



CHROMALENS PRECISION MAPPING AS AN INNOVATIVE SYSTEM FOR MICROZONAL HAIR ANALYSIS: STRUCTURE, ALGORITHM, AND COMPARISON WITH CLASSICAL COLORING TECHNIQUES

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Abstract. *The present article focuses on substantiating the theoretical foundations of the innovative ChromaLens Precision Mapping system, which integrates micro-zonal analysis of the hair fiber, optical mapping, and biometric parameters within the process of professional hair coloring. The relevance of this approach is determined by contemporary evidence from trichology, physics, and hair fiber chemistry, demonstrating that traditional coloring techniques (balayage, airtouch, foil methods, slicing) largely fail to account for several critically important structural and optical properties of the hair. These include variability in porosity, thermal conductivity, cuticular integrity, and the spectral behavior of pigments—all of which significantly influence color stability and the degree of chemical damage. Such factors explain the high unpredictability of outcomes characteristic of conventional methods.*

ChromaLens Precision Mapping is positioned as a science-driven technology that enables detailed diagnostics of 8–15 micro-zones of the hair shaft and the development of individualized formulas tailored to their specific optical, biometric, and photometric characteristics. The study analyzes key optical mechanisms relevant to the ChromaLens Precision Mapping approach, including the refractive properties of keratin structures, the interplay of diffuse and specular reflection, and the spectral variability of color under different lighting conditions.

The results indicate that the application of ChromaLens Precision Mapping ensures higher reproducibility of color outcomes, reduced chemical load on the hair, enhanced photometric color stability, and minimized structural degradation of the fiber compared with classical techniques. The proposed system thus represents a qualitatively new model of premium hair coloring, integrating analytical and diagnostic tools with practice-oriented algorithms to achieve a high degree of precision and predictability.

Keywords: *coloring, hair, photometric color stability, professional color science, ChromaLens Precision Mapping.*

Introduction

Hair coloring in the professional sphere remains a very complex procedure, as it involves not only chemistry, but also biology, physics, optics, and the structure of the hair itself. Although techniques such as balayage, airtouch, foil methods, and slicing have long been popular, they are mostly based on the experience of the stylist rather than on accurate diagnosis. As a result, the outcome often depends on the “hand” of the specialist, may differ significantly from what was expected, is difficult to repeat, and the chemical effect on the hair is uneven because different areas of the hair have different properties.



Scientific research shows that hair is a biopolymer composite with a complex multilayer structure, whose optical properties are determined by the interaction of the cuticle, cortical ball, and melanin granules [1; 2]. Even minimal changes in the structure of the cuticle can modify the spectral reflection profile by 15–35%, which directly affects pigment behavior, color balance, and visual stability of the result. At the same time, local differences in porosity, elasticity, hydration, and thermal conductivity cause uneven penetration of oxidants and dye mixtures, especially in traditional techniques that do not provide for zonal correction of formulas [3].

The lack of standardized methods for assessing the structural and optical characteristics of hair before dyeing is a significant limitation of modern coloristic. In practice, it is not uncommon for a single procedure to produce different shades on areas of hair with different porosity or different root zone temperatures. This significantly reduces the predictability of the result and increases the risk of damage to the hair structure due to excessive alkaline exposure or uncontrolled lightening.

In these conditions, there is a need to introduce new-generation technologies capable of taking into account the multi-level heterogeneity of hair, the spectral properties of light, the reactivity of different microzones, and the chemical picture of the process. One such technology is ChromaLens Precision Mapping (CLPM), an innovative microzone hair analysis system that combines instrumental diagnostics, optical mapping, mathematical modeling, and personalized formula selection.

Literature Review

In recent years, there has been growing scientific interest in the structural morphology of hair, the mechanisms of hair damage, its interaction with chemical agents, and the optical characteristics of the hair surface. In particular, the works of A. J. Grosvenor [4] and D. H. Kim [5] have established that the refractive index of keratin, the shape of the cuticle scales, and the orientation of surface microstructures determine the intensity and nature of light scattering, which is critically important for color prediction.

Research in the field of structural hair biochemistry by F. B Camargo [6] and R. Mantuan Gasparin [7] shows that porosity is the main predictor of chemical reactivity.



Hair with high porosity is characterized by accelerated dye penetration and uneven distribution, which causes significant tonal deviations within a single procedure. All this makes it difficult to achieve stable results with traditional techniques that use universal formulas without taking biometric parameters into account.

