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COMPARATIVE ANALYSIS OF COLD ATMOSPHERIC PLASMA GENERATION PARAMETERS AND CHARACTERISTICS OF PLASMA DEVICES USED IN AESTHETIC MEDICINE

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Abstract

The article discusses the theoretical and practical aspects of the use of cold atmospheric plasma in aesthetic medicine. It presents the physical principles of creating cold atmospheric plasma, as well as reveals the features of its formation and key parameters that determine the properties of a plasma discharge. Plasma devices are classified according to several criteria: the type of discharge, the method of exposure, the design features and the environment in which they operate. Particular attention is paid to the parameters of plasma generation as an object for comparative evaluation. These parameters include spatial, gas dynamic, and energy characteristics. A comparative analysis of plasma devices has been performed in terms of their technical and operational properties, which are important for cosmetology practice. The practical significance of equipment parameters affecting the controllability of procedures, the accuracy of exposure and reproducibility of results is considered. The article discusses in detail the security issues related to the use of plasma technologies. Key problems have been identified and prospects for further development of this area have been outlined. It is concluded that in order to ensure the safety and increase the efficiency of plasma devices, it is necessary to standardize their parameters and improve control systems.

Keywords: *cold atmospheric plasma, aesthetic medicine, cosmetology, plasma devices, plasma generation parameters, plasma jet, dielectric barrier discharge, hardware cosmetology, comparative analysis, safety of plasma technologies*

Relevance of the study

In the field of aesthetic medicine, there is a growing interest in hardware techniques that provide a controlled and gentle effect on the skin. One of the promising directions is the use of cold atmospheric plasma. This technology allows procedures to be carried out with minimal thermal damage and high processing accuracy.

Cold atmospheric plasma is a partially ionized gas that forms at atmospheric pressure and has a low temperature. This makes it an ideal tool for non-invasive and minimally invasive cosmetic procedures. The effectiveness and safety of such procedures largely depend on the parameters of plasma generation and the design of the devices used.

Many plasma devices on the market differ in principle of operation and technical characteristics. However, there is no single approach to comparing them, which makes it difficult for cosmetologists to choose the equipment and optimal operating modes.

Therefore, a comparative assessment of the parameters of cold atmospheric plasma generation and the characteristics of plasma devices is becoming an urgent task aimed at improving the effectiveness and safety of cosmetic procedures.

The purpose of the study

The purpose of this study is to compare the parameters of cold atmospheric plasma generation and the characteristics of plasma devices used in aesthetic medicine in terms of their usefulness in cosmetology.

Materials and research methods

The research examined scientific papers on plasma physics at atmospheric pressure, as well as the principles of operation of plasma devices and their use in aesthetic medicine. In addition, the technical characteristics of modern plasma devices were reviewed.

The following methods were used in the work: analysis and generalization of scientific literature on the research topic, comparative analysis of technical parameters of various plasma devices.

The results of the study

Cold atmospheric plasma is a partially ionized gas that is formed at atmospheric pressure because of an electric discharge. Unlike high-temperature plasma, it is characterized by a nonequilibrium state in which the energy of electrons significantly exceeds the energy of heavy particles. At the same time, the gas temperature remains low, usually below 40–50 °C, which makes it safe for use in aesthetic practice (Gerasimenko M. Yu., Zaitseva T. N., Evstigneeva I. S., 2019, p. 79).

The key feature of cold atmospheric plasma is the combination of active physical and chemical components. These include charged particles (electrons and ions), ultraviolet radiation, electric fields, and reactive oxygen and nitrogen species (RONS), which are formed because of the interaction of high-energy electrons with gas molecules. This combination of factors determines the functional properties of plasma and makes it especially attractive for hardware cosmetology (Batdyeva A. I., 2022).

