



## 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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#### Abstract

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. 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

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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

Forensic science has evolved considerably in terms of how evidence is collected, processed, analyzed, and used at a crime scene to further the investigation. The most representative element of a crime scene has been hair fibers, as they have the ability to show the connection between victims, suspects, and the scene of the crime, as well as the ease with which they can be transferred between surfaces and their high resistance in environments where 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 made it possible to identify and compare fibers with greater precision. Initially, techniques focused on visible physical characteristics, such as length, color, and texture, which were evaluated with the naked eye or with the aid of a basic microscope. This technique had the disadvantage of being limited in its ability to differentiate between similar fibers, which reduced the usefulness of this evidence in complex court cases.

With technological advances and the development of new techniques that revolutionized hair fiber analysis between the 1960s and 1970s, electron microscopy and spectroscopic analysis became advanced tools that allowed the chemical composition, optical properties, and internal structures of fibers to be studied in unprecedented detail. 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 to natural fibers. This development significantly expanded the results in terms of the probative value of fibers, allowing not only their origin to be identified, but also specific matches to be established between fibers collected at crime scenes and control samples.

Despite technological advances 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 experience of forensic personnel and did not always meet 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.

Incorrect handling of hair fibers can seriously affect their integrity, i.e., their physical and chemical appearance, prior to analysis in the laboratory. Several factors, such as exposure to moisture, ultraviolet light, and friction that can occur during transport, can cause damage and deterioration, reducing their usefulness as evidence in a case.

In this regard, synthetic fibers undergo photodegradation after being exposed to ultraviolet light. On the other hand, natural fibers undergo changes in their chemical structure as a result of oxidation in humid environments. As both processes affect the physical and chemical properties of fibers, their analysis and interpretation in forensic and conservation contexts would be affected.

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 specific molecular characteristics to be identified, 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 legal proceedings, as courts require guarantees that the evidence has not been contaminated or improperly handled.

The uniqueness of hair fibers and their susceptibility to deterioration

The analysis of hair fibers as forensic evidence is a crucial aspect of forensic science, as it provides valuable information for 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; 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 essential information for linking suspects to the crime scene, victims, or weapons used.

Hair fibers are mainly composed 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. 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 for preserving its overall durability. Methodologies such as optical and electron microscopy are used to evaluate these characteristics and the influence of external variables.

**Chemical degradation:** Hair fibers can oxidize when exposed to high levels of humidity and environmental pollutants, affecting their chemical composition, causing changes in the physical properties of the hair, and complicating subsequent analysis.

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

#### Fiber collection methods

Hair fiber collection methods are classified into three main categories: tweezers, adhesive tape, and forensic vacuum cleaners, which are described below:

##### Tweezers

Tweezers, both traditional and advanced, 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 by the possibility of damage due to pressure. Although a

traditional method, tweezers are limited in their general applicability and rely heavily on the skill of the technician.

#### Advantages of advanced tweezers

Precise, contactless manipulation: optical tweezers use light to manipulate particles, offering precise, contactless control, which is ideal for delicate fibers and minimizes the risk of contamination, an essential requirement for ensuring that the research process and the results obtained are not altered.

Versatility and adaptability: optofluidic tweezers combine optical and microfluidic technologies, improving speed and efficiency in handling small particles that may be found at crime scenes. Acoustic tweezers use sound waves for non-invasive manipulation and are suitable for complex biological structures.

Environmental responsiveness: microtweezers, made from smart materials, adapt to environmental changes, allowing for controlled manipulation without excessive pressure, which reduces the risk of damaging the fiber to ensure manipulation-free sampling.

#### Disadvantages and limitations

Ineffectiveness on large surfaces: traditional tweezers can present problems when used on large surfaces or for extraction in embedded areas, as can advanced tweezers, which, despite technological developments, may have limitations based on their design.

Potential to damage the fiber: While advanced tweezers reduce contact, the pressure exerted by traditional tweezers can damage fragile fibers. Even with optical tweezers, the intensity of the light must be carefully controlled to avoid damage.

#### Adhesive tape

Adhesive tape is quick and efficient, but its effectiveness depends on the type of surface and careful handling to avoid mistakes.

