P- ISSN 1991-8941 E-ISSN 2706-6703 Journal of University of Anbar for Pure Science (JUAPS) Open Access
2024,(18), (01):190 – 196

Exploring Spectroscopic Techniques in the Forensic Examination of Synthetic Textile Fibers

Raghda Alsayed [1], Russel Altahan[2], Mohammed Al-Mashhadani[1], Hawraa Hazim[1], Mohammed Kadhom[3], Dheaa Zageer[4], Omar Al-Obaidi[5], Rahimi Yusop[6], Seenar Hameed[1], Emad Yousif[1]*

[1] Department of Chemistry, College of Science, Al-Nahrain University, Baghdad, Iraq
[2] Department of Chemistry, College of Science, University of Baghdad, Baghdad, Iraq
[3] Department of Environmental Science, College of Energy and Environmental Science, Alkarkh University of Science, Baghdad, Iraq
[4] Forensic DNA Center for Research and Training, College of Science, Al-Nahrain University, Baghdad, Iraq
[5] Department of Chemistry, College of Sciences, University of Anbar, Iraq
[6] Department of Chemical Sciences, Faculty of Science and Technology, University Kebangsaan Malaysia, Bangi, Selangor, Malaysia.

A R T I C L E I N F O

Received: 26 / 11 /2023
Accepted: 28 / 01 / 2024
Available online: 19 / 06 / 2024

DOI: 10.37652/juaps.2024.144921.1166

Keywords:
Forensic science, Fiber analyses, Microspectroscopy identification, DNA,. Spectroscopic Techniques, Forensic Examination, Synthetic Textile Fibers

A B S T R A C T

Forensic medicine, an essential discipline in criminal investigations, meticulously examines evidence to exonerate individuals under suspicion. Fiber analysis, widely recognized within forensic science, plays a crucial role in this process. Despite its intricate nature, fiber analysis lacks the reliability of DNA analysis as a primary tool for perpetrator identification. This paper explores the practical application of fiber analysis in real-life scenarios, outlining a systematic approach. It begins with the identification of available fiber types, followed by a description of diverse identification methods and optimal timing for implementation. The report includes Microspectroscopy identification, rigorous comparison controls, and various sample analyses. While microscopic and instrumental analyses reveal the intrinsic composition of fibers, coloration scrutiny adds specificity, especially for fibers like cotton or wool. Challenges in forensic fiber analysis include minute sample sizes, a preference for non-destructive techniques, and complexities associated with modern dye formulations. Despite these challenges, forensic fiber analysis remains a valuable component in criminal investigations, contributing to the comprehensive understanding of evidence derived from crime scenes.

Introduction

In the intricate web of forensic investigations, trace evidence emerges as a critical nexus, comprising micro-level elements that traverse the boundaries of individuals, locations, and objects. The primary purpose of utilizing trace evidence is to establish crucial links between suspects, victims, and crime scenes. This expansive category encapsulates a rich variety of materials, spanning from fibers, paint, and glass to gunshot residue, soil, and a myriad of other elements [1, 2].

*Corresponding author at: Department of Chemistry, College of Science, Al-Nahrain University, Baghdad, Iraq
ORCID:https://orcid.org/0000-0003-1458-4724;Tel:+9647705839300
E-mail address: emad_yousif@hotmail.com

At the foundational fabric of textile composition lies the elemental entity—the fiber. This essential component finds itself categorized into two overarching classifications: natural and man-made fibers. Natural fibers encompass cellulose-based fibers derived from the seeds, stems, and leaves of plants, protein-based fibers sourced from animal hair, wool, or silk, and mineral-based fibers with asbestos, the sole naturally occurring mineral fiber, now banned in many countries. In contrast, man-made fibers are bifurcated into three classes: regenerated fibers, born from naturally occurring fiber-forming polymers like viscose from cellulose; synthetic fibers, birthed from non-renewable sources like polyester; and inorganic fibers, originating from inorganic materials such as carbon and glass [3, 4].

