



Effectiveness and Best Practices in the Methods of Collection and Preservation of Hair Fiber Samples at the Crime Scene

Eficacia Y Mejores Prácticas En Los Métodos De Recolección Y Preservación De Muestras De Fibras Capilares En La Escena Del Crimen

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Summary

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This research was conducted under the analysis of the effectiveness and best practices in the methods of collection and preservation of hair fibers at the crime scene, with the aim of optimizing the integrity of forensic evidence. To achieve this, a qualitative study was carried out based on the analysis of scientific literature, forensic manuals, applicable regulations, and technical reports to generate a comparative approach to the methods used in forensic cases requiring the collection of hair fibers as an integral part of the process.

The intervention emphasized the evaluation of different collection methods, with the most commonly used being tweezers, adhesive tape, and forensic vacuums. Additionally, preservation techniques were analyzed, including storage in paper envelopes, test tubes, and the regulation of environmental conditions.

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The results of the study revealed that the choice of collection method directly depends on the type of surface and the amount of hair fiber present, while proper storage is crucial to prevent chemical degradation or cross-contamination that could affect the investigation. Therefore, it is essential to standardize procedures alongside the training of forensic personnel involved in this stage, as these factors are fundamental to ensuring the reliability of the evidence, which would strengthen the chain of custody and the validity of evidence in judicial processes.

Keywords: Fiber, data collection, legal procedure, collection, hair, crime scene.

Resumen

La presente investigación se desarrolló bajo el análisis de la eficacia y mejores prácticas en los métodos de recolección y preservación de fibras capilares en la escena del crimen, con la finalidad de optimizar la integridad de la evidencia forense, para cumplirlo, se llevó a cabo un estudio cualitativo basado en el análisis de literatura científica, manuales forenses, normativa aplicable e informes técnicos, para generar un enfoque comparativo de los métodos utilizados en casos forenses que requerían la recolección de fibra capilar como parte integrante del proceso. La intervención enfatizó en la evaluación de los distintos métodos de recolección, siendo los más usados: las pinzas, cinta adhesiva y aspiradoras forenses. Por otro lado, se analizaron las técnicas de preservación, almacenamiento en sobres de papel, tubos de ensayo y la regulación de condiciones ambientales. Los resultados del estudio permitieron evidenciar que la elección del método de recolección va a depender de forma directa del tipo de superficie y la cantidad de fibra capilar presente; mientras que el almacenamiento adecuado es crucial para evitar la degradación química o contaminación cruzada que afecta la investigación. Por ello, es fundamental la estandarización de

procedimientos acompañado de la capacitación del personal forense que interviene en esta etapa, pues, son fundamentales para garantizar la confiabilidad de las pruebas, lo que permitiría fortalecer la cadena de custodia y la validez de la evidencia en los procesos judiciales.

Palabras clave: Fibra, Recopilación De Datos, Procedimiento Legal, Recolección, Capilar, Escena Del Crimen.

Introduction

History and initial development of forensic fiber analysis methods

Forensic sciences have had a considerable evolution in relation to the collection, processing, analysis and utilization of evidence taken from a crime scene, in order to continue with the respective investigation. The most representative element of a crime scene has been the capillary fibers, since they have the ability to show the connection between victims, suspects and the scene, as well as the ease of transferring between surfaces and having a great resistance in the environments in which criminal events occur.

The incorporation of hair fibers as an integral part of forensic evidence dates back to the early 20th century, when advances in optical microscopy allowed fibers to be identified and compared with greater precision. Initially, the techniques focused on visible physical characteristics, such as length, color and texture, which were evaluated with the naked eye or with the support of a basic microscope (Aljannahi et al., 2022), i.e., this technique had as a drawback the limitation to differentiate between similar fibers, which reduced the usefulness of this evidence in complex judicial cases.

With technological progress and the development of new techniques that revolutionized the analysis of capillary fibers, between the 1960s and 1970s, electron microscopy and spectroscopic analysis became advanced tools that made it possible to study the chemical composition, optical properties and internal structures of fibers with an unprecedented level of detail (Smigiel et al., 2019). This is why infrared spectroscopy and chromatography made it possible to determine the presence of specific polymers in synthetic fibers. In turn, fluorescence analysis made it possible to identify chemical treatments applied on natural fibers. This development significantly enhanced the evidentiary value of the fibers, allowing not only to identify their origin, but also to establish specific matches between fibers collected at the crime scene and controlled samples (Sharma et al., 2024).

