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Forensic Applications of Chemical Imaging: Latent Fingerprint Detection Using Visible Absorption and Luminescence

ABSTRACT: Chemical imaging technology is a rapid examination technique that combines molecular spectroscopy and digital imaging, providing information on morphology, composition, structure, and concentration of a material. Among many other applications, chemical imaging offers an array of novel analytical testing methods, which limits sample preparation and provides high-quality imaging data essential in the detection of latent fingerprints. Luminescence chemical imaging and visible absorbance chemical imaging have been successfully applied to ninhydrin, DFO, cyanoacrylate, and luminescent dye-treated latent fingerprints, demonstrating the potential of this technology to aid forensic investigations. In addition, visible absorption chemical imaging has been applied successfully to visualize untreated latent fingerprints.

KEYWORDS: forensic science, fingerprints, fingerprint detection, spectroscopy, chemical imaging, forensic light source

There are many methods and sequences for the detection of latent fingerprints on porous and nonporous surfaces that are in common use today (1). Ninhydrin and DFO are two widely used methods for the detection of latent fingerprints on porous surfaces such as paper. Ninhydrin reacts with amino acids present in latent fingerprints. This reaction causes the ridges to appear a dark purple against the background due to the formation of "Ruhemann's purple." Due to the high stability of amino acids, ninhydrin can detect latent fingerprints greater than 30 years old. Ninhydrin-treated fingerprints can be enhanced using a metal salt treatment (usually zinc) resulting in strongly luminescent fingerprints when cooled with liquid nitrogen. Upon the application of heat, DFO (1,8-diaza-9-fluorenone) also reacts with amino acids in latent fingerprints to give pale purple ridges that show strong luminescence at room temperature. DFO is regarded as the more sensitive of the two reagents.

Cyanoacrylate fuming is the most widely used method for fingerprint detection on nonporous surfaces such as glass and plastic. Cyanoacrylate (superglue) fumes react with the moisture and greasy component of the latent fingerprint to form a hard polymeric layer over the ridges of the fingerprint. The contrast of fingerprints treated with cyanoacrylate can be further enhanced by various methods including luminescent stains and vacuum metal deposition (VMD). For nonluminescent surfaces, treatment of cyanoacrylate-developed prints with a luminescent stain can prove invaluable. Many different stains exist and should be chosen according to the characteristics of the substrate. Commonly used stains include Rhodamine 6G, Basic Yellow 40, and Basic Red 28.

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Few methods permit the visualization of latent fingerprints without treatment; thus, chemical imaging was evaluated as a potential means of detecting untreated latent prints. In addition, chemical imaging was evaluated for its potential to increase the sensitivity of detecting latent fingerprints developed by conventional methods. For the purpose of this study, the following treatments were considered: Ninhydrin, 1,8-diaza-9-fluorenone (DFO), and cyanoacrylate fuming with subsequent luminescent staining.

Chemical Imaging

Chemical imaging combines molecular spectroscopy and digital imaging for the chemical analysis of materials (2,3). Fluorescence chemical imaging and visible absorbance chemical imaging (color analysis) provide many benefits and increased capabilities for forensic scientists. Chemical imaging is a nondestructive technique, requiring little to no sample preparation, thus decreasing potential contamination and increasing the efficiency of sample analysis. Chemical imaging rapidly provides high spatial/spectral resolution data and both qualitative and quantitative chemical information on both organic and inorganic species.

Conventional imaging systems collect data at one specific color, often employing a single barrier optical filter configuration or at up to three colors using a red, green, and blue (RGB) camera. As a result, fingerprint detection on complex substances, including paper, curved surfaces, colored or dark objects can be challenging. Chemical imaging separates an image into its component colors in a quantitative manner by collecting multiple images at a variety of wavelengths. Many more wavelengths are recorded than conventional (RGB) color imaging. This enables the analysis software and subsequently the examiner to discern usable evidence from a background on a pixel-by-pixel basis. Unwanted background including fluorescence, texture, and colors can be efficiently minimized, revealing the detail of the fingerprint.

