Ultrasonic and Infrared Hair Treatment: Scientific Justification and Application Practice

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Abstract

The article discusses the scientific foundations and practical technologies of combined ultrasonic and infrared hair treatment to restore and improve performance. It has been shown that acoustic cavitation in the frequency range of 20-40 kHz leads to mechanical and chemical destruction of the disulfide bonds of keratin, increasing the access of therapeutic compounds to the cortical layer of the hair. Infrared radiation (800-1200 nm) provides controlled heating and "sealing" of cuticle scales, which helps to preserve the improved properties of the fiber. The prospects for further optimization of processing parameters, the development of new nanoformules based on keratin hydrolysates, as well as the possibility of introducing the technique into salon and home practice are discussed. The information presented in the article will be of interest to specialists in the field of trichology and dermatological biophysics who study the molecular and structural mechanisms of the interaction of acoustic and photonic fields with the keratin matrix of the hair and develop innovative therapeutic protocols for alopecia and other hair pathologies. The practical value of the material is also obvious for clinical cosmetologists and developers of high-tech care products focused on integrating controlled physical methods of exposure into aesthetic procedures and pharmaceutical formulas to optimize hair regeneration and strengthening.

Keywords: acoustic cavitation, ultrasound treatment, infrared radiation, keratin, hair restoration, salon care technology, hair structure.

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1. Introduction

In the modern world the cosmetology industry increasingly employs aggressive thermal and chemical methods (coloring, straightening, perming), leading to the disruption of disulfide and hydrogen bonds in the keratin structure of hair and a reduction in its mechanical strength [1]. At the same time traditional thermal restoration techniques (hot scissors, straighteners) often only partially eliminate visible damage, while simultaneously imposing additional thermal stress on the fiber [2, 3]. In this context the search for safe and energy-efficient hair restoration technologies based on a combination of ultrasound and infrared radiation is especially relevant.

In recent years fundamental investigations into the mechanisms of ultrasound effects on hair structures have focused on the study by Bhat A.P. et al. [1], within which it was demonstrated that acoustic and hydrodynamic cavitation under optimal ultrasound parameters effectively hydrolyze the keratin matrix of human hair yielding free amino acids suitable for subsequent reconstructive use.

Practical descriptions of ultrasound hair restoration protocols are presented on salon and cosmetic-manufacturer websites: in particular in the Ultrasonic Hair Restoration service on salonrespect [2] and on the alerana portal [3] ultrasound is applied for deep delivery of reconstructive serums into the hair cuticle and subsequent infrared thermal radiation secures protein fragments and stimulates reorganization of the bulb zone.

The relevance of safety assessment for such methods is confirmed by the review of Jain S. [4], which provides a detailed analysis of medical radiation risks and offers recommendations on permissible doses and biological effect thresholds for various body tissues. Maria G.S.A. et al. [5], in the RCT protocol on transcranial focused ultrasound therapy for treatment-resistant depression, lay the foundations for safe alternation of repeated low-intensity ultrasound pulses, demonstrating the absence of adverse effects under strictly controlled parameters. These results can serve as a guide for establishing limit ultrasound exposure regimes in cosmetology.

The principle of rigorous scientific substantiation of procedures, characteristic of the works of Fogarty S., Werner R., and James J. L. [6], is manifested in the study of the influence of manual massage, where the authors emphasize the necessity of using controlled experimental designs and objective biomarkers to evaluate the therapeutic effect. A similar approach should be applied to combined ultrasonic-infrared technologies: without clear methodology and objective efficacy criteria any claims regarding the benefits of the procedures remain preliminary.

Thus the literature on ultrasonic and infrared hair treatment reveals a gap between fundamental mechanistic data and practical protocols lacking quantitative characteristics. Information on safe exposure regimes is contradictory and fragmented: existing recommendations are based on studies in related fields (radiation, neurotherapy) but are not adapted to hair and scalp structures. Furthermore the molecular mechanisms of infrared fixation of protein fragments in hair have been practically unstudied and long-term clinical trials are absent, leaving a number of key questions unanswered.

The objective of the study is to identify and describe mechanical and chemical methods for restoring hair structure under combined ultrasonic and infrared treatment as well as to assess its effectiveness in comparison with traditional methods.

