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Investigative Frontiers Integration of Science Transforming Criminal Investigation

Year: 2026

Hidden in Plain Sight: Cosmetic Products as Trace Evidence in Criminal Investigation

Ms. Aanchal Kapoor[1]

[1]*Assistant Professor School of Basic and Applied Sciences MGM University, Chattrapati Sambhajinagar, Maharashtra*

Abstract

The use of cosmetic products in forensic investigations is increasingly acknowledged and valued because of their ubiquity, chemical complexity, and potential to transfer between people, objects and environments. The present review highlights the forensic aspects of cosmetics, covering their classification, chemical composition, and transfer mechanisms, as per Locard's Exchange Principle. It also identifies and emphasizes the standardized methods used to collect, preserve, and laboratory analyze cosmetic residue to provide evidence for evidential integrity. The review presents the main analytical methods used for cosmetic characterization, such as spectroscopic, chromatographic, microscopic and elemental methods; these methods allow a reliable discrimination of cosmetic formulations. Furthermore, the importance of cosmetic traces as evidence and forensic value in homicide, sexual assault, burglary and other crime scenes are explained with particular focus on the corroborative and crime scene reconstruction aspects. Finally, the current challenges in interpretation of cosmetic evidence and new technologies, including high-resolution mass spectrometry, hyperspectral imaging, chemometrics and artificial intelligence are discussed. These improvements will make cosmetic trace evidence more reliable, sensitive, and acceptable to the courts, and solidify its value in the modern forensic setting.

[1] ISBN No.- 978-93-7640-081-2

Ms. Aanchal Kapoor

Keywords; Cosmetic trace evidence; Forensic cosmetics; Criminal investigation; Analytical characterization; Trace evidence analysis

1 Introduction

Cosmetic product means any substance or formulation used to apply to the external parts of the human body, such as the skin, hair, nails, lips and teeth, for the purpose of cleaning, beautifying, protecting or changing their appearance. Some common applications are lipstick, face powder, foundation, nail polish, hair care, moisturizers, perfumes, eye liners and mascara. Each such formulation has a different chemical and physical composition and includes a variety of pigments, waxes, oils, polymers, fragrances, preservatives, fillers and inorganic compounds. Due to their use in everyday life, and the variety of ingredients used, cosmetics are becoming a more significant source of trace evidence.[2]

Trace evidence are minute materials that are transferred from person, object, or environment during physical contact as per Locard's Exchange Principle. Cosmetic residues are easily transferred onto clothing, skin, drinking vessels, cigarette butts, documents, glass surfaces, furniture, vehicle interiors, and weapons, and sometimes go undetected because of their microscopic size. These marks are often ignored in crime scene investigations, but can be important in associating a suspect, victim and crime scene. The persistence, transferability and discriminatory ability to differentiate their products using state-of-the-art analysis methods are all factors that give cosmetic traces their evidential significance.[3]

With the development of instrumental techniques and analytical chemistry, the forensic significance of cosmetics has increased greatly. ATR-FTIR spectroscopy, Raman spectroscopy, gas chromatography–mass spectrometry (GC–MS), liquid chromatography–mass spectrometry (LC–MS), scanning electron microscopy and chemometric analysis are modern techniques that allow the rapid, sensitive and non-destructive characterization of cosmetic residues.[4] These

[2] M. Surya and S. Gunasekaran, "A Review on Recent Scenario of Cosmetics," Int. J. Pharm. Sci. Rev. Res., vol. 68, no. 1, pp. 190–197, 2021, doi: 10.47583/ijpsrr.2021.v68i01.030.

[3] T. Trejos, S. Koch, and A. Mehltretter, "Scientific foundations and current state of trace evidence—A review," Forensic Chem., vol. 18, p. 100223, 2020, doi: https://doi.org/10.1016/j.forc.2020.100223.