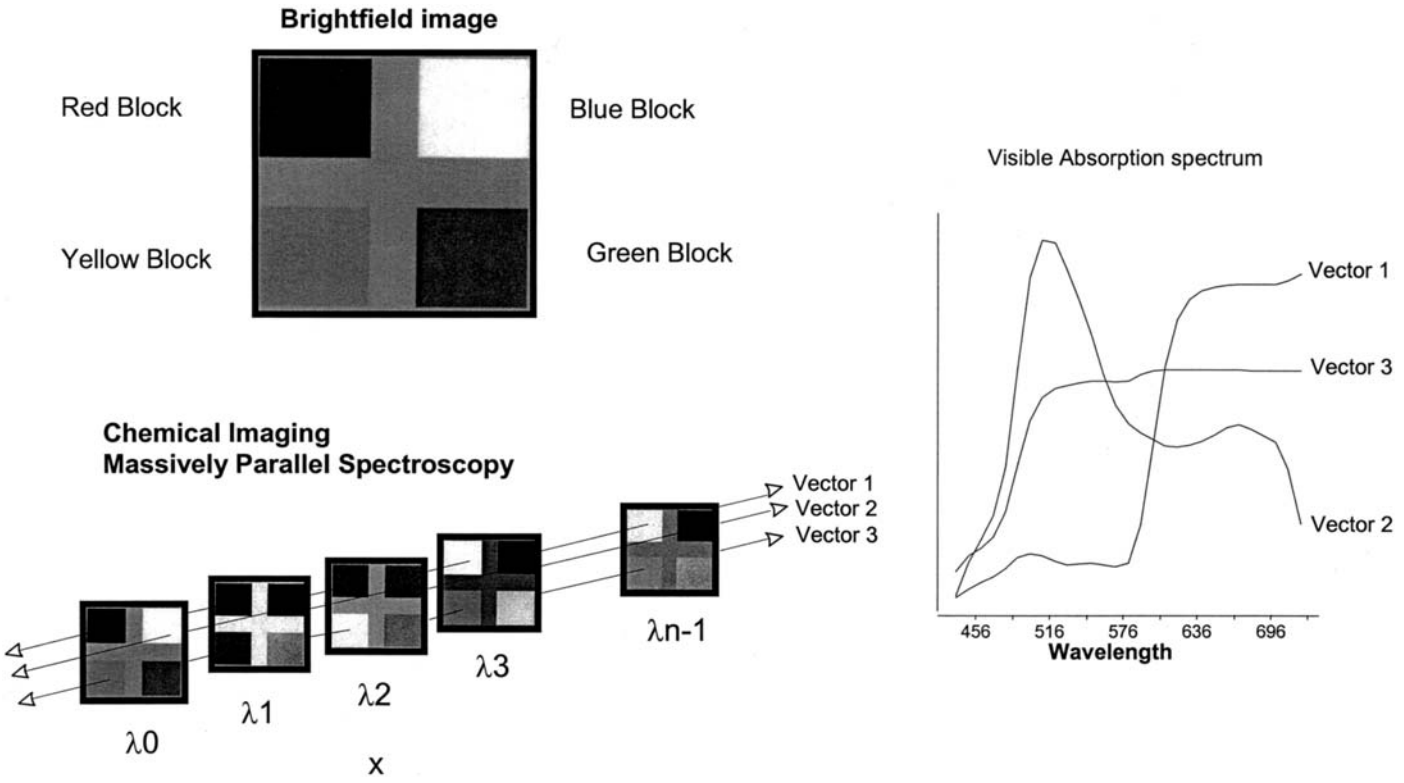

FIG. 1—*Chemical imaging concept: molecular spectroscopy and digital imaging for chemical analysis of materials.*

Chemical imaging combines molecular spectroscopic and digital imaging information by recording images of the sample as a function of wavelength through the use of an efficient electro-optic imaging spectrometer. A fully resolved spectrum unique to the material is recorded for each pixel location in the image. As a result, millions of spectra are generated corresponding to spatial locations at the sample surface by tuning the imaging spectrometer over a range of wavelengths and collecting images in a sequential fashion. As the imaging spectrometer is tuned over a designated spectral range, a finite optical band pass of light is transmitted through the spectrometer and the reflected light or fluorescence emission spectrum is recorded for each image pixel. The typical data collected using chemical imaging technology is shown in Fig. 1. Contrast in the resulting chemical images is indicative of the varying amounts of absorption, emission, or scattering that occurs at each spectral interval sampled by the imaging spectrometer.

