White-light vs. short-wavelength ultraviolet illumination of fingerprints developed with columnar thin films of Alq3

Stephanie L. Plazibat\textsuperscript{a}, Stephen E. Swiontekb, Akhlesh Lakhtakia\textsuperscript{b,*} and Reena Roy\textsuperscript{a}

\textsuperscript{a}Forensic Science Program, Pennsylvania State University, University Park, PA 16802, USA;
\textsuperscript{b}Department of Engineering Science and Mechanics, Pennsylvania State University, University Park, PA 16802, USA

Abstract

The deposition of a columnar thin film (CTF) of Alq3 on partial-bloody fingerprints has recently been shown to yield better development than many traditional development techniques. The Alq3-CTF-developed fingerprint is illuminated by short-wavelength ultraviolet (UV) light, to take advantage of the luminescence of Alq3. Experiments were undertaken to test the hypothesis that white-light illumination of Alq3-CTF-developed fingerprints is inferior to UV illumination. Objective and subjective grading of photographs of 18 Alq3-CTF-developed fingerprints on brass strongly indicate that white-light illumination is likely to be suitable for comparison; if that fails to yield a strong conclusion, then a photograph taken with short-wavelength UV illumination should be examined by a human. This procedure would reduce not only UV-induced health hazards in the laboratory but also the chance of denaturing potentially useful DNA information contained in the fingerprint.

Keywords: Alq3; columnar thin film; fingerprint development; ultraviolet light; white light

Résumé

Le dépôt d’un film mince en colonnes (FMC) de Alq3 sur des empreintes partiellement sanglantes a récemment été démontré comme une technique de révélation meilleure que les techniques traditionnelles. Les empreintes révélées par la technique du FMC-Alq3 sont éclairées par une lumière ultraviolette (UV) de courtes longueurs d’ondes afin de prendre avantage de la luminescence de Alq3. Des expériences ont été entreprises pour tester l’hypothèse que l’éclairage à la lumière blanche de ces empreintes révélées au FMC- Alq3 est inférieur à l’éclairage par UV. Le classement objectif et subjectif de 18 photographies d’empreintes révélées au FMC- Alq3 sur le laiton a clairement montré que l’éclairage à la lumière blanche est convenable pour une comparaison; si cela ne donne pas de conclusion solide, alors une photographie prise à l’éclairage UV de courtes longueurs d’ondes devrait être examinée par un humain. Cette procédure permettrait non seulement de diminuer les risques pour la santé reliés à l’utilisation des rayons UV mais aussi de diminuer les risques de dénaturer l’ADN potentiellement utile contenu dans l’empreinte.

Mots-clés : Alq3; film mince en colonnes; révélation d’une empreinte digitale; la lumière ultraviolette; la lumière blanche
Introduction

Many techniques to develop latent fingerprints have been devised, because fingerprints found at a scene can be useful to either identify or eliminate persons of interest [1, 2]. Some development techniques take advantage of the chemical composition of the fingerprint residue. Other development techniques require the dispersal of an appropriately coloured powder that sticks to the fingerprint residue.

An emerging development technique for fingerprints is the columnar-thin-film (CTF) technique [3–5]. CTFs are commonly employed as optical coatings to change the amplitude, polarization state, and the spectrum of light [6]. The procedures to grow CTFs have been known for over a century [7] and continue to be improved [8, 9].

A CTF is essentially a collection of parallel nanoscale columns. These columns are deposited upright on top of the fingerprint residue, thereby preserving the topology of the fingerprint [10]. Therefore, the development of the fingerprint does not rely upon the physical and chemical properties of the constituents of the fingerprint residue [3, 4].

A CTF is deposited atop a latent fingerprint on a substrate that is mounted on a planar platform in a low-pressure chamber. A solid material chosen especially for the specific substrate [4] is heated in a boat inside the chamber. Under the right combination of pressure in the chamber and temperature of the boat, the solid material evaporates as a collimated vapour. This vapour is directed obliquely towards the substrate that is rotated rapidly about a central normal axis passing through it. A dense CTF with upright nanoscale columns grows on the top of the fingerprint residue. When the CTF is of a desired thickness, typically 50–1000 nm depending on the deposited material and the substrate [4], the deposition process is stopped.