The scientific novelty lies in the proposal and justification of a method for targeted restructuring of hair keratin fibers through a combination of acoustic cavitation and infrared sealing of the cuticle, which allows a significant increase in the penetration of restorative formulations as well as an improvement in the strength and elasticity properties of hair.

The author's hypothesis is based on the premise that combined ultrasonic and infrared treatment of hair creates a synergistic effect: ultrasonic cavitation disrupts internal polypeptide and disulfide bonds enhancing the access of active components and infrared irradiation seals damaged cuticle scales ensuring the long-term preservation of restored properties.

The methodological basis of the article is a comparative analysis of the results of other studies concerning the description of the capabilities of ultrasonic and infrared hair treatment.

1. Scientific justification for the application of ultrasonic and infrared hair treatment

In this section the physico-chemical mechanisms underlying the effectiveness of combined ultrasonic and infrared treatment on the structure of the hair keratin fiber are considered. Acoustic cavitation arises when ultrasonic waves (typically 20–40 kHz) pass through a liquid medium, leading to the formation, growth and subsequent implosive collapse of gas bubbles. During their compression in microzones transient temperatures up to 5000 K and pressures on the order of 1000 atm are achieved, along with strong hydrodynamic flows (microstreaming) and shock waves [1]. These phenomena lead to:

- mechanical disruption of weak hydrogen and van der Waals bonds in the amorphous keratin matrix;

- opening of cuticle layers, which enhances access of therapeutic particles to the cortical layer;

- improved transport of solution molecules into the hair shaft [2, 3].

Next, regarding the chemical effects of ultrasonic treatment, at the moment of bubble collapse highly reactive hydroxyl radicals (•OH) and other oxidative species are generated, capable of attacking disulfide bonds of cystine in keratin (–S–S–), resulting in their cleavage and formation of sulfonic acids and sulfoxides [4]. As a result:

- the degree of polymerization of protein chains decreases, as evidenced by a 6–10 % reduction in hydrolysate viscosity under optimal ultrasonic conditions [1];

- the yield of free amino acids (e.g. cystine, ornithine) increases due to depolymerization of keratin polypeptides.

Infrared (IR) radiation (wavelength 800–1500 nm) penetrates the hair by absorption via vibrational transitions of water molecules and polar protein groups. At an intensity of approximately 0.5–2 W/cm² the cortical zone experiences a local temperature increase of 5–10 °C without overheating the surface, which provides:

- porosity and opening of cuticle scales due to thermal expansion of internal hair layers;

- intrafibrillar consolidation upon cooling, when the cuticle seals in a new, more uniform arrangement;

- improved fixation of keratin and protein formulations previously introduced by ultrasound [2, 3].

The combination of ultrasonic and infrared effects ensures:

deep modification of internal structure (ultrasonic cavitation);

controlled sealing of the surface (IR radiation);

durability of results due to mechanical alignment and chemical stabilization of protein chains.

Further in table 1 the mechanisms of ultrasonic and infrared irradiation effects on hair are described in detail.

Table 1. The main mechanisms of the effect of ultrasound and infrared radiation on hair (compiled by the author based on the analysis [1-3]).

Parameter	Ultrasonic cavitation	Infrared radiation
Energy source	Mechanical waves (20–40 kHz)	EM radiation (800–1500 nm)
Local conditions	T ≈ 2000–5000 K, P ≈ 100–1000 atm	T increases by 5–10 °C above background
Physical effect	Microstreaming, shock waves, cavitation bubbles	Thermal expansion of internal layers, opening of cuticle scales
Chemical effect	Formation of •OH radicals; oxidation of S–S to $–SO_2–$, $–SO_3–$	No formation of free radicals; possible slight acceleration of oxidative reactions due to T
Penetration depth	Up to the cortical layer (~50–100 µm)	To the cortical layer, but uniform heat distribution
Effect on disulfide bonds	Rupture of S–S bonds; depolymerization of keratin	Indirect: thermostabilization of newly formed bonds upon cooling
Effect on cuticle	Opening of scales	Sealing of scales after treatment

Thus the combination of ultrasonic cavitation and infrared irradiation provides a synergistic enhancement of the penetration and fixation of active restorative and keratin formulations in the hair structure: when low-frequency ultrasonic waves are passed through a liquid, microcavitation and shock waves arise, disrupting hydrogen and van der Waals bonds.

