Dye-soaked cotton pads for latent blood fingerprint development

Zhinan Fan¹ · Chi Zhang¹ · Rongliang Ma² · Li-Juan Fan¹

Received: 4 July 2020 / Accepted: 12 October 2020 / Published online: 24 October 2020

© Springer Nature Switzerland AG 2020

Abstract

Visualization of latent blood fingerprints (LBFPs) at violent crime scenes is very important for identifying criminals, while current reagents/methods for developing LBFPs still have more or less limitations. Here, we advance a new strategy for LBFP development based on the dye-soaked cotton pads as “ensemble” materials. The cotton pad was first soaked in the dye solution and then placed on the substrate with deposited blood fingerprint for development. After peeling off the pad, uniform and legible fingerprint patterns were obtained in all cases where different dyes and substrates were employed. The dye-soaked pads displayed superior developing effect compared with those using conventional methods (immersing, smearing and spraying). The pad-based method exhibited many other merits, such as little damage to the fingerprint patterns and less dye stains left on fingerprint and substrate, as well as the reusability. This pad-based method was also applicable for developing sebaceous latent fingerprints by replacing the small molecular dyes with fluorescent conjugated polymer nanoparticles. In all, the dye-soaked cotton pad developing protocol is feasible, cost-effective and universally applicable for developing different types of latent fingerprints on various substrates.

Graphic abstract

Keywords Forensic science · Latent fingerprint · Fingerprint development · Blood · Cotton pad · Dye-soaked

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s42452-020-03671-5>) contains supplementary material, which is available to authorized users.

✉ Rongliang Ma, marl2013@163.com; ✉ Li-Juan Fan, ljfan@suda.edu.cn | ¹Department of Polymer Science and Engineering, College of Chemistry, Chemical Engineering and Materials Science, Soochow University, Suzhou 215123, People's Republic of China. ²Institute of Forensic Science, Ministry of Public Security, Beijing 10038, People's Republic of China.

SN Applied Sciences (2020) 2:1879 | <https://doi.org/10.1007/s42452-020-03671-5>

1 Introduction

Fingerprints have been well known as one of the most important forensic evidences since ancient time. The fingerprint patterns formed by ridges and furrows are unique to each person, unchanged throughout the entire life and easy to be left on the objects touched by fingers [1–5]. Many violent crime scenes involve blood residue. Blood residue provides important personal information for identification and recognition [6–9]. Analysis of bloodstain pattern serves a significant role in reconstructing a criminal action and identifying suspects linked to the crime scene [9–11]. Blood fingerprints contain rich information to be used to identify a criminal suspect [12–16]. However, in many cases, the crime scenes are chaotic with limited evidence preserved. Bloodstains may be deliberately damaged or cleaned by criminals to cover up personal trace. Thus, collecting legible visible blood fingerprints at a crime scene remains a challenge [17]. Latent blood fingerprints (LBFPs), which are invisible to naked eyes and often neglected by criminals at crime scenes, can provide great help for crime investigation if visualized. Therefore, the LBFP development techniques are very important for identification of criminals in violent cases.

To collect LBFPs effectively, the LBFP development techniques have been continually improved over time. The methods can be summarized into two major categories: optical techniques and chemical enhancement [18]. In general, optical techniques are first used; and if the result is unsatisfactory, chemical enhancement is employed. The chemical enhancement method involves selection of a chemical reagent and adoption of an

appropriate operational protocol in order to develop LBFPs. Nowadays, many chemical reagents have been demonstrated to be effective for developing LBFPs [6, 10, 18–27]. However, there are not many options available for operating methods. The most commonly used methods include immersing, spraying and smearing. These methods have limitations more or less. Pre-treatment and/or post-treatment of the fingerprints is often required during the developing process. Some reagents are inconvenient to be carried and stored, and sometimes need a relatively long developing time. Additionally, the immersing method only works for substrates of small size; the smearing method may cause uneven development and even damages to the fingerprint patterns; and the spraying method may bring harm to the operator due to the large amount of solvent volatilization. Because of these drawbacks, current available methods for LBFPs developing have limited success for practical application in the casework. It is of great significance to develop new and low-toxic materials/methods with high-efficiency for LBFPs detection under various situations.

