Exploration of Methods for Revealing Latent Lip Prints on Disposable Paper Cups

Peng Li[1], Liangbing Liu[2], Yifeng Shao[3,*]
[1]*Department of Criminal Technology and Intelligence, Hubei University of Police, Wuhan, Hubei, China*
[2]*Criminal Investigation Division, Wuhan Public Security Bureau, Wuhan, Hubei, China*
[3]*Criminal Technology Unit, Criminal Investigation Brigade, Gaoming Branch of Foshan Public Security Bureau, Foshan, Guangdong, China*

Abstract: Lip prints, as biological traces left on the surface of objects through human contact, hold significant value in multiple fields. For instance, in criminal investigation applications, the position, morphology, and temporal persistence of lip marks can help infer a suspect's drinking behavior at the scene and their duration of stay, thereby playing an important role in reconstructing crime scenarios. Latent lip prints are often left on disposable paper cups at crime scenes. However, due to interference from hydrophobic cup coatings (polyethylene/wax) and the easy degradation of trace biological components, traditional detection methods (such as DNA analysis) face limitations including high cost and poor timeliness. Targeting these challenges, this study explores rapid lip-print development techniques suitable for disposable paper cups. Through both physical development and chemical staining approaches, it investigates the optimal detection method for revealing latent lip prints on disposable paper cups and proposes innovative solutions. Experimental results indicate that compared with powder development methods, the ninhydrin staining technique is more suitable for revealing latent lip prints on disposable paper cups. This study establishes a low-cost, easy-to-operate lip-print development system, provides new ideas for the extraction of trace biological evidence, and has practical significance in scenarios such as rapid on-site screening in criminal investigations.

Keywords: Biological Traces; Crime Scene; Disposable Paper Cup; Latent Lip Print; Rapid Development Techniques

1. Introduction

In crime scene investigation and forensic identification, biological traces (such as fingerprints, saliva, DNA, blood, lip prints, skin flakes, etc.) serve as key physical evidence for identifying suspects [1]. Advances in trace examination technologies have significantly improved the accuracy and efficiency of case solving, thereby driving progress in criminal science [2]. Lip prints fall under the domain of forensic odontology research, and some scholars have found distributional differences in lip patterns among ethnic groups and genders. As a type of contact biological trace, lip prints may carry exfoliated cells, saliva DNA, or cosmetic residues, giving them unique evidentiary value. Previous studies have shown that the line texture of human lips is unique, and its pattern distribution contains identifiable individual characteristics, similar to fingerprints, demonstrating high specificity [3]. Lip patterns consist of mucosal folds formed by wrinkles and grooves on the vermilion border, located between the inner lip mucosa and the skin. Lip prints are unique to each individual, thus revealing the potential of using lip patterns for suspect identification. In recent years, with the development of machine learning, deep learning, and various big-data models, automatic lip-print recognition technology has attracted increasing attention in livestock management and personal identification fields [4–7]. However, in current police crime-scene investigation work, lip prints are not sufficiently valued. In some investigations where other evidence is scarce, lip prints extracted from surfaces such as doors, cups, cigarettes, and windows may become crucial evidence for identifying or excluding suspects [8]. Disposable paper cups, commonly found in public places (e.g., conferences, hotels, crime scenes), may be used and discarded by suspects. If latent lip prints can be extracted

from such cups, they may provide associative evidence for identifying suspects. With the judicial system's increasingly strict requirements for maintaining the integrity of the chain of custody, studying rapid development techniques for latent lip prints on disposable paper cups is of substantial practical significance in forensic work.

2. Structural Materials of Disposable Paper Cups

Mainstream disposable paper cups currently circulating on the market typically consist of coated material on the inner side and pulp material on the outer side. The first type features an inner layer of polyethylene (PE) plastic film, generally 15–30 μm thick, uniformly applied to the inside of the cup through a hot-melt extrusion process. This prevents liquid penetration and enhances the cup's waterproof, oil-resistant, and sealing properties, while also providing leak-proofing, safety, and heat-resistant characteristics. The second type uses substances such as paraffin (or bio-based materials like PLA) to coat the inner wall of the cup with a layer of lipid-based polymer film, thereby achieving waterproof and oil-resistant effects and preventing liquid seepage [9].

3. Composition of Latent Lip Prints and Their Development Mechanisms

3.1 Composition of Latent Lip Prints

Common substances present on the surface of human lips include saliva, exfoliated skin residues, and cosmetic lip product residues, among which:

Saliva components: Water is the main constituent of saliva and may leave trace organic materials after evaporation; enzymes (such as amylase), which break down food, with extremely small residual amounts; electrolytes (sodium and potassium ions), such as inorganic salts in saliva.

Exfoliated skin residues: Keratinocytes, including tiny flakes shed from the lips; sebum, mainly natural oils secreted from the lip area.

