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TECHNICAL NOTE

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Revisiting the Thermal Development of Latent Fingerprints on Porous Surfaces: New Aspects and Refinements*

ABSTRACT: Although the ability to develop latent fingerprints on paper using heat alone has been noted previously, it has been considered impractical for casework and inferior to other techniques. Here a new refinement of the technique is demonstrated for the high quality development of latent fingerprints on porous surfaces such as paper. Fingerprints deposited on various papers were developed by exposing them to hot air with a temperature in the vicinity of 300°C, for periods of *c.* 10–20 sec. Several different heating methods were tested. The novel observation was made that after shorter heating times, fluorescent prints could be observed. These became visible after longer heating times, as noted by earlier workers, but with greatly improved contrast compared with their results. Prints from various donors (and aged prints) were developed with excellent ridge contrast. Direct heating methods (such as with a hot plate or press) produced inferior results. The refined technique, which is simple, safe and inexpensive compared with conventional methods, has great potential for use in forensic laboratories.

KEYWORDS: forensic science, fingerprints, fingermarks, thermal development, fluorescence, charring

There are a number of techniques currently used for the detection of latent fingerprints on porous surfaces (such as paper). These include both optical (e.g., ultraviolet [UV] imaging) or, more commonly, chemical treatment (e.g., ninhydrin).

Optical detection techniques that yielded some positive results for the detection of untreated latent fingerprints on porous surfaces include selective absorption (for weak fingerprints in blood, for example), luminescence imaging (using a laser), and UV imaging. There has been some mention in the literature of "inherently luminescent" fingerprints (1–3). Although it has been suggested that common fingerprint constituents such as aromatic amino acids may produce UV luminescence (4), it is generally accepted that this observed luminescence is the result of the fingerprints being contaminated by luminescent products picked up from the environment. Furthermore, luminescence of latent fingerprints is generally only observed when laser or other high-powered illumination is used (1–3). For this reason, these methods have found use mainly as preliminary nondestructive techniques and generally suffer from poor success rates that have been reported to be as low as 10% (2).

The most common chemical treatments for fingerprints on porous surfaces include physical developer (PD) and multimetal deposition as well as amino acid-sensitive reagents such as ninhydrin, 1,8-diazafluoren-9-one (DFO) and 1,2-indandione. Despite the array of techniques available to the forensic examiner, there is always a need to develop new fingerprint detection techniques. In particular, it is desired to develop methods that can:

- offer increased sensitivity and signal-to-noise ratio;
- be readily deployed at crime scenes;
- be introduced in sequences of detection techniques or in sequences with other forensic investigation methods (e.g., DNA profiling);
- simplify the detection process by reducing the number of steps or allowing automation;
- reduce the overall cost of fingerprint processing;
- avoid the use of hazardous chemicals (5).

Here we present a technique that involves the development of latent fingerprints on porous surfaces via the application of heat alone. This technique is simple, safe, and cheap, and also has the potential to be field deployable.

Following an exhaustive literature survey and discussions with researchers and experts in the field, it became apparent that little has been reported on latent fingerprint development via the application of heat alone. Scott's Fingerprint Mechanics (6), as revised by Olsen in 1978, cites earlier publications from the 1940s in which heat is applied to paper by an iron. It was concluded at the time that heat is not a practical method for the intentional development of fingerprints, although useful fingerprints may be inadvertently developed in building fires, etc. During a recent study on the best techniques for the development of fingerprints on articles retrieved from arson scenes, Bleay et al. (7) briefly noted that "…there are many ways in which marks may be developed by the action of heat and soot. Examples observed are preferential soot deposition on fingerprint ridges, heat development of marks on paper, and marks becoming "baked" onto metal surfaces."

An image is provided showing a faint mark revealed by the action of heat alone on "glossy card." It is not clear whether this mark was the result of soot deposit on the glossy coating, nor is it clear at which temperatures the development occurred.

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In 1981, Almog and Marmur (8) re-investigated heat as a fingerprint development technique on paper and concluded that "charring" was inferior to ninhydrin development, particularly for prints older than a few days. These authors "baked" the fingerprints at 260–275°C for 20–30 sec, and observed that a background coloration appeared in all samples.

More recently, research has been conducted into a technique involving the application of low-temperature heat (*c*. 80°C) using a hair dryer for the development of latent fingerprints on thermal paper (9,10). This technique was never extended to ordinary paper, which does not contain the same heat-sensitive chemicals and therefore does not behave in the same manner as thermal paper at these temperatures.

