

Overview of the application of laser technologies in medicine and cosmetics

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Abstract – The development of laser technology in recent decades has led to a rethinking of many dogmas in the field of medicine and cosmetics. Practices that have been known for years are undergoing a significant change and pushing forward the development in these areas, bringing exceptional benefits to people and significantly supporting the work of medical professionals, as well as taking the cosmetic industry on a qualitatively new path.

Keywords – laser technology; lasers in medicine; lasers application on cosmetics; low- and high-energy lasers.

I. INTRODUCTION

Laser technology (light amplification by stimulated emission of radiation) is the amplification of light by stimulated emission of electromagnetic waves. A laser consists of an energy source, an active substance, a resonator and a light guide. Lasers are characterized by **coherence** and **monochromaticity** (they emit rays of the same wavelength). Depending on their power, they are **low-** and **high-energy**. **Low-energy** ones with a power of up to 75 mW are mainly used in physiotherapy, to penetrate a few millimeters deep into the tissues. **High-energy** are used in surgery to achieve precision and reduce operative blood loss. The most commonly used in practice are **He-Ne** laser and **CO₂** lasers.

II. IMPLEMENTATION

Applications in medicine - laser technology, entering medicine, allows the implementation of specialized therapies for certain diseases, without the use of traditional surgical means and drugs. It is applicable in the treatment and prevention of diseases of diverse etiology.

In the field of **surgery** (Fig.1) and **neurosurgery**, new generations of surgical robots have been entering for several decades, successfully performing complex surgical manipulations with a precision unattainable with conventional methods. They perform minimally invasive surgical interventions in hard-to-reach places, and the operative field is reduced to a minimum. The risk of unwanted effects is minimal, the method is gentle on adjacent tissues, organs, and systems, as the laser is removed with the targeted part without damaging healthy adjacent tissues. The operations are accompanied by minimal blood loss, and the subsequent formation of "stitches" closing the surgical wound allows for a quick recovery, compared to conventional surgery [1,2,3].

The impact of laser technologies in ophthalmology is serious, they are applied more and more successfully to

improve vision with reduced visual acuity, astigmatism, to treat some retinal diseases, some forms of glaucoma. [4]



Fig. 1. Application of operating robots with laser energy

Lasers are part of daily practice in the field of nephrology [5] and have been successfully used in kidney stone disease (breaking up certain types of stones). In gynecology [6] they are used for several manipulations (surgical interventions in the small pelvis, various interventions on the cervix, vagina, ovarian ablation, removal of polyps, as well as surgical interventions to remove adhesions).

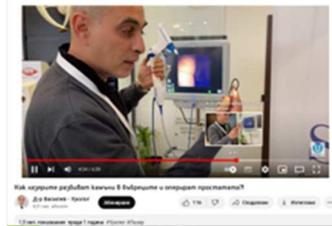


Fig. 2. Application laser technology on urological practice [8]

The challenges in the use of laser technologies in **urology** (Fig.2) (operations for prostate diseases, including for partial removal in prostatitis, tumor diseases) are related to solving classic cases minimally invasively, by means of endoscopic methods [7, 8]. Green lasers, diode lasers, holmium lasers and thulium lasers are widely used for the removal of soft tissue benign and malignant tumors, while the holmium laser is mainly used for breaking stone structures [5].

The thulium laser, thanks to innovations in technology, in addition to continuous laser radiation (CW), also generates high-energy, short light pulses with a high operating frequency. This allows its use in enucleation. Thulium lasers are being increasingly successfully applied with simultaneous hybrid application in: vaporization (enucleation) of the prostate, surgery of tumors without carbonization and sparing surrounding tissue stone breaking. Important advantages of **fiber-thulium technology** are the

smaller module size, allowing for integration into table-top end devices, and the ability of **fiber-laser technology** to use thinner endoscopic fibers. The disadvantage is the limitation in the conducted average optical power (up to 8 W), which reduces their efficiency.