Here, we present a new method based on dye-soaked cotton pads as “ensemble” materials for LBFP development, as shown in Scheme 1. First, cotton pads are soaked in the dye solution, and then, one piece of dye-soaked pad is taken out of the solution and placed on the surface of the LBFP for several minutes. After the cotton pad is removed, the developed LBFP is photographed using a digital camera. While cotton pad has been widely used as cosmetic water wiper and makeup remover because it can absorb and release water easily, to our knowledge, there is no previous report about using cotton pad for fingerprint development. Employing dye-soaked cotton pad

Scheme. 1 The schematic diagram for the preparation of dye-soaked pads followed by fingerprint development

for fingerprint development has many advantages. First, the overall operational process is convenient and simple with no need of pre-treatment and post-treatment of the fingerprint. Second, the dosage of the reagent can be precisely controlled in advance to minimize the waste of reagent. In addition, the dye-soaked cotton pad can be sealed in a bottle or bag for carrying and long-time storage. Third, there is no restriction on the size and location of the fingerprint substrate, which makes the method much easier to search for possible latent fingerprints “on site.” Fourth, since the dye solution is confined in the pad, the amount of solvent evaporated into the air and/or left on the substrate is reduced, thereby greatly reducing environmental pollution and health risks. Finally, such pad usually can be reused for several times.

2 Materials and methods

2.1 Reagents and materials

EDTA anticoagulated sterile chicken blood for collection of LBFPs was purchased from Guangzhou Hongquan Biotechnology Co., Ltd. Absolute ethyl alcohol and glacial acetic acid were obtained from Shanghai Lingfeng Chemical Reagent Co., Ltd. and Chinasun Specialty Products Co., Ltd., respectively. Tetramethylbenzidine (TMB), Coomassie blue, Amido black 10B and acid fuchsin were provided by Aladdin Industrial Corporation. Eosin was provided by Shanghai Qiangshun Chemical Reagent Co., Ltd. Aluminum foil, coverslip and white enamel were purchased from Shanghai Titan Scientific Co., Ltd., Sangon Biotech (Shanghai) Co., Ltd. and Shanghai White Goose Enamel Co., Ltd., respectively. The original cotton pads (100% cotton, non-woven fabric) were purchased from Guangzhou Shangye Cosmetic Tools Co., Ltd. The pads were cut into 2 cm × 3 cm pieces for developing LBFPs in this study.

2.2 Preparation of solutions

2.2.1 Dye solutions

Amido black 10B, Coomassie blue and acid fuchsin dye solutions were prepared according to the formulation in the literature [10]; eosin solution was prepared with a method modified from previous report [28]; and TMB solution was prepared using the method provided by Institute of Criminal Science and Technology, Suzhou Public Security Bureau, Suzhou, China. Amido black 10B (0.1 g), glacial acetic acid (0.5 mL) and absolute ethyl alcohol (9.5 mL) were successively added to a 50-mL conical flask, and then, the flask was shaken by hand until the powders completely dissolved to give a 10 mL Amido black

10B solution. Coomassie blue (0.02 g), glacial acetic acid (1 mL) and absolute methanol (9 mL) were continuously added to a 50-mL conical flask, and then, the flask was shaken by hand to give a 10 mL Coomassie blue solution. Eosin (0.1 g) and absolute ethanol (10 mL) were consecutively added into a 50-mL conical flask, and then, the flask was shaken by hand to give a 10-mL eosin solution. Acid fuchsin (0.02 g) and deionized water (10 mL) were successively added to a 50-mL conical flask; after the mixture was completely dissolved, 10 mL acid fuchsin solution was obtained. A 500-mL conical flask was filled with TMB (5.00 g) and acetone (200 mL), and the mixture was stirred at room temperature until a transparent solution was obtained; then, 30% hydrogen peroxide (6 mL) was added into the flask to give the TMB solution. All dye solutions were stored for future use, except the TMB solution, which was prepared right before LBFP development.

2.2.2 Rinse solution

Glacial acetic acid (5 mL) and absolute ethyl alcohol (45 mL) were added into a 50-mL conical flask. Then, the mixture was stirred to form the rinse solution (50 mL). Finally, the rinse solution was transferred into a 100-mL spray bottle for future use.

2.3 LBFP deposition and development

2.3.1 LBFP deposition and fixing

All the fingerprints to be developed were collected by the same procedure after optimization, unless otherwise noted. The donor washed hands with running water and dried naturally; 4 µL of sterilized anticoagulated chicken blood was dropped on the finger. The fingerprints were deposited on various substrates (aluminum foil, white enamel and coverslip) with a certain pressure (75 g) and a certain angle (vertical). The substrates were cleaned with ethanol and dried under natural conditions in advance. The collected fingerprints on the substrates were stored in a dark room under ambient condition (about 25 °C, 1 atm) for 24 h for future use.