An advantage of the chemical imaging system is that the electro-optical imaging spectrometer transmits a high-quality image of the fingerprint while providing spectral discrimination under computer control; hence, image quality is not degraded and the parameters for a particular series of experiments need only be set up once. The more conventional imaging system requires the operator to change barrier filters depending on the enhancement technique being employed. Another advantage of chemical imaging is that, with limited knowledge of a particular fingerprint's absorption or luminescence and any interference from the support, the system can be set up to analyze the fingerprint over a wide spectral range. The user can then utilize the software to isolate the maximum absorbance or emission of a treated fingerprint, thereby optimizing image contrast. Further, the software takes advantage of variability present at multiple wavelengths to further enhance image contrast through the use of multivariate statistical tools.

Fingerprint detection and enhancement is commonly performed using excitation from a suitable forensic light source (FLS), with direct image capture onto photographic film or via a high-sensitivity charge-coupled device (CCD) camera. For luminescent prints, a suitable barrier filter is required that blocks the reflected excitation light and only transmits the weak fingerprint emission. With chemical imaging, the liquid crystal-imaging spectrometer eliminates the need for barrier filters. The aim of this study was to investigate the potential of chemical imaging to increase the contrast and visual quality of fingerprints compared to current methods of detection. The sensitivity of the system was evaluated to determine whether or not it might provide a means of detecting weak fingerprints that remain undetected with current technology.

Materials and Methods

Chemical Imaging

The CONDOR™ Macroscopic Chemical Imaging System (ChemImage Corp.) is equipped with a visible wavelength range liquid crystal imaging spectrometer and a CCD detector on a macroscopic imaging platform. Various excitation source options are available including mercury halide or xenon lamps in combination with a range of excitation filters. The major difference between chemical imaging and conventional methods of latent fingerprint detection is the utilization of a liquid crystal imaging spectrometer. The liquid crystal imaging spectrometer is extremely advantageous because of the fact that is replaces the often numerous barrier filters needed for analysis. Analysis can be performed with less than 1-nm increments from 400 to 720 nm, greatly increasing flexibility in achieving the optimal collection wavelengths, ultimately increasing the sensitivity of the analysis.

ChemImage 5.0 software (ChemImage Corp.) used to process and interpret chemical imaging data far exceeds routine spectral interpretation. Statistical strategies coded in the software can be utilized to extract and summarize key discriminating information, providing a simple-to-interpret graphical interface for powerful spectroscopic analyses.

Contrast is generated in the images based on the relative amounts of light that are produced by the different species located throughout the sample. Since a spectrum is generated for each pixel location, chemometric analysis tools such as principle component analysis (PCA) (4,5) and multivariate curve resolution (MCR) (6,7) can be applied to the image data to extract pertinent information otherwise missed by ordinary univariate (single wavelength) measures.

Preparation of Latent Fingerprints

Two different donors deposited latent fingerprints on three different surfaces—paper, plastic, and glass. One donor was a mid-range secretor and the other a heavy secretor. Fingerprints were deposited onto A4 sheets of paper and plastic (overhead transparencies) by rubbing the middle three fingers onto an oily part of the face and then laying three consecutive sets of fingerprints without recharging the fingers. This served to produce latent fingerprints with varying amounts of secretion. Three sheets of fingerprints on paper were made—one that remained untreated, one for DFO treatment, and one for ninhydrin treatment. Three sheets of fingerprints on plastic were made—one that remained untreated and two for cyanoacrylate treatment with enhancement using two different stains. Three glass slides of latent fingerprints from each donor were made—one that remained untreated and two for treatment with cyanoacrylate and different stains.