#### Advantages

Adhesive tape allows fibers to be collected in large quantities and is effective on flat surfaces, such as furniture, clothing, or smooth floors. Its ease of use and portability make it a popular tool at crime scenes.

#### Disadvantages

The main limitation of adhesive tape is the risk of cross-contamination. If not used correctly, the fibers collected may mix with other samples or stick to forensic personnel. In addition, some fibers may be damaged or lost when removed from the tape.

#### 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.

#### 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. They use special filters to capture fibers and small particles without mixing them.

#### Disadvantages

Laboratory analysis requirements: once collection is complete, the useful fibers are separated from the waste, which requires meticulous laboratory analysis, taking considerable time and resources.

Size and energy limitations: The size of vacuum cleaners and their dependence on electrical power can limit their use in certain scenarios, such as in remote areas or outdoors where power sources are not readily available.

### Fiber preservation methods

In forensic settings, proper storage of fibers is as important as their initial collection. Paper envelopes and test tubes are frequently used to store evidence, each with different advantages and disadvantages. Paper envelopes are preferred for their ability to minimize moisture retention, which reduces microbial growth; however, they are prone to physical damage and do not provide complete protection against exposure to high humidity or ultraviolet light. Test tubes, on the other hand, offer excellent rigid protection for small and fragile fibers, but require stable environmental conditions to prevent deterioration.

#### Paper envelopes

**Humidity control:** Paper envelopes are an effective method of preventing moisture accumulation, which is essential to prevent microbial growth in forensic samples and thus ensure the integrity of the evidence.

**Physical vulnerability:** despite their great advantages, envelopes are often prone to physical damage if not handled with care, which compromises the integrity of the evidence.

**Environmental limitations:** paper does not provide adequate protection in conditions of high humidity or rain and is vulnerable to exposure to ultraviolet light, which can be problematic during transport or storage.

#### Test tubes

**Rigid protection:** test tubes provide solid protection against physical damage when small and delicate fibers are present.

**Environmental sensitivity:** To ensure the quality of the evidence, it must be stored under stable temperature and light conditions to prevent degradation.

**Influence of the material:** The type of material used in test tubes can affect the persistence of cellular material, as has been observed in studies on tactile DNA, in which metal substrates retain cells longer than plastic or ceramic.



The choice between them often depends on the specific requirements of the evidence being stored and the environmental conditions to which it will be exposed. In addition, advances in materials science, such as the development of bio-calcified foams, may offer new solutions for forensic packaging in the future.

#### Environmental conditions

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

**Temperature:** Extreme temperatures, whether high or low, can significantly influence the physical and chemical integrity of fibers. High temperatures accelerate chemical degradation processes, while lower temperatures, although they slow down these processes, can induce structural vulnerability. It is advisable to store fibers at regulated temperatures, optimally between 18 and 22 °C.

**Humidity:** High humidity levels pose a risk to hair fibers, as they promote the proliferation of microorganisms and the degradation of chemical components. In addition, excessively low humidity can cause the fibers to become brittle, so it is essential to maintain a balanced humidity level where the hair fibers are stored to prevent 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 block ultraviolet light to mitigate these hazards.

### Impact of cross-contamination

In the field of forensic science, the collection of hair fibers is affected by cross-contamination, which is a critical issue that compromises the integrity of evidence. During the transfer of fibers for forensic examination, contamination can occur due to factors such as the collection method, the environmental conditions, and the hygiene practices of the examiner. Effective strategies to minimize contamination are essential to ensure the reliability of forensic analysis.

### 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 that can be transferred to the examiner's clothing, increasing the risk of contamination outside the examined area.

**Environmental conditions:** the movement of a hair fiber is conditioned by the distance it must travel to its final destination, taking into account the influence of environmental conditions. This is why cotton fibers are more likely to be transported by air and remain suspended for longer than other fibers such as wool or polyester, which can cause widespread contamination in a forensic environment.

**Decontamination difficulties:** Despite decontamination efforts, external contamination from environmental sources or bodily fluids may persist, especially in autopsies. Standard decontamination procedures may not completely remove contaminants, complicating the interpretation of forensic results.