In addition, a number of studies by T. Imai [8], E. Martins [9], A. B. Ross [10], and S. Cedirian [11] have shown that the temperature of the root zone can change the kinetics of oxidation by 10–18%, causing excessive lightening in areas of high thermal conductivity. In classical techniques, such effects are not compensated for, leading to the so-called “hot root” or uneven tone transition.

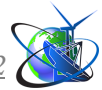
Authors E. Martins [9], A. B. Ross [10], and S. Cedirian [12] note in their studies that hair color can vary by 10–28% depending on the spectral composition of the lighting. This is an important factor for professional colorists, especially in cases of photo shoots, studio work, or runway shoots.

Despite the availability of this scientific data, there are currently no methods that integrate structural, optical, thermographic, and chemical analysis into a single practical system.

The aim of the study was to analyze the current state and justification of the ChromaLens Precision Mapping technology, analyze its structural components and microzonal modeling algorithm.

Research Results

The structure of hair as a biopolymer composite with a multi-level internal organization determines its complex optical, diffusion, and chemical behavior, which significantly affects the results of coloring procedures. Recent studies have shown that the condition of the cuticle, the thickness of the cortical layer, the topography of porosity, and the level of hydration form a heterogeneous reactivity profile along the entire length of the hair shaft [1; 2; 11]. Even minimal disturbances in the integrity of the cuticle can alter the nature of light scattering, reduce optical density, and distort the perception of shade. In such conditions, classical coloring techniques, given their empirical nature and the lack of instrumental diagnostic methods, prove to be insufficiently accurate, as confirmed by the high variability of the final results. Failure



to take into account local physical parameters of hair, such as porosity, elasticity, thermal conductivity, and the level of natural light reflection, leads to uneven transitions, changes in tone under the influence of different lighting spectra, and an increased degree of chemical damage [3; 13; 14].

CLPM technology was developed to eliminate procedural and methodological limitations. Its principle of operation is based on an analysis structure that integrates optical, biometric, thermographic, and morphological parameters of hair. Unlike classical techniques, where the distribution of strands and the choice of formulas are based mainly on the visual experience of the master, CLPM provides a quantitative assessment of the hair cover, dividing it into microzones that differ in their structural state and optical behavior. These microzones are formed based on the diffusion capacity of the hair, the local temperature profile of the scalp, the condition of the cuticle, and the nature of light reflection. Numerous studies confirm that the temperature of the root zone can accelerate the lightening reaction by up to 18%, while porosity affects the rate of oxidant penetration and the ability of hair to retain pigment [5; 9; 10]. Taking these parameters into account is a prerequisite for accurate prediction of the result.

Optical diagnostics is a key element of CLPM, as it allows determining hair behavior under different types of lighting and assessing its refractive properties. Hair with an intact cuticle is characterized by enhanced mirror reflection, which ensures uniform color perception. Hair with a damaged surface, on the other hand, has a significant amount of diffuse scattering, which creates optical artifacts, increases visual dullness, or causes a shift in shade to cool or warm tones depending on the lighting spectrum [6]. That is why CLPM pays special attention to identifying areas with reduced optical density, as they are the main cause of unpredictable reactions during coloring. Compared to traditional techniques, where color is applied evenly to all segments of the hair, the CLPM method allows the formula to be adapted to compensate for local optical differences and prevent uneven results.

The second key element of the system is biometric analysis, which makes it possible to determine the individual profile of the porosity and elasticity of the hair



fiber – parameters that directly affect its chemical sensitivity and reactivity. It has been established that fibers with increased porosity are characterized by accelerated pigment absorption, but due to the structural instability of the cuticle layer, they also demonstrate faster pigment loss after the coloring procedure. Thus, porosity is a determining factor for both the initial coloring result and subsequent color stability.

It has been shown that hair with mixed porosity can produce a difference in tone of up to 40% between segments of the same length [7]. In classic techniques, such differences are not taken into account, which leads to so-called “pigment failure” or uneven lightening. CLPM, on the contrary, involves adjusting the concentration of the oxidant, pH, and exposure time for each microzone. This ensures color reproducibility and significantly reduces the chemical load.

Photometric correction plays a special role in CLPM. It has been proven that hair color can vary by 10-28% depending on the lighting spectrum, particularly with cold spectrum LED lighting or stage lamps with an enhanced red component [8]. For clients who work in studio conditions or often capture their image in photos or videos, this difference is critical. CLPM simulates color behavior under different spectral conditions, which allows for stable results regardless of external lighting. In addition, CLPM emphasizes the structure of the hair and its individual characteristics.