TABLE 1—*Development outline for latent fingerprints on porous surfaces.*

	Treatment
A4 sheets of paper with 6 sets of latent fingerprints	- No Treatment - Dipped twice in DFO and heated for 20 min - Dipped once in ninhydrin and stored in a dark cupboard for 24 h

The latent fingerprint samples were left to age for the following periods before treatment and chemical imaging: 1 day, 1 week, 2 weeks, 4 weeks, and 8 weeks. Additional aged latent prints on paper and plastic supports were obtained from the Australian Federal Police in Canberra. For these samples, the latent prints on paper were aged 2 months, 3 months, 9 years, 15 years, and 19 years. The latent prints on plastic were all 2 years old and were on three different plastic supports: white plastic garbage bag, black plastic garbage bag, and transparent plastic zip-lock bag. All latent prints used in this study had been stored under laboratory conditions in appropriate packaging until required.

Detection of Latent Fingerprints Using Current Techniques

One sample from each age group was treated, as indicated in Tables 1 and 2. The fingerprints were examined using the Poliview forensic imaging system (Rofin, Australia). The excitation and observation wavelengths employed for each fingerprint treatment are listed in Table 3. The Poliview consists of a Polilight forensic light source, a high-resolution CCD camera, a collection of barrier filters, a computer, and associated image capture and analysis software.

Detection of Latent Fingerprints by Chemical Imaging

Latent fingerprints of various ages, on both plastic and paper supports, were placed on the CONDOR™ Macroscopic Chemical Imaging System sample stage. Chemical images were captured in

TABLE 3—*Parameters for fingerprint analysis on the Poliview system.*

Treatment	Excitation Wavelength, nm	Observation Wavelength, nm	Exposure Time
None	None	None	Real time
DFO	530	610	Real time to 13 s
Ninhydrin	White light	565	0.5 s
Cyanoacrylate	White light	565	Real time
Cyanoacrylate + Basic Red/Basic Yellow	450	590	Real time
Cyanoacrylate + Rhodamine 6G	530	590	Real time

TABLE 2—*Development outline for latent fingerprints on nonporous surfaces.*

	Treatment
A4 plastic overhead transparency sheet with six sets of fingerprints	- No treatment - Developed for 30 min with cyanoacrylate fumes - Developed for 30 min with cyanoacrylate fumes, allowed to "set" overnight, and then dyed with a mixture of Basic Red 28 and Basic Yellow 40 - Developed for 30 min with cyanoacrylate fumes, allowed to "set" overnight, and then dyed with Rhodamine 6G

	Treatment
Three glass slides with three fingerprints on each slide	- Developed for 30 min with cyanoacrylate fumes - Developed for 30 min with cyanoacrylate fumes, allowed to "set" overnight, and then dyed with a mixture of Basic Red 28 and Basic Yellow 40 - Developed for 30 min with cyanoacrylate fumes, allowed to set overnight, and then dyed with Rhodamine 6G

the absorption mode over the range 400 to 720 nm at 5-nm increments. Illumination of the samples was by white light from a 300W xenon arc lamp. The camera was a thermally cooled slow scan 512 by 512. The spectral range where the maximum contrast existed was identified from the imaging data. A background analysis was also conducted for the paper support.

Analysis of the latent fingerprints on paper was conducted using ChemImage 5.0. Two data processing strategies were used. The first strategy was to divide the latent fingerprint chemical images by a background image to correct for nonuniformity of the excitation beam, instrument response factors, and substrate emission. The second analysis strategy was to subject the image datasets to a zero offset (subtracts a global minimum from the data points) and vector normalization to correct for nonuniform excitation, instrument response, and to accentuate image contrast. Principal component analysis (PCA) was then applied to the normalized data. PCA is a data exploration and dimensionality reduction technique that also serves to accentuate differences.

Detection of Ninhydrin and DFO-Treated Fingerprints (Absorption) by Chemical Imaging

Latent fingerprints chemically treated with DFO and Ninhydrin were examined in the absorption mode using white light from a xenon arc lamp. Each fingerprint was examined and chemically imaged in the 400 to 720-nm range. The maximum absorption was determined from the spectral information to be 550 nm. The optimal analysis range was determined to be 540 to 580 nm for both reagents, and it is in this range that all further analyses on ninhydrin and DFO-treated fingerprints were made.

The fingerprints were analyzed using the ChemImage 5.0 software. Useful portions of the chemical imaging datasets were extracted and averaged over an experimental range before being compared to the Poliview-captured images in the same software.