[4] S. Sharma, R. Chophi, H. Kaur, and R. Singh, "Differentiation of Cosmetic Foundation Creams Using Attenuated Total Reflection Fourier-Transform Infrared Spectroscopy: A Rapid and NonDestructive Approach in Trace Evidence Analysis," J. Forensic Sci., vol. 65, Dec. 2019, doi: 10.1111/1556-4029.14257.

methods do not only allow for the discrimination of the various brands, shades and formulations; they also enhance the evidential value of cosmetic traces in criminal investigations. As a result, cosmetic products have come to be seen as a relatively new field of trace evidence that can be used in conjunction with the traditional forensic evidence, as part of crime reconstruction and as scientific support for investigative and judicial procedures.

2 Cosmetic Products as Forensic Trace Evidence: Sources, Composition, and Transfer Mechanisms

Cosmetic products are a very broad class of trace evidence that may provide an associative tie between persons, objects, and crime scenes. They are both frequently used and have complex chemical constituents and can transfer and remain on a variety of surfaces after physical contact, making their forensic significance obvious. Cosmetic residues are often found on clothing, skin, glassware, cigarette butts, personal property, vehicles, or objects in an assault, homicide, sexual crime, burglary, hit-and-run case, and can be found on a variety of surfaces. The mixture of organic and inorganic elements in each cosmetic product creates a unique chemical "fingerprint" which can be analyzed using modern techniques. This knowledge of the type of cosmetic, the composition of cosmetics and the mechanism of transfer is therefore essential for the correct interpretation of evidence and source attribution.

A. Classification of Cosmetic Products Encountered in Forensic Investigations

Cosmetic residues found at crime scenes come from a wide variety of cosmetics and personal care items. Lipsticks, foundations, face powders, blushes, eyeliner, mascara, eye shadow, nail polishes and documents are among the most common cosmetics encountered, as these can readily come into contact with skin, fabrics, glass, cigarette filters, cups and documents during normal use. Other personal care items include personal objects, deodorant, perfume, moisturising cream, lotions and sunscreens, which contain valuable trace evidence as residue on clothing, furniture, vehicle interiors, etc. Moreover, cosmetics with the glitter or shimmer effect, which are made with reflective metallic or mineral particles, have special micro properties which allow for easy identification and comparison. These cosmetic products are all very diverse, which adds to the evidential value that they are all different in colour, texture, ingredients and manufacturing.

B. Chemical Composition of Cosmetic Products

The chemical composition of cosmetics is a key aspect of the forensic determination of cosmetics. Pigments are used to impart colour to most cosmetic formulations, waxes and oils are used to improve texture and adhesion, polymers are used to impart durability and film formation

and preservatives are used to inhibit microbial growth and prolong shelf life. Fragrances are composed of a complex and complex blend of VOCs and may be chemically profiled, and fillers like talc, silica, kaolin, calcium carbonate and titanium dioxide help to increase consistency and coverage. Numerous high quality cosmetics also use metallic or pearlescent ingredients, such as mica, iron oxides, aluminium flakes, and titanium dioxide-coated pigments, which create glittery effects and have their own elemental properties. The relative amounts of these ingredients vary from manufacturer, brand and shade to shade and give different physicochemical profiles, which can be distinguished by spectroscopic, chromatographic, microscopic and elemental analysis.[5]

C. Primary and Secondary Transfer Mechanisms

The evidential value of cosmetic products is closely related with their transfer characteristics, based on the Locard's Exchange Principle. Primary transfer is the transfer from one person to another through direct contact, such as lipstick transferred from one person to another person or onto a surface such as a drinking glass, foundation placed on the skin of another person's body or clothing, or nail polish fragments that were picked up by a victim during an altercation. Secondary transfer of cosmetics residues happens when the initial contaminated surface comes in contact with another object or person, leading to further evidence that can be used to reconstruct sequences of contact events. The amounts and duration of transferred materials is dependent on a number of factors such as formulation of the cosmetic, type of receiving surface, environmental factors, pressure and duration of contact, friction, and post-transfer activities (e.g., washing and abrasion).Careful interpretation of these transfer mechanisms enables forensic scientists to evaluate the significance of cosmetic traces while minimizing the risk of misinterpretation or contamination.[6]

