL HFE-7100

*Application:*

Short immersion into the working solution, long enough to soak through, then air dried

Development in the dark, at least for 24 hours, at room temperature

**1,2-Indanedione/Zinc [UNIL recipe–unpublished*]**

*Solution(s):*

Indanedione (stock): 0.125 g 1,2-indanedione dissolved in 50 mL ethyl acetate, 50 mL methanol, and 5 mL acetic acid, then diluted with 395 mL petroleum ether

Zinc chloride (stock): 0.2 g zinc chloride in 5 mL absolute ethanol, 0.5 mL ethyl acetate, and 95 mL petroleum ether

Working solution: mix 100 mL of 1,2-indanedione solution with 2 mL zinc chloride stock solution

*Application:*

Short immersion into the working solution, long enough to soak through, then air dried

Development under the heat press (165 °C for 10 seconds)

Observation in luminescence (exc. 505 nm, obs. 590 nm)

*(* any other conventional recipe would suit; this recipe is inspired from Wallace-Kunkel et al. [23] and has been modified because of stability issues)*

**Ninhydrin [24]**

*Solution(s):*

Working solution: 4 g ninhydrin dissolved in 20 mL methanol, 10 mL acetic acid, and 70 mL ethyl acetate, then diluted in 900 mL petroleum ether

*Application:*

Short immersion into the working solution, long enough to soak through, then air dried

Development in the dark, at least for 24 hours, at room temperature (or in a humidity chamber at 80 °C and 65% RH for a few minutes)

**DABCO [8]**

*Solution(s):*

Working solution: 11.22 g DABCO* dissolved in 60 mL ethanol, then diluted in 940 mL petroleum ether

*Application:*

Short immersion of the darkened thermal paper, the whitening effect is immediate

Note: some thermal papers may be insensitive to this post-treatment

[* DABCO = 1,4-Diazabicyclo[2.2.2]octane ; Sigma-Aldrich #D27802]

**Single-Metal Deposition (SMD) [25]**

The reader is referred to the literature regarding multi-metal deposition (MMD) or single-metal deposition (SMD).