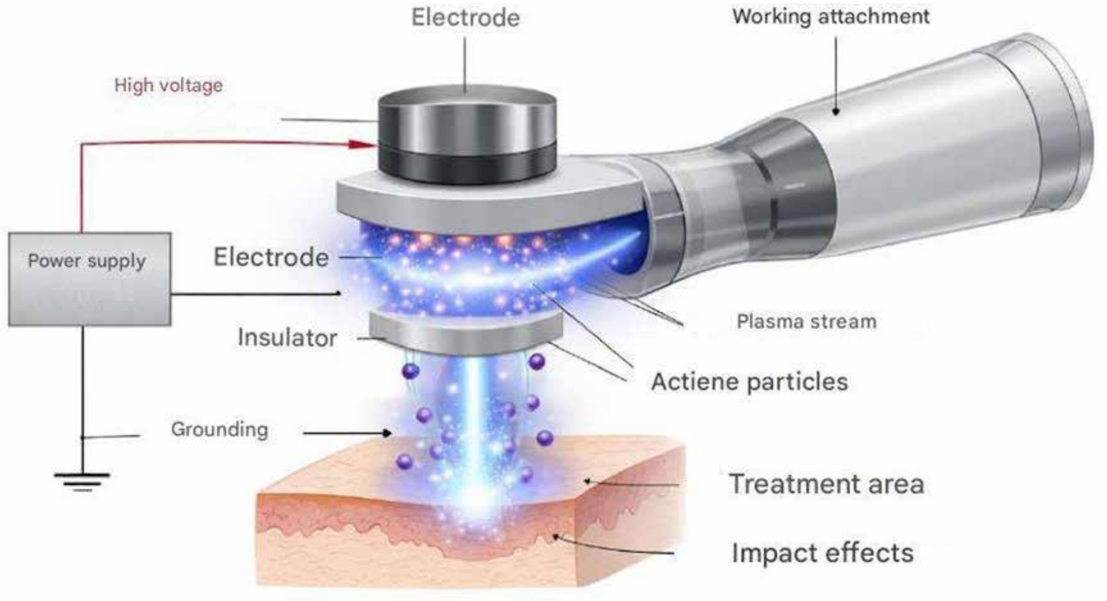
Plasma is formed in various ways in cosmetic devices. Plasma jets and dielectric barrier discharges (DBD) are the most popular. In the first case, plasma is created in a gas stream and supplied as a directed jet. In the second case, plasma is formed at the point of contact of the electrode with the treated surface. These two types of discharges are used in most modern plasma devices used in aesthetic medicine.

From a physical point of view, the plasma parameters depend on the characteristics of the electric discharge and the gaseous medium in which it occurs. The main parameters include voltage, frequency, power, electron density, and plasma temperature. For example, cold atmospheric plasma is characterized by an electron temperature at the level of fractions of an electron volt and a particle concentration reaching $10^{14} - 10^{17}$ m^{-3}. This indicates a high reactivity at a relatively low thermal load.

In scientific and applied practice, electrical and optical diagnostic methods are used to correctly describe and compare plasma processes. The electrical characteristic includes an analysis of voltage, current, and pulse shape, while the chemical characteristic includes an assessment of the composition of active particles using spectroscopy. These approaches are necessary to ensure reproducibility of the results and the ability to compare different devices.

To visually explain the principle of formation of cold atmospheric plasma in cosmetology devices, we propose to consider the scheme of plasma discharge occurrence and its penetration into the working area shown in the figure.

Figure 1. *Schematic diagram of cold atmospheric plasma generation in a cosmetology device (developed by the author)*



The classification of plasma devices used in aesthetic medicine is based on three main criteria: the physical principle underlying the generation of a discharge, the method of action on the treated surface, and the design features of the devices. There are several main types of cold atmospheric plasma sources in the scientific literature, which have become the basis for the creation of modern cosmetology devices (Table 1).