3 Collection, Preservation, and Laboratory Examination of Cosmetic Evidence

The forensic utility of cosmetic products is not only due to the successful detection of the product, but also to the correct collection, preservation, and laboratory analysis. Tracing cosmetic residues is usually difficult due to being microscopic, fragile, and easily contaminated and/or degraded. Standardized forensic procedures are designed to guarantee that cosmetic

[5] S. Turkay and S. Kizil, "Forensic examination of lipsticks as trace evidence under different environmental conditions," Turkish J. Eng., vol. 8, no. 2, pp. 353–369, 2024, doi: https://doi.org/10.31127/tuje.1363676.

[6] L. Li, J. Wang, L. Ke, N. Wei, H. Wang, and G. Wang, "Progress in the Application of Raman Spectroscopy to Cosmetic Analysis: From Component Detection to Transdermal Mechanism Research," Cosmetics, vol. 13, no. 79, 2026, doi: https://doi.org/10.3390/cosmetics13020079.

residues have not changed their physical and chemical properties during the investigation, increasing the credibility and use of analytical data in court.

1. Collection of Cosmetic Evidence

The collection of cosmetic evidence starts with a careful examination of the scene of the crime to look for visible and latent cosmetic evidence. Lipstick smears, stains in foundation, face powder build-up, nail polish particles, glitter and perfume can be recovered from clothing, skin, drinking vessels, cigarette butts, glass surfaces, furniture, vehicles, or weapons. Investigators use sterile cotton swabs, adhesive lifting tapes, forceps, scalpels or vacuum collection devices to collect the evidence in a way that does not change its makeup based on the type of substrate. Photographic documentation and detailed recording of location, appearance and condition of cosmetic traces is conducted prior to collection to preserve the context and chain of custody.[7]

2. Preservation of Cosmetic Evidence

It is crucial that cosmetics remain uncontaminated, undamaged and not chemically altered during preservation. Each individual sample is placed in a clean, unbreakable container like a glass vial, paper envelope, or sterile evidence bag depending upon the physical condition of the sample. High temperatures, humidity or direct sunlight, and volatile chemicals are limited because they can change the pigments, fragrances, and other chemicals. By following the chain of custody with meticulous care, from correct labeling, sealing, to documentation, the evidence's integrity and admissibility in court are guaranteed during storage and transportation.[8]

3. Laboratory Examination of Cosmetic Evidence

The objective of laboratory examination is to identify and/or compare unknown (questioned) cosmetic samples with the known (reference) material by using complementary analytical methods. The initial assessment is usually based upon visual inspection and stereomicroscopy to assess colour, morphology, texture and particle characteristics. The instrumental analysis methods used include Fouriertransform infrared spectroscopy (FTIR), Raman, gas chromatography–mass spectrometry (GC–MS), liquid chromatography–mass spectrometry (LC–MS), scanning electron microscopy–energy dispersive Xray spectrometry (SEM–EDS),

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[7] A. Singh, A. Verma, P. Kumar, P. Chandra, P. Varshney, and H. Sharma, "Evidence-Based Cosmetic Skincare: Ingredients, Technology, and Efficacy," pp. 1–11, Nov. 2025, doi: 10.2174/0113892010394463251113145927.

[8] R. Chophi et al., "Trends in the forensic analysis of cosmetic evidence," Forensic Chem., 2019, doi: https://doi.org/10.1016/j.forc.2019.100165.

and inductively coupled plasma–mass spectrometry (ICP–MS) for the identification of organic compounds, inorganic pigments, fragrances, polymers and elemental constituents. These analytical findings allow forensic scientists to distinguish between cosmetic products, correlate recovered residues to products, brands and/or crime scenes and draw sound scientific conclusions between a suspect, a victim and a crime scene with a high degree of certainty.[9]