The identification of fibers stands as a linchpin in forensic analysis, with most fibers composed of polymers expansive molecules containing numerous repeating atomic units. Distinct types of fibers exhibit substantial variations in both physical and chemical properties [5]. Microscopic Appearance: Fibers showcase a panoply of appearances, ranging from smooth textures to those adorned with longitudinal striations or cross patterns. Morphologies may span rod-like to ribbon-like, with synthetic fibers often exhibiting inherent luster. Manufacturers, cognizant of consumer preferences, frequently introduce chemicals or pigments to augment the non-glossy aesthetic [6].
Staining: The divergent reactions of fibers to various stains emerge as an invaluable tool for identification. Variances in the chemical nature of fibers result in distinct reactions, facilitating the differentiation of fiber types [7].

Burning Characteristics: The response of different fibers to flame presents a spectrum of behaviors, with some melting, contracting, or curling under the influence of heat. The combustion dynamics, including speed, persistence, and post-flame characteristics such as pungent smells and residue appearance, contribute significantly to the identification process [8]. Fiber examination methods encompass a dichotomy of destructive and non-destructive approaches, contingent upon the extent of damage incurred during analysis. The amalgamation of chromatographic methods with mass spectrometers emerges as a sophisticated yet destructive technique. Chromatographic techniques, classified based on mobile phase characteristics, include Liquid Chromatography (LC) and Gas Chromatography (GC). LC–MS, a pervasive method, facilitates the separation and identification of dye components in trace fibers. Conversely, pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS) deploys thermal energy to dismantle chemical bonds, revealing molecular fragments and unraveling the composition of the fiber itself [9, 10].

Spectroscopic techniques, such as Raman spectroscopy, Fourier transform infrared spectroscopy (FT-IR), and X-ray fluorescence spectroscopy (XRF), stand as instrumental aides in fiber analysis. Chromatographic methodologies, exemplified by Thin Layer Chromatography (TLC) or High-Performance Liquid Chromatography (HPLC), further augment the expansive toolkit available for comprehensive fiber examination [11]. This intricate and multifaceted approach underscores the dynamic evolution and heightened sophistication within the domain of forensic science, particularly in navigating the complexities entwined with unraveling trace evidence. The aim of this work is to investigate and elucidate the application of spectroscopic techniques in the forensic analysis of synthetic textile fibers, with a focus on advancing our understanding of their unique spectral signatures for enhanced forensic examination and evidence interpretation.

Materials and Methods

- **Microscopic Fiber Identification**

An evaluation of the feasibility of differentiating various fibers was conducted using the equipment available in the University of Nahrain's laboratory a Meiji Techno microscope in Tokyo, Japan. In a ZEISS Microscopy, Germany microscope, specifically employing common fabrics found in the local market cotton, polyester, silk, and fur. The experiment aimed to ascertain the practicability of fiber identification solely through microscopic analysis. The appropriate degree of magnification selected for this study was = 40 μm.

- **Infrared Microspectroscopy**

The Infrared Microspectroscopy analysis was performed utilizing the equipment situated in the DNA Center Labs at Al Nahrain University. Four distinct fibers—cotton, silk, fur, and polyester—were subjected to scrutiny, along with two conditions for one fiber, namely molten cotton and preserved cotton. The objective was to validate the capability of Infrared Microspectroscopy in distinguishing between different fibers and ensuring that variations in fiber conditions do not impede accurate recognition.