2.3.2 Cotton pad development procedure

The cotton pads for fingerprint developing were prepared by completely soaking 2 pieces of cotton pads (2 cm × 3 cm) in a dye solution (300 µL) in the lucifugal weighing bottle, and were sealed and stored in the same bottle for future use. For developing, one piece of the cotton pads was taken out by a tweezer and then placed directly on the substrate with

the suspected LBFP. After 1–2 min, the pad was peeled off the substrate and the developed LBFP was dried naturally.

2.3.3 Immersing development process/procedure

The substrate carrying LBFP was first placed in the dye solution (2 mL). After 1–2 min, the substrate was taken out and rinsed by the rinse solution to wash off the excess dye solution. Finally, the fingerprint was dried naturally until the rinse solution on the fingerprint substrate was completely evaporated.

2.3.4 Spraying development procedure

The dye solution was poured into the spray bottle (30 mL). Then, the dye solution was sprayed evenly on the substrate to completely cover the fingerprint. After about 2 min, the rinse solution was sprayed to rinse off the excess dye solution on the fingerprint and the substrate. Finally, the fingerprint was dried naturally until the rinse solution on the fingerprint substrate was completely evaporated.

2.3.5 Smearing development procedure

First, a small cotton ball was infiltrated with a dye solution. The LBFP substrate was gently smeared by the cotton ball with the dye solution until the solution covered the fingerprint. Then, the fingerprint was rinsed by the rinse solution to remove the excess dye solution. Finally, the developed fingerprint was naturally dried until the rinse solution on the fingerprint substrate was completely evaporated.

2.4 Instruments

The morphology of the cotton pad was characterized by optical microscope images on a SK200 optical microscope (Motic China Group Co., Ltd.). The developed and dried LBFP was photographed under natural light. The digital photographs were taken by Huawei P9 plus mobile phone in professional mode (ISO 1250, S 1/125, EV 0, AF-C). The pressure of the LBFPs deposition was measured by an analytical balance on an AL104 electronic balance (Mettler Toledo Instruments (Shanghai) Co., Ltd.). The contact angle was measured by JC2000D6 contact angle measuring instrument (Shanghai Zhongchen Digital Technic Apparatus Co., Ltd.).

3 Results and discussion

3.1 General considerations

Several common chemical reagents in different colors were employed to prepare dye-solution-soaked pads.

More specifically, Amido black 10B in black-blue, Coomassie blue in blue, TMB in light sea green, acid fuchsin and eosin in fuchsia were selected as the representative dyes, based on the consideration of that they have been commercialized and are often used in practical blood fingerprint development at crime scenes with standardized methods [10]. Three substrates, aluminum foil, white enamel and coverslip, as representatives, were employed. All of them are in light color; thus, the developed fingerprint may have a sharp contrast to the background for easy observation. To investigate the affinity between the substrates and blood, the contact angle measurements were carried out. In general, the smaller the contact angle is, the stronger the affinity will be. As shown under the left column of Fig. 1, aluminum foil has the weakest affinity to blood, and the affinities of coverslip and white enamel are similar and relatively stronger. The original deposited blood fingerprints are shown under the right column of Fig. 1. Note that a piece of white non-fluorescent paper was placed under the transparent coverslip to increase the visibility of the fingerprint. The legibility of the fingerprint pattern on each substrate is different. The pattern on the aluminum foil can be seen with the naked eyes at a certain angle; the patterns of the fingerprints on coverslip

Fig. 1 Contact angle images of blood (left) and the representative digital photographs of undeveloped blood fingerprint (right) on aluminum foil, coverslip and white enamel

and white enamel are somewhat invisible with only a little yellowish color. It is plausible that such result is due to the different properties of different substrates, especially the affinity toward blood and the background.

3.2 Optimization

The developing process was carried out as described in Scheme 1. To make the experiments reproducible and the results comparable, the developing process was optimized for different scenarios or conditions. The optimization was first carried out on the conditions of latent fingerprint deposition. The development result could be affected by the blood dosage and the pressure of fingerprint deposition [29–32]. The aluminum foil was selected as the substrate for this optimization, based on the consideration that the color and pattern of fingerprint could be clearly observed on the aluminum foil and the effect upon changing condition might be obvious. The pressure of fingerprint deposition was precisely controlled by the operator with an electronic balance. Various volumes of blood (2, 4, 6, 8 and 10 μL) were dropped on the fingerprints deposited with the pressure of around 50 g. The images of the blood fingerprints are shown in Fig. 2a. In addition, the pressure for deposition fingerprint was set as 25, 50, 75 and 100 g, respectively, with a fixed blood dosage of 4 μL . The images are shown in Fig. 2b. Ultimately, 4 μL of blood and 75 g of pressure was chosen in the experiments considering the best image among the blood fingerprints images obtained in Fig. 2.