Detection of Luminescent Fingerprints by Chemical Imaging

The recommended excitation and detection wavelengths for DFO, Basic Red/Basic Yellow mix, and rhodamine 6G were used as an experimental guide (1). Excitation was provided by a suitably filtered xenon arc lamp. Experiments were conducted using the liquid crystal imaging spectrometer in the range of 400 to 720 nm with 5-nm increments to determine the maximum emission of the chemically treated fingerprint and thus the optimal range in which to analyze the fingerprint. The maximum emission for each fingerprint treatment and the optimal range in which to analyze each fingerprint, as determined by experimentation with the CONDOR™, is shown in Table 4.

The fingerprints were examined using ChemImage 5.0. Useful portions of the chemical imaging datasets were extracted and averaged over an experimental range before being compared to the Poliview-captured images in the same software. The comparison between the fingerprint images captured with the conventional imaging system and those captured with the chemical imaging system was a visual comparison of ridge detail and minutiae.

TABLE 4—*Fingerprint detection parameters for the CONDOR™ Macroscopic Chemical Imaging System (excitation provided by a xenon arc lamp filtered to operate at 550 nm).*

Fingerprint Treatment	Excitation Wavelength, nm	Maximum Emission, nm	Optimal Range
Basic Red + Basic Yellow	550	600	580–620
Rhodamine 6G	550	560	540–680
DFO	550	580	570–650

FIG. 2—*One-week-old latent fingerprints on a clear plastic sheet: CONDOR™ (left), Poliview (right).*

Results and Discussion

Untreated Latent Fingerprints

Fingerprints deposited on clear acetate sheets could be detected on both imaging systems without complications. The weaker the fingerprint deposit, the less contrast could be achieved. Figure 2 shows a latent fingerprint on a clear acetate sheet as captured by both the conventional imaging system (right) and the chemical imaging system (left).

Latent fingerprints on paper surfaces were much more difficult to detect. As expected, the conventional imaging system was unable to detect any of the latent fingerprints without treatment. In contrast, latent fingerprints were detectable with the chemical imaging system due to the enhancement of subtle differences between the latent print and background using various processing strategies described below.

Taking a chemical imaging set of both the latent fingerprint and the plain paper background was the first method of detection attempted. ChemImage software tools were applied to divide the image by the background. The result of this is seen in Fig. 3. Although a complete fingerprint image cannot be seen, ridge detail is visible. The texture of the background is increased, however, using this method.

A second method of detecting the latent fingerprint was examined. The latent fingerprint was captured by the macroscopic chemical imaging system in the visible range. Using ChemImage software, the fingerprint was then treated by using the zero offset and vector normalization tools. Figure 4 (left) shows the latent print after treatment in ChemImage, with the image extracted at 430 nm. Ridge detail is visible and the core of the fingerprint pattern is visible. In Fig. 4 (right), with an image extracted at 495 nm, the central part of the fingerprint is less visible, but the outer ridges exhibit a great amount of contrast.

After using the zero offset and normalization techniques, the latent fingerprint dataset was further treated in ChemImage by prin-

cipal component analysis (PCA). Figure 5 shows the results of principal component analysis, averaged in the range 430 to 480 nm (left) and extracted at 475 nm (right). PCA emphasized the ridge characteristics that could already be seen using the zero offset and normalization techniques. While these preliminary results are very promising, more testing needs to be performed with such techniques in order to optimize the detection of untreated latent fingerprints on paper by chemical imaging. However, the results here are noteworthy as they indicate the potential of chemical imaging to extract ridge details that are undetectable by existing conventional methods.

Ninhydrin-Treated Fingerprints

The ninhydrin-treated fingerprints on paper were examined and captured by the conventional imaging system and subsequently by the macroscopic chemical imaging system. The same fingerprints captured on the two systems were then analyzed using ChemImage software in order to make the images the same size and place them side by side for direct comparison.