In this study, we show that very rapid heating in dry air in the vicinity of 300°C will very successfully develop latent fingerprints on paper in two stages: (i) a UV-fluorescent (but otherwise invisible) fingerprint is developed after short heating times and (ii) a visible fingerprint with excellent ridge detail and contrast is developed after further heating.

Materials and Methods

Fingerprints were prepared and deposited on a range of porous surfaces according to the following general method. The donors' hands were thoroughly washed, rinsed, and dried before swiping a cleaned finger across an oily region of the face (forehead, nose, or neck) and finally placing the mark on the desired surface. Samples were then treated within 48 h. Aged samples were prepared in the same manner and stored in paper envelopes in ambient conditions for the specified period.

During some experiments, eccrine-rich fingerprints were prepared by placing the cleaned hands of a donor in a latex powder-free glove. The donor then undertook 5 min of vigorous exercise to produce sweaty hands before removing the glove and depositing a series of depleted prints on the desired surface. Eccrine-rich fingerprints were compared with sebaceous-rich fingerprints from the same donor (prepared using the general method described above).

During this study, fingerprints from a range of randomly selected donors (five male, five female) were also examined. For these experiments, the donors' hands were not washed prior to the deposition of fingerprints as described above.

A range of paper and cardboard (board) surfaces were used during this study. The following copy paper samples were supplied by Australian Paper (Mount Waverley, Australia):

- "Australian™ 80% recycled" 80 gsm white copy paper.
- "Reflex®" 80 gsm white copy paper.
- "Reflex® colours" 80 gsm colored copy paper—blue, green, gold, pink, and yellow.

The following paper and board samples were supplied by Edwards Dunlop Paper (Chullora, Australia):

- Copy board, offset 250 gsm.
- Gloss paper and board—"Gloss Art Paper" 113 and 300 gsm.
- Matt paper and board—"Matt Art Paper" 113 and 300 gsm.
- Heavy duty cardboard—"Duplex Board" 450 gsm.

A number of other paper samples (of unknown source) were also tested including magazine paper, newspaper, and U.S. origin white copy paper.

Paper samples were treated by one of the following heating methods: Leister Triac S Hot Air Blower (Leister Process Technologies, Riedstrasse, Switzerland); Singer Magic Steam Press MSP7 (Singer, NSW, Australia); Dick Smith temperature controlled soldering station—model 137 with custom-made aluminum heat block (40 × 40 × 25 mm); B & L Tetlow wire embedded element furnace (B & L Tetlow Pty Ltd, Vic., Australia); and Hewlett Packard 5890 Series II gas chromatography (GC) oven (Hewlett Packard, Palo Alto, CA). Details of heat treatment temperatures and periods can be found in the Results and Discussion section.

Photographs were captured on a Nikon F90× with 100 ISO film in manual exposure mode. Luminescent images were captured using Rofin Polilight as light source with either 350 nm, 450 nm, or 505 nm excitation and orange (549 nm) high-pass camera filter.

Results and Discussion

After the observation that the rapid heating of paper could lead to fluorescent and even visible development of latent fingerprints, several different heating methods were studied systematically in an attempt to confirm, understand, and control this process. These heating methods and the results they yielded are itemized below, but the general sequence of fingerprint development, where this occurred, was that after a short heating time, the (still invisible)

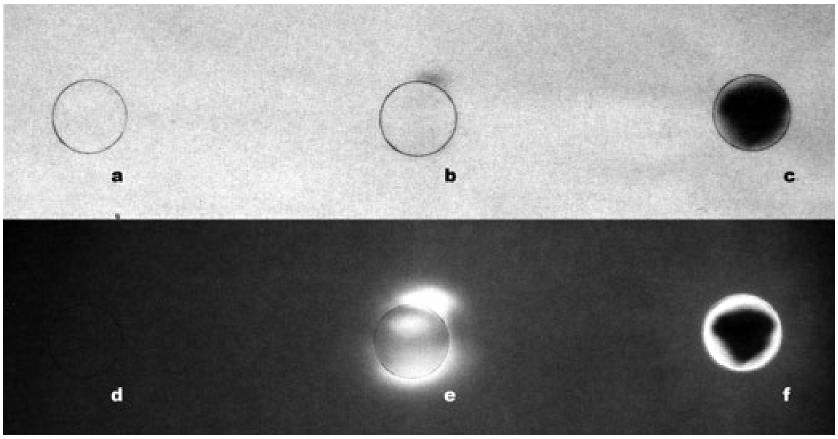

FIG. 1—*Three sections of white copy paper viewed under white light (a–c) and under luminescence visualization (d–f). Regions (a) and (d) show the paper prior to any thermal treatment. Regions (b) and (e) show paper that has been exposed to a short period of thermal treatment (circled area only) such that almost no visible change has occurred under white light (b) but the heated area fluoresces under UV (e). Regions (c) and (f) show paper that has been exposed to a longer period of thermal treatment (circled area only) such that the heated area is visible under white light (c) and the fluorescence under UV has diminished (f).*