Second, the optimal conditions were investigated for preparation of dye-soaked cotton pads. The cotton pads were cut into small pieces (2 cm $\times$ 3 cm) to just cover one fingerprint in this laboratory-based experiment. To make the preparative process more effective, 2 pieces of pads were prepared at the same time, based on the consideration of the volume of the weighing bottle as the container employed in our study and the convenience of observing the status of cotton pads during immersing. Afterward, the volume of a dye solution for immersing the cotton pad was optimized. White enamel was selected as the substrate in this part because of the white background color for good visualization and sharp contrast with the developed colored image. Coomassie blue was employed as the dye solution here, as a randomly selected representative. The result of development changed when the volume of the development solution for soaking the cotton pad was changed. The ideal result would be that LBFPs could be well developed without the background being stained.

The photographs and optical microscopic images of the Coomassie blue-soaked cotton pads are shown under the left and middle columns of Fig. 3, respectively. The color of the cotton pads became darker when the volume of the dye solution increased from 100 to 400 μL . Evidently, 400 μL of the dye solution could not be completely absorbed by the cotton pad, since some residue was observed at the bottom of the container. The optical microscopic images in Fig. 3 show that more amounts of the dye solution were absorbed into the pores between the fibers of the cotton pads when the volume of the dye

Fig. 2 **a** Digital photographs of representative undeveloped blood fingerprints deposited using different volumes of blood with the same pressure (50 g); **b** Digital photographs of representative undeveloped blood fingerprints deposited using different pressures (in gram) with the same volume of blood (4 μL). The photographs were taken under natural light

Fig. 3 Digital photographs of the cotton pads soaked with different volumes of Coomassie blue solutions (100 μ L, 200 μ L, 300 μ L and 400 μ L) (left), the corresponding microscopic images of the pads (middle) and the digital photographs of developed LBFPs on white enamel substrate (right)

solution was increased until finally almost all pores were filled up. At the same time, the color of the cotton pads changed from grayish blue to brilliant blue. The dye filled pore and the color of the cotton pad no longer changed when the volume of the dye solution reached 300 μ L. The corresponding developing results are shown under the right column of Fig. 3. The developed patterns were in light blue color, with discontinuous and indistinct ridge lines at first. When the volume of the dye solution increased to 300 μ L or 400 μ L, the patterns became legible and bright in color. Based on the observation that there was almost no solution residue when the cotton pad was soaked in the 300 μ L dye solution, 300 μ L was considered as the optimized volume of the dye solution for preparing two pieces of the dye-soaked cotton pads (2 cm $\times$ 3 cm).

Therefore, after optimization, the conditions for preparation of dye-soaked pads and fingerprint development were set and the whole process is shown in the video in electronic supplementary information. Usually, the overall process has three parts: the first part is the preparation of the cotton pads, the second part is the blood fingerprint pre-treatment, and the last part is the fingerprint development. For the first part, the above optimized protocol is for the laboratory process. In practical applications, the cotton pads can be prepared to different sizes according to the actual crime scene requirements. In addition, the scale-up production of immersed cotton pads can be achieved by increasing the volume of dye solution in proportion. During the scale-up, some conditions may be adjusted slightly according to the real situation, but several issues always need attention. First, ample volume of the dye solution

absorbed by each piece of cotton pad must be guaranteed. Second, the uniform distribution of the dye solution on each piece of cotton pad needs to be ensured by making each piece of cotton pad contact with the dye solution at the same time. Then, the dye-soaked cotton pads are expected to have long storage time if they are placed in a closed container or a sealed plastic bag, and they are ready for use whenever needed, though the storage time has not been investigated in our study. Before fingerprint development, usually a blood fixing step is necessary to fix the blood in the fingerprint [18, 33]. This step has been done by storing the LBFPs at room temperature for 24 h in this study, instead of using the chemical fixing reagent as in many protocols. Note that the unified fixing step is just for comparing the developing result in this study. In real application, the LBFP usually is left on-site for several hours to a couple of days or even longer time. For the fingerprint developing process, in order to achieving a good development and fingerprint detection result, the cotton pad needs to be gently pressed to ensure a closer contact with the substrate; the extension and shortening of the development time is necessary according to the environmental conditions (e.g., temperature and humidity). More importantly, an eye should be kept on the status of the cotton pad to ensure that the development process completes before the cotton pad becomes dry. In addition, the cotton pad should not be moved during developing, otherwise fingerprint pattern may be damaged. In all, the whole protocol for preparation of the dye-soaked pad as well as the procedure for developing LBFPs is simple, facile and easy to scale up for mass production.