The results shown in Fig. 6, in terms of comparison between the two techniques, are representative of the quality obtained with fin-

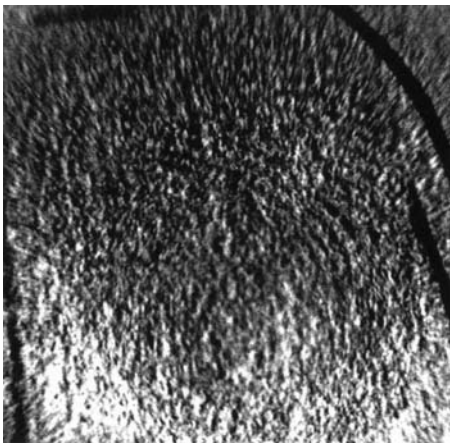

FIG. 3—*Fresh latent fingerprint on paper with the image divided by the background (CONDOR™ detection only).*

FIG. 6—*Two-month-old fingerprint on paper treated with ninhydrin: CONDOR™ (left), Poliview (right).*

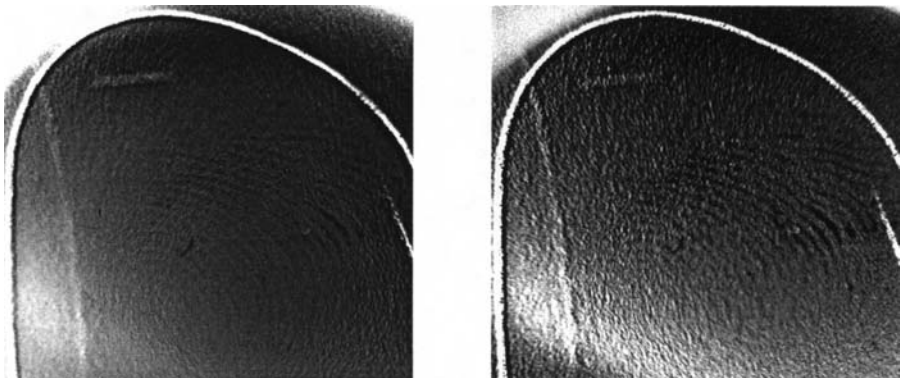

FIG. 4—*Latent fingerprint on paper with treatment in ChemImage software by zero offset and normalization (CONDOR™ detection only). Images extracted at 430 nm (left) and 495 nm (right).*

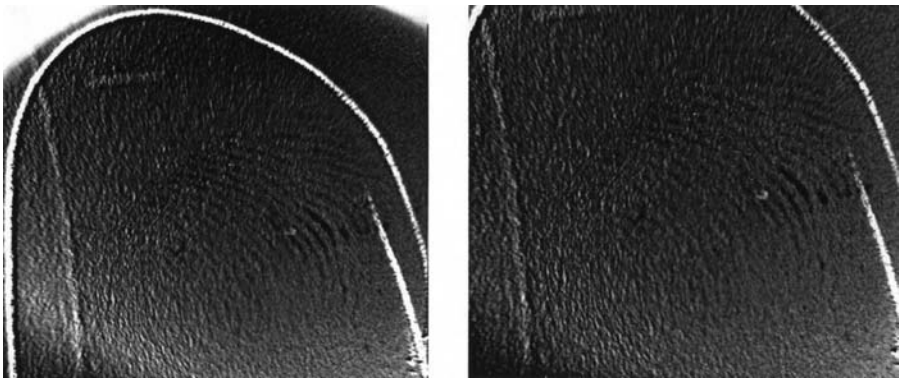

FIG. 5—*Latent fingerprint on paper treated in ChemImage software by zero offset, normalization, and PCA (CONDOR™ detection only). Image averaged over the range 430 nm to 480 nm (left) and extracted at 475 nm (right).*

gerprints of various ages. Both the macroscopic chemical imaging system and the conventional imaging system offer similar degrees of discrimination in contrast and image quality for the examination of ninhydrin-treated fingerprints. Uneven illumination is an issue with both instruments, although this issue is perhaps easier to resolve with the chemical imaging system with its fixed light source rather than with the conventional imaging system where the light source (Polilight) is an extension of the system.