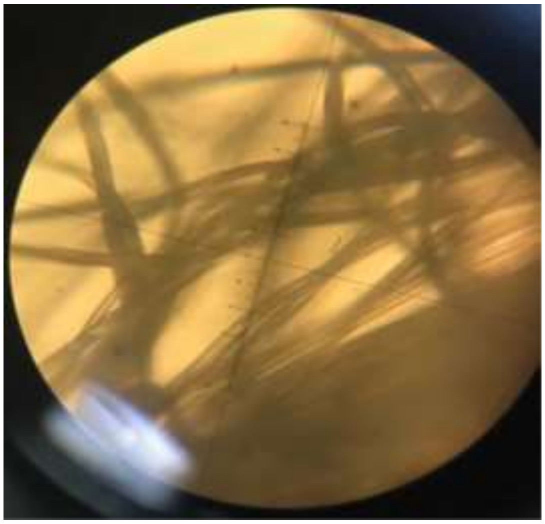
The laboratory tests undertaken for this paper served the dual purpose of affirming the viability of fiber analysis using the available tools and demonstrating the potential for visual differentiation among fibers. Furthermore, the study illustrated that Infrared (IR) analysis contributes to the discrimination between various fibers and variations of similar fibers.

The selected fabrics for this demonstration included silk, fur, cotton, and polyester, with an additional exploration of two states of cotton—molten and preserved—offering a comprehensive assessment of the analytical capabilities.

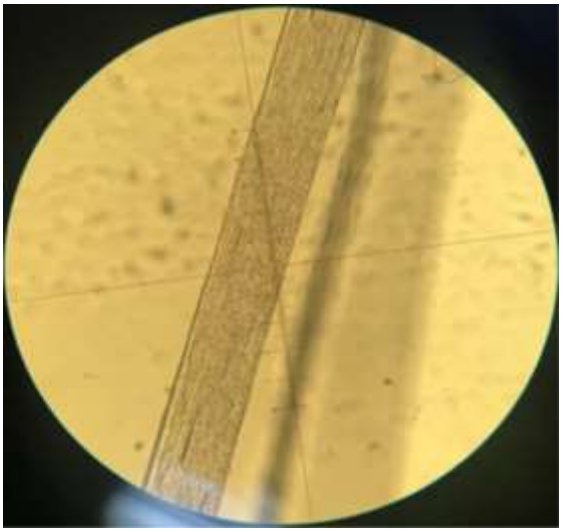
Results and discussion

In the domain of forensic analysis, a profound understanding of the fundamental concepts, strengths, and, notably, the limitations of analytical techniques is paramount for forensic analysts. This comprehension is pivotal not only for the judicious utilization of these techniques within a forensic analytical framework but also for drawing accurate conclusions from the results, elevating them to the status of credible evidence. The chemical nature of fibers, as observed by microscopists or analyzed through microspectrophotometry (MSP), provides critical information, as depicted in Figure 1. This information can serve various purposes, such as discriminating between dyes with similar colors but different chemical compositions, unveiling the presence of additional dyes in trace amounts, establishing connections between fibers and sources with diverse fiber compositions, and offering insights into the original application of the investigated fibers. The importance of this information underscores the need for guidelines and standards, encompassing aspects like quality, education, and training, to be developed across all disciplines. While many practices may be in use, their documentation is imperative to ensure transparency and reproducibility.

Assumptions, inferences, and the significance of all interpretations derived from analytical techniques should be meticulously documented. This documentation is crucial for maintaining a clear record of the analytical process and ensuring that the reasoning behind the conclusions drawn is transparent. Furthermore, it highlights the need for ongoing research to address gaps in knowledge and provide a direction for the continuous improvement of forensic analytical methods. It is imperative to emphasize the necessity for a comprehensive approach in which all forensic scientists and their institutions adhere to acceptable performance levels. This entails the development of standardized practices, continuous training and education, and the establishment of a culture that prioritizes rigorous documentation and adherence to ethical standards. Such measures are vital for upholding the credibility and reliability of forensic science in legal contexts.