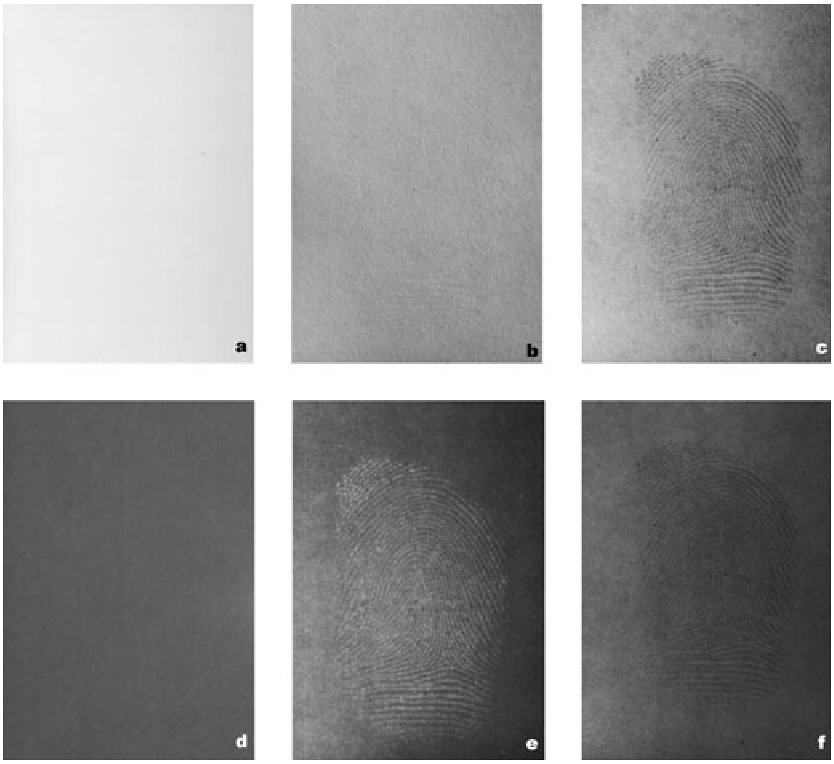

FIG. 2—*Photographic sequence analogous to Fig. 1 of fingerprints on white copy paper viewed under white light (a–c) and under luminescence visualization (d–f) prior to exposure to thermal treatment (a and d), following a short exposure to thermal treatment (b and e), and following a longer exposure to thermal treatment (c and f).*

fingerprint ridges fluoresced under 505 nm illumination and could be observed using a 450-nm filter. Longer heating times generally led to dark brown-colored development of the fingerprint ridges, typically against a pale brown (scorched) background of the rest of the paper. Further heating caused loss of ridge contrast as all of the paper turned dark brown before it combusted or disintegrated. These stages of development mirror those of clean paper itself upon heating: first a change in its fluorescent properties, followed by visible browning (see Fig. 1), implying that the thermal development of fingerprints is simply an acceleration of this process caused by sebaceous and/or eccrine material transferred to the paper. Figure 2 shows the sequential heat treatment of a latent fingerprint on white copy paper. The latent fingerprint is not visible (Fig. 2*a*) nor fluorescent (Fig. 2*d*) prior to heat treatment. Upon heating, the print becomes fluorescent (Fig. 2*e*) before becoming clearly visible (Fig. 2*c*). The contrast between the fingerprint ridges and the paper background of a thermally developed fingerprint such as that shown in Fig. 2*c* can be further improved by illuminating the surface with UV and photographing with no camera filter (Fig. 3). The UV seems to even out some of the variation in the paper background and render the print more visible.

Hot Air Gun

The hot air gun was calibrated using a thermocouple to measure the temperature of the air emitted at two distances from the device, 3 cm and 6 cm, for 10 different heat settings spanning the full range. This corresponded to a temperature range of 45–360°C at 6 cm and 60–535°C at 3 cm. Note that these were air temperatures and it must be assumed that the paper at these distances approached, but probably did not reach, the same temperatures, especially as it was placed on a metal plate that would have conducted away some of the heat.