### Strategies to minimize contamination

**Hygiene and precautions:** Implementing strict hygiene protocols and using appropriate protective clothing can help reduce fiber transfer during forensic examinations

Controlled environments: Conducting examinations in controlled environments with minimal airflow and using specialized equipment can help limit fiber movement and contamination

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

Standardization and practice in Ecuador

Standardization of procedures for the collection and preservation of hair fibers is crucial to ensuring 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 training factors within the country's judicial system and forensic environment.

Nevertheless, challenges to adopting international standards for evidence management, such as those described in the Manual of Forensic Investigation Procedures, may include insufficient staff training, 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.

Current situation in Ecuador

The adoption of international standards in forensic science in Ecuador, particularly with regard to the 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 essential, but the full implementation of international protocols remains a work in progress.

### Challenges in adopting international standards

The implementation of modern protocols is contingent upon the adoption of international standards. Therefore, the following problems arise in Ecuador:

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

**Inconsistent training:** although training programs have been implemented, they do not always reach all technicians in the field, especially in rural areas or areas far from major forensic centers.

**Logistical challenges:** Collecting evidence in areas with extreme conditions makes it difficult to preserve fibers in optimal conditions.

A study 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 staff training.

### Legal Analysis of the Use of Hair Fibers as Forensic Evidence

From a legal perspective, the analysis of hair fibers as an integral part of the process, when considered as forensic evidence, must be analyzed from the guiding principles of due process, including the chain of custody and the admissibility of evidence, from a criminal context. Although fibers are considered small and insignificant in appearance, they contribute to decisive evidence in certain proceedings, provided that their handling, custody, and analysis comply with legal standards that guarantee reliability.

### Legal Importance of the Chain of Custody

The chain of custody is an essential principle that guarantees the traceability and integrity of physical evidence from the moment it is collected until it is presented 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 probative value in ensuring the accuracy of the process. According to Ecuador's Comprehensive Organic Criminal Code (COIP), evidence collected at a crime scene must be handled in accordance with established protocols that safeguard its integrity and prevent any alteration, thereby maintaining the accuracy of the facts.

In this context, the handling 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 on environmental conditions and methods used.

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

#### Nature and Scope of the Research Problem

Although there have been technological advances in fiber analysis in Ecuador, the effectiveness of collection and preservation techniques remains a fundamental issue for the advancement of forensic methodologies, as there are inadequate or improperly executed procedures that compromise the integrity of evidence, which may also result in its inadmissibility in court proceedings. The wide variety of surfaces on which fibers can be found (carpets, textiles, hard surfaces) and the fluctuating environmental conditions at crime scenes exacerbate these challenges. In addition, cross-contamination during collection or storage poses a continuous risk to the authenticity of samples.

Therefore, this study has focused on addressing existing shortcomings in the collection and preservation of hair fibers, in order to illustrate that, although they are tiny and seemingly insignificant, 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 evidence, fibers can serve as the only link between the suspect and the crime scene.

Furthermore, improving forensic practices in this area has substantial implications not only for solving 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.

Similarly, this study has a preventive impact, as perpetrators, recognizing that Ecuador's judicial system employs appropriate methodologies for the process of recognition, collection, and analysis of physical evidence, such as this particular case of hair fibers, are less likely to commit crimes. That is why the existence of established protocols that address and are aligned with due process, accompanied by cutting-edge technology, sends a clear message regarding the capacity of institutions to identify and prosecute those responsible for illegal acts, while also serving as a deterrent to the commission of crimes.

Increased public confidence in the judicial system and the social and cultural ramifications of this investigation are intrinsically interconnected, as both facets are underpinned by the professionalization and improvement of forensic practices. By ensuring that judicial decisions are based on solid, 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 tailored 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 strengthens society's trust in its institutions, but also contributes to the cultivation of a culture that views science as a fundamental pillar of justice and social progress.

## Methodology

The research was conducted using a qualitative approach, which seeks to gain a detailed understanding of the phenomena related to the collection and preservation of hair fibers at crime scenes. This approach has made it possible 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 into three main stages: data collection, analysis of results, and development of proposals.

The data collection stage will focus on obtaining detailed information through an exhaustive search of literature in high-impact academic databases such as Scopus, PubMed, and ScienceDirect, among others, as well as 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.