One of the characteristics of CLPM is its ability to minimize structural damage to hair. The chemical processes used in traditional techniques, such as alkaline lifting of the cuticle and uncontrolled lightening, lead to the destruction of keratin disulfide bonds and degradation of the lipid layer. Scientific studies have shown that intensive lightening without taking into account porosity reduces the mechanical strength of hair by 25-40% [9]. CLPM, thanks to zonal pH regulation, preliminary protein reconstruction, and adaptive selection of oxidants, significantly reduces the degree of structural degradation. In addition, uniform toning, achieved by compensating for optical and biometric differences, prevents excessive repeated exposure to individual areas of hair, which is a common problem with traditional methods.

Taken together, these parameters show that CLPM is based on: the system combines the optical, biometric, and photometric properties of hair to create precisely



tailored individual formulas. Unlike conventional coloring techniques, CLPM allows you to work with hair in a more structured and precise way, relying not on the “eye of the master,” but on specific hair characteristics that are measured. This sets a new standard where the result is predictable and confirmed by instrumental data.

Traditional methods (balayage, airtouch, slicing, or classic foil methods) do not take into account the complex heterogeneity of hair and individual characteristics of hair structure, so the color often turns out to be unstable or uneven. CLPM, on the other hand, works with clear zonal formulas, scientifically based pH corrections, photometric calculations, and additional protective protocols. As a result, hair is significantly less damaged, and the color remains stable in different types of lighting. Thus, CLPM can be considered a modern, innovative, premium coloring system of the new generation. CLPM is a tool-based diagnostic structure based on quantitative parameters and standardized micro-zonal procedures. In this sense, CLPM is similar to scientific laboratory protocols, which makes comparison with classic techniques not only necessary but also methodologically sound. Since traditional techniques historically emerged as artistic approaches, they do not include diagnostic stages, statistical parameters, and the internal logic of safe pH regulation (Table 1).

It should be noted that none of the traditional techniques has the potential for standardization, since the final result depends on the human factor, the condition of the hair at the time of the procedure, the room temperature, and the speed at which the master performs the individual stages. CLPM, on the contrary, reduces the influence of subjective factors by creating a microzonal map and correcting chemical parameters in accordance with local biometric characteristics. That is why the comparison presented in Table 1 allows us to evaluate not only methodological differences, but also the scientific validation of CLPM as a technology.

The results show that all common coloring techniques, although popular, are still highly dependent on the stylist's experience. Therefore, the result can be unpredictable, and the level of chemical exposure can be unstable. The main problem with such methods is that they do not take into account the natural characteristics of hair, such as different porosity or how each section reflects light. This often results in spots, uneven



lighting, or a color that looks different under different lighting conditions.

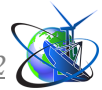
Table 1 - Comparative characteristics of ChromaLens Precision Mapping (CLPM) and classical staining techniques

Criterion	Balayage	Airtouch	Foil techniques	Slicing	CLPM
Porosity consideration	No	Partial	None	None	Complete (biometric diagnostics)
Optical hair analysis	Not available	Not available	Not available	Not available	Optical stratification (mirror/diffuse reflection)
Microzonal differentiation	None	None	None	None	8–15 microzones with separate formulas
pH control	Not available	Not available	None	None	Individual pH control in the formula
Photometric stabilization	Absent	Absent	Absent	None	Stabilization for different lighting spectra
Level of structural damage	Average	Medium	High	Medium	Low (reconstruction + zonal chemistry)
Reproducibility of results	Low	Average	Average	Low	High (instrumental diagnostics)
Suitability for photography	Variable	Variable	Variable	Variable	High (photometric analysis)

Traditional techniques do not control pH, even though it is pH that affects cuticle preservation and damage reduction. They also do not perform microzonal work, i.e., they do not analyze hair in separate areas. This reduces the accuracy of the result. In addition, such techniques do not take into account the optical properties of hair, which determine how the color will look under studio, daylight, or LED lighting. Therefore, in shooting conditions or when the lighting changes, the color may change or “break.”

CLPM, on the other hand, analyzes how hair reflects light, both diffuse and specular. This makes it possible to predict how the color will look in the studio, on stage, or under LED lights, which is especially important for professional photo and video shoots.

The biggest difference between the approaches is the level of hair damage.



Traditional techniques do not have mechanisms for controlling pH or assessing hair reactivity, so they often cause cuticle weakening and brittleness. CLPM is different: the technology includes protective and restorative steps, zonal formula adjustments, and oxidation control. This significantly reduces chemical stress and keeps the hair structure healthy. As a result, the color is accurate, even, and long-lasting, and the hair is less damaged and stronger in the long term. Given the differences in hair structure, optical behavior, and reactivity to chemical agents identified during the study, there is a need for a comparative analysis of traditional coloring techniques and CLPM technology. Such an analysis allows not only to quantitatively assess the methodological differences between the approaches, but also to demonstrate which diagnostic parameters (porosity, optical density, local thermoregulation, photometric stability, and chemical load) are overlooked by classical techniques (Table 2).