At a heating distance of 6 cm, an air temperature of 160°C did not give rise to any fluorescent or visible development of fingerprints on white copy paper after heating for 8 min. Fingerprint development started to be observed at temperatures above *c*. 220°C, and at 245°C, fluorescent prints were developed after 6 min of heating. By 310°C, fluorescent fingerprints were developed after 45 sec, turning visible (brown) after *c*. 1 min. This process accelerated with further increases in temperature (15 and

FIG. 3—*Thermally developed fingerprint on white copy paper (a) under white light and (b) under UV with no camera filter.*

30 sec at 340°C) but not surprisingly the paper quickly started to burn.

At a heating distance of 3 cm, the same temperatures could be achieved at lower heat gun settings, but the temperature was understandably more difficult to control and there was a greater requirement that the paper be kept very flat. It was not possible at either heating distance to develop fingerprints that had been deposited on paper that was subsequently crumpled and smoothed out. General drawbacks of the air gun were that it gave poor temperature resolution and uneven heat distribution, and therefore made the rate of heating difficult to control, so that the quality of fingerprint development was not very reproducible. Another disadvantage is that it can only be used to develop small areas of a page; obviously it would be desirable to be able to develop the whole page/sample at once.

Direct Contact Heating

In an attempt to control the temperature and rate of heating more precisely, attempts were made to develop fingerprints using direct contact heating with the heat press (160–200°C), the domestic iron (180°C), and a metal heating block attached to a soldering iron (*c*. 300°C). The heat press did not seem to achieve a high enough temperature for visible fingerprint development, and yielded only weakly fluorescent prints. The domestic iron was unable to develop fingerprint contrast: the entire area contacted by the iron was rendered either fluorescent or was scorched, depending upon the duration of contact. The heating block did yield some fingerprint development, but with poor contrast due to scorching (Fig. 4). This supports the idea that fingerprint development is achieved by different rates of heating of the paper background and the paper that has absorbed the fingerprint material. Direct contact heating seems to force the two regions to heat at the same rate, whereas slightly different rates of heating seem to be achievable using hot air. This idea led to further testing using two different types of oven/furnace.

Muffle Furnace

The nominal temperature of the muffle furnace was typically set in the vicinity of 300°C; monitoring of the actual temperature with a thermocouple showed that at its most stable, it oscillated by ±10°C. As the door had to be opened to admit the sample, the "initial" temperature at which the paper sample was heated was generally 20–30°C cooler than nominal. For an initial temperature of *c*. 300°C, the times for fluorescent and then subsequent visible fingerprint development were 10 and 20 sec, respectively. Figures 5–9 show some results obtained for the thermal development of fingerprints from a range of donors on a range of paper surfaces. Some general observations were as follows:

- Fingerprints showing good ridge detail were obtained from all donors tested (Fig. 5).
- Fluorescent prints were observed prior to visible print development (as described above) for all paper types (examples shown in Figs. 6*a–c*) except for some of the colored papers, which were observed to have their own background fluorescence at the wavelengths used to observe the prints.
- Visible prints could be developed on every type of paper tested (examples shown in Figs. 6*d–f* and 7).
- Using the furnace, it was possible to develop fingerprints on crumpled paper, because of the uniformity of heating that the furnace afforded (Fig. 8).

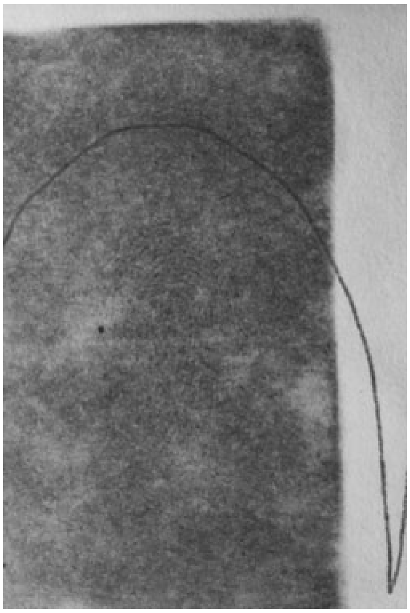

FIG. 4—*Fingerprint on white copy paper thermally treated via direct contact heating.*

