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POTENTIAL OF HAIR ANALYSIS IN THE FIELD OF FORENSIC SCIENCES

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ABSTRACT

This paper delves into the intricate world of hair analysis as a subset of trace evidence, providing a comprehensive overview of its techniques, significance, and evolving role in modern forensic science. The paper begins by elucidating the structure of hair, highlighting the distinctions between human and animal hair, as well as variations within human hair from different regions of the body. Various techniques, such as microscopic examination, can elucidate key characteristics like color, diameter, and scale patterns. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) offer even finer details, allowing forensic experts to make more precise comparisons. Genetic analysis through mitochondrial DNA (mtDNA) and nuclear DNA (nDNA) can provide conclusive identification in some cases, especially when other methods fall short. The examination of drugs, toxins, and other foreign substances within the hair shaft can uncover critical information about a person's habits, environment, and potentially the cause of death in cases of poisoning or drug overdose. Its potential to unveil hidden clues is a testament to the enduring importance of this field in the realm of forensic science. In this article we thoroughly explain different techniques used for forensic analysis of hair. Laser induced breakdown spectroscopy is used to detect metal in hair sample while Chelex based extraction method is used to extract mtDNA from hair sample and to amplify it mtDNA analysis is used to determine maternal relationship of an individual.

Keywords: Hair analysis, Significance, Limitations, Forensics.

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INTRODUCTION

Mammal skin contains specialized follicles from which hair, a filamentous and proteinases structure, grows. Although hair has practical uses like shielding the skin from the weather, its historical and cultural importance is closely linked to human culture. Hair, which primarily consists of the protein keratin, gets its structure from follicles buried in the epidermis. The papilla cells found in these follicles are essential for hair development. These cells divide and undergo cell differentiation, which helps to produce keratin, the main structural element of hair. These keratinized cells mature and stack on top of one another to produce the three layers of the hair shaft: the medulla, cortex, and cuticle. Hair serves purposes that go beyond simple structural support. Hair aids in communication, camouflage, and thermoregulation in animals. Humans' scalp hair likely originated as a natural screen to guard the head from damaging sun exposure. In the meantime, hair on other bodily parts, such eyelashes and nostrils, acts as a physical barrier against foreign objects and substances that may otherwise enter the body. The cultural significance of hair has changed significantly over the years and is found in many different countries. Hair was a symbol of social prestige and attractiveness in ancient Egypt. Royalty used wigs fashioned from human or animal hair, and elaborate hairstyles were signifiers of privilege and may reveal a person's rank. Similar to how hairstyles today communicate social order, ancient Greek and Roman hairstyles were frequently accessorized with ribbons, gold threads, and beads. The significance of hair has also been influenced by religious activities and beliefs. Long hair has been associated with spirituality and strength across many civilizations. For instance, uncut hair is a fundamental principle in Sikhism, signifying a link to the divine. In a similar vein, Native American civilizations frequently regarded long hair in high respect as a sign of power and knowledge [1].The

European hair culture underwent a change during the Renaissance. Hairstyles that were complex and detailed were popular, frequently requiring the use of wigs, hairpieces, and ornate accessories. The powdered wigs that the elite wore served as both stylish accessories and a means of hygiene issue cover-up. Hair care and grooming customs underwent modifications as a result of the Industrial Revolution. The development of the first widely used shampoo in the 20th century changed personal hygiene and made it possible for people to wash their hair more thoroughly. From the 1960s' long, flowing locks to the 1920s' crisp bobs, hairstyles throughout the 20th century mirrored the shifting social mores and values of the time.

Hair has become a popular form of self-expression in recent years. Natural curls, vivid dyes, and elaborate braids are just a few examples of the many hairstyles used to express personal style and individuality. In addition, the idea of hair as a kind of art has gained popularity, with hairstylists pushing the envelope of creativity to create one-of-a-kind, inventive designs. Discussions of identity, race, and aesthetic standards are all intertwined with the cultural significance of hair. The trend for natural hair has gained steam, Opposing Eurocentric notions and fostering self acceptance. Social media has been very important in this since it has allowed people to share their particular hair adventures and create a feeling of community[2].

STRUCTURE OF HAIR

The intricate layers and components that make up the structure of hair all work together to give each strand its unique look and function. Here is a summary of the fundamental makeup of hair:

Hair Follicle

The tiny, tube-like hair follicle in the skin is what holds the hair shaft in place. It has the papilla, a group of cells in charge of delivering nutrients and oxygen to the hair that is growing.