3.3 Development of LBFPs

LBFPs on various substrates were developed according to the above optimized protocol. Note that this method based on dye-soaked cotton pad can be applied to a variety of dyes and substrates for LBFP development, while other conventional methods usually have limitations in selection of dyes or substrates. For comparison, three commonly used methods for LBFP development (smearing, immersing and spraying methods) were also employed, in parallel with the pad-based method. Figure 4 shows the developed LBFPs on the coverslip by the above four methods. With the dye-soaked cotton pad method, LBFPs on coverslip were well developed by all of the five dye solutions and the fingerprint patterns in all images were very clear. However, other methods apparently displayed less ideal results. With the immersing method, no fingerprint image was observed when Coomassie blue/TMB/acid fuchsin was used and only part of the fingerprint image was observed when Amido black 10B solution was used. The fingerprint image could be observed, but

the image was over-stained and very unclear when eosin solution was employed. Several reasons might account for such results. First, the rinsing process might take away the dye on the fingerprint together with the fingerprint residues, resulting in the fingerprint image partly or fully illegible. This happened in the application of Coomassie blue/TMB/acid fuchsin/Amido black 10B. Second, the dye solutions might stain the background as well as the fingerprint ridges. This led to some unevenness in the dye distribution on the fingerprint in the smearing method. Spraying method generally outperformed smearing and immersing methods. However, some images of developed LBFPs were still not satisfactory. In the case of eosin and acid fuchsin, some fingerprints were damaged and there were abundant stains on the developed fingerprints in the application using Amido black 10B and Coomassie blue. Interestingly, LBFP developed by TMB almost displayed no patterns. In conclusion, the dye-soaked cotton pad method demonstrated to be superior to other conventional methods in developing LBFPs on the glass coverslip.

The superiority of using dye-soaked cotton pad method was also proved in developing blood fingerprint on other substrates, such as aluminum foil and white enamel. The developed images on these two substrates are shown in Figs. 5 and 6, respectively. The developing results of the blood fingerprints on aluminum foil with the conventional methods (Fig. 5) were not very ideal, in some aspects. Sometimes the image was not clear enough for recognition, or was damaged. In all, the developing results using the conventional methods were not as good as using the pad method; very likely, the external force exerted onto the fingerprint when developing or the rinsing process had some negative effects on the developing results since the affinity between aluminum foil and blood was relatively weak. As for the LBFPs on the white enamel substrate (Fig. 6), the contrast between the white substrate and the developed LBFPs by all methods was very good. The developed LBFPs on the white enamel had the most legible patterns for all dye solutions. However, damage and staining of fingerprint patterns still occurred when using the smearing method and the spraying method, though the white enamel had good affinity with blood. In addition, the immersing method was not applicable for developing LBFPs on the white enamel at all, since the white enamel substrate had large size and there was no appropriate container to soak it in our laboratory-based experiment. In addition, a large amount of reagent would be used for immersing large-size substrate. Therefore, the inconvenience to develop LBFPs on large-size substrate would be one of the shortcomings of the immersing method. As seen from Fig. 4, 5 and 6, the LBFPs developed by cotton pads on all three substrates had legible patterns, the distribution of dye on fingerprints was uniform, and

Fig. 4 The representative photographs of the developed LBFPs on coverslip by four methods (cotton pad, immersing, smearing and spraying) and five dye solutions (Amido black 10B, Coomassie blue, TMB, eosin and acid fuchsin) under natural light

there was almost no stain of developing/rinsing solution left on the fingerprints and substrates. Compared with the dye-soaked cotton pad method, conventional methods produced developed LBFPs with darker color and less legibility in most cases, though sometimes they also performed well.

As seen from the above results, there was usually some dye solution left on the fingerprint residues and the substrate, requiring additional drying process when immersing, smearing and spraying methods were employed. Moreover, it was necessary to rinse the over-dyed fingerprint with the rinse solution, after which another drying

Fig. 5 The representative photographs of the developed LBFPs on aluminum foil by four methods (cotton pad, immersing, smearing and spraying) and five dye solutions (Amido black 10B, Coomassie blue, TMB, eosin and acid fuchsin) under natural light

process might be needed. The dye-soaked cotton pad method could avoid overstaining by properly controlling the amount of the dye solution in advance, and no rinsing operation was needed since excess dye solution seldom remained on the fingerprint after the development. In addition, the dye-soaked cotton pad method can be

applied to substrates of various sizes and at different locations, such as horizontal or vertical positions. Moreover, it consumes less volume of dye solution, compared with other methods, which reduces the cost for developing and the pollution to the environment.