DFO Treated Fingerprints—Absorbance

Images of DFO-treated prints were captured under white light on both the macroscopic chemical imaging system and the conventional imaging system. The same fingerprint images taken by the two instruments were concatenated using ChemImage 5.0 software in order for a direct comparison to be made. Concatenate is a tool that allows the user to merge two images side by side into one image. This tool is useful for situations when the user cannot image two objects side by side, but would like to perform analyses on those images as if they had been collected side by side.

As the amount of fingerprint deposit decreases, the higher sensitivity of the chemical imaging system became more evident, with more detail being captured in comparison with the conventional imaging system. An example of this can be seen in Fig. 7. The background texture of the paper was a greater hindrance for the conventional imaging system than for the macroscopic chemical imaging system.

DFO-Treated Fingerprints—Luminescence

The superior sensitivity of chemical imaging compared to that of the conventional imaging system was easily seen in the luminescence mode with DFO-treated fingerprints. With strong DFO-developed prints, both systems recorded images of acceptable quality. However, with weaker deposits, particularly those aged for several years, better fingerprint detail was observed using the chemical imaging technique. Figures 8 and 9 show examples of prints aged for 19 years that were subsequently developed with DFO and visualized in the luminescence mode.

Cyanoacrylate-Treated Fingerprints

Figure 10 depicts a heavy fingerprint deposit on plastic after cyanoacrylate fuming only. Although the fingerprint is easily detected, the contrast with the background is not as good as that obtained after treatment with a luminescent stain. In terms of observable ridge detail, both imaging systems produced similar quality with minutiae being easily identified. In most cases, better contrast was obtained using chemical imaging. Weaker fingerprint deposits were less readily detected after cyanoacrylate treatment

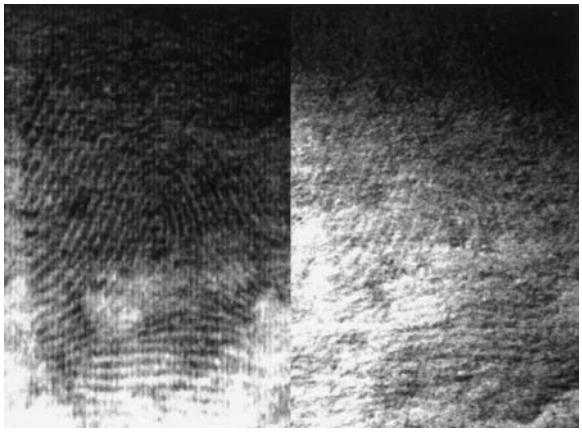

FIG. 7—*Two-month-old fingerprint on paper treated with DFO and viewed in the absorption mode: CONDOR™ (left), Poliview (right).*

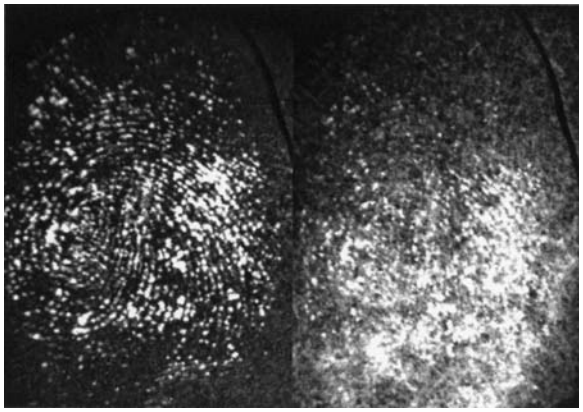

FIG. 8—*Fingerprints on paper aged for 19 years and developed with DFO, with observation in the luminescence mode: CONDOR™ (left), Poliview (right).*

FIG. 9—*Fingerprints on paper aged for 19 years and developed with DFO, with observation in the luminescence mode: CONDOR™ (left), Poliview (right).*

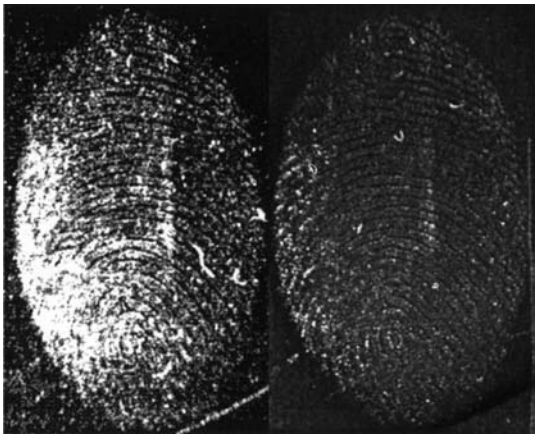

FIG. 10—*Two-week-old fingerprint on plastic after cyanoacrylate treatment (no stain): CONDOR™ (left), Poliview (right).*

alone, and these prints generally required enhancement with a luminescent stain.