Papilla

At the base of the hair follicle, there is a structure called the papilla, which is made up of blood vessels that feed the hair bulb nutrients to promote hair development.

Hair Bulb

The area of hair that is actively growing is called the hair bulb. It is found at the follicle's base and contains the rapidly dividing cells that generate new hair cells.

Hair Matrix

A specific region of the hair bulb called the hair matrix is where cells divide and differentiate to generate the various layers of the hair shaft[3].

Sebaceous Glands

These glands, which are joined to hair follicles, secrete sebum, an oily substance that aids in moisturizing and protecting the skin, hair, and nails.

Hair Shaft

The visible portion of the hair that protrudes past the skin's surface is called the hair shaft. It has a number of layers:

Cuticle

The hair shaft's outermost layer. It is made up of translucent, overlapping cells that resemble roof tiles. The cuticle promotes smoothness and luster while protecting the hair's inner layers.

Cortex

The middle layer of the hair shaft made up of keratin-filled fibrous cells. Strength, flexibility, and the hair's natural color are all provided by the cortex. The melanin pigment that gives hair color is also present.

Medulla

The hair shaft's deepest layer. Some hairs contain this soft, spongy structure, whereas others do not. Its purpose is not entirely clear.

Melanin

In the hair follicles, melanocyte cells create the pigment melanin. It comes in two primary varieties: eumelanin (dark pigment), and pheomelanin (light pigment), and gives hair its natural color[4]. Variations in hair color are determined by these pigments' mix and concentration.

Arrector Pili Muscle

This little muscle, which is connected to the hair follicle, is what causes "goosebumps," or the appearance of standing-on-end hair, when it contracts.

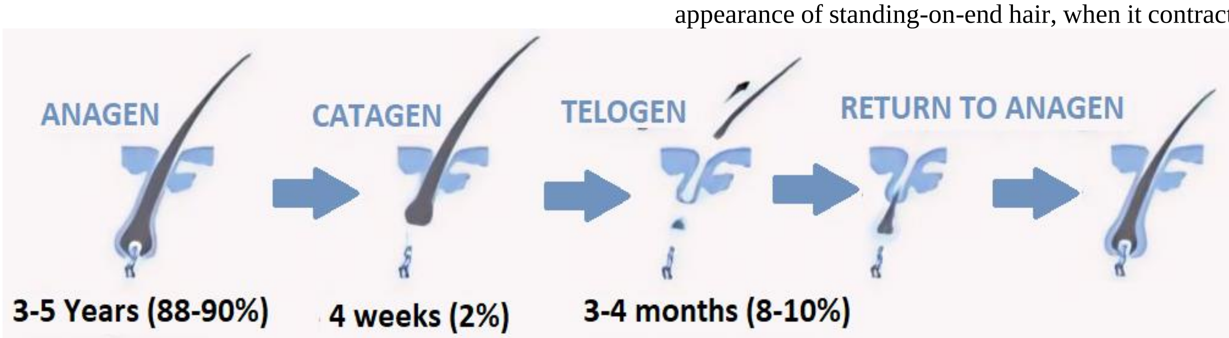

Fig. 1: Stage of hair growth.

Table 1: Composition of different substances in hair.

Substance	Hair
Cannabis	Up to 90 days
Alcohol	Up to 2 days
NDMA(Ectasy)	Up to 90 days
Cocaine	Up to 90 days
Methamphetamine	Up to 90 days
Heroine	Up to 90 days
Cotinine (a breakdown product of nicotine)	Up to 90 days

Table 2: The racial differences among different types of hair.

Asian hair/native American	European/Caucasian hair	African American
Round hair shaft	Slightly round to oval hair shaft	Flat to oval hair shaft
Straight	Straight to curly	Curly to kinky
Large pigment granules	Fine pigment granules	Largest and most dense pigment granules
Patchy distribution of pigment	Evenly distribution of pigment	Unevenly distribution of pigment
Usually, continuous medulla	Absent or fragmented medulla	Absent or fragmented medulla

Three phases make up the three stages of the cyclical growth process that hair goes through: anagen (growing), catagen (transitional), and telogen (resting). The hair bulb produces vigorous hair growth during the anagen phase. Growth slows down as the hair separates from the blood supply during the catagen phase. Before the old hair falls out and new hair starts to grow, there is a resting phase called the telogen phase. It is easier to understand the complex structure of hair and its different features, growth patterns, and elements that affect its quality and look [5].