Tris (8-hydroxyquinolinato) aluminum, commonly known as Alq3, has proven to be a favourable evaporant material for partial-bloody fingerprints that have been deposited on a brass substrate [4, 5]. Alq3 is an organometallic chelate whose main use is in organic light-emitting diodes, as it is a stable and highly fluorescent material [11–13]. Alq3 can be strongly excited by ultraviolet light in two broad spectral regimes centred at wavelengths of 260 and 390 nm [13], and has a broadband emission spectrum peaking at about 550 nm [14]. Fingerprints developed with Alq3 CTFs appear greenish when visualized with short-wavelength ultraviolet (UV) illumination [4, 5].

Short-wavelength UV radiation from the sun, but not from manmade sources, is filtered out by ozone in the atmosphere. Exposure to this radiation has two major disadvantages: (i) it can cause skin cancer [15], cataracts and macular degeneration [16]; (ii) it can mutate DNA [15, 17], thereby damaging potentially probative DNA evidence within the fingerprint residue [18]. Because of these pitfalls, it would be advantageous to visualize Alq3 CTF-developed fingerprints without UV illumination.

In particular, white-light illumination would be highly convenient — because not only does it eliminate exposure to UV radiation, but it also allows for a more convenient camera setup. As white-light illumination of Alq3-CTF-developed fingerprints had not been evaluated earlier in comparison to short-wavelength UV illumination [4, 5], we decided to determine if the former performs equally or better than the latter.
Partial-bloody fingerprints were used for the work reported in this communication, as these kinds of fingerprints are commonly found at crime scenes. A partial-bloody fingerprint has both a bloody part and a non-bloody part. Both parts have to be developed for visualization. Traditional techniques employ developmental cascades, whereby a sequence of development techniques is used to develop both parts [19–22]. If one of the development techniques in the developmental cascade employs a water-rinsing step, such as with a protein-specific stain such as amido black [21], DNA can be lost.

Very recently, Williams et al. [5] proposed and examined a one-step alternative by depositing Alq$_3$ CTFs on several partial-bloody sebaceous-only fingerprints on several nonporous substrates. A split-print methodology was adopted to compare the CTF technique to several traditional development techniques, using both objective computer-based grading [23] and subjective grading by a trained but uncertified examiner. Alq$_3$-CTF development was found to be superior to development with the traditional techniques employed in the study [5] for partial-bloody fingerprints on brass and anodized aluminum. Unlike the traditional techniques used, the Alq$_3$-CTF deposition was successful in developing the entire fingerprint on these substrates.

The plan of this communication is as follows. The next section describes the method of collection of fingerprints, their development with Alq$_3$ CTFs, and their quality grading under white-light and short-wavelength UV illumination. The section after contains the results obtained and a discussion thereof. The manuscript concludes with closing remarks in the fourth section.

Materials and methods

For the purpose of comparing the qualities of white-light and short-wavelength UV illumination of Alq$_3$-CTF-coated fingerprints, we selected brass as the substrate material since it is commonly found in household fixtures such as door knobs, and in objects such as bullet casings often found at crime scenes. The chosen fingerprints contained a mixture of eccrine and sebaceous secretions.

Fingerprint collection

Eighteen fingerprint samples, each on a 1 in × 1 in square of a brass (Alloy 260, McMaster-Carr, Chicago, IL, USA) sheet, were harvested. The middle finger of the right hand of a single donor was used for each sample to maintain consistency. First, the donor washed their hands with soap and water. Next, after waiting for 5 min, the fingertip was swiped across the face and hairline of the donor ten times. This was done to ensure both eccrine and sebaceous secretions were present in the fingerprint. A fingertip of the donor other than the middle finger of the right hand was pricked, and blood was swiped onto the middle finger of the right hand. This fingertip was then pressed onto the brass substrate. This harvesting procedure was used to simulate evidence encountered at crime scenes.

Every sample was allowed to dry for approximately 24 h before development in the CTF chamber. This ageing period allows the samples to mimic a real crime-scene fingerprint and helps remove water vapour from the fingerprint.
CTF deposition

A ∼50-nm-thick CTF of Alq₃ (Sigma-Aldrich, St. Louis, MO, USA) was deposited on six samples at a time in a low-pressure chamber (Torr International, New Windsor, NY, USA) [24, 25]. The low-pressure chamber has an inner height of 24 in, its cross-section has a D shape with a 16 in diameter and a 15 in depth, it is made of 1 in thick steel to withstand a base pressure of 10⁻⁷ Torr, and it can accommodate substrates of 3.8 in diameter. In order to perform this deposition, the bottoms of the brass substrates were affixed to the planar surface of a rotatable platform inside the chamber, the platform was tilted for an average vapour flux angle of 20° as measured with respect to the platform’s plane, and Alq₃ was loaded in a tungsten boat located inside the chamber. A shutter between the boat and the substrates was positioned to prevent any vapour flux from reaching the substrates until desired, the chamber was closed, and the base pressure was reduced to 10⁻⁴ Torr. Then, the substrate-carrying platform was rotated at 180 rpm about a central normal axis passing through the platform, a current was passed through the tungsten boat so as to evaporate Alq₃, and the shutter was repositioned to let the vapour flux. With the help of a quartz crystal monitor mounted close to the six substrates, the CTF deposition rate was loosely controlled at ∼0.2 nm/s.