Table 1. *The main types of plasma devices and their characteristics*

Classification criteria	Device type	Brief description
Type of discharge	Plasma jet	Directed plasma flow, requires gas
	DBD-rank	Plasma generation between electrodes without gas
Method of exposure	Direct	Plasma is formed in the treatment area
	Indirect	Plasma is supplied through a stream or medium
Construction	Single-electrode	Simple layout, compact design
	Coaxial	Stable discharge, high controllability
	With a dielectric barrier	Current limitation, safety
Working environment	Inert gases	Stability and focus
	Atmospheric air	Easy operation

A source: author's development

When comparing plasma devices used in aesthetic medicine, special attention is paid to the characteristics that determine the spatial distribution of plasma and its interaction with the treated surface. These characteristics include length and shape of the plasma jet, diameter of the impact zone. Scientific studies show that the jet length can vary from a few millimeters to several centimeters, depending on the type of device, voltage and gas used. This, in turn, affects the accuracy and locality of processing.

Another important parameter is the distance from the plasma source to the treated surface. Experiments show that increasing this distance reduces the concentration of active particles and reduces the intensity of exposure, while the minimum distance ensures maximum plasma flow density.

In practical application, this requires taking into account the geometry of the nozzle and the stability of the working tool position. One of the key parameters is the uniformity of the plasma discharge. Depending on the generation mode, the discharge can be diffuse or filamentous (filamentous). A diffuse discharge is characterized by a uniform distribution of plasma, while separate microchannels form a filament discharge. These characteristics directly affect the processing quality and reproducibility of the results, which becomes especially important when comparing different devices.

Another important parameter to consider when working with a plasma jet is the gas flow rate. It has been noted in scientific papers that changes in gas flow rate affect the jet length, discharge stability, and distribution of active particles. An increase in the flow velocity, as a rule, leads to an elongation of the jet and an improvement in its directivity; however, this may affect the plasma density (Shemshuk M. I., Korotkiy V. N., Serov D. N., 2018, p. 62).

For a more objective assessment of the efficiency of plasma jet devices, an energy density indicator is used, which demonstrates the amount of energy transferred per unit area. This parameter depends on the device's power, exposure time, and processing area, and allows you to compare different operating modes.

The comparison of plasma devices used in aesthetic medicine is based on an assessment of their technical, design and operational characteristics, which affect the controllability of the process and the stability of plasma generation. Scientific papers emphasize that the key factors determining the differences between devices are the type of plasma source, the gas medium used, the configuration of the electrodes and the power supply (Table 2).

Table 2. *Comparative characteristics of plasma devices*

Comparison criteria	Plasma jet	DBD devices
Controllability of impact	High (adjustable by nozzle and gas)	Average (depending on electrode position)
Length of the plasma region	Up to 30–40 mm	Limited by the discharge zone
Discharge stability	High when using gas	Depends on design
Energy consumption	From mW to tens of watts	Usually lower for localized discharge
Construction	More complex (gas, nozzle)	Simpler
The possibility of adjustment	Wide	Limited

A source: according to scientific research

The differences between them are due to a number of physical and technical characteristics. Controllability, stability of plasma generation, and the ability to fine-tune modes are especially important for cosmetology practice. This ensures the predictability of the result and the convenience of the specialist's work.

The practical value of plasma device parameters in aesthetic medicine is determined by their effect on the controllability of the procedure, reproducibility of the result, and comfort of the specialist. Specialized sources emphasize that the stability of the electrical characteristics and operating modes of the device ensures predictable effects, which is especially important when performing repetitive cosmetic procedures and standardizing protocols (Vorobyov K. P., Zinnurova A. B., Bakina O. V., Spirina L. V., Zhavoronok T. V., 2024, p. 359).

One of the most important aspects is the possibility of fine-tuning the operating modes of the plasma device. Modern models are equipped with power, frequency and pulse duration control systems, which allows them to be adapted to various tasks and conditions. Digital interfaces and pre-installed programs greatly simplify the choice of modes and reduce the likelihood of errors when using the equipment.