In the early 1990s, the use of laser technologies in **gastroenterology** (Fig.3) was registered in first time (for surgical interventions of the esophagus, stomach, colon, extrahepatic bile ducts and abdominal parenchymal organs, in acute gastrointestinal hemorrhages treated endoscopically, in hemorrhoids, hemangioma, lymphangioma and others). High-energy lasers, instruments and staplers are used, as well as new methods of surgical interventions with the creation of a laser mechanical suture with an adjustable period of tissue compression. Methods for laser "welded" anastomoses of hollow organs of the gastrointestinal tract have been tested. In endoscopic surgery, methods have been developed to stop acute gastrointestinal bleeding using CO₂, YAG-neodymium and argon lasers, laser methods to remove polyps, villous tumors of the stomach, recanalization of the esophagus and colon with stenotic tumors of these organs [9,10].



Fig. 3. Application of the laser in gastroenterology

A methodology was developed and experimental studies were conducted for laser transmural revascularization of the myocardium, which introduced the technology into **clinical cardiac surgery**[11].

Lasers are widely used in **phlebology** [12], by means of **Endovenous Laser Obliteration (EVLO)**. Reports of the first applications of lasers in phlebology (Fig.4) date back to 1981, using a dye laser with a wavelength of 577 nm to repair damaged microvessels. The technology is based on the effect of the selective absorption of laser energy with a certain wavelength by various tissue components, leading to their selective destruction. In 1983 investigated selective coagulation and microvascular hemostasis with intravascular exposure to laser radiation.[13]

In 1997, a study of the optical properties of blood using laser radiation with wavelengths of 400 - 2500 nm was presented. Data were obtained on the absorption of energy by optical components of blood (hemoglobin and water). The optimal wavelengths of laser radiation, which are maximally absorbed by various blood substances, have been determined. The resulting pattern is still used in all **EVLA (Endovenous Laser Ablation) lasers**. In 1998-1999 reports [14] of clinical intravascular use of a diode laser (810 nm) for EVLA are emerging. The method is called **EVLT (Endovenous laser therapy)** [15]. In 2001, data were summarized on the intravascular injection of a laser fiber to

deliver laser energy to the GSV, using a **diode laser** with a wavelength of 810 nm. After one year of observation, vein obliteration was registered in 100% of patients.

The process of thrombotic occlusion after thermal exposure to laser radiation was described in 2002. According to him, the mechanism of EVLA [16] is based on the absorption of light energy by hemoglobin and the indirect effect of thermal energy on the vascular wall. As a result of the thermal effects, steam bubbles are formed in the blood, having a damaging effect on the endothelium of the venous wall. The volume of the resulting vapor bubbles correlates with the power of the laser beam. In this case, the maximum penetration depth of the laser beam through the blood is 0.3 mm (at a wavelength of 940 nm). The conclusion of this study is that laser radiation does not cause damage to the endothelium, due to its complete absorption by hemoglobin.



Fig. 4. Laser treatment of varicose veins

In 2008 angiologists report the results of elimination of perforating discharge using EVLO. 100% obliteration of 67 perforating veins was reported with an energy flux of 50J achieving obliteration in 90% of cases with energy parameters of 180J.

In 2009 Phlebologists report testing a new type of **conduit** called **JACKET** (Fig.5). They have a spherical working end, allowing to create a uniform distribution of laser energy along the perimeter of the vessel. This type of fiber does not require the use of catheters for insertion into the vessel. Results of a clinical trial comparing the effectiveness of radiofrequency ablation and EVLA with the JACKET catheter are presented. It was found that there were no significant differences in the duration of the procedure, the speed of postoperative rehabilitation and complications. At the same time, the cost of consumables for EVLO turned out to be significantly lower [17,18].