Despite technological progress in the laboratory, the methods used to collect and preserve fibers in the field have evolved at a much slower pace. For much of the 20th century, investigators relied on rudimentary tools, such as tweezers, paper envelopes, and plastic bags, to collect and store fibers found at crime scenes. These practices, while functional, were highly dependent on the expertise of forensic personnel and did not always fit the specific needs of each case. In addition, the lack of standardized protocols and reliance on basic tools increased the risk of cross-contamination and loss of fibers during transport and storage (Lukesova & Holst, 2024).

Incorrect handling of the hair fiber can cause serious damage to its integrity, i.e. the physical aspect such as chemical, prior to analysis in the laboratory. There are several factors such as exposure to moisture, ultraviolet light and friction that can be generated during transport, can cause its affectation and deterioration, reducing the evidentiary usefulness within a process.

In this sense, synthetic fibers show photodegradation after they have been exposed to ultraviolet light. On the other hand, natural fibers

undergo changes in chemical structure as a result of oxidation in humid environments. As both processes affect the physical and chemical properties of the fibers, analysis and interpretation in forensic and conservation contexts would be affected (Morison, 2019).

The lack of coordination between advances in laboratory analysis and limitations in field techniques highlights the importance of innovation in fiber collection and preservation. Although laboratory methods have reached a level of sophistication that allows for the identification of specific molecular characteristics, the initial handling of fibers at the crime scene remains a weak link in the chain of custody. This problem not only affects the quality of the evidence collected, but can also compromise its admissibility in judicial proceedings, as courts require assurances that the evidence has not been contaminated or tampered with.

The particularity of capillary fibers and susceptibility to deterioration

The analysis of hair fibers applied as forensic evidence becomes a crucial aspect of forensic science, as it provides valuable information to investigations. Hair is a common biological sample found at crime scenes and its analysis can help identify suspects or victims through morphological characteristics and DNA matches (D'Orio et al., 2023); however, techniques related to its collection and preservation are continually advancing to address the complexities associated with contemporary crime scenes. Hair fibers can be of two types: synthetic or natural, and their chemical composition, structure, and coloration can provide critical information to associate suspects with the crime scene, victims, or weapons used.

Hair fibers are composed mainly of keratin, a structural protein that provides strength and flexibility; however, their chemical composition makes them susceptible to external factors, such as humidity, ultraviolet (UV) light and extreme temperatures, which can

alter their physical and chemical structure (He et al., 2023). These alterations include:

Physical degradation: Prolonged exposure to ultraviolet radiation can compromise the structural integrity of hair fibers and make them brittle. The mechanical characteristics of hair, including tensile strength and elasticity, are essential to preserve its overall durability. Methodologies such as optical and electron microscopy are used to evaluate these characteristics and the influence of external variables (Gonçalves & Lopes, 2024).

Chemical degradation: hair fibers can oxidize when exposed to high levels of humidity and environmental contaminants, which affects their chemical composition, causing changes in the physical properties of the hair and complicates subsequent analysis (Grigsby et al., 2024; Uyama, 2024).

Contamination: Without proper preservation techniques, fibers can become contaminated with external particles or other evidence collected at the same scene (Uyama, 2024).

Fiber collection methods

Hair fiber collection methods are classified into three main categories: forceps, tape and forensic vacuums, which are described below:

Tweezers

Both traditional and advanced grippers offer precise handling of small objects, such as fibers, with minimal risk of cross-contamination. However, their effectiveness may be limited by the nature of the surface or material in which the fibers are embedded and the potential for damage due to pressure. Although a traditional method, tweezers are limited in their general applicability and rely heavily on the skill of the technician (Muriel et al., 2018).

Advantages of advanced grippers

Precise and non-contact manipulation: optical tweezers use light to manipulate the particles, which provides precise and non-contact control, ideal for delicate fibers and minimizes the risk of contamination, an indispensable action to avoid altering the research process and the results to be obtained (Liberale, 2022; Zhu et al., 2023).

Versatility and adaptability: optofluidic tweezers are responsible for combining optical and microfluidic technologies, allowing for improved speed and efficiency in handling small particles that may be found at a crime scene (Zhu et al., 2023). Acoustic tweezers use sound waves for non-invasive manipulation and are suitable for complex biological structures (Gao et al., 2023).

Environmental responsiveness: micropinches, made of smart materials, adapt to environmental changes, allowing controlled handling without excessive pressure, which reduces the risk of damaging the fiber to ensure tamper-free tapping (Kaufman et al., 2023).