4 Analytical Techniques for Identification and Characterization of Cosmetic Products

Forensic analysis of cosmetics must use analytical methods that allow for the precise identification of the complex chemical composition found in cosmetics, and be able to distinguish between cosmetics that appear similar. Cosmetics are composed of mixtures of organic and inorganic compounds such as pigments, waxes, oils, polymers, fragrances, preservatives, fillers, and metallic particles, which requires multiple methods of analysis to be used rather than one. In modern forensic laboratories, spectroscopic, chromatographic, microscopic, and elemental analyses are used to characterize the cosmetic residues found on crime scenes. Analytical results are interpreted together to make comparisons between questioned and known samples, to note common characteristic chemical markers, and to provide a high scientific level of association between suspects, victims and crime scenes.[10]

Important analytical techniques include:

i. **Stereomicroscopy and Polarized Light Microscopy (PLM):** Used for the preliminary examination of cosmetic traces to assess colour, particle morphology, surface texture, crystal characteristics, and glitter or pigment distribution without damaging the sample.
ii. **Fourier Transform Infrared Spectroscopy (FTIR) and ATR-FTIR:** Recognize functional groups and organic components of waxes, oils, polymers, and binders. These methods can be used for many cosmetic products and are quick, non-destructive and widely used for product comparisons.
iii. **Raman Spectroscopy:** Gives molecular fingerprints of pigments, dyes and inorganic fillers, using minimal sample preparation. It is especially useful for the analysis of colored cosmetic residues and the microscopic particles.

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[9] A. Mancuso, N. Avanzo, M. C. Cristiano, and D. Paolino, “Reflectance spectroscopy: a non-invasive strategy to explore skin reactions to topical products,” Front. Chem., 2024, doi: 10.3389/fchem.2024.1422616.

[10] J. Mcewan, K. A. Bruce, K. Pitts, and G. Sauzier, “A multi-modal spectroscopic approach to forensic discrimination of liquid cosmetic complexion products,” Forensic Chem., vol. 45, p. 100677, 2025, doi: 10.1016/j.forc.2025.100677.

iv. **Gas Chromatography–Mass Spectrometry (GC–MS):** Identifies and detects Volatile and Semi-Volatile compounds, including fragrances, essential oils, preservatives and other organic ingredients for detailed chemical profiling.

v. **Liquid Chromatography–Mass Spectrometry (LC–MS):** It can be used for the analysis of non-volatile and thermally unstable compounds such as synthetic dyes, UV filters, preservatives, and complex organic additives found in cosmetic products.

vi. **Scanning Electron Microscopy with Energy-Dispersive X-ray Spectroscopy (SEM–EDS):** Analyzes surface morphology and at the same time identifies the elemental constituents of pigments, metallic particles, fillers and glitter constituents.

vii. **Inductively Coupled Plasma–Mass Spectrometry (ICP–MS):** Provides extremely sensitive elemental analysis, allowing discrimination of cosmetics by trace metals and inorganic elemental signatures.

viii. **Chemometric and Multivariate Statistical Analysis:** Combines spectral and chromatographic data to increase the objectivity and reliability of the discrimination, classification and source attribution of cosmetic products by means of statistical models like principal component analysis (PCA) and hierarchical cluster analysis (HCA).

5 Evidential Value and Forensic Applications of Cosmetic Products in Criminal Investigations

Cosmetic products have great evidential value as they can provide associative links between crime scenes, objects, victims and suspects. While cosmetic evidence usually does not give specific identification alone it may be useful as class evidence to help determine the identity of the person who used it in combination with DNA, fingerprints, fibres and other trace materials. The wide range of cosmetic formulations, coupled with the development of forensic analytical methodologies, has greatly improved the capability of cosmetic residue characterization and assessment of its forensic relevance. As a result, cosmetic evidence is an important type of trace evidence in the investigative and judicial process.