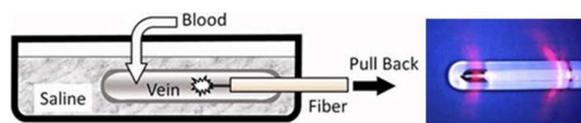


Fig. 5. A new type of conduit called JACKET [17]

Percutaneous laser coagulation. The successful use of lasers in the treatment of facial telangiectasias is the basis of the treatment method for reticular varicose veins of the legs. The sclerotherapy method is difficult to apply when removing vessels with a diameter of less than 1 mm, and it also has unwanted side effects (hyperpigmentation and

epidermal necrosis). For the treatment of large and deep vessels, lasers are used, in which absorption in hemoglobin and scattering in the skin are less pronounced. In this case, homogeneous heating and sclerosis are achieved in accordance with the same principle of selective photothermolysis. Lasers in the infrared range meet these requirements: **alexandrite** (755nm), **diode** (810, 940, 970nm), **Nd-YAG** (1064nm).

Oxyhemoglobin absorbs at 755 and 1064 nm very weakly and selective photothermolysis is sometimes accompanied by thermal damage to the skin, therefore the role of alexandrite and Nd-YAG lasers is rather auxiliary. **Diode lasers** with a range of 810-970 nm are most suitable for selective sclerosing of vessels with a diameter of up to 1.5 mm. In this range, the dispersion is very low and the absorption of oxyhemoglobin is relatively low, and provides heating of the vessels throughout the cross section. Here, **yellow-green lasers** with a wavelength of 532 nm, as well as **alexandrite** and **Nd-YAG lasers**, are the most effective and safe for the treatment of surface vessels with a diameter of up to 0.5 mm (especially in the face area). For vessels with a diameter of more than 1.5 mm, the most effective is the method of microsclerotherapy. For the largest vessels of the lower extremities, diode lasers in the 800-1000nm range are most effective.

In **oncology**: lasers are used in the treatment of tumors, polyps and pre-cancers. Various methods are applied, such as tumor irradiation, focused beam coagulation, and others in order to reduce the size of the tumor or its destruction and removal.

Objective criteria for therapeutic efficacy and toxicity of internal photosensitizers in photodynamic therapy of malignant neoplasms have been developed. Screening studies of photosensitizers were carried out for the selectivity of accumulation in tumors, their toxicity, pharmacodynamics depending on the initial state of the organism, the dosage form and the methods of administration of the treatment. Morphological features of photodestruction of various tumors were studied, experimental studies were conducted to develop optimal parameters for photodynamic destruction of tumor tissue. The methods of photodynamic therapy introduced by Professor E. F. Stranadko [18] in clinical practice gave a start to the treatment of malignant neoplasms with external localization (skin, early stages of breast cancer, cancer of the oropharyngeal region, tumors with inconvenient localizations). Research has been conducted on the development, clinical testing and application of second generation photosensitizers, photoactive drugs and metal compounds for photodynamic therapy. Methods are being developed to deliver photosensitizers to target tissues for selective accumulation.

Laser technology provides a number of advantages in the treatment of certain diseases of a **neurological nature**: in neuritis, neuralgia, radiculitis, plexitis.

In **physiotherapy practice** (Fig.6), the energy absorbed by the tissues is converted into heat. Laser therapy increases cell metabolism, increases blood flow and stimulates microcirculation in the treated area, reduces tissue swelling, has an anti-inflammatory and pain-relieving effect. Laser procedures are widely applicable for inflammatory and degenerative diseases of the musculoskeletal system (arthritis, arthrosis, tendovaginitis), after traumatic injuries, as well as in complex physiotherapy treatment of diseases with a multifaceted etiology.

Low-energy lasers LLLT (Low level laser therapy) are widely used in physiotherapy [19]. LLLT (phototherapy or photobiomodulation) refers to the use of photons in non-thermal irradiation to alter biological activity. The technology uses **coherent light sources (laser)**, **incoherent consisting of filtered lamps or light emitting diodes (LED)** or a combination of both. Stem cells are activated, helping to restore and heal tissues, in which low doses of laser irradiation increase cell proliferation of fibroblasts, lymphocytes, keratinocytes and endothelial cells. The mechanism of proliferation results from photostimulation of mitochondria in which photons are absorbed by the cell's mitochondrial chromophores. As a result, reactive oxygen species increase, activate signaling pathways and regulate transcription factors, leading to an increase in growth factors. LLLT promotes angiogenesis, enhances neovascularization, increases collagen synthesis, which promotes healing of acute and chronic wounds.