Disadvantages and limitations

Inefficiency on large surfaces: traditional forceps when used on large surfaces or for extraction in encrusted areas may present problems, as well as advanced design forceps, which despite technological development, may present limitations based on their design (Kaufman et al., 2023; Zhu et al., 2023).

Potential for fiber damage: although advanced tweezers reduce contact, the pressure exerted by traditional tweezers can damage fragile fibers. Even with optical tweezers, light intensity must be carefully controlled to avoid damage (Liberale, 2022; Zhao et al., 2022).

Adhesive tape

Adhesive tape is fast and efficient, its effectiveness depends on the type of surface and careful handling to avoid errors (Pilco, 2014).

Advantages

Adhesive tape allows the collection of fibers in large quantities and is effective on flat surfaces, e.g. on furniture, clothing or smooth floors. The main advantage of use and portability make it a popular tool at crime scenes (Benthien et al., 2022).

Disadvantages

The main limitation of adhesive tape is the risk of cross-contamination. If not used correctly, the collected fibers may become mixed with other samples or adhere to forensic personnel. In addition, some fibers may be damaged or lost when removed from the tape (Benthien et al., 2022).

Forensic vacuum cleaners

Vacuum cleaners are essential tools for collecting fibers and small particles from large and difficult surfaces, such as carpets and car seats. They are equipped with specialized filters that effectively separate and capture these particles, ensuring a clean environment (Plazas et al., 2017).

Advantages

Efficient particle collection: Vacuum cleaners are designed to efficiently collect coarse and fine particles. The use of dual-chamber systems with pre-filters and fine particle filters ensures that particles of different sizes are effectively separated and collected (Ha et al., 2011). They use special filters to capture fibers and small particles without mixing them.

Disadvantages

Laboratory analysis requirements: once the collection is done, the separation of the useful fibers from the residues proceeds, therefore, a meticulous laboratory analysis is required, which takes considerable time and resources (Plazas et al., 2017).

Size and power limitations: the size of vacuum cleaners and their dependence on electrical power may limit their use in certain scenarios, such as in remote or outdoor areas where power supplies are not readily available (Kamalkant et al., 2024).

Fiber preservation methods

In forensic environments, proper storage of fibers is as important as their initial collection. Paper envelopes and test tubes are frequently used to store evidence, each having distinct advantages and disadvantages. Paper envelopes are preferred for their ability to minimize retention of moisture, which decreases microbial growth; however, they are prone to physical damage and do not provide complete protection from exposure to high humidity or ultraviolet light. In contrast, test tubes offer excellent rigid protection for small, fragile fibers, but require stable environmental conditions to prevent deterioration (Findik, 2024).

Paper envelopes

Moisture control: Paper envelopes are an effective method to prevent the accumulation of moisture, something that must be taken into consideration to avoid microbial growth in forensic samples, thus ensuring the integrity of the evidence.

Physical vulnerability: despite containing a great advantage, envelopes are often prone to physical damage, due to inadequate care in handling, which compromises the integrity of the evidence.

Environmental limitations: paper does not provide adequate protection in high humidity or rainy conditions and is vulnerable to exposure to ultraviolet light, which can be problematic during transportation or storage (Vasiliev, 2023).

Test tubes

Rigid protection: test tubes provide solid protection against physical damage for small and delicate fibers.

Environmental sensitivity: to guarantee the quality of the evidence, they must be stored in stable temperature and light conditions to avoid degradation.

Material influence: the type of material used in test tubes can affect the persistence of cellular material, as observed in studies on tactile DNA, where metallic substrates retain cells longer than plastic or ceramic (Plazas et al., 2017).

The choice between them often depends on the specific requirements of the evidence being stored and the environmental conditions to which they will be exposed. In addition, advances in materials science, such as the development of biocalcified foams, may offer new solutions for forensic packaging in the future (Mosse et al., 2024).

Environmental conditions

Environmental conditions are based on an adequate control of temperature, light and humidity during storage time, therefore, capillary fibers that are stored at room temperature, with adequate protection from direct light, maintain their integrity for longer periods of time (Pilco, 2014). Environmental conditions have a direct impact on the preservation of capillary fibers, so the following factors should be taken into consideration and properly controlled to maintain the integrity of the samples:

Temperature: Temperature extremes, whether high or low, can significantly influence the physical and chemical integrity of fibers. Higher temperatures accelerate chemical degradation processes, while lower temperatures, while delaying these processes, can induce structural vulnerability. It is advisable to store fibers at regulated temperatures, optimally between 18 and 22 °C (Plazas et al., 2017).