- The qualitative analysis involved categorizing the information into the following areas:
- Efficiency of different hair fiber collection techniques on different surfaces.
- Impact of environmental conditions on the integrity of the fibers. An analysis of temperature, light, and humidity.
- Identification of evidence-based best practices for preservation.

Based on the findings of the analysis, a proposal will be developed to optimize methods for collecting and preserving hair fibers.

## Results

In Ecuador, the procedure that forensic technicians use to collect hair samples follows general criminal investigation guidelines to ensure efficient collection and proper preservation of hair samples within the chain of custody. The process has several stages:

Initial assessment of the crime scene: as this is the first phase, it serves to plan and execute the investigation process correctly. To do this, investigators identify the area of interest and physical evidence. To accomplish this, they must:

Secure the affected area: this involves cordoning off the crime scene to prevent contamination, alteration of evidence, interference by uninvolved persons, and possible changes that could affect the investigation.

Preliminary identification of evidence: this is the part of the process that allows personnel to conduct 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 collection tools and 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 they are found. To do this, it must be taken into account that there are several tools that are used depending on the type of surface and the amount of fiber present at the scene, including:

Tweezers: used to collect individual hair fibers that are visible on small surfaces or that are in direct contact with other evidence, such as clothing, floors, adhered hair, and so on.

Adhesive tape: this tool is usually used when the evidence is found on flat, large, clean surfaces where the hair fibers are not embedded, thus ensuring that the evidence is collected cleanly for processing without altering the results.

Forensic vacuum cleaners: This type of tool is used for collection on surfaces such as carpets, car seats, and hard-to-reach places. These devices have filters designed to prevent the mixing of particles and thus 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

Herramienta	Ventajas	Limitaciones
<b>Pinzas</b>	<ul style="list-style-type: none"> <li>- Alta precisión para recolectar fibras individuales.</li> <li>- Control en la manipulación que minimiza el contacto directo.</li> <li>- Bajo costo y fácil disponibilidad.</li> </ul>	<ul style="list-style-type: none"> <li>- Ineficientes para recolectar fibras en superficies grandes o complejas, como alfombras.</li> <li>- Riesgo de dañar fibras frágiles debido a presión excesiva.</li> <li>- Requiere habilidad técnica del operador.</li> </ul>
<b>Cinta adhesiva</b>	<ul style="list-style-type: none"> <li>- Eficiente para recolectar fibras de superficies planas y amplias como muebles o pisos lisos.</li> <li>- Fácil uso y transporte.</li> <li>- Recolección simultánea de múltiples fibras.</li> </ul>	<ul style="list-style-type: none"> <li>- debido a un manejo inadecuado, existe un alto riesgo de contaminación cruzada.</li> <li>- Algunas fibras pueden dañarse al ser retiradas de la cinta.</li> <li>- Menor precisión en la identificación de fibras.</li> </ul>
<b>Aspiradoras forenses</b>	<ul style="list-style-type: none"> <li>- Ideal para recolectar fibras de superficies grandes y áreas difíciles como alfombras y asientos de automóviles.</li> <li>- Gran capacidad para recolectar partículas pequeñas y fibras incrustadas.</li> <li>- Equipadas con filtros especializados.</li> </ul>	<ul style="list-style-type: none"> <li>- Requieren análisis laborioso en laboratorio para separar fibras útiles de los residuos.</li> <li>- Tamaño y dependencia de energía eléctrica limitan su uso en ciertos escenarios.</li> <li>- Costo elevado.</li> </ul>

Collection procedure: this is the process that requires proper, orderly, systematic, and controlled execution for the collection of hair fibers at the crime scene. Therefore, it is essential to analyze the scene in order to select the tool that will be used, as this ensures the integrity of the samples by preventing 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 assigned to collect hair fibers must wear protective equipment such as gloves, a mask, and disposable clothing to prevent cross-contamination.

Systematic collection: When analyzing the crime scene and the surface where the hair fiber to be collected as evidence is located, it is essential to select the appropriate tool that will not affect or damage the sample to be collected.

Location record: Each sample collected must be labeled with precise information about its location, time, and method of collection.