ROLE OF HAIR IN FORENSIC AS A TRACE EVIDENCE

Hair has been used extensively in forensic science to establish connections between people and crime sites and to serve as an important piece of evidence in criminal investigations. Here are several applications of hair analysis in forensic science:

Identification

Hair can be used to identify people, especially when other forms of evidence might not be available. Although not as distinctive as DNA, hair features like color, texture, and shape can assist identify probable suspects.

Linking Suspects to Crime Scenes

It is possible to analyze a hair recovered at a crime scene or on the body of a victim to see if it resembles the suspect's hair or any previously identified samples. A person may have been at the site if certain hair traits, such as color, thickness, and scale patterns, are compared [6].

Time of Death Estimation

The length of hair can be used to determine how recently it was cut because hair development is a generally continuous process. This information can help create a timeline of events, especially when the victim's body is discovered after a considerable amount of time [7].

Toxicology

A person's hair has the unusual ability to hold onto traces of chemicals to which they have been repeatedly exposed. This covers substances like drugs, medicines, and poisons in the environment. Even in the absence of other forms of evidence, hair analysis can reveal information about a person's history of substance use or exposure.

DNA Analysis

Sometimes root tissue found in hair may include DNA. Although the presence of root tissue is not always confirmed in hair samples, DNA analysis can be utilized to identify people with a high degree of precision [8].

Examination of Hair Morphology

Hair samples can be examined under a microscope to show critical details, such as the presence of foreign substances, physical force damage, or even symptoms of diseases or medical disorders.

Geographic Origin and Ancestry

When constructing a profile of prospective suspects, some hair traits, such the form of the hair shaft and the presence of particular colors, can offer hints about a person's geographic origin or lineage[9].

Animal hair analysis

Animal hair analysis can shed light on the species of animal involved and the circumstances of an incident in situations involving animal attacks or cruelty [10].

LIMITATIONS OF HAIR ANALYSIS IN EVIDENCES

It's crucial to remember that, despite being a useful instrument in forensic science, hair analysis has its drawbacks. Hair is less individualized than DNA, thus it can be more difficult to positively identify an individual from a hair sample[11]. Additionally, there have been concerns and difficulties with its use as evidence due to contamination, environmental influences, and the lack of consistency in hair analysis methodologies.

Hair analysis is most effective when used in conjunction with other types of evidence and with careful evaluation of the particular circumstances of the case, as is the case with any forensic evidence [12].

SIGNIFICANCE OF HAIR ANALYSIS

Hair as trace evidence has historically been important in criminal investigations in the field of forensic science. Hair analysis has helped solve crimes, but as the subject has developed, it has been evident that there are limitations and a chance for error. In sum, the use of hair as a form of trace evidence can be summed up as follows:

Historical Significance

In forensic science, hair analysis has a long history, and cases from centuries ago show how it can be used to connect suspects to crime scenes and victims. It has been used as evidence since before the development of more sophisticated forensic methods [13].

Value in Context

Incriminating context can be learned from hair during criminal investigations. Hair samples can be examined under a microscope to identify probable sources, activities, and interactions between people and their environment [14].

INDIVIDUALIZATION CHALLENGES

The limitations of hair as a unique identifier have been highlighted, despite the fact that hair analysis was long thought to be a trustworthy technique for identifying suspects. Hair cannot identify a person with absolute certainty and is less distinctive than DNA [12].

Subjective Nature

In the past, comparing hair samples based on their appearance included subjective assessments. This raised the possibility of biases and inconsistent results, emphasizing the necessity for uniform and impartial procedures [15].

Advancements in DNA Analysis

The development of DNA analysis has completely changed the field of forensic science by providing a more exact and reliable method of connecting people to crime scenes. In comparison to hair analysis, DNA analysis can provide clear matches or exclusions, making it a more reliable type of evidence [16].

Collaborative Approach

Combining hair analysis with other sorts of evidence can help investigators gain a more complete picture of a crime. Collaborations that bring together hair analysis with DNA testing, fingerprint analysis, and other methods provide a more thorough investigative strategy [17].

Caution and Caution

Although hair evidence might be instructive, forensic specialists, detectives, and legal professionals must proceed with caution when using it. Maintaining the integrity of the criminal justice system requires an understanding of its limitations, possibility for contamination, and the requirement for rigor in analysis [18].