After the CTF had attained the required thickness of ∼50 nm, the shutter was positioned to prevent the vapour flux from reaching the substrates, the current through the boat was turned off, the platform’s rotation was stopped, and the chamber was opened to the atmosphere after ∼10 min.

Photography of developed fingerprints

After CTF deposition, every sample was individually photographed with a Nikon D3000 10.2 megapixel camera (Tokyo, Japan). A Nikon 60 mm macro lens (Tokyo, Japan) was used. The camera produced images of 2300 pixel/in resolution. Since the Universal Latent Workstation (ULW, Version 5.9, US Federal Bureau of Investigation) was used for objective grading (described in the next subsection), and its maximum resolution is 1000 pixel/in, there was no need to use a higher-resolution camera. No filters were used during photography, regardless of the type of illumination. The shutter speed was set at 1/30 and the aperture was set as f5.6 for white-light illumination, but these quantities were changed to 1/1.6 and f5.0 for short-wavelength UV illumination.

The camera was set up on a fixed stand to maintain consistent lighting and photographing conditions. In turn, a white-light halogen lamp (Capsylite 100 W 120 V Spot, Osram Sylvania, Danvers, MA, USA) and a short-wavelength UV lamp (254 nm, Model LS-7CB, Raytech, Middletown, CT, USA) were used to illuminate the sample for photography. The halogen lamp was fixed 9 in away from the sample at an elevation of 25°. The distance of the handheld UV lamp from the sample varied between 6 and 7 in and its elevation varied between 40° and 50°. All other lights in the room as well as the long-wavelength UV lamp were turned off when photographs were taken with the UV light. Long-wavelength illumination (365 nm) available with the UV illumination source was not used because it is 25 nm distant from the centre of the long-wavelength excitation regime of Alq₃, whereas the short-wavelength illumination (254 nm) is just 6 nm
distant from the centre of the short-wavelength excitation regime of Alq₃. The appropriate illumination source was turned on for 5 min before taking a photograph to ensure constant illumination.

**Quality-grading schemes**

Photographs of the fingerprint samples were graded on quality using an objective scheme and a subjective scheme. The objective grading scheme employs a combination of three different software packages: ULW Version 5.9, GNU Image Manipulation Program (GIMP®), and Mathematica®. The methodology has been described elsewhere in detail [9]. In essence, a clarity map is obtained from an uploaded fingerprint photograph. Coloured pixels are assigned to the photograph based on various levels of clarity: background, debatable ridge flow, debatable minutiae, and definitive minutiae. A pixel-counting algorithm then determines the percentage of pixels relating to each clarity level. The grade \( G_{\text{obj}} \in [0, 100] \) for overall image quality equals the percentage of pixels determined to be of definitive-minutiae clarity.

Every photograph was also subjectively graded by a trained but uncertified examiner (the first author) visually comparing it with the photograph of a control fingerprint obtained carefully on brass from the middle finger of the right hand of the sole donor; see Figure 1. The control fingerprint had only sebaceous residue [5] and had been collected without blood, so that the examiner knew the actual ridge flow and minutiae for the whole fingerprint. Each Alq₃-CTF-coated fingerprint was assigned a percentage score based on the quality compared with this control fingerprint, taking into consideration clarity, contrast, and observable detail within the fingerprint. This percentage score was the subjective grade \( G_{\text{sub}} \in [0, 100] \).

---

Figure 1. White-light photograph of the control fingerprint used for subjective grading. [To view this figure in colour, please see the online version of this Journal.]
Results and discussion

Figure 2 shows photographs of Sample no. 2 in white light and short-wavelength UV light. According to the objective quality-grading scheme, the white-light illumination outperformed the UV illumination by a considerable margin ($G_{\text{white}}^{\text{obj}} = 25$, $G_{\text{UV}}^{\text{obj}} = 0.38$), but the subjective grades for both illumination conditions are equal ($G_{\text{white}}^{\text{sub}} = G_{\text{UV}}^{\text{obj}} = 70$).