Strong cyanoacrylate-developed prints were readily observed after treatment with a luminescent stain. For such prints, the image from the conventional imaging system and the image from the chemical imaging system showed comparable contrast and detail. However, weaker fingerprint deposits treated with cyanoacrylate and a luminescent stain were more readily observed using chemical imaging. A representative example is shown in Fig. 11, with chemical imaging giving a better overall result for a 2-year-old fingerprint on a white plastic garbage bag after treatment with cyanoacrylate and Basic Red/Basic Yellow stain. The chemical imaging system picked up more detail, which is noticeable in the bottom right hand corner of each image.

The fingerprint shown in Fig. 12 was deposited on glass one week before being fumed with cyanoacrylate and stained with rhodamine 6G. The chemical imaging fingerprint on the left shows slightly more contrast than the Poliview fingerprint shown on the right. This enhanced contrast facilitates the identification of fingerprint minutiae.

FIG. 11—*Two-year-old fingerprint on a white plastic garbage bag after treatment with cyanoacrylate and Basic Red/Basic Yellow stain (observation in the luminescence mode): CONDOR™ (left), Poliview (right).*

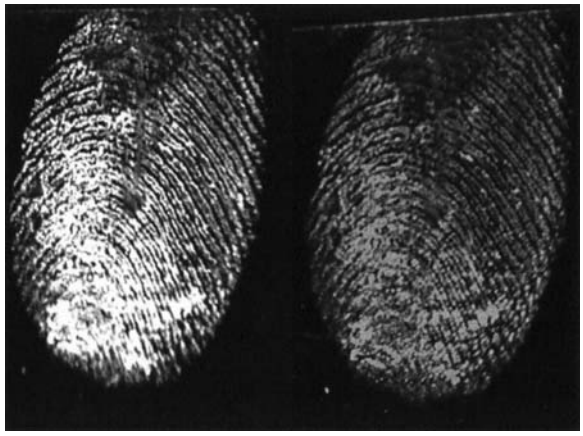

FIG. 12—*One-week-old fingerprint on a clear glass slide after treatment with cyanoacrylate and rhodamine 6G (observation in the luminescence mode): CONDOR™ (left), Poliview (right).*

Conclusions

The absorption-mode analysis of untreated latent fingerprints on paper surfaces by chemical imaging showed immense promise, with ridge detail able to be detected on fresh fingerprints using the CONDOR™ system followed by ChemImage software analysis. This is certainly an area for future research, as such a nondestructive optical method for detecting untreated prints would be of significant benefit. The results also highlight the enhanced sensitivity offered by chemical imaging that permits the detection of ridge detail that may go undetected using conventional imaging techniques.

When treated fingerprints captured on both systems were compared qualitatively, it was found that the CONDOR™ Macroscopic Chemical Imaging system produced results that were at least as good as, and in many cases better than, those obtained using the Poliview system. The imaging of ninhydrin-developed prints was similar for both systems. However, chemical imaging displayed superior sensitivity for the detection of weak DFO-developed fingerprints on paper in both the absorption and luminescence modes. Similarly, fingerprints on nonporous surfaces treated with cyanoacrylate and a luminescent stain showed slightly more ridge detail and better contrast using the CONDOR™ Chemical Imaging system rather than the conventional Poliview system, especially for weaker fingerprint deposits.

This preliminary study has explored the potential of chemical imaging for the detection of latent fingerprints. The results suggest that this new technology has great potential when compared to conventional image capturing systems such as the Poliview. However, further research is required to validate and optimize the technique for a wider range of fingerprint detection methods and for prints on a wider range of substrates.

Acknowledgments

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