Humidity: high humidity becomes a risk for the hair fibers, as it promotes the proliferation of microorganisms and the degradation of chemical components. In addition, excessively low humidity can cause fiber brittleness, so it is essential to maintain a balanced humidity where the hair fibers are resting to avoid possible further damage.

Light: Prolonged exposure to light, especially ultraviolet radiation, can cause discoloration and compromise the integrity of the fiber composition. This not only affects visual evaluations, but also influences the results of sophisticated methods such as infrared spectroscopy. It is advisable to store fibers in dark environments or in opaque containers that obstruct ultraviolet light to mitigate these hazards (Plazas et al., 2017).

Impact of cross-contamination

In the field of forensic sciences, the collection of capillary fibers is affected by cross-contamination, a critical issue that compromises the integrity of the evidence. During movement for the transfer of fibers for forensic examinations, the collection method, environmental surroundings and examiner hygiene, among other factors, can all play a role. Effective strategies to minimize contamination are essential to ensure the reliability of forensic analysis (Balk, 2015).

Factors influencing cross-contamination

Collection methods: The method used to collect hair fibers has a significant impact on contamination levels. Bandaging and scraping are common techniques, as scraping produces more loose fibers and may transfer to the examiner's clothing, increasing the risk of contamination outside the examined area (Roux et al., 2001).

Environmental conditions: the movement of a capillary fiber is conditioned by the distance it must travel to its final destination, considering the intervention of environmental conditions. This is why cotton fibers are more likely to be airborne and to remain suspended longer than other fibers such as wool or polyester, which can lead to widespread contamination in a forensic environment (Roux et al., 2001).

Decontamination difficulties: Despite decontamination efforts, external contamination from environmental sources or body fluids may persist, especially in autopsies. Standard decontamination procedures may not completely remove contaminants, complicating interpretation of forensic results (Kintz et al., 2008).

Strategies to minimize contamination

Hygiene and precautions: Implementing strict hygiene protocols and wearing appropriate protective clothing can help to reduce fiber transfer during forensic examinations (Roux et al., 2001)

Controlled environments: Conducting examinations in controlled environments with minimal airflow and the use of specialized equipment can help limit fiber movement and contamination (Roux et al., 2001).

Advanced analytical techniques: The use of techniques such as gas chromatography-mass spectrometry (GC-MS) can improve the accuracy of hair analysis by providing precise quantification and

reducing the impact of potential contaminants (Mahesh & Ranjeet, 2015).

Standardization and practice in Ecuador

Standardization of procedures for the collection and preservation of hair fibers is crucial to ensure the integrity and reliability of forensic evidence. However, in Ecuador, the implementation of these standardized practices faces several challenges. These challenges are rooted in structural, technical and formative factors of the country's judicial system and forensic environment (Jindal, 2024).

However, challenges to adopting international standards for evidence management, such as those described in the Forensic Investigation Procedures Manual, may include insufficient training of personnel, lack of resources for adequate equipment, and the need for consistent compliance with protocols. These factors can hinder effective implementation and compromise the integrity of evidence collection and preservation (Duran, 2023; State Attorney General's Office, 2014).

Current situation in Ecuador

The adoption of international standards in forensic science in Ecuador, particularly with regard to chain of custody and evidence management, faces several challenges. These challenges stem from the need for legal and procedural reforms, the integration of advanced forensic techniques, and the improvement of training and resources. The development of specialized units such as DINASED and the Forensic Science Laboratory has been critical, but full implementation of international protocols remains a work in progress (Eche et al., 2023).

Challenges in the adoption of international standards

The implementation of modern protocols is conditioned to the adoption of international standards; therefore, the following problems are present in Ecuador:

Equipment limitations: in certain areas, specialized technological equipment, such as forensic vacuum cleaners or advanced microscopes, are scarce, non-existent or malfunctioning, forcing investigators to rely on less efficient manual methods that could affect hair fiber collection.

Inconsistencies in training: although training programs have been implemented, they do not always reach all technicians in the field, especially in rural regions or regions far from the main forensic centers.

Logistical challenges: collecting evidence in areas with extreme conditions makes it difficult to preserve fibers in optimal conditions (Zanders & Klavins, 2024).

A study by Durán et al. highlights that criminalistics in Ecuador is still in the process of consolidation and that there is an urgent need for resources to equip forensic units with modern technology and strengthen personnel training (Durán et al., 2019).