Figure 3 shows photographs of Sample no. 8. The objective grades are $G_{\text{white}}^{\text{obj}} = 1.8$ and $G_{\text{UV}}^{\text{obj}} = 9.2$ under white-light and UV illumination,
respectively, while the subjective grades are \( G_{\text{sub}}^{\text{white}} = 5 \) and \( G_{\text{sub}}^{\text{UV}} = 25 \). Both subjectively and objectively, UV illumination gave better results than white-light illumination.

The results of implementing the objective grading scheme on the white-light and short-wavelength UV photographs of all 18 samples are provided in Table 1. For each scheme, a relative difference \( D_{\text{obj}} = 1 - \left( \frac{G_{\text{obj}}^{\text{UV}}}{G_{\text{obj}}^{\text{white}}} \right) \) between the grades for the white-light and the short-wavelength UV photographs of each sample was calculated as a comparative measure, as the amount of blood on the fingerprint varied from sample to sample. A threshold of 0.05 was established for \( D_{\text{obj}} \) to be considered significant, because smaller differences are too minute for the software to differentiate meaningfully.

According to Table 1, white-light illumination provided a better-quality image than short-wavelength UV illumination for 78% of the samples, but the reverse was true for 17% of the samples. For just one of 18 samples, \( G_{\text{obj}}^{\text{white}} \) and \( G_{\text{obj}}^{\text{UV}} \) turned out to be equal.

Analogous data from the subjective quality-grading scheme for all 18 samples are provided in Table 2. According to this scheme, white-light illumination provided a better-quality image than short-wavelength UV illumination for 39% of the samples, but the reverse was true for 50% of the samples. For just 11% of the samples, \( G_{\text{obj}}^{\text{white}} \) and \( G_{\text{obj}}^{\text{UV}} \) were found to be equal.

The objective quality-grading scheme is overwhelmingly more successful with white-light illumination than with short-wavelength UV illumination. White-light illumination is as good or superior to short-wavelength UV illumination for 83% of the samples, whereas short-wavelength UV illumination is as

| Sample no. | White-light illumination \( G_{\text{obj}}^{\text{white}} \) | Short-wavelength UV illumination \( G_{\text{obj}}^{\text{UV}} \) | \( D_{\text{obj}} \) | Better illumination |
|------------|-----------------|-----------------|-----------------|-----------------|
| 1          | 11              | 4.4             | 0.6             | White           |
| 2          | 25              | 0.38            | 0.98            | White           |
| 3          | 19              | 0.1             | 0.99            | White           |
| 4          | 22              | 2.1             | 0.9             | White           |
| 5          | 28              | 5.7             | 0.8             | White           |
| 6          | 32              | 0.96            | 0.97            | White           |
| 7          | 2.4             | 1.8             | 0.25            | White           |
| 8          | 1.8             | 9.2             | 4.11            | UV              |
| 9          | 2.7             | 2.7             | 0               | Equal           |
| 10         | 6.4             | 3.2             | 0.5             | White           |
| 11         | 0.13            | 24              | -183.62         | UV              |
| 12         | 5.2             | 2.4             | 0.54            | White           |
| 13         | 10              | 9               | 0.1             | White           |
| 14         | 18              | 0.36            | 0.98            | White           |
| 15         | 8.6             | 3.7             | 0.57            | White           |
| 16         | 2.9             | 0               | 1               | White           |
| 17         | 1.6             | 0.44            | 0.725           | White           |
| 18         | 0.8             | 1.9             | -1.375          | UV              |

Table 1. Results of implementing the objective quality-grading scheme on all 18 samples.
good or superior to white-light illumination for only 22% of the samples. The difference can be attributed to the ULW software detecting greater contrast between the ridges and valleys of the white-light photographs of fingerprints than in green photographs enabled by the luminescence of the Alq3 CTFs.

A quite different conclusion emerges from the implementation of the subjective quality-grading scheme. White-light illumination is as good or superior to short-wavelength UV illumination for 50% of the samples, whereas short-wavelength UV illumination is as good or superior to white-light illumination for 61% of the samples. Clearly, human operators perform differently from automata in perceiving contrast.