The main difference between CLPM and traditional techniques is the scientific nature of the diagnostic procedures. In traditional techniques, the stylist assesses the condition of the hair only “by eye.” This significantly reduces the accuracy of formula selection. Important factors such as porosity, local damage to the cuticle, the ability of hair to reflect light, or how pigment is distributed within the hair shaft remain unmeasured. Therefore, it is impossible to take them into account correctly when dyeing. CLPM solves this problem: the system uses specific tests and measurements, thanks to which the stylist receives real data rather than subjective impressions, on the basis of which the formula is created.

Taking into account the temperature of the scalp is also a very important part. In classic techniques, this is completely ignored, although it is the temperature that affects the speed of lightening and oxidation reactions. This is why “hot roots” or differences in tone along the length of the hair appear. CLPM compensates for this: the system selects the oxidant concentration and exposure time for each area separately, so the result is even, even if the hair is different in nature.

Another advantage is photometric analysis. Classic techniques do not take into account how color will look under different lighting conditions. CLPM calculates optical parameters (such as density and reflectance) so that color remains consistent



under studio, daylight, or LED lighting. This is especially important for photo and video shoots, as well as for work in the fashion industry.

Table 2 - Comparison of diagnostic parameters in classical staining techniques and the CLPM system

Diagnostic parameter	Balayage / Airtouch / Foil / Slicing	CLPM (ChromaLens Precision Mapping)
Porosity assessment	Visual, subjective	Quantitative: moisture absorption test, elasticity, cuticle index
Optical density determination	Not performed	Optical stratification: diffuse and specular light reflection
Analysis of cuticle condition	Visual assessment, inaccurate	Microscopic criteria: level of cuticle damage, structural segmentation
Scalp temperature map	Not taken into account	Taken into account: local thermal zones affect exposure time and oxidant concentration
Prediction of hair reactivity	Not possible	Algorithmic, based on biometrics and optics
Microzonality	Absent	8–15 microzones with individual formulas
pH control	Not performed	Systemic pH control + formula modification according to zone reactivity
Photometric analysis	Not available	Color stability assessment under LED, studio, and daylight lighting
Predictability of results	Variable, depending on the technician	High, standardized
Level of hair damage	Medium or high	Low due to controlled chemical exposure

In conclusion, ChromaLens Precision Mapping represents a completely new approach to professional coloristics. It is a system that combines optical diagnostics, biometrics, and photometry into one sophisticated algorithm. Unlike traditional methods, which depend on the experience of the stylist, CLPM allows you to predict the result and repeat it regardless of who is working.

The scientific basis of CLPM allows you to view hair not as a homogeneous material, but as a complex structure with different zones that react differently to dye and light. Thanks to the microzonal approach, formulas can be tailored to the actual



differences in hair – its porosity, elasticity, thermal conductivity, and ability to reflect light. As a result, the chemical effect is distributed precisely and in a controlled manner, eliminating the shortcomings inherent in traditional techniques.

Conclusions

The analysis shows that the ChromaLens Precision Mapping system is a completely different approach to hair coloring than traditional techniques. It differs in how the result is formed, how accurate it can be, and how safe the process is for the hair itself. While classic methods do not take into account the fact that hair is uneven along its entire length, CLPM, on the contrary, evaluates each area separately using optical, biometric, and photometric data. This makes it possible to create an individual formula for each micro-section of hair. This approach ensures even color, more accurate prediction of how the hair will react to dye, shade stability under any lighting, and minimal damage.

The practical application of CLPM confirms its microzonal approach, taking into account the properties of the hair—how it reflects light, how it conducts heat, and what its chemical balance is. CLPM uses formulas adapted to each zone, instrumental diagnostics, and pH control, which significantly reduces chemical stress on the hair. As a result, CLPM can be considered a modern, scientifically based premium coloring system that meets high professional standards and may become a new technological benchmark for the industry.

Prospects for Further Research

A promising direction is the creation of models that can predict how pigment will behave in hair, using data from optical and biometric diagnostics.