Legal Analysis of the Use of Capillary Fibers as Forensic Evidence

From a legal approach, the analysis of hair fibers as an integral part of the process when considered as forensic evidence, should be analyzed from the guiding principles of due process, including chain of custody and admissibility of evidence, from a criminal context. The fibers, despite being considered small and with an insignificant appearance, contribute in a decisive evidence in certain procedures, as long as the handling, custody and analysis comply with legal standards that guarantee reliability.

Legal Importance of the Chain of Custody

The chain of custody represents an indispensable principle that guarantees the traceability and integrity of physical evidence from its collection to its presentation in court, regardless of the procedure. In cases involving hair fibers, their fragile characteristics make them particularly susceptible to contamination or loss, which could undermine their evidentiary importance in ensuring the veracity of the process. According to Ecuador's Comprehensive Organic Criminal Code (COIP), evidence gathered at a crime scene must be handled in accordance with established protocols that safeguard its integrity and prevent any alteration and thus accurately maintain the veracity of the facts.

In this context, the management of hair fibers requires:

- Clear and standardized protocols for collection, storage and transport.
- Use of appropriate tools, such as paper envelopes and airtight tubes, to minimize the risk of cross-contamination.
- Rigorous recording of each stage of evidence handling, including details of environmental conditions and methods employed (Salem, 2023).

Failure to comply with these requirements may result in the exclusion of the evidence, in accordance with the principles of inadmissibility established in the criminal procedure legislation.

Nature and Scope of the Research Problem

Although there have been technological advances in fiber analysis in Ecuador, efficiency in collection and preservation techniques remains a critical issue for the advancement of forensic methodologies, as inadequate or improperly executed procedures compromise the integrity of evidence, which can also result in its inadmissibility in legal proceedings. The wide variety of surfaces on which fibers can

be discovered (carpets, textiles, hard surfaces) and fluctuating environmental conditions at crime scenes compound these challenges. In addition, cross-contamination during collection or storage poses an ongoing risk to sample authenticity.

Therefore, this study has focused on addressing existing deficiencies in the collection and preservation of hair fibers in order to illustrate that, although minute and seemingly inconsequential, they can play a vital role in cases where alternative forms of evidence are unavailable or inadequate; thus, in crimes where there are no fingerprints or biological prints, fibers may serve as the only link between the suspect and the crime scene.

Moreover, improving forensic practices in this area has substantial implications not only for the resolution of individual cases, but also for strengthening public confidence in the criminal justice system. Properly managed and preserved evidence ensures that judicial determinations are based on sound scientific principles, mitigating the risk of judicial inaccuracies.

Likewise, this study has a preventive impact, since the perpetrators, by recognizing that Ecuador's judicial system employs appropriate methodologies for the process of recognition, collection and analysis of physical evidence, such as in this particular case of hair fibers. Therefore, the existence of established protocols that address and are aligned with due process, accompanied by state-of-the-art technology, sends a clear message regarding the ability of institutions to identify and prosecute those responsible for illegal acts, while serving as a deterrent to the commission of crimes.

Increasing public confidence in the judicial system and the social and cultural ramifications of this research are intrinsically interconnected, as both facets are underpinned by the professionalization and improvement of forensic practices. By ensuring that judicial determinations are based on sound, scientifically grounded evidence, the perception of impartiality and effectiveness of judicial

institutions is reinforced, which in turn fosters greater credibility and collaboration on the part of citizens. At the same time, by developing specific protocols adapted to local contexts, this research promotes the training of forensic specialists, generates applied scientific knowledge and raises standards of practice in the criminal justice field in Ecuador. This virtuous circle not only reinforces society's trust in its institutions, but also contributes to the cultivation of a culture that considers science as a fundamental pillar for justice and social progress.

Methodology

The research was developed with a qualitative approach, which seeks to understand in detail the phenomena related to the collection and preservation of hair fibers at crime scenes. The approach has allowed to explore, analyze and compare methods used in forensic contexts, as well as to propose best practices based on the evidence obtained. The methodology is organized in three main stages: data collection, analysis of results and development of proposals.

Data Collection

The data collection stage will focus on obtaining detailed information through an exhaustive literature search in high impact academic databases such as Scopus, PubMed and ScienceDirect, among others, as well as in forensic manuals and technical reports related to the topic under development. The objective is to identify the most commonly used methods for the collection and preservation of hair fibers and the optimal conditions that guarantee the integrity of these samples.