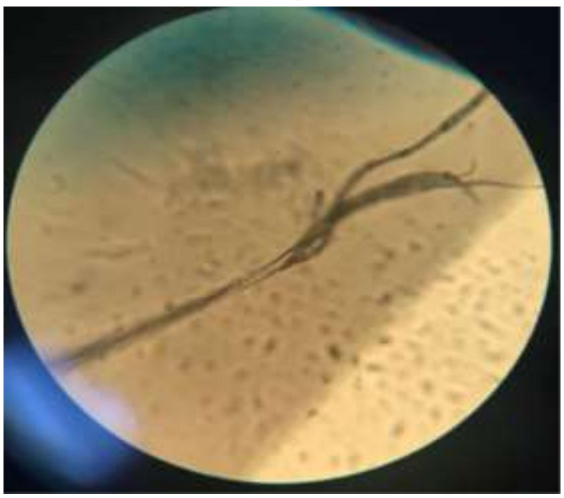


Silk fiber specimen



Polyester fiber specimen

Fur fiber specimen



Cotton fiber specimen

Figure 1. Fiber identification Analyses by microspectrophotometry (MSP).

The chemical insights garnered through microscopists' observations or microspectrophotometry (MSP), as illustrated in Figure 1, play a pivotal role in forensic investigations. This information serves several purposes, including (a) discriminating between dyes with similar colors but distinct chemical compositions; (b) unveiling the presence of additional dyes in quantities too minute to induce noticeable color differences in fibers; (c) establishing connections between fibers and sources containing highly mixed fibers; and (d) providing insights into the original application of the investigated fibers. The imperative need for guidelines and standards encompassing quality, education, and training is evident, emphasizing the significance of documentation for practices across disciplines. Assumptions, inferences, and the significance of interpretations derived from these analytical techniques necessitate meticulous documentation. Moreover, documenting the needs and directions for further research is crucial to ensure comprehensive understanding and informed adherence to evolving practices. A strong recommendation underscores the necessity for actions to ascertain that forensic scientists and their institutions consistently meet acceptable performance levels.

Effectiveness in implementing these recommendations is strongly advocated through the adherence to a rigorous quality assurance (QA) program. It is emphasized that acceptable QA is best achieved through accreditation, with the cost being comparatively small when weighed against the potential loss of quality and credibility without it. However, this is not to negate the importance of continued research and development in methodologies and technologies across the entire spectrum, from evidence collection to interpretation of analyses. Advocating and aggressively pursuing research is crucial, necessitating greater outreach to the scientific community. New methods and techniques must undergo validation, a defined process assessing their ability to reliably obtain results, defining required conditions, determining analytical procedure limitations, and identifying aspects that must be monitored and controlled [12, 13]. Validated methods are essential to the forensic sciences, are inherent in providing quality and stability to continuously evolving scientific fields. For some analytical results, only qualitative assessments of the significance are conveyed.

The absence of a clearly defined, statistically derived approach for conveying the significance of an association can lead some to question the meaningfulness of such associations in forensic science. In response to this challenge, blind validity testing, also known as black box testing, presents a potential avenue for assessing the current identification and elimination standards and identifying potential limitations within specific forensic applications or disciplines [14]. Blind validity testing involves subjecting examiner interpretations to rigorous examination using various inputs representing a range of defined categories of specified items of evidence. This approach aims to determine whether a level of accuracy can be consistently achieved in forensic examinations. By systematically testing examiner interpretations without prior knowledge of the ground truth, it becomes possible to evaluate the reliability and validity of forensic methodologies and the consistency of results [15]. This method provides an objective means of assessing the effectiveness of forensic techniques and helps identify areas that may require refinement or improvement. Blind validity testing, by its nature, enhances the scientific rigor and credibility of forensic analyses by subjecting them to systematic scrutiny. It ensures that forensic science practices align with established standards and can provide more robust and defensible results in legal proceedings.