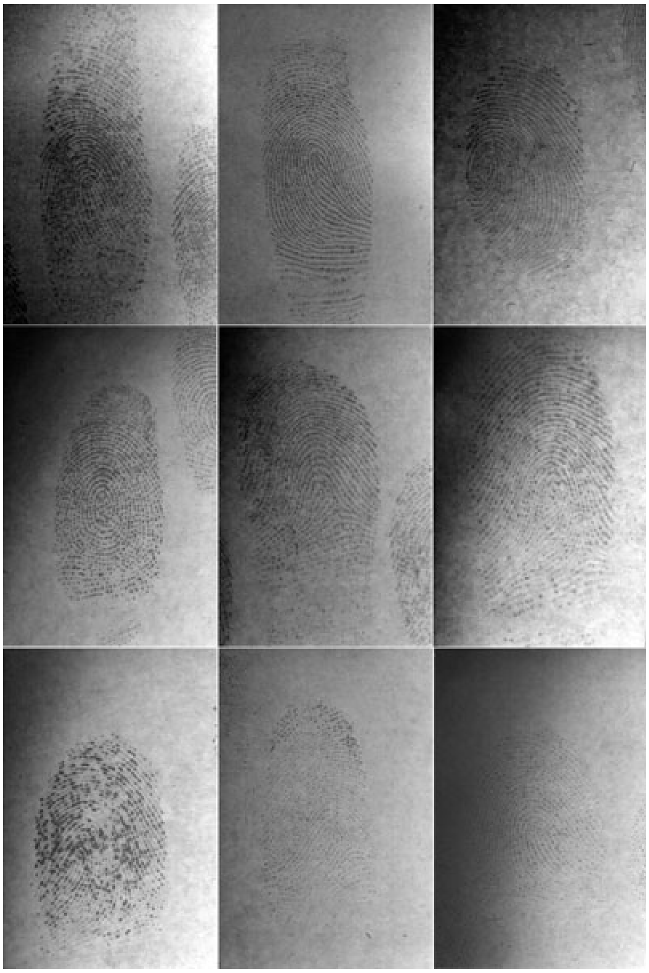

FIG. 5—*Thermally developed fingerprints on white copy paper from nine different donors.*

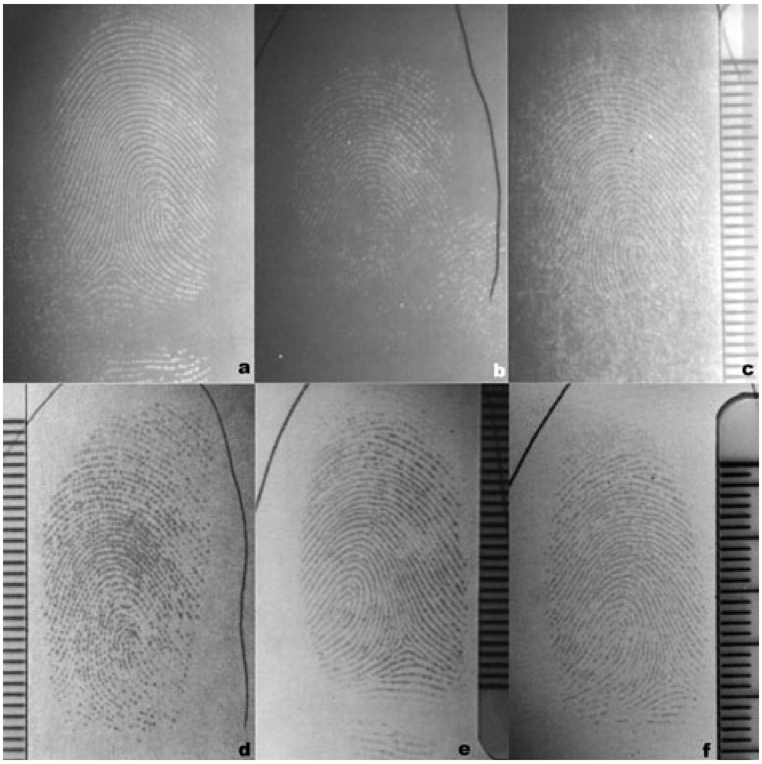

FIG. 6—*Thermally developed fingerprints on (a and d) pink paper, (b and e) copy board, offset 250 gsm, (c and f) gloss paper/"gloss art paper" 113 gsm. Images (a–c) show prints viewed under luminescence visualization—these prints are invisible or faint under white light. Images (d–f) show prints under white light.*