Cosmetic residues: Waxes (such as beeswax, microcrystalline wax) commonly found in lipsticks or lip balms, providing solidity and gloss; oils (such as castor oil, mineral oil) used for moisturizing and potentially leaving oily traces; pigments or dyes, the coloring components of lipsticks (such as organic pigments or titanium dioxide); preservatives (such as phenoxyethanol) used to extend the shelf life of cosmetics.

3.2 Development Mechanisms of Latent Lip Prints

When the skin of the lips contacts a paper cup, physical adsorption and surface residue deposition occur, causing trace amounts of oils (sebum and wax/oil contained in lip balm), proteins (salivary enzymes, skin cells), and pigments (lipstick dyes) to adhere to the surface of the cup through physical adsorption or micro-permeation, thereby forming latent lip prints.

This study adopts powder brushing and chemical staining methods to develop latent lip prints on disposable paper cups. The principle of powder brushing development is to use powders that adsorb oils or water to enhance the visibility of traces; for example, magnetic powders can reveal slight oil contamination (similar to the powder-based fingerprint development technique) [10]. The chemical staining method relies on chemical reactions that cause specific components in the trace to undergo colorimetric changes, making the prints visible; for example, reacting with amino acids to form a purple complex (ninhydrin staining method) [11].

4. Experimental Preparation

4.1 Experimental Materials and Specimens

Ninhydrin spray (Beijing Huaxing Ruian Technology Co., Ltd.), ninhydrin fuming chamber (Beijing Brant Police Equipment Co., Ltd.), gold-colored magnetic fingerprint powder (Zhuhai Meiyin Technology Co., Ltd.), magnetic powder brush, polyethylene-coated disposable paper cups (Dongguan Jiale Paper Products), wax-coated disposable paper cups (Zhejiang Shuangfeng New Materials), disposable medical rubber gloves, stainless-steel pointed tweezers, Nikon D7100 DSLR camera, fully enclosed chemical-resistant goggles, disposable medical surgical masks.

4.2 Preparation of Latent Lip Print Samples on Disposable Paper Cups

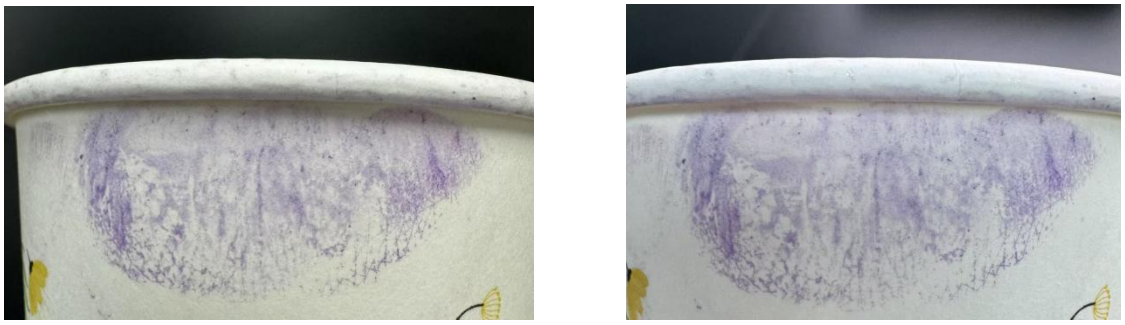
This experiment uses polyethylene-coated disposable paper cups and wax-coated disposable paper cups. Volunteers were instructed to wear disposable medical rubber gloves to avoid fingerprint contamination that

could interfere with development results. Volunteers then used the cups in a normal drinking manner, applying standardized lip pressure and controlling contact angle and lip moisture to form lip-print samples. The samples were then stored under controlled temperature and humidity conditions for 1 hour and 24 hours, respectively. In this way, two sets of latent lip-print samples were produced on disposable paper cups with trace retention times of 1 hour and 24 hours.

5. Experimental Results and Discussion

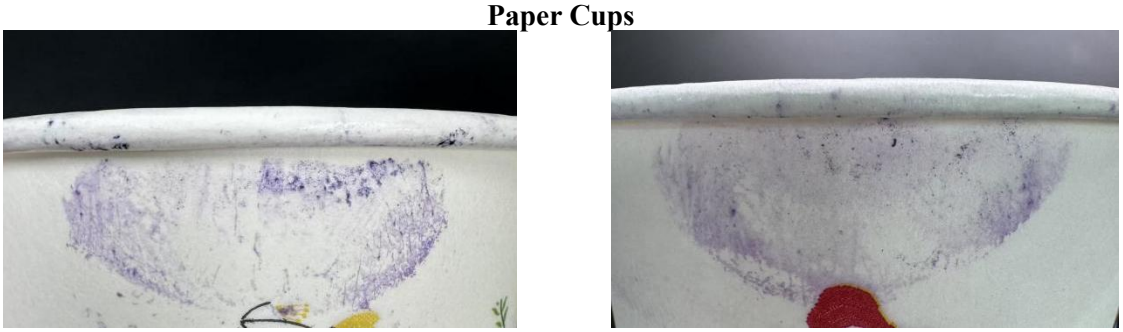
5.1 Development of Latent Lip Prints on Disposable Paper Cups Using the Ninhydrin Staining Method