### Closing remarks

If a ULW-based scheme is deployed to identify an Alq3-CTF-developed fingerprint, our data strongly indicate that white-light illumination is superior to short-wavelength UV illumination. The use of white light will reduce the chances of denaturing potentially useful DNA evidence within the fingerprint samples — which may be particularly important in samples containing just a few cells and, thus, extremely low levels of DNA [26, 27]. Moreover, adverse effects on the health of forensic workers would be reduced as also the need for special camera setups. If an Alq3-CTF-developed fingerprint were to be identified by a human, our data indicates that short-wavelength UV illumination is somewhat superior to white-light illumination.

### Table 2. Results of implementing the subjective quality-grading scheme on all 18 samples.

| Sample no. | White-light illumination $G_{\text{white}}^{\text{sub}}$ | Short-wavelength UV illumination $G_{\text{UV}}^{\text{sub}}$ | $D_{\text{sub}} = 1 - (G_{\text{UV}}^{\text{sub}} / G_{\text{white}}^{\text{sub}})$ | Better illumination |
|------------|----------------|----------------|--------------------------------------|------------------|
| 1          | 40             | 50             | -0.25                                | UV               |
| 2          | 70             | 70             | 0                                    | Equal            |
| 3          | 25             | 15             | 0.4                                  | White            |
| 4          | 70             | 65             | 0.07                                 | White            |
| 5          | 75             | 50             | 0.33                                 | White            |
| 6          | 80             | 80             | 0                                    | Equal            |
| 7          | 60             | 30             | 0.5                                  | White            |
| 8          | 5              | 25             | -4                                   | UV               |
| 9          | 55             | 20             | 0.64                                 | White            |
| 10         | 10             | 45             | -3.5                                 | UV               |
| 11         | 5              | 70             | -13                                  | UV               |
| 12         | 10             | 25             | -1.5                                 | UV               |
| 13         | 70             | 85             | -0.21                                | UV               |
| 14         | 60             | 50             | 0.16                                 | White            |
| 15         | 75             | 50             | 0.33                                 | White            |
| 16         | 5              | 65             | -12                                  | UV               |
| 17         | 60             | 75             | -0.25                                | UV               |
| 18         | 15             | 60             | -3                                   | UV               |
Given the hazards associated with UV radiation, we suggest that white-light illumination should be used first, whether for a human or a computer to examine an Alq$_3$-CTF-developed fingerprint for either the identification or the elimination of a suspect. If that examination fails to yield a strong conclusion, then a photograph taken with short-wavelength UV illumination should be examined by a human. A study is currently underway to confirm if damage to DNA is reduced if Alq$_3$-CTF-developed fingerprints are exposed to white-light illumination rather than to short-wavelength UV illumination.

Acknowledgements
This work was supported in part by the Charles Godfrey Binder Endowment at the Pennsylvania State University.

Disclosure statement
No potential conflict of interest was reported by the authors.

References
1. Lee HC, Gaensslen RE. Advances in fingerprint technology. 2nd ed. Boca Raton (FL): CRC Press; 2001. Chapter 3, Methods of latent fingerprint development; 105—175.
2. Yamashita B, French M, Bleay S, Cantu A, Inlow V, Ramotowski R, Sears V, Wakefield M. The fingerprint sourcebook. Washington (DC): National Institute of Justice; 2011. Chapter 7, Latent print development, pp. 7—1 to 7—67.
3. Lakhtakia A, Shaler RC, Martín-Palma RJ, Motyka MA, Pulsifer DP. Solid-state acquisition of fingerprint topology using dense columnar thin films. J Forensic Sci. 2011;56(3):612—616. doi: 10.1111/j.1556-4029.2010.01685.x
4. Muhlberger SA, Pulsifer DP, Lakhtakia A, Martín-Palma RJ, Shaler RC. Optimized development of sebaceous fingermarks on nonporous substrates with conformal columnar thin films. J Forensic Sci. 2014;59(1):94—102. doi: 10.1111/1556-4029.12307
5. Williams SF, Pulsifer DP, Lakhtakia A, Shaler RC. Visualization of partial bloody fingermarks on nonporous substrates using conformal columnar thin films. Can Soc Forensic Sci 2015;48(1):20—35. doi: 10.1080/00085030.2014.987464
6. Hodgkinson IJ, Wu Qh. Birefringent thin films and polarizing elements. Singapore: World Scientific; 1997.
7. Mattox DM. The foundations of vacuum coating technology. Norwich (NY): Noyes Publication; 2003.
8. Lakhtakia A, Messier R. Sculptured thin films: Nanoengineered topology and optics. Bellingham (WA): SPIE Press; 2005.
9. Piegari A, Flory F. (Eds.) Optical thin films and coatings. Cambridge (United Kingdom): Woodhead; 2013.
10. Swiontek SE, Pulsifer DP, Lakhtakia A. Quality of development of latent sebaceous fingermarks coated with thin films of different morphologies. J Vac Sci Technol B 2014;32(2):020605. doi: 10.1116/1.4867440
11. Cai M, Xiao T, Chen Y, Shinar R, Shinar J. Indium-tin-oxide-free tris(8-hydroxyquinoline) Al organic light-emitting diodes with 80% enhanced power efficiency. Appl Phys Lett. 2011;99(15):153303. doi: 10.1063/1.3634210
12. Noguchi Y, Tamura T, Kim HJ, Ishii H. Device properties of Alq$_3$-based organic light-emitting diodes studied by displacement current measurement. J Photon Energy. 2012;2(1):021214. doi: 10.1117/1.JPE.2.021214
13. Kishore VVNR, Aziz A, Narasimhan KL, Periasamy N, Meenaksi PS, Wategaonkar S. On the assignment of the absorption bands in the optical spectrum of Alq3. Syn Met. 2002;126(2–3):199–205. doi: 10.1016/S0379-6779(01)00553-7