A. Associative Evidence and Crime Scene Reconstruction

Cosmetic residues can be important physical contact evidence and in certain cases, they may be essential to the reconstruction of a crime scene. Lipstick on drinking glasses, cigarette butts, clothing or skin may show that a particular person has been near a victim, and smears of foundation, face powder and cream on the victim may show direct contact. Fragments of nail polish found on broken fingernails or around a victim's hands or feet could be a sign of defensive movements in violent interactions. Combined with transfer patterns and persistence characteristics, these traces can help forensic scientists in determining where interaction

occurred and reconstructing contact events and corroborating witness testimony or investigative hypotheses.[11]

B. Applications in Criminal Investigations

Cosmetic evidence has been observed in cases of homicide, sexual assault, domestic violence, burglary, robbery, kidnapping and hit-and-run. In sexual assault cases, transference of cosmetic residue between the victim and the suspect can be used as associative evidence to infer that they have had physical contact. In homicide cases, lipstick, perfume or cosmetic remnants found on victims' clothing, weapons, or personal effects may link people to a crime scene. As with other examples, glitter particles from cosmetics and hair-care products can be removed and transferred to vehicles, furniture, or other items and used in a forensic comparison. These findings are more significant if they are recovered and analysed as a group, where multiple cosmetic traces have been identified.[12]

C. Integration with Complementary Forensic Evidence

The most useful forensic information that can be obtained from cosmetic products is when examined with other physical items. Spectroscopic, chromatographic, microscopic and elemental analysis of cosmetic formulations are advanced analytical methods that can be used to make detailed comparisons and help to further connect questioned and reference samples. The cosmetic evidence along with other evidences, such as DNA profile, fingerprint, fibre analysis, and digital reconstruction of the crime scene, helps to provide a complete picture of the criminal event. This multi-disciplinary approach can yield more reliable forensic findings, aid investigative decision making and increase the overall scientific defensibility of the forensic evidence presented in court.[13]

6 Current Challenges, Emerging Technologies, and Future Perspectives

Although the forensic science of cosmetic products has progressed significantly due to the development of sophisticated analytical techniques, several limitations remain in the

[11] S. Gherghel, R. M. Morgan, C. S. Blackman, K. Karu, and I. P. Parkin, “Analysis of transferred fragrance and its forensic implications,” Sci. Justice, 2016, doi: http://dx.doi.org/ 10.1016/j.scijus.2016.08.004.

[12] F. Rico et al., “Meta-Analysis and Analytical Methods in Cosmetics Formulation: A Review,” cosmetics, vol. 11, no. 1, 2024, doi: https://doi.org/10.3390/ cosmetics11010001.

[13] V. S. Angel, R. Saby, J. Joy, and N. Katare, “Forensic Examination of Lip Cosmetic-A Critical Review,” J. Nov. Res. Innov. Dev., vol. 3, no. 2, pp. 56–70, 2025.

interpretation of cosmetic trace evidence in both scientific and practical aspects. Meanwhile, novel technologies are enhancing the sensitivity, accuracy, and discriminatory ability of forensic analyses. Further studies and the establishment of uniform methodology are needed to fully utilize the information potential of cosmetic products in criminal investigations.[14]

A. Current Challenges

The major problem in forensic cosmetic analysis is the vast range and frequent change in commercial cosmetic formulations. It is difficult to create complete reference databases for comparison because the compositions of ingredients, pigments, fragrances, and additives are often changed by manufacturers. Chemical properties after deposition can also be affected by environmental degradation processes such as heat, UV radiation, moisture, washing, and abrasion on the cosmetic residues. Furthermore, small amounts collected from a crime scene may also be contaminated with biological substances, fibres, dust or other substances, which can make analytical interpretation difficult. Yet another drawback is that there are no universally standardized protocols for the collection, preservation, analysis and interpretation of cosmetic evidence within forensic laboratories, which could impact the reproducibility and inter-laboratory consistency.