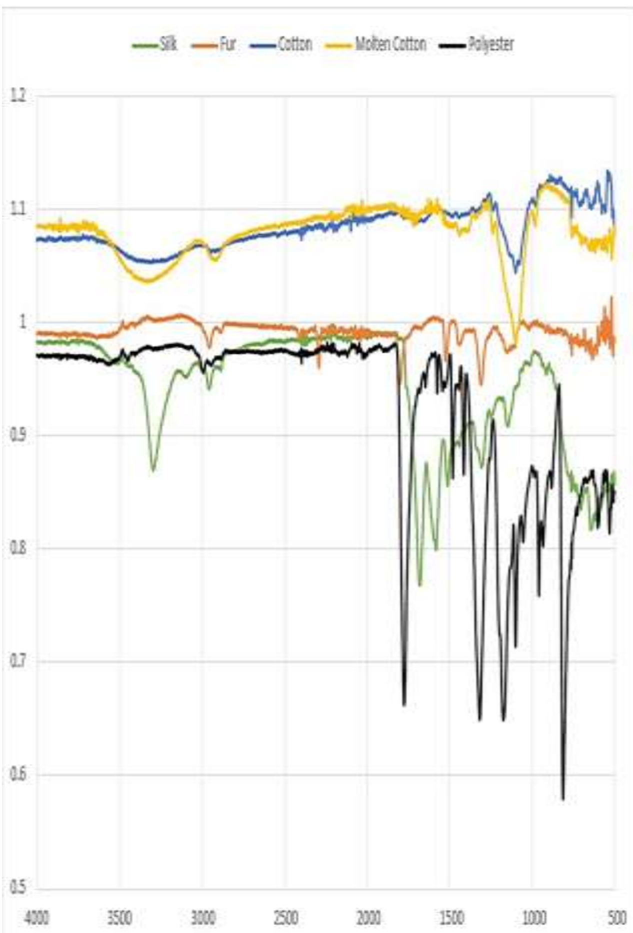


Figure 2. The outcomes of the analysis featuring the Fourier-transform infrared (FTIR) spectra chart for various fibers.

In this work, we employed Fourier-Transform Infrared (FTIR) spectroscopy to determine whether the four types of fibers—cotton, silk, fur, and polyester—can be distinguished from one another. We also looked at the melting behavior of cotton. The major objective was to determine whether this technique could distinguish these fibers even when they are in disparate environments. Like a specialized scanner, FTIR spectroscopy provides information about the compounds present in a material. It accomplishes this by illuminating the substance and observing how light is absorbed by it. This informs us of the special composition of the substance. Using FTIR, we examined fur, polyester, cotton, and silk and discovered that every fiber had a unique pattern of absorption. The various chemicals and linkages in the fibers caused these patterns. For instance, the cellulose in cotton caused it to have high absorption bands at around 3400 cm^{-1} and 1030 cm^{-1} as shown in Figure 2. A unique pattern was seen in silk due to the presence of amide groups. Fur possessed distinct qualities related to keratin, but polyester exhibited traits related to esters and a very strong, crisp band at 1723 cm^{-1}. So, FTIR made it simple for us to distinguish between different fibers. We also investigated the melting behavior of cotton. The FTIR pattern of melted cotton differs from that of ordinary cotton because of the heat-induced modification of its chemical structure. FTIR was still able to identify the material as melted cotton, though. This demonstrates that FTIR is useful even in situations where fibers are not in the same circumstances. To put it simply, this study indicates that FTIR is a valuable technique for differentiating between fibers, even after they have undergone modification, such as melting cotton. This has applications in the fields of textiles and forensics. It's crucial to keep in mind that FTIR has certain limits, and to ensure that it functions well in practical settings, more circumstances and fiber types should be examined in future studies. Overall, though, FTIR is a useful technique for identifying fibers.

Conclusions

In conclusion, forensic medicine, as an essential and meticulous scientific discipline, plays a pivotal role in ensuring justice by providing unbiased examination and scrutiny of evidentiary materials from crime scenes. Among the various techniques and methodologies within the field of forensic science, fiber analysis stands out as a universally acknowledged component in criminal investigations. While its importance is undeniable, it's important to recognize the nuanced nature of fiber analysis and its limitations when compared to the more reliable DNA analysis. This manuscript has sought to shed light on the practical application of fiber analysis in real-life scenarios, outlining a systematic approach for its implementation. The process involves identifying different types of fibers, utilizing various identification methods, and discerning the optimal timing for their use. Microspectroscopy, rigorous comparison controls, and sample analyses all contribute to the comprehensive examination of fibers. Furthermore, the meticulous study of coloration becomes crucial, especially when dealing with fibers like cotton or wool, where broader composition analysis may offer limited utility. Despite the challenges posed by minute sample sizes, the preference for non-destructive techniques, and the complexity associated with modern dye formulations, forensic fiber analysis remains a vital tool in the pursuit of justice. Its contribution to the exoneration of individuals under suspicion cannot be overstated, and its role within the broader framework of forensic science remains indispensable in solving crimes and ensuring a fair and just legal system.