14. Martin-Palma RJ, Miller AE, Pulsifer DP, Lakhtakia A. Angular distribution of light emission from compound-eye cornea with conformal fluorescent coating. Appl Phys Lett. 2014;105(10):103703. doi: 10.1063/1.4895114

15. Pfeifer GP, You Y-H, Besaratinia A. Mutations induced by ultraviolet light. Mutat Res. 2005;571(1–2):19–31. doi:10.1016/j.mrfmmm.2004.06.057

16. Taylor HR, West S, Muñoz B, Rosenthal FS, Bressler SB, Bressler NM. The long-term effects of visible light on the eye. Arch Ophthalmology. 1992;110(1):99–104. doi:10.1001/archophthalm.1992.01080130101035

17. Sinha RP, Häder D-P. UV-induced DNA damage and repair: a review. Photochem Photobiol Sci. 2002;1(4):225–236. doi: 10.1039/b201230h

18. Tamariz J, Voynarowska K, Prinz M, Caragine T. The application of ultraviolet irradiation to exogenous sources of DNA in plasticware and water for the amplification of low copy number DNA. J Forensic Sci. 2006;51(4):790–794. doi: 10.1111/j.1556-4029.2006.00172.x

19. Trozzi TA, Schwartz RL, Hollars ML. Processing guide for developing latent prints. Washington (DC): Federal Bureau of Investigation; 2000.

20. Bossers LCAM, Roux C, Bell M, McDonagh AM. Methods for the enhancement of fingerprints in blood. Forensic Sci Int. 2011;210(1–3):1–11. doi: 10.1016/j.forsciint.2011.04.006

21. Sears VG, Prizeman TM. Enhancement of fingerprints in blood — part 1: The optimization of amido black. J. Forensic Ident. 2000;50(5):470–480.

22. Sears VG, Butcher CPG, Fitzgerald LA. Enhancement of fingerprints in blood — part 3: Reactive techniques, acid yellow 7, and process sequences. J. Forensic Ident. 2005;55(6):741–763.

23. Pulsifer DP, Muhlberger SA, Williams SF, Shaler RC, Lakhtakia A. An objective fingerprint quality-grading system. Forensic Sci Int. 2013;231(1–3):204–207. doi: 10.1016/j.forsciint.2013.05.003

24. Williams SF, Pulsifer DP, Shaler RC, Ramotowski RS, Brazelle S, Lakhtakia A. Comparison of the columnar-thin-film and vacuum-metal-deposition techniques to develop sebaceous fingerprints on nonporous substrates. J Forensic Sci. 2015;60(2):295–302. doi: 10.1111/1556-4029.12648

25. Swiontek SE, Lakhtakia A. Vacuum-metal-deposition and columnar-thin-film techniques implemented in the same apparatus. Mater Lett. 2015;142(1):291–293. doi: 10.1016/j.matlet.2014.12.038

26. van Oorschot RAH, Jones MK. DNA fingerprints from fingerprints. Nature 1997;387 (6635):767. doi: 10.1038/42838

27. Alessandrini F, Cecati M, Pesaressi M, Turchi C, Carle F, Tagliabruno A. Fingerprints as evidence for a genetic profile: Morphological study on fingerprints and analysis of exogenous and individual factors affecting DNA typing. J Forensic Sci. 2003;48(3):586–592.