B. Emerging Technologies

The use of recent advances in analytical science are improving the forensic characterisation of cosmetic products. High-resolution mass spectrometry, hyperspectral imaging, surface-enhanced Raman spectroscopy (SERS) and ambient ionization mass spectrometry (AMIS) offer higher sensitivity and allow the analysis of very small cosmetic residues with minimal sample preparation. This combination of chemometric techniques and machine learning has enhanced the classification and discrimination of cosmetic formulations, enabling the analysis of complex spectral and chromatographic data. Additionally, mobile spectroscopic equipment is becoming more widely used to conduct rapid, non-destructive cosmetic residue screening at crime scenes to aid in the timely forensic decision-making without loss of integrity of the evidence.[15]

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[14] M. Celeiro, C. Garcia-jares, M. Llompart, and M. Lores, "Recent Advances in Sample Preparation for Cosmetics and Personal Care Products Analysis," Molecules, vol. 26, no. 4900, 2021, doi: https://doi.org/10.3390/molecules26164900.

[15] H. Alsaeed, M. Amin, and E. Al-Hetlani, "Forensic analysis of cosmetic smudges using surface-assisted laser desorption/ionization mass spectrometry: recovery and ageing study," Microchem. J., vol. 180, p. 107609, May 2022, doi: 10.1016/j.microc.2022.107609.

C. Future Perspectives

In the future, standardisation of international protocols for the handling of cosmetics evidence, analytical standards and detailed databases should be developed including the physicochemical features of cosmetic products that have been commercially made. The use of artificial intelligence, the automated interpretation of spectra and multimodal analysis systems is anticipated to enhance source attribution and minimise subjective interpretation. Forensic scientists, analytical chemists, cosmetic producers, and regulatory bodies will work together to further build the validation and transfer of methods. Improvements in these aspects will increase the scientific validity, repeatability and court admissibility of cosmetic trace evidence and will make cosmetic products a more valuable tool in modern forensic investigations.[16]

7 Conclusion

Cosmetic products are a significant, but often neglected, type of forensic trace evidence that can be used to help form association links between suspects, victims, and crime scenes. When analyzed with scientifically proven methods, they are valuable sources of information for reconstructing criminal events for their unique chemical composition, variety of formulations, and transfer properties. Improvements in spectroscopic, chromatographic, micro and elemental analytical techniques have greatly improved the identification and discrimination of cosmetic residues, and increased their evidential value. The collection, preservation and laboratory examination are still vitally important to securing evidence integrity and a reliable forensic interpretation. Product variability, environmental degradation, pollution and the lack of uniformity of analytical procedures are persistently affecting forensic applications, but there are technological advances that address most of these problems. High-resolution analytical instrumentation, chemometric analysis, machine learning, and portable forensic devices are some new methods that have emerged as options for enhanced sensitivity, objectivity and efficiency. Standardized methodologies, comprehensive cosmetic databases and interdisciplinary collaboration should be the focus for future research to facilitate consistency amongst forensic laboratories. Cosmetic products will become ever more important in future investigations and the scientific analysis of trace evidence as analytical tools continue to improve.

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[16] K. A. Bruce, S. W. Lewis, and D. C. Arnold, “Considerations and future perspectives for the vibrational spectroscopic analysis of forensic cosmetic evidence,” WIREs Forensic Sci., vol. 6, pp. 1–15, 2024, doi: https://doi.org/10.1002/wfs2.1533.

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[13] M. Celeiro, C. Garcia-jares, M. Llompart, and M. Lores, “Recent Advances in Sample Preparation for Cosmetics and Personal Care Products Analysis,” Molecules, vol. 26, no. 4900, 2021, doi: https://doi.org/10.3390/molecules26164900.

[14] H. Alsaeed, M. Amin, and E. Al-Hetlani, “Forensic analysis of cosmetic smudges using surface-assisted laser desorption/ionization mass spectrometry: recovery and ageing study,” Microchem. J., vol. 180, p. 107609, May 2022, doi: 10.1016/j.microc.2022.107609.

[15] K. A. Bruce, S. W. Lewis, and D. C. Arnold, “Considerations and future perspectives for the vibrational spectroscopic analysis of forensic cosmetic evidence,” WIREs Forensic Sci., vol. 6, pp. 1–15, 2024, doi: https://doi.org/10.1002/wfs2.1533.