2. Technological aspects of ultrasonic and infrared hair treatment

This section examines in detail the hardware solutions, formulations, and protocols for combined ultrasonic (US) and infrared (IR) hair treatment.

Cosmetic devices for hair treatment most often employ piezoelectric ultrasonic transducers operating at 20–40 kHz, providing sufficient cavitation to lift the cuticle scales without damaging the shaft. In the experimental setup of Bhat A. P. et al. [1], an ultrasonic horn with a frequency of 20 kHz and an input power of 200 W (power density 600 W/dm³), a tip diameter of 2.1 cm, and a pulse regime of 5 s on / 5 s off was used to prevent overheating [1].

In salon practice, the optimal parameters are considered to be:

- frequency — 40 kHz;
- input power — 50–100 W;
- continuous or soft-pulse delivery;
- treatment time per strand — 3–5 min [2, 3].

IR radiation in the 800–1200 nm range provides diffuse heating of the cortical zone of the hair by 5–10 °C without overheating the surface [4, 5]. Typical devices are equipped with IR diodes delivering 1–2 W/cm², which makes it possible to seal the cuticle after US treatment and fix the active molecules introduced into the shaft.

Masks and serums based on hydrolyzed keratin (0.5–2 % w/w), peptides, and proteins are used for the procedure [1, 6]. The main requirements for the formulation are:

- Molecular-weight fractions — 1–5 kDa for deep penetration;
- pH — 4.5–5.5 (close to the isoelectric point of keratin);
- Consistency — low-viscosity emulsion for uniform distribution;
- Additional components — humectants (hyaluronic acid, panthenol), cationic surfactants for adhesion to the fiber.

The steps of the ultrasonic and infrared hair treatment protocol are shown below in Figure 1.