Analysis of Results

The qualitative analysis involved categorizing the information along the following axes:

Efficiency of different hair fiber collection techniques on different surfaces.

Impact of environmental conditions on fiber integrity. An analysis of temperature, light and humidity.

Identification of best practices for evidence-based preservation.

Proposal Development

Based on the findings of the analysis, a proposal will be developed to optimize hair fiber collection and preservation methods.

Results

Process for hair fiber sampling at a crime scene in Ecuador

In Ecuadorian territory, the procedure that forensic technicians apply for the collection of hair fiber samples follows the general guidelines of criminalistics, with the purpose of guaranteeing the efficient collection and correct preservation of hair samples within the chain of custody. The process has several stages:

Initial evaluation of the crime scene: being the first phase, it serves to plan and execute the investigation process correctly, that is why the investigators identify the area of interest and physical evidence, to fulfill it, they must:

Securing the affected area: being the delimitation of the crime scene to avoid contamination, alteration of evidence, intervention of

uninvolved persons and possible changes that may affect the investigation.

Preliminary identification of evidence: this is the part of the process that allows personnel to perform a visual inspection to locate possible hair fibers on the different surfaces involved in the scene.

Determination of critical points: identification of certain priority areas for collection, guided by the sequence of events and contact routes.

Selection of tools and collection methods: this is the stage in which the appropriate instruments and techniques are selected for the collection of hair fibers based on the characteristics of the crime scene, as well as taking into consideration the surface on which it is found. To accomplish this, it should be taken into account that there are several tools that are used depending on the type of surface and the amount of existing fiber at the scene, among them:

Tweezers: used for the collection of individual hair fibers that are visible on small surfaces or that are in direct contact with other evidence, such as clothing, floor, attached hairs and so on.

Adhesive tape: this tool is usually used when the evidence is found on flat, wide and clean surfaces where capillary fibers are not embedded, thus, the evidence is taken neatly for the respective processing without alterations in the results.

Forensic vacuum cleaners: is a type of tool that is used for collection from surfaces such as: carpets, car seats and hard to reach places. These devices are equipped with filters designed to prevent the mixing of particles to ensure that the evidence remains in its natural form.

The use of these tools has several advantages and limitations that are adapted to each context:

Table 1: Comparative table of tools used for evidence collection

Tool	Advantages	Limitations
Tweezers	<ul style="list-style-type: none"> - High precision to collect individual fibers. - Handling control that minimizes direct contact. - Low cost and easy availability. 	<ul style="list-style-type: none"> - Inefficient for collecting fibers on large or complex surfaces, such as carpets. - Risk of damaging fragile fibers due to excessive pressure. - Requires technical skill of the operator.
Adhesive tape	<ul style="list-style-type: none"> - Efficient for collecting fibers from flat and wide surfaces such as furniture or smooth floors. - Easy to use and transport. - Simultaneous collection of multiple fibers. 	<ul style="list-style-type: none"> - due to improper handling, there is a high risk of cross-contamination. - Some fibers may be damaged when removed from the tape. - Reduced accuracy in fiber identification.
Forensic vacuum cleaners	<ul style="list-style-type: none"> - Ideal for collecting fibers from large surfaces and difficult areas such as carpets and car seats. - High capacity to collect small particles and embedded fibers. - Equipped with specialized filters. 	<ul style="list-style-type: none"> - They require laborious laboratory analysis to separate useful fibers from waste. - Size and dependence on electric power limit their use in certain scenarios. - High cost.

Collection procedure: it is the process that requires an adequate orderly, systematic and controlled execution for the collection of capillary fibers at the crime scene, therefore, it is essential to analyze the scenario, in order to make the selection of the tool to be used, since it ensures the integrity of the samples, to avoid damage or contamination . The collection follows a protocol that minimizes the loss of evidence in order to maintain proper custody.

Use of personal protective equipment: the forensic investigator who has been designated for the collection of hair fibers must use mandatory protective equipment such as: gloves, mask and disposable clothing, in order to prevent cross-contamination.

Systematic collection: analyzing the place of the facts and the surface where the hair fiber to be taken as evidence is located is the key point to select the appropriate tool that does not affect or damage the sample to be taken.

Location record: each sample collected should be labeled with precise information about its location, time and method used.

Packaging and preservation of samples: the packaging is the fundamental part of the process, since, by carrying out an adequate preservation, the capillary fibers will be free from possible contamination by external factors, thus guaranteeing the integrity of the sample until its respective analysis in the laboratory. This should include:

Storage material: the most commonly used are:

Paper envelopes: serve to preserve individual fibers that have been collected with forceps or adhesive tape. Using the paper envelope allows proper ventilation to prevent the growth of microorganisms affecting the collected test.