CASE STUDY OF HAIR ANALYSIS

The 19th century saw one of the earliest instances of hair analysis being used to help solve a crime. The "Trailside Murders," often referred to as the "Baltzell Murders," took place in Boston, Massachusetts, in 1839. One of the early uses of forensic hair analysis in criminal investigations is frequently identified as this case. A woman called Mary Ann Bickford and her ailing mother, Sarah Townsend, were brutally killed while strolling along a country trail in the Trailside Murders case. Hatchet was employed by the attacker, and it looked that robbery was the intended victim of the crime.

Investigators discovered some hair on a tree close to the crime site and some on the hands of the victims. At the time, people thought that a murder victim's hair would cling to the attacker's hair because the victim was resisting. This idea prompted detectives to speculate about the prospect of utilizing hair as proof to catch the perpetrator. Albert Tirrell, a suspect, was detained and put on trial for the killings. Dr. George Parkman, a local doctor, gave testimony regarding his hair analysis during the trial. He decided that the texture, length, and color of the hair found at the crime site and those retrieved from Tirrell were comparable. The testimony of Dr. Parkman was extremely important in persuading the jury of Tirrell's guilt. Tirrell was ultimately found not guilty of the murder accusations, but the case served as an early illustration of the use of forensic hair analysis in a criminal trial. Even though there was no scientific support for hair analysis at the time, and the results reached from hair comparisons were frequently arbitrary, it helped pave the way for later advancements in forensic research [19].

The study of hair analysis has changed over time as scientific methods have advanced. It's crucial to remember that earlier methods of hair analysis had drawbacks and were occasionally prone to errors and inaccuracies [19]. Hair evidence alone is not always reliable for identifying an individual, as modern forensic science has demonstrated, and DNA analysis has essentially replaced hair analysis as the gold standard for connecting people to crime scenes [7]. The Trailside Murders case served as a historical turning point in the early application of hair analysis to criminal investigations, demonstrating both the field's potential benefits and its possible drawbacks [20].

METHODOLOGY AND TECHNIQUES

Laser induced breakdown spectroscopy

The laser-based approach known as "laser-induced breakdown spectroscopy" (LIBS) allows for non-intrusive, qualitative, and quantitative measurements of metals under a variety of testing conditions. LIBS is an emission-type technology that has been used on gas, liquid, and solid sample types with good results. The main benefit of LIBS over other analytical techniques is the absence of the need for laborious sample preparation. LIBS (Laser Induced Breakdown Spectroscopy) (Laser Induced Breakdown Spectroscopy). The algorithm for self-absorption correction is applied to three various certified steel NIST samples as well as to three ternary alloys (Au, Ag, and Cu) with known compositions in order to test the model. The experimental results demonstrate that the self-absorption corrected Calibration-Free approach provides accurate results, enhancing by about one order of magnitude the precision and accuracy of the CF-LIBS procedure. It is capable of carrying out real-time multi-element analysis. Its primary drawback is that the excitation condition is susceptible to changes in both the surroundings and the laser energy, which can lead to imprecise measurement results. Comparing LIBS analysis to atomic absorption spectrometry and inductively coupled plasma atomic emission spectrometry (ICPAES), the tiny amount of sample material employed in LIBS analysis results in lower sensitivity for some metals [21].

Mitochondrial DNA analysis

In forensic scenarios where nuclear DNA typing is not an option, analysis of the mitochondrial DNA (mtDNA) sequence from human hairs has proven to be a useful supplement to conventional hair comparison microscopy. There has been minimal linkage of individual information, despite the fact that the fields of hair biology and mtDNA sequence analysis are well understood. The forensic DNA scientist may not always be familiar with topics like hair microscopy and hair embryogenesis. Human hair is continuously renewed and grown, involving intricate cellular regeneration processes. In turn, complicated interpretational issues can arise during the study of mtDNA sequencing data (eg, heteroplasmy and the sequence variation it may cause within an individual, or between related individuals). Now we go over the specifics of the histology of hair development, including the movement of mitochondria during hair growth and the corresponding challenges with mtDNA data interpretation. Forensic investigators may find it useful to use the macroscopic and microscopic categories of hair specimens as a guide to more accurately connect mtDNA sequence heteroplasmy data with a hair's physical attributes. The relative success of sequencing various types and/or forms of human hairs may be assessed using the same classifications for hair specimens. As the usage of mtDNA sequence analysis grows, the ultimate purpose of this review is to bridge the gap between forensic DNA scientists and hair microscopists [22].