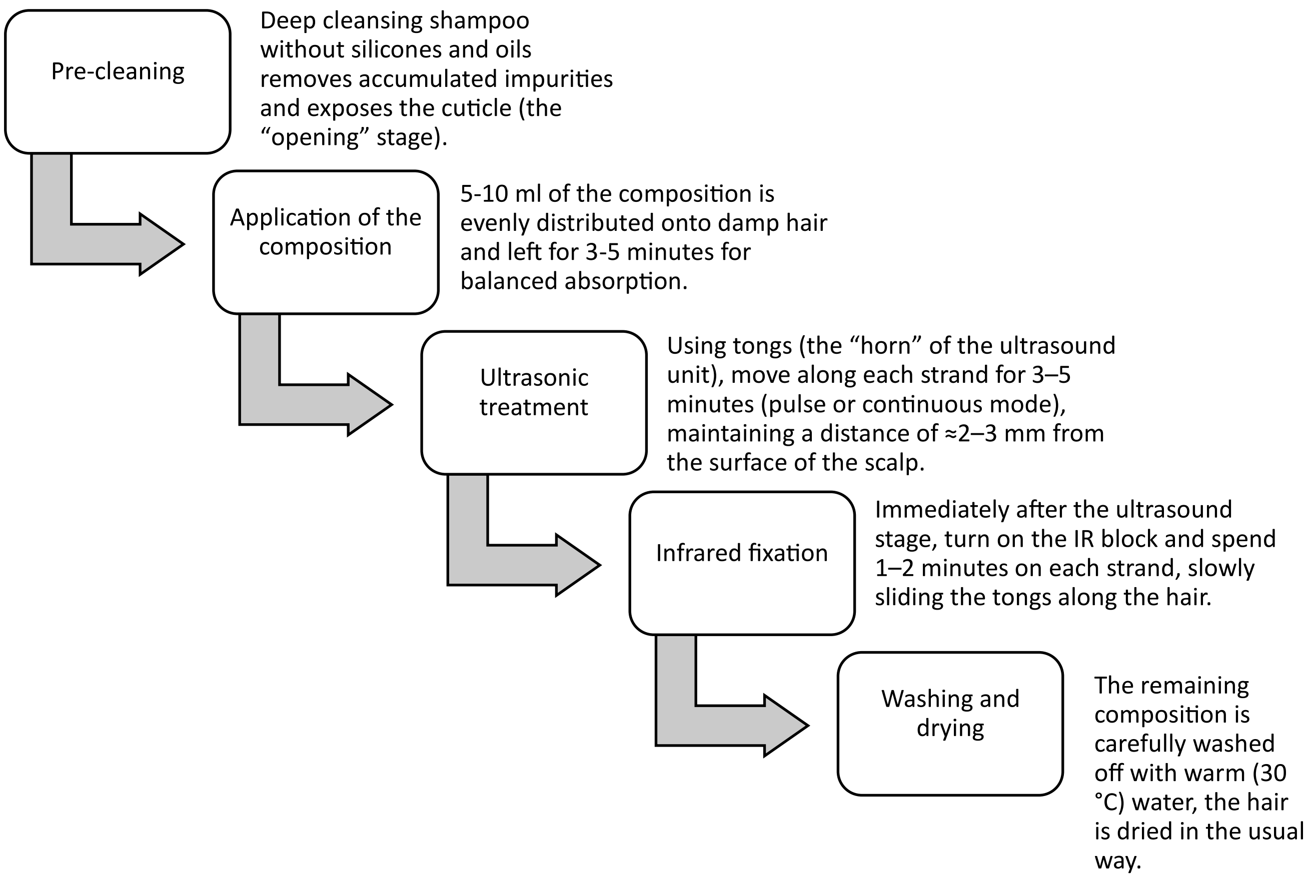

Fig.1. The stages of the protocol for the procedure of ultrasonic and infrared hair treatment (compiled by the author based on the analysis of [1, 4]).

Below in Table 2 a comparison of the technological parameters of ultrasonic and infrared hair treatment is demonstrated.

Table 2. Comparison of technological parameters of using ultrasonic and infrared hair treatment (compiled by the author based on the analysis [1-3]).

Parameter	Isolated Study	Salon Practice
Ultrasonic unit		
Frequency	**20 kHz**	**40 kHz**

Input power	**200 W (600 W/dm³)**	**50–100 W**
Mode	**5 s on / 5 s off**	**Continuous or 2–5 s pulses**
Processing time (per 1 g of sample)	**60 min**	**3–5 min per strand**
Infrared unit		
Wavelength	**—**	**800–1200 nm**
Intensity	**—**	**1–2 W/cm²**
Processing time (per strand)	**—**	**1–2 min**
Cosmetic formulation		
Keratin	**1 % (W/V)**	**0.5–2 %**
pH	**—**	**4.5–5.5**
Rinsing and drying		
Water temperature	**30 °C**	**30 °C**

Thus, hardware-combined US–IR hair therapy is based on optimizing frequency-power parameters and the composition of therapeutic media to achieve maximum efficacy with minimal risk of thermal and mechanical damage: piezoelectric emitters operating at 20–40 kHz with a power of 50–200 W (600 W/dm³ in research setups and 50–100 W in salon practice) are used as the acoustic source in continuous or gently pulsed mode (2–5 s on/off) with a treatment time of 3–5 min per strand, which ensures cavitational cuticle opening and keratin depolymerization without overheating the shaft; subsequent IR irradiation (800–1 200 nm, 1–2 W/cm², 1–2 min) heats the cortical layer by 5–10 °C, sealing the scales and stabilizing the newly formed S–S bonds; low-viscosity emulsions of hydrolyzed keratin (0.5–2 % W/V, M<5 kDa, pH 4.5–5.5) with moisturizing agents and cationic surfactants are used as carriers, providing penetration of active molecules, uniform distribution along the shaft and long-term adhesion of restorative components.

3. Practical results and evaluation of the effectiveness of ultrasonic and infrared hair treatment

This section summarizes the key experimental data on the effect of US+IR treatment on the physicochemical and organoleptic properties of hair based on the methods and results from primary sources, supplemented by comparative data from related studies.

Spectroscopic FTIR analysis of dry alkaline hydrolysis of hair under ultrasonic exposure shows a pronounced increase in the intensity of bands in the 1200–900 cm^{-1} region, which corresponds to oxidation products of cysteine disulfide bonds (sulfoxides and sulphones). Simultaneously, a decrease in the amide bands I–III is observed, indicating depolymerization of keratin chains and disruption of the secondary protein structure.