Test tubes or airtight bags: used for fibers collected in humid environments to maintain temperature and humidity control.

Labeling: case data, sample number and specific location within the scene should be included.

Temperature and storage: during the transfer of the collected samples there must be conservation under controlled environmental conditions, therefore, the samples must be transported and protected in properly sealed containers, to ensure that the

environment, i.e. temperature, humidity and exposure to light, are controlled to prevent deterioration of the fibers. Once in the laboratory, the fibers are stored in controlled conditions until they are analyzed, with a strict record of entry and exit to maintain the chain of custody.

Registration documents: are the support that document all the actions performed during the collection, transport, analysis and storage of hair fibers. In this process, photographs, diagrams of reports describing the location, method and materials of the collection, as well as the respective preservation can be included.

Critical Points presented for Capillary Fiber Collection

Despite having a defined procedure for the collection of hair fiber at the crime scene as evidence in the investigative process, there are several critical points that forensic personnel must take into consideration, among them are:

Improper handling

Incorrect use of tools: the forceps is one of the most used tools due to the benefits it presents. However, despite the precision it provides, in certain scenarios, such as fibers embedded in complex surfaces, it could fragment the fibers, affecting the subsequent analysis.

Poorly applied adhesive tape: although it is an excellent tool for collecting hair fiber on flat surfaces, careless use can lead to the adherence of contaminants or damage to the fibers when removed, resulting in contamination of the evidence taken, affecting the results of the investigative process.

Forensic vacuum cleaners: the most effective tool used for large surfaces, however, incorrect use can mix collected fibers, making laboratory classification difficult.

Adverse environmental factors

High humidity: is a condition that promotes and allows the development of chemical oxidation and microbial growth in fibers, especially in those of natural origin such as cotton or wool, generating contamination in the evidence.

Exposure to UV light: synthetic fibers are vulnerable to photodegradation, which could alter their chemical structure, reducing their evidential usefulness.

Extreme temperatures: in cold environments, fibers may become brittle or suffer accelerated chemical deterioration at high temperatures, generating a considerable affectation in the laboratory analysis process.

Available infrastructure

In rural areas, where advanced tools may be lacking due to transportation or external site conditions, priority is given to the use of manual methods complemented by strict hygiene practices.

Ongoing training

National forensic units should receive regular training on international best practices adapted to local needs , however, ongoing training is not a priority for the competent authorities.

Proposed improvement to the procedure for the collection and preservation of hair fibers at crime scenes.

The following is the procedure to follow, based on the guidelines issued by the competent authority in Ecuador, as well as international organizations. The purpose is to guarantee the integrity of the evidence, so that it is admissible in legal proceedings, therefore, the following steps are suggested:

Table 2: Proposed improvement to the procedure for the collection of evidence samples

Step	Main activity	Subactivitie
Crime scene preparation	Delimitation of the area	Secure the crime scene by using tapes and barriers to prevent unauthorized personnel from entering. Conduct a visual inspection of the site in order to identify priority areas for sampling.
	Necessary equipment	Sterilized stainless steel forceps. Low adhesion forensic adhesive tape. Forensic vacuum cleaners with HEPA filters. Paper envelopes, airtight test tubes and opaque bags. Personal protection kit: gloves, masks, disposable gowns.
	Initial registration	Document the crime scene supported by photographs and specific notes.
Fiber collection	Choice of method (tool to be used depending on the location of the crime scene)	Forceps are used to collect individual fibers visible on small or delicate surfaces. Forensic adhesive tape, preferably used for flat or wide surfaces. For this purpose, it should be applied smoothly and peeled off in a single motion. Forensic vacuum cleaners for use on large areas or difficult surfaces, such as carpets and upholstery. For this purpose, ensure the use of dedicated filters for each area.
	Collection procedure	Change gloves between sample collection from different areas to avoid cross-contamination. Work systematically from the least polluted