Ergonomics and the design of the working nozzles also play a key role. As noted in scientific and technical descriptions, the shape and size of the nozzle determine the accuracy of positioning and the convenience of performing procedures. Compact and weight-balanced devices significantly reduce the workload of a specialist and increase processing accuracy, especially when working with small areas.

The stability of the parameters during the procedure is crucial. In a number of studies, it has been found that fluctuations in voltage or power can negatively affect plasma characteristics, which in turn will affect the uniformity of exposure. Therefore, devices equipped with a parameter monitoring and stabilization system are considered preferable for practical use.

It is also worth noting the convenience of maintenance and operation. Devices that do not require complex preparation, replacement of gas cylinders or frequent calibration are becoming increasingly popular in cosmetology rooms. This makes it possible to significantly reduce the preparation time for procedures and increase overall work efficiency (Borkhunova E. N., Taganov A. V., 2017, p. 87).

The safety of using cold atmospheric plasma in aesthetic medicine depends on several factors: the physical characteristics of the discharge, the design of the equipment, and compliance with operating rules. Scientific publications emphasize that one of the most important aspects is the control of thermal effects. When set correctly, the plasma temperature should be close to the ambient temperature, which minimizes the risk of overheating of the treated surface.

Control of electrical characteristics plays a key role in ensuring process safety. Current limitation, the use of dielectric barriers and switching power modes help to prevent uncontrolled discharge transition. The technical descriptions note that modern devices are equipped with parameter stabilization systems and automatic shutdown when deviating from the set modes.

Maintaining distance and exposure time is also an important aspect. Experimental studies show that reducing the distance between the electrode and the surface leads to an increase in energy density, which requires precise control of the tool position. Increasing the exposure time, in turn, contributes to the accumulation of energy, so the parameters of the procedure must be strictly regulated.

It is also important to consider the electrical safety and grounding requirements of the equipment. The use of certified devices that comply with safety standards significantly reduces the risk of electric shock and ensures stable operation of the device. In addition, it is necessary to strictly follow the manufacturer's instructions and regularly check the technical condition of the equipment.

Despite the rapid development of plasma technologies in aesthetic medicine, a number of problems remain related to their practical application. The main problems and directions of plasma technology development are presented in Table 3.

Table 3. *The main problems and directions of development of plasma technologies*

Aspect	Existing problems	Development prospects
Parameter estimation	Differences in measurement techniques	Standardization of indicators
Reproducibility	Dependence on external conditions	Stabilization and control systems
Mode management	Limited setup	Intelligent control systems
Device design	Limited versatility	Miniaturization and ergonomics
Practical application	Lack of unified protocols	Development of application standards

A source: author's development

Further development of plasma technologies in the field of cosmetology is associated with the improvement of parameter control methods, standardization of characteristics and modernization of device designs. These tasks will make the use of plasma equipment in aesthetic practice more efficient and reliable.

Conclusions

The study revealed that the parameters of cold atmospheric plasma generation and the design features of plasma devices significantly affect the controllability, stability and reproducibility of hardware procedures in aesthetic medicine. It is established that the type of discharge determines the differences between the devices, the medium used, the configuration of the electrodes and the power supply modes. This requires a comprehensive approach to their assessment.

The practical significance of the parameters lies in the possibility of fine-tuning the operating modes, which ensures ease of operation and increases the predictability of results in cosmetology practice. The safety of using plasma technologies is achieved by monitoring electrical and energy characteristics, observing the distance and time of exposure, as well as using certified equipment.

It has been revealed that the main obstacles to the development of plasma technologies in aesthetic medicine are the lack of uniform methods for assessing parameters and insufficient standardization of application protocols. The prospects for further progress are related to the introduction of monitoring and control systems, as well as standardization of characteristics and improvement of device designs. This, in turn, will improve the efficiency and reliability of using plasma technologies for aesthetic purposes.

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