Fig. 6. Application of laser in physiotherapy [20]

In practice, LLLT is focused on reducing pain and inflammation, repairing tissues and promoting their regeneration. Photobiomodulation changes the oxidation/reduction state of mitochondria and leads to a significant increase in ATP synthesis. Activation of the sodium/potassium pump changes the permeability of the cell membrane to calcium.

Phototherapy affects (Fig.7) cellular activity by:

- stimulates cell growth
- increases cellular metabolism
- improves cell regeneration
- induces an anti-inflammatory response
- promotes the reduction of swelling
- reduces the formation of fibrous tissue
- stimulates nerve function
- stimulates the long-term production of nitric oxide
- reduces the formation of bradykinin, histamine
- stimulates the production of endorphins

These photobiological reactions are the cause of pain relief in patients treated with phototherapy.

The primary effect of photoreception comes from the interaction of cellular mitochondria and photons, converting photon energy into chemical energy used to regulate cellular activity.



Fig. 7. Phototherapy affects [19]

The secondary effect occurs in the same cell induced by the primary. Secondary effects include cell proliferation, protein synthesis, degranulation, growth factor secretion, myofibroblast contraction, and neurotransmitter modification (depending on cell type and sensitivity).

Combined treatment: In biomedical LLLT therapy, the therapy works synergistically to regenerate the cell, increase its energy production, leading to an improvement in overall neurological health. Detoxification pathways and processes in the body are stimulated, eliminating various harmful metabolic waste products (foreign antigens of viruses and bacteria).

Laser technologies are permanently entering **dentistry** (Fig.8), with a tendency in the near future to replace traditional treatment methods [21].



Fig. 8. The laser in dentistry

Laser technologies are successfully applied in the treatment of periodontitis and are used in the fabrication of 3D bridges. With the introduction of diode lasers into practice, the devices become more compact and affordable.

Diode lasers belong to the **high-energy lasers** with a wavelength in the range 700–1100 nm, which allows painless, bloodless coagulation and vaporization of soft tissues. This practically includes performing almost all operative interventions on soft tissues in the oral cavity.

Low-energy lasers with a wavelength of 600 nm have a therapeutic and regenerating effect on these tissues. **High-energy lasers** of the type Nd YAC, Erbium, CO₂ are used in the treatment of hard dental tissues (removal of carious tissue). For now, these lasers are only applicable to easily

accessible, superficial caries, but the technology is progressing. When treating caries, the results are comparable to those when using an ultrasonic (piezo) technique, which works successfully in deep and hard-to-reach caries. The main component in the apparatus is a laser diode activated by an electric current. The diode emits monochromatic light that is focused, defocused and transmitted by means of flexible optical fibers. Light is invisible with non-ionizing heat radiation that does not cause changes in the cellular DNA region. The laser is usually air-cooled. **The high-energy laser system** is suitable for the treatment of: abscess, adenoma, aphthae, biopsies, bio-stimulation, teeth whitening, curettage of gum pockets, desensitization of sensitive dental tissues, drainage, epulis, excision, fibroma, fistulas, frenectomies, gingivectomies, gingivoplasty, hemangioma, hemostasis, herpes, hyperplasia, implant exposure, incisions, root canal sterilization, pulp coagulation, mucocele, operculectomy, papilloma, peri-implantitis, sulcus retraction, sulcus sterilization, fistula canals, vestibuloplasty.

With the help of a laser, the traditional way of introducing **vaccines** is replaced by the implantation of subcutaneous microparticles with prolonged release of the active substance.

In **dermatology** (as a border area between medicine and cosmetics), the laser technique is widely used for: treatment of acne, rosacea, vitiligo, neurodermatitis, urticaria, herpes zoster, removal of warts, cicatrixes, superficial dilated blood vessels in nail mycosis, treatment and prevention of hair loss and alopecia, improving the appearance of the skin and counteracting age-related changes. In dermatological plastic surgery, methods of treatment with different types of lasers have been developed and clinically applied in patients with benign and malignant skin tumors, hypertrophic and keloid scars, vascular and pigment lesions and cosmetic defects [22].