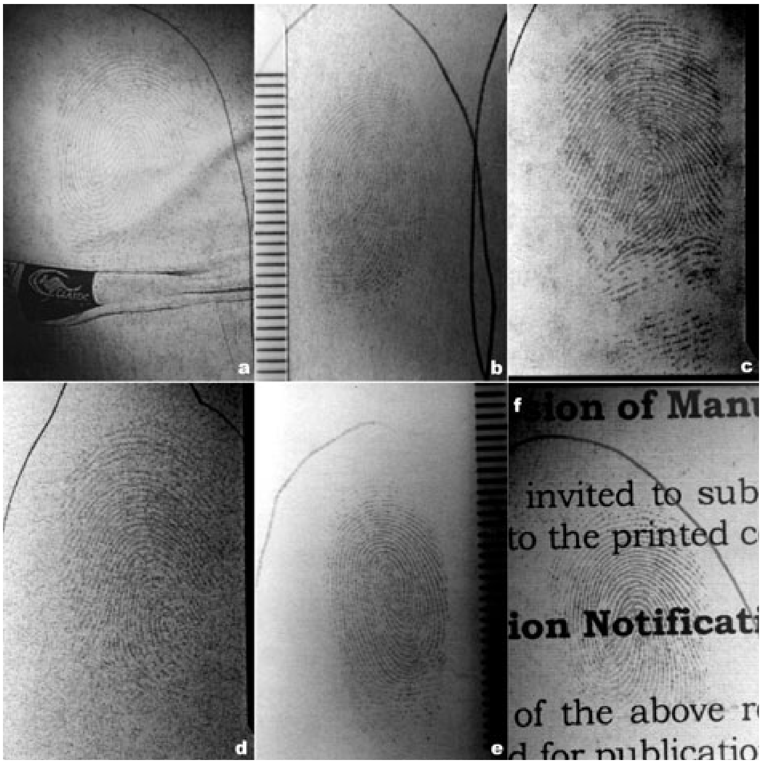

FIG. 7—*Thermally developed fingerprints on (a) magazine paper, (b) newspaper, (c) gloss board/"gloss art paper" 300 gsm, (d) matt paper/"matt art paper" 113 gsm, (e) U.S. origin white copy paper, and (f) U.S. origin textured white copy paper.*

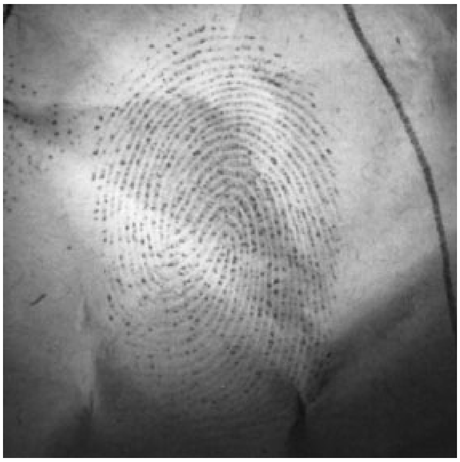

FIG. 8—*Thermally developed fingerprint on crumpled white copy paper.*

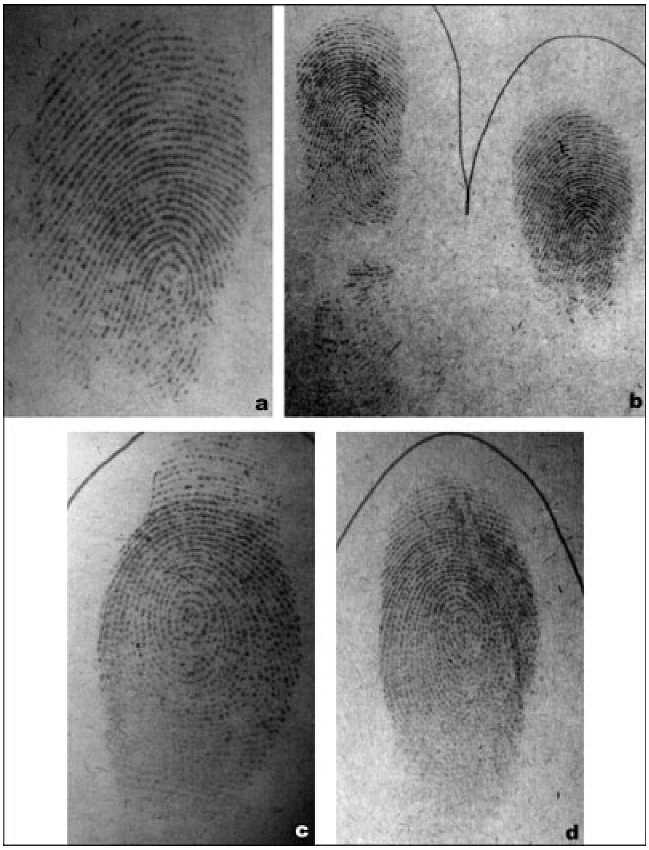

FIG. 9—*Thermally developed fingerprints on white copy paper that have been aged prior to treatment. (a) Print aged 1 week from male donor, (b) print aged 7 weeks from male donor, (c) print aged 1 week from female donor, and (d) print aged 7 weeks from female donor.*

- One- and 7-week-old prints could be developed in the furnace (Fig. 9).
- Fingerprints could still be developed if the heating process was interrupted and recommenced.
- Heating times had to be varied for different types of paper, such as newspapers, coated papers, and cardboards.