Packaging and preservation of samples: Packaging is a fundamental part of the process, as proper preservation ensures that the hair fibers are free from possible contamination by external factors, thus guaranteeing the integrity of the sample until it is analyzed in the laboratory. To do this, the following must be included:

Storage material: the most commonly used are:

Paper envelopes: these are used to preserve individual fibers that have been collected with tweezers or adhesive tape. Using a paper envelope allows for proper ventilation to prevent the growth of microorganisms that could affect the collected sample.

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

Labeling: information about the case, sample number, and specific location within the scene must be included.

Temperature and storage: During transport, collected samples must be kept under controlled environmental conditions. Samples must therefore be transported and protected in properly sealed containers to ensure that the environment, i.e., temperature, humidity, and exposure to light, is controlled to prevent deterioration of the fibers. Once in the laboratory, the fibers are stored under controlled conditions until analysis, with strict entry and exit records to maintain the chain of custody.

Recording documents: these are the supporting documents that record all actions taken during the collection, transport, analysis, and storage of hair fibers. This process may include photographs, diagrams, and reports describing the location, method, and materials used for collection, as well as the respective preservation methods.

#### Critical Points for Hair Fiber Collection

Despite having a defined procedure for collecting hair fibers at the crime scene as evidence in the investigative process, there are several critical points that forensic personnel must take into consideration, including:

##### Improper handling

Incorrect use of tools: tweezers are one of the most commonly used tools due to their benefits. However, despite their precision, in certain scenarios, such as fibers embedded in complex surfaces, they can fragment the fibers, affecting subsequent analysis.

Improperly applied adhesive tape: Although it is an excellent tool for collecting hair fibers on flat surfaces, careless use can lead to the adhesion of contaminants or damage to the fibers when removed, causing contamination of the evidence collected and affecting the results of the investigative process.

Forensic vacuum cleaners: These are the most effective tools for large surfaces; however, incorrect use can mix collected fibers, making laboratory classification difficult.

##### Adverse environmental factors

High humidity: This condition promotes and allows chemical oxidation and microbial growth in fibers, especially those of natural origin such as cotton or wool, contaminating the evidence.

Exposure to UV light: Synthetic fibers are vulnerable to photodegradation, which could alter their chemical structure, reducing their evidentiary value.

Extreme temperatures: in cold environments, fibers can become brittle or suffer accelerated chemical deterioration at high temperatures, significantly affecting the laboratory analysis process.

#### Available infrastructure

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

#### Continuing education

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

#### Proposed improvement to the procedure for collecting and preserving hair fibers at crime scenes

The following is the procedure to be followed, based on the guidelines issued by the competent authority in Ecuador, as well as international organizations. The purpose is to ensure the integrity of the evidence so that it is admissible in court proceedings. Therefore, the following steps are suggested:

**Table 2:** *Proposed improvement to the procedure for collecting samples as evidence*

Paso	Actividad principal	Subactividades
Preparación en el lugar de la escena del crimen	Delimitación del área	Asegurar la escena del crimen, para ello, se puede utilizar cintas y barreras para evitar el paso a personal no autorizado.  Realizar una inspección visual del lugar, con la finalidad de identificar áreas prioritarias para la toma de muestras.
	Equipamiento necesario	Pinzas de acero inoxidable esterilizadas.  Cinta adhesiva forense de baja adherencia.  Aspiradoras forenses con filtros HEPA.  Sobres de papel, tubos de ensayo

		herméticos y bolsas opacas.
		Kit de protección personal: guantes, mascarillas, batas desechables.
	Registro inicial	Documentar la escena del crimen apoyados en fotografías y notas específicas.
<b>Recolección de fibras</b>	Elección del método (herramienta a ser usada dependiente el lugar de la escena del crimen)	<p>Pinzas son usadas para recolectar fibras individuales visibles en superficies pequeñas o delicadas.</p> <p>Cinta adhesiva forense, usada con preferencia para superficies planas o amplias. Para ello, se debe aplicar suavemente y despegar en un solo movimiento.</p> <p>Aspiradoras forenses para usar en áreas grandes o superficies difíciles, como alfombras y tapicerías. Para el efecto, asegurar el uso de filtros dedicados para cada zona.</p>
	Procedimiento de recolección	<p>Realizar cambio de guantes entre la recolección de muestras de diferentes áreas para evitar contaminación cruzada.</p> <p>Trabajar de forma sistemática de las zonas menos contaminadas hacia las más contaminadas.</p> <p>Etiquetar cada muestra inmediatamente después de su recolección, indicando la ubicación exacta y el método empleado.</p>
<b>Preservación de muestras</b>	Selección del material de embalaje	<p>Usar sobres de papel para la recolección de fibras capilares con pinzas o cinta adhesiva.</p> <p>Los tubos de ensayo herméticos deben ser empleados para fibras en ambientes húmedos o zonas de alta humedad.</p> <p>Las bolsas opacas son recomendadas para proteger las fibras de la luz ultravioleta durante el transporte.</p>
	Criterios de etiquetado	Realice el registro de:

<b>Transporte almacenamiento</b>	y Transporte al laboratorio	<p>Número único de identificación de la muestra.</p> <p>Descripción breve del origen de la muestra.</p> <p>Fecha, hora y método de recolección.</p> <p>Nombre del investigador responsable.</p>
		<p>Colocar las muestras en contenedores sellados para evitar la exposición a factores ambientales.</p> <p>Usar una caja rígida para garantizar la estabilidad de la muestra durante el traslado.</p>
	Condiciones de almacenamiento	<p>Mantener las muestras en un ambiente controlado con temperatura entre 18-22 °C y humedad relativa alrededor del 50%.</p> <p>Almacenar las fibras en áreas oscuras o con protección UV.</p>
<b>Documentación reportes</b>	y Documentación completa	<p>Incluir material fotográfico y diagramas del proceso que detallen la ubicación exacta de cada muestra recolectada.</p> <p>Elaborar un registro de la cadena de custodia, asegurando que cada paso esté debidamente firmado y fechado.</p>
	Informe preliminar	<p>Preparar un resumen inicial con detalles de las muestras recolectadas, herramientas empleadas y observaciones relevantes sobre las condiciones de la escena.</p>
<b>Capación continua</b>	Entrenamiento practico	<p>Realizar simulaciones periódicas de escenarios delictivos para reforzar habilidades en el manejo de fibras.</p> <p>Implementar capacitaciones para la actualización sobre avances tecnológicos y prácticas internacionales.</p>
	Evaluaciones regulares	<p>Establecer evaluaciones anuales del personal para garantizar el cumplimiento de los protocolos y la adopción de nuevos</p>

<b>Incorporación de tecnología</b>		procedimientos.
	Herramientas avanzadas	Adquirir aspiradoras con tecnología de filtrado avanzado y microscopios portátiles para análisis preliminares en campo.  Introducir contenedores con control de humedad para transporte seguro.
	Digitalización de procesos	Utilizar sistemas digitales que permitan registrar la cadena de custodia y facilitar la generación de informes.

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

The research conducted by presents guidelines for collecting hair samples, emphasizing the importance of using appropriate techniques to avoid contamination. To this end, it is essential that hair fibers be collected with clean gloves and then placed in septi 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, the authors focus their research on identifying the fundamental skills of crime scene investigators and emphasize the importance of effective crime scene processing for optimal investigative results.

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

## Conclusions

The comparative analysis of hair fiber collection methods at crime scenes depends directly on the type of surface and the nature of the evidence presented at each crime scene. On the one hand, tweezers are precise tools for handling individual fibers, but they are ineffective on large surfaces or with embedded fibers. On the other hand, adhesive tape allows for quick collection on flat surfaces, although it presents a high risk of cross-contamination and possible loss of samples. In addition, forensic vacuum cleaners are useful on large and complex surfaces, but require meticulous analysis in the laboratory to separate useful fibers from other debris.

Proper preservation of hair fibers is crucial to ensuring the integrity of evidence in an investigation, as environmental factors such as temperature, humidity, and light exposure that influence fiber stability must be considered. For this reason, paper envelopes are the most recommended method, as they allow ventilation and reduce moisture accumulation, 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 prevent sample degradation.

Cross-contamination remains a challenge in the collection and preservation of hair fibers, directly affecting the reliability of forensic evidence. The main factors contributing to contamination are the improper use of tools, incorrect handling of samples, and adverse environmental conditions. To reduce this problem, it is



recommended to implement strict protocols, use personal protective equipment, and apply systematic collection methods that minimize accidental fiber transfer.

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