Volunteers first wore disposable medical rubber gloves, protective goggles, and disposable medical masks to ensure anti-contamination and safety protection. The paper cup was placed on a clean surface with the lip-print area facing upward. Ninhydrin spray was applied evenly to the lip-print region from a distance of 10–15 cm until the surface was slightly moistened (avoiding excessive wetting that might damage the cup). The sprayed paper cup lip-print sample was then placed in a DFO/ninhydrin constant-temperature oven (80–100°C) and heated for 5–10 minutes to accelerate color development. After development, the lip-print region exhibited purple or blue-purple spots. The samples were observed under natural light and photographed using a camera. The ninhydrin staining results for polyethylene-coated disposable paper cups and wax-coated disposable paper cups, under different trace-retention times, are shown in Figure 1 and Figure 2.



(a) Retained for 1 hour (b) Retained for 24 hours

Figure 1. Ninhydrin Staining Results of lip-print Samples on Polyethylene-coated Disposable Paper Cups



(a) Retained for 1 hour (b) Retained for 24 hours

Figure 2. Ninhydrin Staining Results of Lip-print Samples on Wax-coated Disposable Paper Cups

5.2 Development of Latent Lip Prints on Disposable Paper Cups Using the Powder Brushing Method

Volunteers first wore disposable medical rubber gloves, protective goggles, and disposable medical masks to avoid contamination and prevent powder from entering the eyes and respiratory tract. Operations were conducted in a clean and wind-free environment to prevent powder dispersion. A magnetic fingerprint brush was dipped into a small amount of gold-colored magnetic fingerprint powder and gently shaken to ensure even powder coverage on the brush head. The magnetic fingerprint brush was then suspended 1–2 cm above the lip-print area on the paper cup surface, using magnetic force to allow the powder to roll across the surface. Emphasis was placed on developing the cup rim contact area. Gentle motions were used to avoid friction that could damage the trace. Lip prints (oil

residues, saliva residues) adsorbed the powder and gradually became visible. Excess powder was removed by lightly blowing on the surface or tilting the cup to allow the powder to fall off. Side lighting or ring lighting was used to enhance contrast before photographing and documenting the trace. The powder brushing results for polyethylene-coated and wax-coated disposable paper cups at different trace-retention times are shown in Figure 3 and Figure 4.

(a) Retained for 1 hour (b) Retained for 24 hours

Figure 3. Powder Brushing Results of Lip-print Samples on Polyethylene-coated Disposable Paper Cups

(a) Retained for 1 hour (b) Retained for 24 hours

Figure 4. Cyanoacrylate Fuming Results of Lip-print Samples on Wax-coated Disposable Paper Cups

5.3 Discussion of Experimental Results

Experimental results indicate that when using the ninhydrin staining method on polyethylene-coated disposable paper cups, the clarity, completeness, and contrast of latent lip prints—whether retained for 1 hour or 24 hours—were the highest. The developed latent lip prints were sufficiently clear for forensic identification purposes. In comparison, the clarity and completeness of lip prints developed on wax-coated disposable paper cups were slightly lower than those on polyethylene-coated cups, though the revealed lip prints were still generally adequate for evidentiary examination. When using the powder brushing method, regardless of whether the lip-print samples had been retained for 1 hour or 24 hours, the development results showed minimal difference between polyethylene-coated and wax-coated cups, indicating that trace-retention time had little impact on this method. The lip prints developed on polyethylene-coated cups exhibited better completeness, while those on wax-coated cups showed higher clarity. However, the overall effectiveness of the powder brushing method was slightly lower than that of the ninhydrin staining method. Even so, the lip prints developed on both types of disposable paper cups using the powder brushing method were still generally suitable for forensic identification.

6. Experimental Conclusion

This study investigated the applicability of various methods for developing latent lip prints on disposable paper cups. By comparing the ninhydrin staining method and the powder brushing method, the effectiveness of each technique in visualizing latent lip prints on cups with different trace-retention durations was evaluated. The experimental results demonstrate that the ninhydrin staining method provides clearer and more effective visualization of latent lip prints on disposable paper cups, making it suitable for trace biological evidence detection in forensic science.

However, the study also found that factors such

as lip-print retention time, environmental temperature and humidity, and cup coating material significantly influence development effectiveness. Particularly, wax-coated disposable paper cups may reduce reagent penetration efficiency. Future research could focus on optimizing probe-molecule specificity, developing dual-modality development techniques (e.g., optical + chemical simultaneous imaging), and integrating artificial intelligence for assisted lip-print comparison to enhance practical application value in casework.

The findings of this study provide a feasible approach for the extraction and identification of latent biological traces on disposable paper cups. Nevertheless, further verification under actual crime-scene conditions is necessary to assess stability and reliability, thereby promoting standardized application within forensic science.

Funding Project

Supported by the Scientific Research Project of Hubei University of Police (HJ2024QN08).

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