As greater control over the temperature and the rate of heating seemed desirable at this point, testing moved to the fan-forced GC oven.

GC Oven

Samples (white copy paper) developed in the GC oven were subjected to a linear temperature ramp taking them from 100°C to 300°C in every case, at rates that varied from 5°C/min to 70°C/min. All of these experiments were conducted until visible prints could be observed on the paper. In general, no visible prints were observed before 220°C, and the best prints were obtained with the fastest heating rate of 70°C/min, although all of the ramps developed fingerprints (see Fig. 10). The faster heating ramps gave results comparable to those obtained using the muffle furnace, and so it was concluded that the best results were obtained using a shorter exposure time at a higher temperature.

Other Surfaces

In addition to developing fingerprints on paper and paper products, preliminary testing has shown that it is possible to thermally develop fingerprints on other porous surfaces, such as untreated wood and cotton-based fabrics. Further work on these surfaces is in progress, and will be the topic of a future article.

Hypothesis

To summarize, the conditions required for the thermal development of fingerprints are rapid heating in air to a temperature of

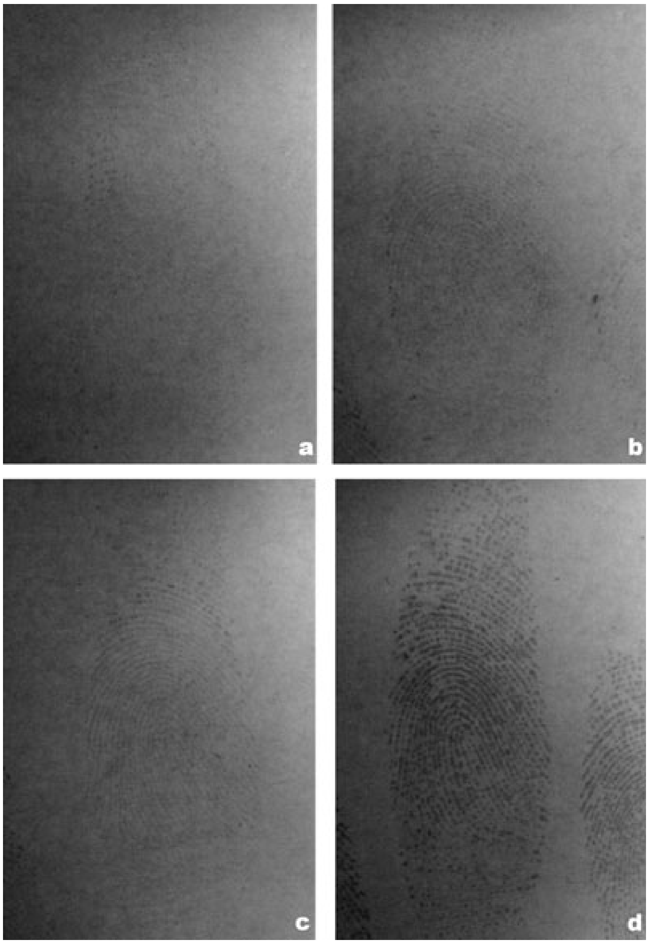

FIG. 10—*Fingerprints on white copy paper thermally developed by introduction to an oven initially set to 100°C and then heated at a rate of (a) 5°C/min, (b) 20°C/min, (c) 40°C/min, and (d) 70°C/min until development was achieved.*