Fig. 6 The representative photographs of the developed LBFPs on white enamel by four methods (cotton pad, immersing, smearing and spraying) and five dye solutions (Amido black 10B, Coomassie blue, TMB, eosin and acid fuchsin) under natural light

In order to investigate whether the fingerprints developed by the cotton pad method would be clear enough for individual identity recognition, parts of the developed LBFP images were magnified (Fig. 7). Evidently, the details of the friction ridge were clearly observed, such

as bifurcation, ridge ending and short ridge. Even the 3rd-level features were visible after magnification that would certainly help the identification effectiveness using fingerprint.

Fig. 7 Digital photographs of a developed LBFP under natural light and some magnified regional images with three levels of details on white enamel substrate developed by Coomassie blue-soaked cotton pad

3.4 The reusability of the dye-soaked cotton pad for fingerprint development

Another prominent advantage for cotton pad method is that the pads may be reused. To investigate the reusability of each piece of cotton pad for LBFP development, five LBFPs deposited with exactly the same condition on the white enamel substrate were developed using the same piece of cotton pad soaked with Coomassie blue solution. The photographs of the cotton pads and the developed LBFPs are shown in Fig. 8. The color of cotton pads became lighter gradually after each reuse for fingerprint development. The optical microscopic images further suggested that the amount of the remaining dye solution in the pores between the fibers of cotton pads decreases after each reuse. The pattern of the developed LBFPs gradually became less legible and some ridges of the fingerprint became discontinuous. For the LBFP developed with the fifth reuse of the pad, most ridges of the developed LBFPs became discontinuous. Therefore, one piece of cotton pad soaked with Coomassie blue solution could be reused for developing LBFP on white enamel for up to four times. Similar outcomes are expected for other dye solutions and substrates, though sometimes the result may vary to a certain degree based on the nature of different solutions and substrates. The reusability of the cotton pad makes the dye-soaked cotton pad fingerprint developing process cost-effective; and its availability and portability make this method potentially commercially attractive.

3.5 Developing blood fingerprint deposited mimicking real scenes

To make all the developing effect comparable, above developments were carried out on fingerprints deposited with same condition by washing and drying the hand first before touching the blood. However, in real crime scene, blood fingerprint may contain many other components, including endogenous substance (such as sweat, metabolite) and exogenous substance (such as sebaceous, dust), rather than a single blood component. Therefore, in order to investigate whether pad-based method is potential to be applied in real cases, blood fingerprints containing complex components were developed. Without any pre-treatment such as washing by running water, the donor's finger touched desk with dust, clothes and oily part of the human body to ensure the finger contain dust, sebaceous, sweat and/or other ingredients. Then, 4 μ L of sterilized anticoagulated chicken blood was dropped on the finger. The resultant fingerprints were deposited on white enamel substrates and developed by dye-soaked cotton pads. As shown in Fig. 9, legible patterns of developed fingerprints indicate the method can be used to develop fingerprints containing multiple components. Therefore, the pad-based method has potential to be used in practical crime scenes.

3.5.1 Extension to sebaceous latent fingerprints development

This study mainly focuses on the blood fingerprint development; thus, the dye solutions selected are mainly for their good interaction with blood. If the appropriate developing solution is used, such cotton pad method can also extend to sebaceous fingerprints development. Previously, fluorescent poly(p-phenylenevinylene) (PPV) nanoparticles in colloidal solution were reported to be used for sebaceous fingerprints development with an immersing method [34]. The same PPV colloidal solution was used for soaking the cotton pad and then developing sebaceous fingerprints. As seen from Fig. 10, the sebaceous latent fingerprints developed by the cotton pad and immersing methods had more legible fingerprint patterns compared with the patterns resulted from the smearing and spraying methods. Since the conditions for developing the sebaceous latent fingerprint were not optimized, the results were less ideal. These results were good enough to demonstrate that the cotton pad method would be applicable for sebaceous latent fingerprint development.

Fig. 8 Digital photographs and optical microscopic images of the Coomassie blue-soaked cotton pads with before the cotton pad was used for the 1st, 2nd, 3rd, 4th and 5th times (left and middle); and the corresponding development result of LBFPs on white enamel substrate (right)

Fig. 9 The representative photographs of the developed contaminative blood fingerprints on white ceramic by five dye solutions (Amido black 10B, Coomassie blue, TMB, eosin and acid fuchsin) under natural light

Fig. 10 The representative photographs of the developed sebaceous latent fingerprints on aluminum foil by four protocols (cotton pad, immersing, smearing and spraying) under natural light and 365 nm light

4 Conclusion

A new strategy for LBFPs development was demonstrated successful by employing the dye-soaked cotton pads. The conditions for preparing dye-soaked pad were optimized and generalized for scale-up. The LBFPs on three substrates were developed with five different dyes using the dye-soaked cotton pad and three other methods for comparison. The results showed that the dye-soaked cotton pad method was superior to the other three methods for fingermark detection and identification. The cotton pad method also showed other advantages, such as reusability, no need for post-treatment and applicability for developing fingerprints without blood. The protocol is feasible, cost-effective and has potential to be a viable blood fingerprint development technique for practical applications.

