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HAIR TRACE ELEMENTS ANALYSIS: A BIOMONITORING TOOL FOR THE ENVIRONMENTAL EXPOSURES AND HEALTH RISKS

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Abstract

Human hair serves as a unique biomonitoring tool due to its ability to accumulate the trace elements over time, reflecting the environmental exposures and dietary intake. This study employed the Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to analyze the elemental composition of human hair samples of different colors—red, black, blonde and gray. The results revealed varying levels of essential and toxic elements across different hair types, indicating the potential exposures to the environmental pollutants. Notably, red and blonde hair exhibited higher concentrations of Cu, Fe, and Pb, which could be attributed to the environmental and dietary sources as well as the presence of metals in the hair coloring products. Gray hair also showed elevated Cu and Pb levels, possibly reflecting both environmental contamination and dietary intake. Non-washed hair generally displayed higher metal levels compared to washed samples, suggesting a prolonged exposure and accumulation. These findings highlight the utility of hair analysis as a non-invasive method for assessing the long-term metal exposures and their implications for human health.

***Keywords**: human hair, metals, environmental exposure, biomonitoring tool, ICP-MS*

1. INTRODUCTION

Human hair, a vital component of the integumentary system, comprises up to 80% keratin, a protein characterized by its α-helix conformation and intermolecular disulfide bonds that confer the mechanical strength and resilience [1]. The mechanical properties of hair allow it to stretch up to 30% before breaking, making it comparable to the copper wire of similar thickness [1]. The keratin hydrophilic nature contributes to a hair ability to retain up to 10% water [1].

The color and thickness of human hair are primarily determined by the type and distribution of melanin pigments synthesized within melanocytes located in the hair follicles [2]. Melanin biosynthesis involves the enzymatic oxidation of tyrosine, resulting in the formation of two main types of melanin: eumelanin, responsible for black and brown hair colors, and pheomelanin, which imparts yellow and red hues (Slominski et al., 2004). The varying concentrations and types of melanin pigment in hair contribute to its diverse range of colors, from blonde to black, with red hair typically containing higher levels of pheomelanin [2].

Apart from its structural and pigmentary roles, the human hair also acts as a reservoir for trace elements essential for physiological processes. Essential elements such as iron (Fe), copper (Cu), and zinc (Zn) play the crucial roles as cofactors in enzymatic reactions involved in metabolism and cellular function [3]. For instance, iron is essential for oxygen transport and energy metabolism, while zinc is involved in immune function and wound healing [3]. The levels of these elements in hair can reflect a long-term dietary intake and metabolic status [3].

Conversely, hair can accumulate the non-essential or toxic elements such as lead (Pb), cadmium (Cd), and mercury (Hg) from the environmental exposure [4]. These elements, even in trace amounts, can interfere with the enzyme function and cellular processes, potentially leading to the adverse health effects [4]. The accumulation of toxic elements in hair can serve as a biomarker of the environmental pollution and occupational exposure [4].

Hair growth occurs in distinct phases—anagen (growth), catagen (transition), and telogen (resting or shedding)—dictated by the hair follicle cyclical activity [5]. This cyclical nature, combined with the hair slow growth rate of approximately 1 cm per month, allows for the accumulation of elemental content over time [5]. Thus, the chemical composition of hair reflects the environmental exposures and nutritional status over a period of months, providing a retrospective biomonitoring tool for assessing the long-term environmental pollution levels and human health impacts [5].

This study is aimed to analyze the elemental composition of human hair of different colors, red, black, blonde and gray, using the Inductively Coupled Plasma Mass Spectrometry (ICP-MS). By characterization of these elemental profiles, it is asked to clarify the environmental impacts on the hair composition and explore the potential correlations with health outcomes. Understanding of these relationships enhances the utility of hair analysis as a non-invasive biomonitoring tool in the environmental and public health research.

2. EXPERIMENTAL

The five hair samples (Table 1) were processed, as follows: except for blonde and part of red hair, all samples were degreased by washing them in an aqueous detergent solution with vigorous shaking for several minutes. Subsequently, each sample was treated with a 0.1M EDTA solution for 5 minutes. The air-dried hair was then weighed into the Teflon cuvettes.