Reference

[1] E. Canetta, K. Montiel, and A. Adya, "Morphological changes in textile fibers exposed to environmental stresses: Atomic force microscopic examination," *Forensic Sci. Int.*, *vol* 191, pp. 6–14, 2009. https://doi.org/10.1016/j.forsciint.2009.05.022

[2] D. B. Lin, and J. L. Pan, "Analysis and improvement on propagation efficiency of high-speed asymmetric differential transmission system," *In The 2004 IEEE Asia-Pacific Conference on Circuits and Systems*, *IEEE*, 2004. Proceedings. *vol.* 1, pp. 329-332, 2004.

[3] F. Taroni, S. Bozza, A. Biedermann, and P. Garbolino, "Data Analysis in Forensic Science: A Bayesian Decision Perspective,". Chichester, UK: John Wiley & Sons, Ltd, 2010.

[4] J. Robertson, C. Roux "Protocols for fiber examination and initial preparation". In Robertson, J., Roux, C., Wiggins, K. G. (Eds.), *Forensic Examination of Fibres, 3rd Edition*, Boca Raton: CRC Press, pp. 119-126, 2018.

[5] H. S. Rashed, et al. "A comparative investigation of two handheld near-ir spectrometers for direct forensic examination of fibres in-situ." *Vibrational Spectroscopy* 113 (2021): 103205. https://doi.org/10.1016/j.vibspec.2020.103205

[6] D. Q. Balbas, et al. "Non-invasive identification of textile fibres using near-infrared fibre optics reflectance spectroscopy and multivariate classification techniques." *The European Physical Journal Plus*, *vol* 137, pp. 1-15, 2022. https://doi.org/10.1140/epjp/s13360-021-02267-1

[7] C. Roux, J. Robertson, and R. Palmer, "Persistence and Recovery. In Saukko, P. J., Houck, M. M. (Eds.), Encyclopedia of Forensic Sciences," 2nd edition, *Waltham: Academic Press*, pp. 117-123, 2013.

[8] I. E. Dror, "Cognitive and Human Factors in Expert Decision Making: Six Fallacies and the Eight Sources of Bias," *Analytical Chemistry*, *vol*92(12), pp. 7998–8004, 2020. https://doi.org/10.1021/acs.analchem.0c00704

[9] L. Skokan, A. Tremblay, and C. Muehlethaler, "Differential shedding: a study of the fiber transfer mechanisms of blended cotton and polyester textiles," *Forensic Sci. Int.*, *vol* 308, pp. 110181, 2020. https://doi.org/10.1016/j.forsciint.2020.110181

[10] M. Burke, et al. "Reflective spectroscopy investigations of clothing items to support law enforcement, search and rescue, and war crime investigations," *Forensic science international*, *vol* 304, pp. 109945, 2019. https://doi.org/10.1016/j.forsciint.2019.109945

[11] P. Peets, et al. "Reflectance FT-IR spectroscopy as a viable option for textile fiber identification," *Heritage Science*, *vol* 7.1, 1-10, 2019. https://doi.org/10.1186/s40494-019-0337-z

[12] J. Liang, et al. "Forensic fiber analysis by thermal desorption/pyrolysis-direct analysis in real time-mass spectrometry," *Analytical chemistry*, *vol* 92.2, pp. 1925-1933, 2019. https://doi.org/10.1021/acs.analchem.9b04167