Acknowledgements The authors acknowledge the financial support from the Natural Science Foundation of the Jiangsu Higher Education Institutions of China (No. 18KJA430014), the Fundamental Research Funds for the Central Public-Service Research Institutes (No. 2018JB019) and the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study approved by College of Chemistry, Chemical Engineering and Materials Science, Soochow University Academic Committee.

Informed consent The authors are responsible to ensure that the health and privacy of the human subject have been protected in accordance with established ethical guidelines and declarations. The donor voluntarily agreed to take part in this study. The donor has received and read written informed consent. In addition, the donor understood all of the benefits and risks associated with the study, and signed the form.

References

1. Polson CJ (1950) Finger prints and finger printing: a historical study. *J Crim L Criminol* 41:495–517
2. Hale AR (1952) Morphogenesis of volar skin in the human fetus. *Am J Anat* 91:147–181. <https://doi.org/10.1002/aja.1000910105>
3. Lee HC, Gaensslen RE (2001) History and development of fingerprinting. *Advances in fingerprint technology*, 2nd edn. CRC Press, Boca Raton
4. Wang M, Li M, Yu A, Wu J, Mao C (2015) Rare earth fluorescent nanomaterials for enhanced development of latent fingerprints. *ACS Appl Mater Interfaces* 7:28110–28115. <https://doi.org/10.1021/acsami.5b09320>
5. Hazarika P, Russell DA (2012) Advances in fingerprint analysis. *Angew Chem Int Ed* 51:3524–3531. <https://doi.org/10.1002/anie.201104313>
6. Maloney MS, Housman DG, Gardner RM (2014) Evidence processing and documentation. *Crime scene investigation: procedural guide*. CRC Press, Boca Raton
7. Cadd S, Li B, Beveridge P, O'Hare WT, Campbell A, Islam M (2016) The non-contact detection and identification of blood