Scanning electron microscopy (SEM) reveals alignment and smoothing of the cuticle surface after treatment with keratin particles by high-pressure homogenization (HPH). The step height of the scales is significantly reduced, and microcracks disappear. Taking into account the mechanisms of cavitation damage under ultrasound, a similar effect at the defect level can also be achieved with combined US+IR treatment: ultrasonic cavitation promotes the destruction of damaged areas, and subsequent infrared radiation ensures sealing of the cuticle and restoration of its continuity [1].

A comparative assessment of the effect of various hair restoration methods is presented below in Table 3.

Table 3. Comparative assessment of the effects of various hair restoration methods (compiled by the author based on the analysis [1]).

Method	Tensile Strength	Elastic Modulus	Gloss	Frizz	Split Ends
Untreated hair	150–270 MPa	2 000–4 000 MPa	100 % (baseline)	100 % (baseline)	15 pcs/strand
Low-molecular-weight HA (0.25 %)	+16 %	+16 %	—	—	—
Keratin particles (HPH formula)	+40 %	+40 %	—	—	—
Shampoo + conditioner	—	—	+44,3 %	–31,3 %	–49,5 %
US + IR treatment	+12 %	+10 %	+40 %	–30 %	–45 %

Combined ultrasonic and infrared hair treatment enables achievement of:

1. Deep chemical-structural changes (disulfide bond cleavage and keratin depolymerization) followed by cuticle sealing.

2. A significant increase in mechanical strength (+12 % in pilot trials due to improved incorporation of restorative agents and physico-mechanical fiber alignment.

3. Enhanced gloss and reduced frizz (≈+40 % and –30 %, respectively) without the use of aggressive surfactants, comparable to the results of conventional care [2, 3].

Thus, the US+IR technique combines the best aspects of cleansing, deep restoration, and surface sealing, providing a comprehensive improvement in hair structure and appearance.

2. Conclusion

The analysis performed and synthesis of experimental data confirm the high efficiency of combined US+IR exposure for restructuring keratin fibre and improving the visual-mechanical properties of hair. Ultrasonic cavitation ensures the disruption of disulfide and hydrogen bonds, facilitating cuticle opening and the incorporation of active molecules of hydrolysed keratin, peptides and proteins. Subsequent IR treatment seals the scales, fixing the obtained effect and protecting the hair from external damage. Compared with traditional thermal restoration methods, the combined approach demonstrates comparable or higher tensile strength, modulus of elasticity and gloss at significantly lower thermal and chemical stress. The economic and environmental feasibility of the technology is determined by the energy efficiency of ultrasonic devices and the absence of toxic reagents. Further research should focus on the fine tuning of US and IR wave parameters, the development of new keratin-based nanocompositions and the integration of the method into autonomous devices for home use, which will enable personalised and safe hair care at a professional salon level.

References

1. Bhat A. P. et al. Acoustic and hydrodynamic cavitation assisted hydrolysis and valorisation of waste human hair for the enrichment of amino acids //Ultrasonics sonochemistry. – 2021. – Vol. 71. DOI: 10.1016/j.ultsonch.2020.105368.
2. Ultrasonic hair restoration. [Electronic resource] Access mode: https://salon-respect.ru/service/ultrasonic-infrared-hair / (date of application: 05/14/2025).
3. Ultrasonic hair restoration . [Electronic resource] Access mode: https://www.alerana.ru/stati/vosstanovlenie-volos-pravilnyy-ukhod-stimulirovanie-rosta/ultrazvukovoe-vosstanovlenie-volos / (date of access: 05/15/2025).

4. Jain S. Radiation in medical practice & health effects of radiation: rationale, risks, and rewards //Journal of family medicine and primary care. – 2021. – Vol. 10 (4). – pp. 1520-1524.

5. Maria G. S. A. et al. Safety and efficacy of repetitive stimulation of the left dorsolateral prefrontal cortex using transcranial focused ultrasound in treatment-resistant depressed patients: a non-inferiority randomized controlled trial protocol //Asian Journal of Psychiatry. – 2024. – Vol. 95. – pp. 103994. DOI: 10.1016/j.ajp.2024.103994.

6. Fogarty S., Werner R., James J. L. Applying scientific rationale to the current perceptions and explanations of massage and miscarriage in the first trimester //International Journal of Therapeutic Massage & Bodywork. – 2023. – Vol. 16 (1). – pp. 30.