Mineralization was conducted using a microwave digestion system (ETHOS, Milestone, Italy). Each sample was digested with 6 mL of 65% HNO_3 and 2 mL of 30% H_2O_2 at 200°C for 20 minutes, utilizing a total power of 1350W. Following digestion, the resulting solutions were transferred to the standard vessels and diluted with deionized water to a final volume of 25.0 mL.

Table 1. *Hair samples categorized by the color, treatment, gender, age and weight*

Sample	Color	Treated	Gender	Age (years)	Weight (g)
1	Red	washed	female	29	0.930
2	Black	washed	female	21	1.004
3	Gray	washed	male	58	0.900
4	Blond	non-washed	female	23	1.009
5	Red	non-washed	female	29	0.909

The analysis of individual elements was performed using the ICP (Inductively Coupled Plasma) method on the ICP iCap 6500 Duo apparatus manufactured by the Thermo Scientific in England. Calibration curves were established using a multistandard solution: Multi-Element Plasma Standard Solution 4, Specpure®, which included 23 different elements. Specifically, it is focused on the following elements: Al, Ca, Co, Cr, Cu, Fe, Mg, Mn, Ni, Pb, Zn, and Tl.

The standard solutions contained the mentioned elements at the following concentrations: 1 ppb, 10 ppb, 100 ppb, 1000 ppb, and 5000 ppb. These concentrations were used to prepare the calibration standards, allowing the accurate quantification of each element in samples using the ICP analytical technique.

3. RESULTS AND DISCUSSION

The analysis of metal concentrations in hair samples provides the valuable insights into potential environmental and dietary exposures. Figures 1 and 2 illustrate the variations in metal levels across different hair samples, both washed and unwashed, and reveal patterns related to the hair color and treatment.

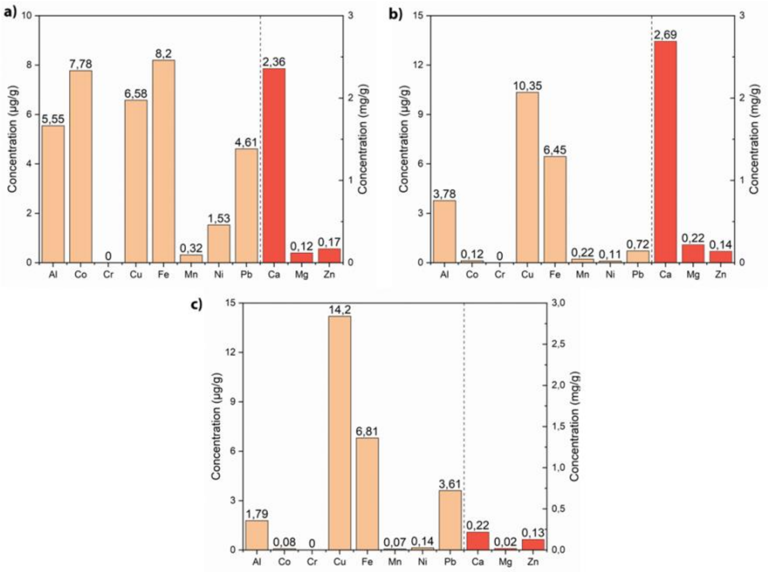

Figure 1. *Concentrations of metals determined in the washed hair samples: red (a), black (b), and gray (c) color*

Red Washed Hair: The elevated levels of aluminum (Al), cobalt (Co), copper (Cu), iron (Fe), nickel (Ni), and lead (Pb) in red washed hair samples could be influenced by exposure from the environmental sources such as air pollution or industrial emissions. Additionally, it is important to consider that hair coloring products used to achieve the red color may contain metals and other chemicals that contribute to these elevated levels. This potential contribution from cosmetics should be factored into the interpretation of these results.

Black Washed Hair: Increased copper levels in black washed hair samples suggest exposure from sources such as cosmetic products or industrial activities. The lower levels of toxic metals like Ni and Pb compared to the red washed hair samples indicate potentially reduced exposure to these elements. This could be due to differences in local environmental conditions, personal habits, or variations in hair treatments.

Gray Washed Hair: Elevated copper and lead levels are observed, indicating a significant exposure to these metals. This could be attributed to the environmental factors or dietary influences. The lower levels of essential elements such as calcium (Ca), magnesium (Mg), and manganese (Mn) might suggest deficiencies or reduced intake, which could affect the overall health and might be influenced by the dietary factors or absorption issues.

