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Infrared Spectroscopic Imaging of Latent Fingerprints and Associated Forensic Evidence

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Abstract

Fingerprints reflecting a specific chemical history, such as exposure to explosives, are clearly distinguished from overlapping, and interfering latent fingerprints using infrared spectroscopic imaging techniques and multivariate analysis.

Introduction

One of the most common methods used by forensic experts at a crime scene is the identification of fingerprints. The pattern of ridges formed on the tips of human fingers has long been regarded as unique to each individual. The differentiation of latent fingerprints originating from eccrine gland secretions from a variety of contaminants is often difficult using current forensic methods. New techniques, however, have been developed for the visualization of fingerprints based on chemical markers.^{1,2} The use of nanoparticles enables fluorescence images of fingerprint pattern that provide chemical information regarding drug use.^{3,4} The application of desorption electro-spray ionization mass spectrometry (DESI-MS) to reconstruct fingerprint images based on exogenous residues has been recently reported as a tool to distinguish individual prints with definitive chemical exposure histories.⁵ Using DESI-MS, distinctive mass/charge fragments from compounds such as cocaine and explosives were detected and used to reconstruct the fingerprints. The reconstruction of fingerprints based on exogenous compounds allows forensic investigators to distinguish prints based on the materials that had been handled, filtering out overlapping eccrine and sebaceous prints that may have previously rendered a print unusable.

Vibrational spectroscopic imaging represents another technique for reconstructing latent fingerprints by generating chemical contrast using spectroscopic signatures identified in fingerprint deposits. While previous studies have successfully detected latent fingerprints on the surfaces of various materials using infrared spectroscopic approaches, the reconstructed fingerprint images were based on eccrine and sebaceous residues rather than exogenous compounds which could be used as associated forensic evidence.^{6–9} In the present study, we apply infrared spectroscopic imaging and principal component analyses to distinguish between overlapping fingerprints through the reconstruction of images based upon exogenous compounds.

Experimental

Latent fingerprint preparation

After blotting a blank fingerprint on aluminum coated slides, 10 μ l of 500 μ g/ml hexahydro-1, 3, 5-trinitro-1, 3, 5-triazine (RDX) explosive solution was deposited on a

second fingertip of a volunteer using a micropipette. The RDX solution was spread and allowed to dry prior to blotting the RDX contaminated fingerprint on top of the blank print containing only natural secretions. Figure 1a displays a white light photograph of the two overlapping latent fingerprints.

Methods

An infrared spectroscopic image of the fingerprints was then acquired in an infrared reflection mode from a 6 mm × 9 mm sample area (two fingerprints overlapped mostly at the upper left quarter of the area). The image was collected within the 4000–700 cm⁻¹ spectral range with 16 scans per pixel at 4 cm⁻¹ spectral resolution and 25 μm spatial resolution using the Perkin-Elmer Spectrum Spotlight 300 imaging system equipped with a liquid nitrogen-cooled MCT linear array detector. The visualization of an infrared fingerprint image relies on effectively identifying and separating spectral features that reflect the chemical properties of the fingerprint's deposits. A combination of multivariate techniques, such as principal component analysis (PCA) and band-target entropy minimization (BTEM), was used to obtain spectral features of interest differentiated from background signals and spectral noise.^{10–14}

Results and discussion

Since sebaceous residues are rich in triglycerides and fatty acids, strong C-H stretching mode vibrations provide a convenient means for generating infrared chemical images representing a fingerprint. As shown in Figure 1b, while a fingerprint image can be obtained based on the infrared absorption at the CH stretching mode region, the two overlapping prints are not distinguishable. The infrared spectrum of solid phase RDX exhibits strong NO₂ deformation and ring stretching modes and weak CH₂ stretching modes.¹⁵ Figures 1e and 1f are infrared spectra of pure RDX crystallites in the 1300–700 cm⁻¹ and 3150–2750 cm⁻¹ spectral regions, respectively. As shown in figures 1c and 1d, the infrared spectra containing NO₂ deformation/stretching and CH₂ stretching bands demonstrate evidence of the RDX compound mixed with the natural secretions. Specifically, vibrational modes directly attributable to RDX are observed at 3070 cm⁻¹ in figure 1d, and also, at 776, 900, 1262 cm⁻¹ at lower frequencies in figure 1c. These modes are clearly delineated above the large background signal inherent to the sebaceous eccrine secretions.

While traces of RDX are observed in some pixels of the infrared fingerprint image, it is not evident which one of the prints the RDX chemicals belong to in cases with overlapped prints. To further identify the association of detected RDX chemicals to the infrared fingerprints in fig. 1b, it is necessary to spatially resolve RDX chemicals from the eccrine and sebaceous secretions using multivariate analysis. The infrared spectral image data sets were subject to singular value decomposition (SVD) methods to obtain basis vectors that account for the most variance in the data. Spectra of major chemical components in the image were then obtained from the minimum number of significant basis vectors using BTEM and/or principal component (PC) rotation (i.e. a linear combination of basis vectors). Pure component spectra from RDX and natural eccrine/sebaceous residues retrieved using the multivariate analyses described above are shown in figures 2a and 2b. By projecting each spectral component onto the original data set, the relative contribution of these components are then calculated and presented as score images. As shown in figure 2d, the ridges of the blank fingerprint on the upper left corner become more prominent since they contain a higher eccrine/sebaceous residue content than the loop-shaped fingerprint containing RDX. In figure 2c, the score image of the RDX spectral component reveals the connection of RDX deposits to one of the two overlapped fingerprints.

The sensitivity of FTIR imaging for these exogenous compounds was established by spotting a known amount of RDX onto a slide and then imaging that specific region. By normalizing the known concentration of RDX to the geometric area where the compound was detected, the limit of detection was determined to be 0.1 ng/pixel. A spectroscopic image of the fingerprint of an individual exposed to RDX and after the washing of their hands, shows that trace residues of RDX can still be detected, as shown in figure 3.

Because of the increased spatial resolution of FTIR imaging, relative to DESI-MS imaging, trace chemical residues trapped between the fingerprint ridges can be clearly detected and spatially resolved while clearly delineating associated forensic evidence from the normal eccrine and sebaceous secretions inherent in the fingerprint.

Conclusions

We demonstrate the utilization of infrared imaging spectroscopy toward identifying latent fingerprints and revealing their chemical history. This straight forward infrared chemical imaging technique does not require sample preparation, derivatization or addition of fluorescent antibodies, but is potentially capable of generating database searchable fingerprints that directly associate forensic evidence with the basic imprint.

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Fig. 1.

(a) A white light photograph of the two overlapping latent fingerprints. The rectangle outlines the sample area imaged by infrared spectroscopy. (b) Fingerprint image obtained based on the infrared absorption of the CH stretching mode region. (c, d) Infrared spectra of fingerprint deposits from a pixel, highlighted in figure 1b, containing mixture of RDX compound and eccrine/sebaceous residues. (e, f) Infrared spectra of pure RDX crystallites.

Fig. 2.

(a) Pure component spectra of RDX retrieved using multivariate analyses in the 1300–700 cm^{-1} region. (b) Pure component spectra of eccrine/sebaceous residues retrieved in the 3150–2750 cm^{-1} region. (c) A score image displaying the distribution of the retrieved RDX component. (d) A score image displaying the distribution of the retrieved eccrine/sebaceous component.

Fig. 3.
Composite image reconstructed from infrared signal observed from oils, skin, and RDX. RDX residues are spatially resolved between the ridges evident from the eccrine and sebaceous secretions in the fingerprint