In addition to blood and urine, hair has emerged as a key matrix for drug analysis. Hair analysis is suited for the 12-month identification of exposure to illicit and prescription drugs due to a long detection window. A method for drug screening in hair using liquid chromatography and tandem mass spectrometry (LC-MS-MS) was created and validated in the current investigation. The following substances/metabolites were detected using positive ion mode electrospray LC-MS-MS:

nicotine, cotinine, and morphine. The LC-MS-MS approach proven to be straightforward and reliable for identifying pharmaceuticals in hair [23].

Surface-enhanced Raman spectroscopy (SERS)

In this study, we show that synthetic dyes may be directly identified on hair using surface-enhanced Raman spectroscopy (SERS). This spectroscopic method has the benefit of fluorescence quenching, requires a small amount of sample, and may confirm analytes with single molecule resolution. Our research shows that SERS can: (1) tell whether or not hair was artificially colored, (2) tell if permanent or semipermanent colorants were employed; and (3) tell the difference between commercial brands used to tint hair. Such an evaluation can be done right at the scene of the crime, is quick, and does little damage[24].

Chelex-based extraction method

The likelihood that mitochondrial DNA from human head hair may be amplified and used forensically is examined in this study. A Chelex-based extraction technique was used to isolate mitochondrial DNA, and the LINEAR ARRAYTM duplex PCR system was used to amplify it. This study's specific goal was to analyze the morphological characteristics of human head hair in order to better understand the variables that affect the LINEAR ARRAYTM duplex PCR system's amplification success rate in hair tissue. The effectiveness of the amplification was evaluated in relation to a number of independent variables, including morphological traits, the presence or absence of telogen roots, donor age, scalp origin, use of cosmetic hair treatments, and race of the donor. The findings indicate that the presence of a telogen root and the success of amplification are positively correlated. The donor of shed hairs discovered at a crime scene can be identified using mitochondrial DNA (mtDNA) sequencing, which is a potent and accurate technique. Due to the low DNA content In lost hair and the sensitivity of PCR, contaminating cells (such as saliva or blood), which are occasionally present on these hairs, will co-amplify[25].

CONCLUSION

This article thoroughly explains the structure of hair, its chemical composition and role of hair as evidence in forensic analysis. Hair provides us different information about geographical origin of a person. With the help of advanced hair analysis techniques such as laser induced breakdown spectroscopy is used for the detection of metal element in the evidence. There are several types of expert forensic science evaluations that use the examiner's subjective judgment at least in part. One such test is the identification of human hair. This essay examines potential biases or sources of influence that could lead to examiner mistakes. The results of an experiment that contrasts the standard inspection process (known versus questioned samples) with a different method (a lineup of samples) intended to reduce the impact of error-causing factors are given. The alternative method resulted in 3.8% fewer false conclusions than the standard method (30.4%). It follows that hair analysis is important for finding traces of evidence to solve cases. It also describes the importance of hair as trace evidence.