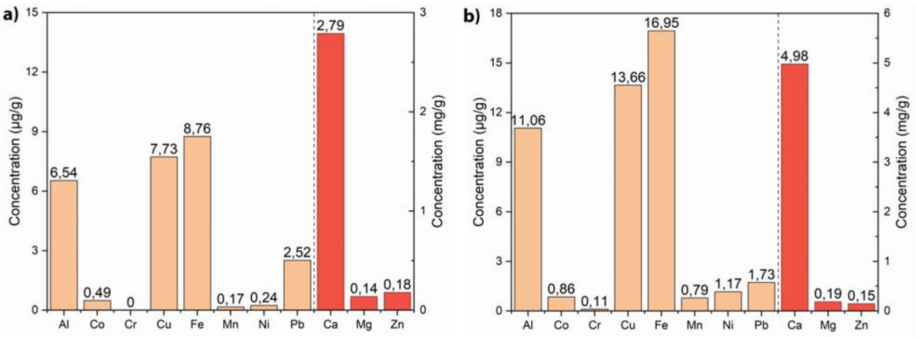

Figure 2. *Concentrations of metals determined in the non-washed hair samples: red (a) and blonde (b) color*

Red Non-Washed Hair: Similar to the red washed hair, the elevated copper, iron, and lead levels in the red non-washed hair indicate a significant exposure to these metals. Considering that the red hair is often colored with products containing metals, this potential source of metal content should be considered. The observed levels in non-washed hair may reflect cumulative exposure from both environmental sources and the metals in hair coloring products.

Blonde Non-Washed Hair: The elevated concentrations of aluminum, copper, iron, and nickel in the blonde non-washed hair could reflect exposure from the environmental sources or dietary intake. However, since the blonde hair is often treated with coloring products, which may contain metals, these treatments could contribute to the observed levels. The non-washed hair shows higher metal concentrations, suggesting a long-term accumulation, which may be influenced by both environmental exposures and residual effects from cosmetic treatments.

Overall, the data reveal that both red and blonde hair samples show higher levels of metals such as copper, iron, and lead, suggesting the considerable environmental and dietary exposures. Gray hair also shows elevated copper and lead levels, pointing to a significant exposure potentially linked to the environmental sources.

The comparison between the washed and non-washed hair demonstrates that the non-washed (untreated) hair typically exhibits higher metal concentrations, reflecting a long-term accumulation and potentially higher exposure levels. This finding underscores the importance of hair treatment history in interpreting the metal concentration data.

These results highlight the effectiveness of hair analysis as a biomonitoring tool for assessing the chronic environmental and dietary exposures to metals. The observed variations, based on hair color and treatment, underscore the need for further studies to explore the specific environmental and dietary factors influencing the metal accumulation. The future studies should be aimed to disentangle the contributions of the environmental exposures and cosmetic products to the metal concentrations in hair. This approach will enhance the understanding of sources of the metal exposure and their potential impacts on human health.

4. CONCLUSION

The analysis of metal concentrations in the human hair has provided the valuable insights into both environmental and dietary exposures. This study demonstrated that the hair samples of different colors, whether washed or unwashed, exhibit varying levels of metal content. The non-washed hair consistently showed higher concentrations of metals, suggesting a long-term accumulation and prolonged exposure. Notable elevations in metals such as copper (Cu), iron (Fe), and lead (Pb) were observed, which may be influenced by both environmental sources and presence of metals in the hair coloring products. Specifically, the red and blonde hair samples exhibited the higher metal levels compared to the black and gray hair, reflecting the potential contributions from the environmental exposure and cosmetic treatments.

The differences in metal concentrations between the washed and non-washed hair highlight the significant impact of hair treatment history on elemental composition. These findings reinforce the utility of hair analysis as a non-invasive method for assessing the chronic metal exposure. To enhance the understanding of metal accumulation and its health implications, the future research should be aimed to disentangle the effects of environmental, dietary, and cosmetic factors on the metal content in hair. Additionally, exploring the correlations between the hair metal levels and specific environmental pollutants, along with the associated health outcomes, will be crucial for informing the effective public health strategies and regulatory measures. This comprehensive approach will improve the knowledge on metal exposure and contribute to more effective management of its impacts on the human health.

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