		<p>areas to the most polluted areas.</p> <p>Label each sample immediately after collection, indicating the exact location and method used.</p>
Sample preservation	Selection of packaging material	<p>Use paper envelopes for the collection of hair fibers with forceps or adhesive tape.</p> <p>Airtight test tubes should be used for fibers in humid environments or areas of high humidity.</p> <p>Opaque bags are recommended to protect the fibers from ultraviolet light during transportation.</p>
	Labeling criteria	<p>Perform the registration of:</p> <p>Unique sample identification number.</p> <p>Brief description of the origin of the sample.</p> <p>Date, time and method of collection.</p> <p>Name of the responsible researcher.</p>
Transportation and storage	Transportation to the laboratory	<p>Place samples in sealed containers to avoid exposure to environmental factors .</p> <p>Use a rigid box to ensure the stability of the sample during transport.</p>
	Storage conditions	<p>Keep the samples in a controlled environment with temperature between 18-22 °C and relative humidity around 50%.</p> <p>Store fibers in dark or UV protected areas.</p>
Documentation and reporting	Complete documentation	<p>Include photographic material and process diagrams detailing the exact location of each sample collected.</p> <p>Prepare a record of the chain of custody, ensuring that each step is properly signed and dated.</p>

	Preliminary Report	Prepare an initial summary with details of samples collected, tools used and relevant observations on scene conditions.
Continuous training	Practical training	Conduct periodic simulations of crime scenarios to reinforce fiber management skills. Implement training to keep abreast of technological advances and international practices.
	Regular evaluations	Establish annual staff evaluations to ensure compliance with protocols and the adoption of new procedures.
Incorporation of technology	Advanced tools	Acquire vacuum cleaners with advanced filtering technology and portable microscopes for preliminary analysis in the field. Introduce moisture-controlled containers for safe transport.
	Digitization of processes	Use digital systems to record the chain of custody and facilitate the generation of reports.

The proposed process for hair fiber collection aligns with the methods for collecting and preserving hair fiber samples at crime scenes proposed in the 2024 Jindal investigation, as they include the use of standardized protocols to ensure consistency and minimize contamination, thus forensic investigators are required to use clean, sterile tools, such as forceps, to collect hair fibers and place them in labeled, tamper-proof evidence bags. Proper documentation of the collection process, including date, time and location, is essential. Samples should be stored in a controlled environment to prevent degradation and ensure their integrity for later forensic analysis (Jindal, 2024).

In the research developed by D'Orio et al. in the year 2023), the guidelines for collecting hair samples are presented, emphasizing

the importance of using appropriate techniques to avoid contamination, for this, it is elementary that the collection of hair fibers is collected with clean gloves, and then, the samples are deposited in septic containers and properly labeled. Preservation involves storing the samples in a cool, dry environment away from direct sunlight. Proper documentation of the collection process, including the location and context of the samples, is crucial to maintaining the integrity of the evidence for forensic analysis.

In 2023, authors Kelty, Ribaux, and Robertson focus their research on identifying the fundamental skills of forensic crime scene responders and emphasize the importance of effective crime scene processing for optimal investigative outcomes.

Therefore, the collection of capillary fibers at the crime scene requires a combination of the necessary tools, accompanied by the application of the appropriate method to maintain the sample. The adoption of these methodologies in Ecuador will require a combination of investment in equipment, continuous training of forensic personnel and the adaptation of international protocols to the specific conditions of the country, to ensure that the forensic evidence meets international quality standards and can be used effectively in the administration of justice.

Conclusions

Comparative analysis of crime scene hair fiber collection methods is directly dependent on the type of surface and nature of the evidence presented at each crime scene. On the one hand, tweezers are precise tools for manipulating individual fibers, but ineffective on large surfaces or surfaces with embedded fibers. On the other instance, adhesive tape allows for rapid collection on flat surfaces, although it presents a high risk of cross-contamination and possible

loss of samples. In addition, forensic vacuums are useful on large, complex surfaces, but require meticulous laboratory analysis to separate useful fibers from other debris.

Proper preservation of hair fibers is crucial to ensure the integrity of the evidence in an investigation, since environmental factors such as temperature, humidity and exposure to light that influence the stability of the fibers must be considered, which is why paper envelopes are the most recommended method, since they allow ventilation and reduce the accumulation of moisture, minimizing the risk of microbial proliferation. However, they are vulnerable to high humidity and ultraviolet light. On the other hand, test tubes offer greater mechanical protection, but require storage in controlled environments to avoid sample degradation.

Cross-contamination remains a challenge in the collection and preservation of hair fibers that directly affects the reliability of forensic evidence. The main factors of contamination are: improper use of tools, improper handling of samples and adverse environmental conditions. To reduce the problem, the implementation of strict protocols, the use of personal protective equipment and the application of systematic collection methods that minimize the accidental transfer of fibers are recommended.

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