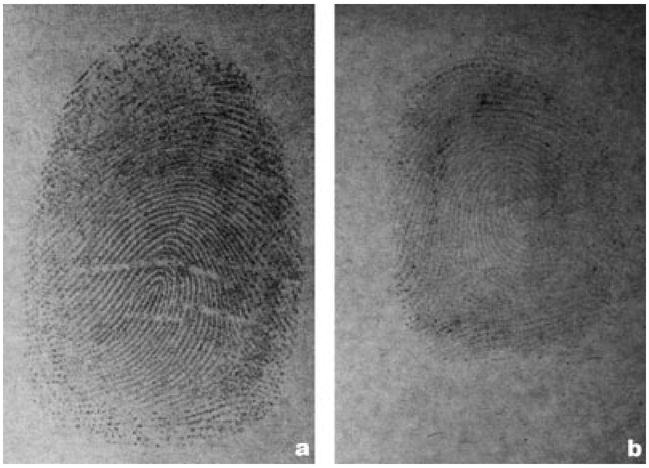

FIG. 11—*Thermally developed (a) eccrine-rich and (b) sebaceous-rich fingerprints on white copy paper.*

between *c.* 220°C and 300°C, above which most common paper becomes scorched and begins to burn. Heating at lower temperatures (e.g., below 200°C) for longer durations does not yield successful visible print development, but heating above 300°C appears to be too rapid for practical purposes. These required conditions at least partly explain why this phenomenon has previously been considered impractical and has received little mention in the literature since 1981. On those occasions when paper was placed in domestic or laboratory ovens or ironed, for example, it would most likely have been at temperatures that were too low for development, or for durations that led to high background coloration or burning of the paper. As noted in the introduction, it would also be rare in building fires that any surviving paper would have been heated under just the right conditions.

The fact that clean paper of most types undergoes the same changes in its fluorescent properties with heating, and then turns brown, suggests that thermal fingerprint development does not occur as a result of a chemical reaction between the paper and the fingerprint constituents. Rather, the simplest explanation at this point is that the fingerprint constituents cause the paper to heat more rapidly than it otherwise would, thus giving rise to the observed contrast. Which fingerprint constituents are more likely to give rise to this effect? The possibilities are eccrine (sweat-related) materials such as water and/or salts, and sebaceous or oily secretions. Figure 11 demonstrates that the thermal development of fingerprints is independent of the type of secretion present. Both eccrine-rich (Fig. 11*a*) and sebaceous-rich (Fig. 11*b*) fingerprints have been developed via this technique. We have observed that saltwater spots dried on paper can be developed quite readily using heat, whereas spots from pure water do not exhibit this effect. These were preliminary tests and do not exclude the possibility that many other substances, when deposited on paper, may give rise to this effect.

Although comprehensive sequence testing has not been completed, there is evidence to suggest that treating samples using the heating methods described here does not preclude further treatment using conventional techniques. Bleay et al. (7) and Deans (11) have examined the effect of heat on fingerprints. In particular, this group was concerned with the recovery of fingerprints from articles that had been exposed to high temperature at arson scenes. They found that many techniques are still effective after an article has been exposed to temperatures of up to 200°C. Techniques such as PD were still effective on items exposed to even higher temperatures. In fact, PD was able to develop marks on charred regions of paper (7). Furthermore, ninhydrin and DFO were also found to be effective techniques for the treatment of papers, which had been exposed to high temperatures (up to 200°C) under laboratory conditions. These techniques performed poorly in simulated fire scenes because the paper was mostly wetted. As the technique described here does not involve the samples becoming wet, it is possible that amino acid-sensitive techniques may still reveal fingerprints after thermal treatment.

Advantages of the Technique

The chief advantage of thermal development of latent fingerprints on porous surfaces such as paper is that no chemical reagents are required. This means that the cost and health/environmental issues associated with the use of fingerprint reagents such as ninhydrin and DFO (and associated solvents) are completely removed. As the only expense (apart from electricity) is the acquisition of a device capable of subjecting samples to a stable air temperature of *c.* 300°C, this refined technique should be accessible to the majority of forensic laboratories. In addition, the ease and speed of fingerprint development mean that it would lend itself to the development of higher volumes of samples than would otherwise be the case with chemical development. They also mean that minimal training or expertise would be needed to develop fingerprints thermally. Other advantages of the technique include its potential portability, the possibility of targeting a range of fingerprint constituents, and its potential as a covert means of developing fingerprints (to the fluorescent, but not visible stage).

Future Work

As mentioned earlier, the thermal development of fingerprints, as refined in this work, may be extended to surfaces other than paper, such as wood and cotton. To enable its application in forensic laboratories, the technique needs to be further tested to determine if it can be used in a fingerprint development sequence, or whether it can only be used by itself. Other testing is needed to determine its efficacy on samples exposed to different environmental conditions, including a larger range of aged samples. More work is needed to compare thermal development with accepted development methods, with sensitivity and effectiveness under different conditions being important criteria to examine. Finally, it is anticipated that new devices will be constructed to enable efficient implementation of this technique for samples on different substrates. It is envisaged that production of these devices will be relatively simple and inexpensive.

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