[13] M. Colella, et al. "The effect of ionizing gamma radiation on natural and synthetic fibers and its implications for the forensic examination of fiber evidence," *Journal of Forensic Sciences*, *vol* 56.3, pp. 591-605, 2011. https://doi.org/10.1111/j.1556-4029.2010.01654.x

[14] P. M. Woods, Trace Evidence Examination. In Wecht, C. H. & Rago, J. T. (Eds.), Forensic Science and Law: Investigative Applications in Criminal, Civil, and Family Justice, Taylor Francis, Baton Rouge, pp. 328-331, 2006.

[15] P. Peets, et al. "Identification and classification of textile fibres using ATR-FT-IR spectroscopy with chemometric methods," *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, vol* 173, pp. 175-181, 2017. https://doi.org/10.1016/j.saa.2016.09.007

.

استكشاف التقنيات الطيفية في فحص الطب الشرعي لألياف النسيج الاصطناعية

رغدة السيد[1] ، رسل الطحان[2] ، محمد المشهداني[1]، حوراء حازم[1]، محمد كاظم[3] ، ضياء زغير[4] ،عمر العبيدي[5] ، رحيمي يعسوب[6] ، سينار حميد[1]، عماد يوسف[1]

[1] قسم الكيمياء، كلية العلوم، جامعة النهرين، بغداد، العراق

[2]قسم الكيمياء، كلية العلوم، جامعة بغداد، بغداد، العراق

[3]قسم علوم البيئة، كلية الطاقة وعلوم البيئة، جامعة الكرخ للعلوم، بغداد، 10081، العراق

[4]مركز الحمض النووي الشرعي للأبحاث والتدريب، كلية العلوم، جامعة النهرين، بغداد، العراق

[5] قسم الكيمياء، كلية العلوم، جامعة الانبار، الانبار، العراق

6- قسم العلوم الكيميائية، كلية العلوم والتكنولوجيا، جامعة كيبانجسان ماليزيا (UKM)، بانجي، سيلانجور، ماليزيا.

emad_yousif@hotmail.com

الخلاصة:

الطب الشرعي، وهو تخصص أساسي في التحقيقات الجنائية، يقوم بفحص الأدلة بدقة لتبرئة او حكم الأفراد المشتبه بهم. ويلعب تحليل الألياف، المعترف به على نطاق واسع في علوم الطب الشرعي، دورًا حاسمًا في هذه العملية. على الرغم من طبيعته المعقدة، يفتقر تحليل الألياف إلى موثوقية تحليل الحمض النووي كأداة أساسية لتحديد هوية الجاني. تستكشف هذه الورقة التطبيق العملي لتحليل الألياف في سيناريوهات الحياة الواقعية، وتحدد النهج المنهجي. يبدأ البحث بتحديد أنواع الألياف المتاحة، يليه وصف لطرق التحديد المتنوعة والتوقيت الأمثل للتنفيذ. ويتضمن البحث تحديد المجهر الطيفي، وضوابط المقارنة الصارمة، وتحليلات العينات المختلفة. في حين أن التحليلات المجهرية والأدواتية تكشف عن التركيب الجوهري للألياف، فإن فحص الألوان يضيف خصوصية، خاصة بالنسبة للألياف مثل القطن أو الصوف. تشمل التحديات في تحليل الألياف الجنائية أحجام العينات الدقيقة، وتفضيل التقنيات غير المدمرة، والتعقيدات المرتبطة بتركيبات الأصباغ الحديثة. على الرغم من هذه التحديات، يظل تحليل ألياف الطب الشرعي عنصرًا قيمًا في التحقيقات الجنائية، مما يساهم في الفهم الشامل للأدلة المستمدة من مسرح الجريمة.

الكلمات المفتاحية: *علوم الطب الشرعي، تحليلات الألياف، تحديد المجهر، والحمض النووي ، التقنيات الطيفية، فحص الطب الشرعي، ألياف النسيج الاصطناعية.*