- stained fingerprints using visible wavelength reflectance hyperspectral imaging: part 1. *Sci Justice* 56:181–190. <https://doi.org/10.1016/j.scijus.2016.01.004>
8. Pereira JFQ, Silva CS, Vieira MJL, Pimentel MF, Braz A, Honorato RS (2017) Evaluation and identification of blood stains with handheld NIR spectrometer. *Microchem J* 133:561–566. <https://doi.org/10.1016/j.microc.2017.04.038>
  9. Bevel T, Gardner RM (2008) Bloodstain pattern analysis: its function and a historical perspective. Bloodstain pattern analysis with an introduction to crime scene reconstruction. CRC Press, Boca Raton
  10. James SH, Kish PE, Sutton TP (2005) Introduction to bloodstain pattern analysis. Principles of bloodstain pattern analysis: theory and practice. CRC Press, Boca Raton
  11. Fletcher C (2006) Crime scene processing. Real crime scene investigations: true-life experts reveal the evedevce behind their most challenging cases. St. Martin's Press, Chichester
  12. Bentolila A, Hartman I, Levin-Elad M (2017) Blood or not blood—that is the question. A non-destructive method for the detection of blood-contaminated fingerprints. *Forensic Sci Int* 278:374–378. <https://doi.org/10.1016/j.forsciint.2017.07.033>
  13. Bialek J, Brzozowski J, Lukasik A (2004) Comparison of the effectiveness of selected methods of contrasting of fingerprints in blood. *Probl Forensic Sci* LIX:50–65
  14. Geller B, Leifer A, Attias D, Mark Y (2018) Fingermarks in blood: mechanical models and the color of ridges. *Forensic Sci Int* 286:141–147. <https://doi.org/10.1016/j.forsciint.2018.03.008>
  15. Cadd S, Li B, Beveridge P, O'Hare WT, Campbell A, Islam MA (2016) A comparison of visible wavelength reflectance hyperspectral imaging and Acid Black 1 for the detection and identification of blood stained fingerprints. *Sci Justice* 56:247–255. <https://doi.org/10.1016/j.scijus.2015.12.007>
  16. Fox A, Gittos M, Harbison SA, Fleming R, Wivell R (2014) Exploring the recovery and detection of messenger RNA and DNA from enhanced fingerprints in blood. *Sci Justice* 54:192–198. <https://doi.org/10.1016/j.scijus.2014.01.001>
  17. Wang Z, Zhang P, Liu H, Zhao Z, Xiong L, He W et al (2019) Robust serum albumin-responsive AIEgen enables latent bloodstain visualization in high resolution and reliability for crime scene investigation. *ACS Appl Mater Interfaces* 11:17306–17312. <https://doi.org/10.1021/acsami.9b04269>
  18. Bossers LCAM, Roux C, Bell M, McDonagh AM (2011) Methods for the enhancement of fingerprints in blood. *Forensic Sci Int* 210:1–11. <https://doi.org/10.1016/j.forsciint.2011.04.006>
  19. Frégeau CJ, Germain O, Fournay RM (2000) Fingerprint enhancement revisited and the effects of blood enhancement chemicals on subsequent Profiler Plus™ fluorescent short tandem repeat DNA analysis of fresh and aged bloody fingerprints. *J Forensic Sci* 45:354–380
  20. Forsythe-Erman J (2001) A comparison of blood enhancement techniques. *Canad Soc Forensic Sci J* 34:159–165. <https://doi.org/10.1080/00085030.2001.10757525>
  21. Webb JL, Creamer JI, Quickenden TI (2006) A comparison of the presumptive luminol test for blood with four non-chemiluminescent forensic techniques. *Luminescence* 21:214–220. <https://doi.org/10.1002/bio.908>
  22. Hong S, Seo JY (2015) Chemical enhancement of fingermark in blood on thermal paper. *Forensic Sci Int* 257:379–384. <https://doi.org/10.1016/j.forsciint.2015.10.011>
  23. Barros HL, Mileski T (2017) Fluorescent benzazole dyes for blood-stain detection and bloody fingermark enhancement. *Forensic Chem* 5:16–25. <https://doi.org/10.1016/j.forc.2017.05.004>
  24. Munro M, Deacon P, Farrugia KJ (2014) A preliminary investigation into the use of alginates for the lifting and enhancement of fingerprints in blood. *Sci Justice* 54:185–191. <https://doi.org/10.1016/j.scijus.2013.11.002>
  25. Thomas P, Farrugia K (2013) An investigation into the enhancement of fingerprints in blood on paper with genipin and lawson. *Sci Justice* 53:315–320. <https://doi.org/10.1016/j.scijus.2013.04.006>
  26. Li BY, Zhang XL, Zhang LY, Wang TT, Li L, Wang CG et al (2016) NIR-responsive NaYF₄:Yb, Er, Gd fluorescent upconversion nanorods for the highly sensitive detection of blood fingerprints. *Dyes Pigments* 134:178–185. <https://doi.org/10.1016/j.dyepig.2016.07.014>
  27. Liu CM, Zhang LY, Li L, Li BY, Wang CG, Wang TT (2018) Specific detection of latent human blood fingerprints using antibody modified NaYF₄:Yb, Er, Gd fluorescent upconversion nanorods. *Dyes Pigments* 149:822–829. <https://doi.org/10.1016/j.dyepig.2017.11.050>
  28. Kaur J, Sodhi GS, Nath S (1996) The application of phase transfer catalysis to fingerprint detection. *Sci Justice* 36:267–269. [https://doi.org/10.1016/S1355-0306\(96\)72612-6](https://doi.org/10.1016/S1355-0306(96)72612-6)
  29. Langenburg G (2008) Deposition of bloody friction ridge impressions. *J Forensic Identification* 58:355–389
  30. Pawluk DTV, Howe RD (1999) Dynamic contact of the human fingerpad against a flat surface. *J Biomech Eng* 121:605–611. <https://doi.org/10.1115/1.2800860>
  31. Girod A, Ramotowski R, Weyermann C (2012) Composition of fingerprint residue: a qualitative and quantitative review. *Forensic Sci Int* 223:10–24. <https://doi.org/10.1016/j.forsciint.2012.05.018>
  32. Cadd S, Islam M, Manson P, Bleay S (2015) Fingerprint composition and aging: a literature review. *Sci Justice* 55:219–238. <https://doi.org/10.1016/j.scijus.2015.02.004>
  33. Farrugia KJ, Savage KA, Bandey H, Daéid NN (2011) Chemical enhancement of footwear impressions in blood on fabric—Part 1: protein stains. *Sci Justice* 51:99–109. <https://doi.org/10.1016/j.scijus.2010.11.001>
  34. Chen H, Ma RL, Chen Y, Fan LJ (2017) Fluorescence development of latent fingerprint with conjugated polymer nanoparticles in aqueous colloidal solution. *ACS Appl Mater Interfaces* 9:4908–4915. <https://doi.org/10.1021/acsami.6b15951>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.