References

1. Thakur, S., Sharma, A., Cieśla, R., Mishra, P. K., & Sharma, V. (2024). A novel approach using ATR-FTIR spectroscopy and chemometric analysis to distinguish male and female human hair samples. *Die Naturwissenschaften*, 111(1), 9. <https://doi.org/10.1007/s00114-024-01896-7>
2. Lourenço, C. B., Fava, A. L. M., Dos Santos, É. M., de Macedo, L. M., Tundisi,



L. L., Ataide, J. A., & Mazzola, P. G. (2021). Brief descriptions of the principles of prominent methods used to study the penetration of materials into human hair and a review of examples of their use. *International journal of cosmetic science*, 43(2), 113–122. <https://doi.org/10.1111/ics.12683>

3. Dias Santos, J., Pinto, P. F., Edwards, H. G. M., & Cappa de Oliveira, L. F. (2022). Characterization by Raman and infrared spectroscopy and fluorescence microscopy of human hair treated with cosmetic products. *Spectrochimica acta. Part A, Molecular and biomolecular spectroscopy*, 280, 121577. <https://doi.org/10.1016/j.saa.2022.121577>

4. Grosvenor, A. J., Deb-Choudhury, S., Middlewood, P. G., Thomas, A., Lee, E., Vernon, J. A., Woods, J. L., Taylor, C., Bell, F. I., & Clerens, S. (2018). The physical and chemical disruption of human hair after bleaching - studies by transmission electron microscopy and redox proteomics. *International journal of cosmetic science*, 40(6), 536–548. <https://doi.org/10.1111/ics.12495>

5. Kim, D. H., Oh, S. H., & Chang, B. S. (2024). Effects of excessive bleaching on hair: comparative analysis of external morphology and internal microstructure. *Applied microscopy*, 54(1), 11. <https://doi.org/10.1186/s42649-024-00104-0>

6. Camargo, F. B., Jr, Minami, M. M., Rossan, M. R., Magalhães, W. V., Porto Ferreira, V. T., & Maia Campos, P. M. B. G. (2022). Prevention of chemically induced hair damage by means of treatment based on proteins and polysaccharides. *Journal of cosmetic dermatology*, 21(2), 827–835. <https://doi.org/10.1111/jocd.14148>

7. Mantuan Gasparin, R., Botelho Lourenço, C., & Ricci Leonardi, G. (2025). Porosity and Resistance of Textured Hair: Assessing Chemical and Physical Damage Under Consumer-Relevant Conditions. *Cosmetics*, 12(3), 93. <https://doi.org/10.3390/cosmetics12030093>

8. Imai, T. (2011). The influence of hair bleach on the ultrastructure of human hair with special reference to hair damage. *Okajimas folia anatomica Japonica*, 88(1), 1–9. <https://doi.org/10.2535/ofaj.88.1>

9. Martins, E., Castro, P., Ribeiro, A. B., Pereira, C. F., Casanova, F., Vilarinho, R., Moreira, J., & Ramos, Ó. L. (2024). Bleached Hair as Standard Template to Insight



the Performance of Commercial Hair Repair Products. *Cosmetics*, 11(5), 150. <https://doi.org/10.3390/cosmetics11050150>

10. Ross, A. B., Maes, E., Lee, E. J., Homewood, I., Marsh, J. M., Davis, S. L., & Willicut, R. J. (2022). UV and visible light exposure to hair leads to widespread changes in the hair lipidome. *International journal of cosmetic science*, 44(6), 672–684. <https://doi.org/10.1111/ics.12810>

11. Cedirian, S., Prudkin, L., Piraccini, B. M., Santamaria, J., Piquero-Casals, J., & Saceda-Corralo, D. (2025). The exposome impact on hair health: etiology, pathogenesis and clinical features – Part I. *Anais brasileiros de dermatologia*, 100(1), 131–140. <https://doi.org/10.1016/j.abd.2024.07.003>

12. Cedirian, S., Prudkin, L., Santana, J. A., Piquero-Casals, J., Saceda-Corralo, D., & Piraccini, B. M. (2025). The exposome impact on hair health: non-pharmacological management. Part II*. *Anais brasileiros de dermatologia*, 100(2), 322–327. <https://doi.org/10.1016/j.abd.2024.08.006>

13. Samra, T., Lin, R. R., & Maderal, A. D. (2024). The Effects of Environmental Pollutants and Exposures on Hair Follicle Pathophysiology. *Skin appendage disorders*, 10(4), 262–272. <https://doi.org/10.1159/000537745>

14. Ali, N., Marsh, J., Godfrey, S., & Williams, D. R. (2018). Aqueous MEA and Ammonia Sorption-Induced Damage in Keratin Fibers. *ACS omega*, 3(10), 14173–14180. <https://doi.org/10.1021/acsomega.8b01189>