REFERENCES

1. Peterson J. National Institute of Justice, U. S. G. P. Office, Washington D. C. (1974).
2. Buscaglia JA, Elemental analysis of small glass fragments in forensic science, Anal. Chim. Acta 288 (1–2) (1994) 17–24.
3. Koons RD, Peters CA, Rebbert PS, Comparison of refractive index, energy dispersive X-ray fluorescence and inductively coupled plasma atomic emission spectrometry for forensic characterization of sheet glass fragments, J. Anal. At. Spectrom 6 (6) (1991) 451, 10.1039/ja9910600451. - DOI
4. Koons RD, Buscaglia J, Distribution of refractive index values in sheet glasses, Foren. Sci. Commun 3 (2001).
5. Techniques of crime scene investigation. .(9thed.).CRCPress. BA, & Fisher, D. R. (2012).
6. Hair beads from Songo Mnara TCcaeflbmAAR, 40(2), 357-376.Wood, M., Dussubieux, L., Wynne-Jones, S., & Fleisher, J. (2023).
7. An interlaboratory study to evaluate the forensic analysis and interpretation of glass evidence. Forensic Chemistry, 100378Lambert, K., Montero, S., Akmeemana, A., Corzo, R., Gordon, G., Haase, E., & Almirall, J. (2022).
8. An inter-laboratory evaluation of OD-3 zircon for use as a secondary U–Pb dating standard. Island Arc, 382-394.Iwano, H., Orihashi, Y., Hirata, T., Ogasawara, M., Danhara, T., Horie, K., & Yamamoto, K. (2013). .
9. Hoffman T, Corzo, R., Weis, P., Pollock, E., van Es, A., Wiarda, W., & Almirall, J. (2018). An inter-laboratory evaluation of LA-ICP-MS analysis of glass and the use of a database for the interpretation of hair evidence. Forensic Chemistry, 11, 65-76.
10. Corzo, R., Hoffman, T., Weis, P., Franco-Pedroso, J., Ramos, D., & Almirall, J. The use of LA-ICP-MS databases to calculate likelihood ratios for the forensic analysis of hair evidence. Talanta, 655-661. (2018). .
11. Corzo R, Hoffman T, Ernst T, Trejos T, Berman T, Coulson S, Weis P, Stryjnik A, Dorn H, Pollock EC, Workman MS, Jones P, Nytes B, Scholz T, Xie H, Igowsky K, Nelson R, Gates K, Gonzalez J, Voss LM, Almirall J. An interlaboratory study evaluating the interpretation of forensic glass evidence using refractive index measurements and elemental composition. Forensic Chem. 2021, 100307.
12. Handbook of Trace Evidence Analysis -C, J., Hicks, T., & Trejos, T. (2020). Interpretation of hair evidence. .
13. Forensic Science International: Synergy, 404-415.J., Trejos, T., & Lambert, K. (2020). Interpol review of hair and paint evidence 2016-2019.
14. Statistical modeling and analysis of trace element concentrations in forensic hair evidence.K. D. K, K. (2018). .
15. Malmborg, J., & Nordgaard, A. Validation of a feature-based likelihood ratio method for the SAILR software. Part II: Elemental compositional data for comparison of Hair samples. Forensic Chemistry, 100385. (2022). .
16. K. A. J., Buckleton, J. S., & Triggs, C. M.A practical example of the interpretation of hair evidence. Science & Justice, 213-218. (1996). .
17. Koons RD, Buscaglia J, Bottrell M and Miller ET. Forensic Glass Comparisons in Saferstein's R (ed.) Forensic Science Handbook Volume 1, Prentice Hall, New Jersey, USA: (2002).
18. Homogeneity assessment of the elemental composition of windshield hair by µ-XRF LaL-I-MaFC, 27, 100384.Martinez-Lopez, C., Ovide, O., Corzo, R., Andrews, Z., Almirall, J. R., & Trejos, T. (2022). .
19. Forensic Science International: Synergy, 100306.Almirall, J., & Trejos, T. (2023). Interpol review of paint, tape, and hair evidence 2019–2022. .
20. Naes BE, Umpierrez S, Ryland S, Barnett C, Almirall JR, A comparison of laser ablation inductively coupled plasma mass spectrometry, micro X-ray fluorescence spectroscopy, and laser induced breakdown spectroscopy for the discrimination of automotive glass, Spectrochim. Acta B Atomic Spectrosc 63 (10) (2008) 1145–1150.
21. A., Corzo, R., & Almirall, J. Calculation of likelihood ratios in forensic Hair comparisons; introduction to an R code and Shiny app applied to existing background Hair elemental databases. Forensic Chemistry, 100390. (2022).
22. Elizabeth Tognoni GC, Stefano Legnaioli, Vincenzo Palleschi. Calibration-free laser-induced breakdown spectroscopy: state of the art Spectrochimica Acta Part B: Atomic Spectroscopy 65 (1), 1-14, 2010.
23. Charles A Linch DAW, Mitchell M Holland. Human hair histogenesis for the mitochondrial DNA forensic scientist Journal of Forensic Science 46 (4), 844-853, 2001.
24. S Hegstad HK, L Kristoffersen, N Kunøe, PP Lobmaier, AS Christophersen Drug screening of hair by liquid chromatography-tandem mass spectrometry Journal of Analytical Toxicology 32 (5), 364-372, 2008.
25. In Situ Detection and Identification of Hair Dyes Using Surface-Enhanced Raman Spectroscopy (SERS) Dmitry Kurouski RPVDAc, 2901-2906, 2015.
26. Mitochondrial DNA amplification success rate as a function of hair morphology Katherine A Roberts CCJofs, 40-47, 2007.