Risks and complications after laser treatment

Laser treatment is widely applicable and highly effective, with proper selection and implementation, the risk of complications is minimized. For this purpose, a preliminary examination is carried out, the benefits and risks are assessed and the patient is informed. In this way, the most effective choice of treatment is achieved and accompanying complex care is indicated for a quick and risk-free recovery:

- **proper preparation:** most often involving (discontinuation: taking certain medications, heavy physical activity, changes in diet and others).
- **risks after the procedure:** depending on the type of treatment performed, some complications can be expected such as: swelling, redness, pain, tingling, changes in the color of the underlying skin, itching, development of secondary infection and others.
- **preventive measures after the manipulation:** depending on the type of laser treatment applied, measures are prescribed in the recovery period.

Taking certain medications, avoiding direct sunlight without protection, heavy physical exertion, avoiding certain cosmetic procedures and others.

- **contraindications:** the use of laser therapy is used with caution in immunocompromised patients with severe immune suppression, autoimmune diseases, after conducting radiotherapy in the face area and subsequent facial laser therapy, pregnant and lactating women, conducting local (for the purposes of dermatology and cosmetology) laser treatment in patients with darker skin and in persons prone to the formation of cicatrixes (scars), as well as against the background of retinoid treatment (it is necessary to stop therapy for at least 4 weeks before laser skin treatment).

Application in Cosmetics

Laser technology is entering the **cosmetic and beauty industry** in a big way, in the form of laser correction of scars (surgical, acne and others), stretch marks, vitiligo treatment, teeth whitening, implantation of microscopic molecules under the skin surface for the purpose of treatment or rejuvenation, laser hair removal, to remove tattoos and others [23,24]. At the end of the last century, lasers became the high-tech equivalent of dermabrasion (deep chemical peels) for so-called "resurfacing" (removing the top layer of the skin).

In aesthetic dermatology, two types of lasers were used - **ablative** and **non-ablative**. In **ablative (resurfacing) lasers**, a strong beam of laser energy is directed at the skin's surface. It heats the water in the surface layer of the skin, because of which it "evaporates". With each successive pass (passage) of the laser over the skin, its upper layers are removed in an extremely precise way, with controlled depth. During the recovery period, the production of new collagen is observed, leading to an improvement in the condition of the damaged skin. The procedure significantly improves the condition of the skin, it becomes stronger, smoother and firmer. In the ablative procedure, wrinkles are greatly reduced, the relief of the skin is smoothed. A disadvantage is the long recovery period (sometimes months), as well as an increased risk of side reactions. There are currently two types of ablative lasers – Erbium: YAG and CO₂ lasers.

Non-ablative lasers have lower energy, they attack the middle layer of the skin (dermis) and do not burn the epidermis (top skin layer). They are used for photo rejuvenation. The recovery period and the risk of side reactions is reduced significantly. The energy emitted by the laser is converted into heat in the dermis, activating the production of new collagen. As a result, finer wrinkles are reduced, superficial capillaries and pigment lesions are removed. A disadvantage of **non-ablative lasers** is that they are less effective and require more procedures.

A third group of laser devices, based on the principle of **fractional technology**, also finds a place in aesthetic

medicine. **Fractional laser resurfacing (photothermolysis)** is a technique that attacks individual areas of the skin, resulting in thousands of tiny sores in the form of columns called "microscopic thermal zones". Each column is surrounded by a healthy, unaffected region. This allows the skin to recover quickly even when treating large surfaces and achieves a result like that of ablative laser resurfacing, but without the risk of side reactions and a long recovery period. Thanks to this technology, it successfully affects:

- wrinkles on the face and around the eyes
- age-related skin changes and skin damaged by the sun
- pigment lesions
- acne scars
- improving the elasticity, texture and turgor of the skin

For optimal results, 1-3 procedures are needed every 3-4 weeks. The results of laser treatment are progressive, optimal improvement is observed after 2-3 months. Since the whole skin is not treated, but specific areas, the procedure is suitable for more delicate areas (neck, décolletage, and hands). During the procedure, minimal discomfort is created, like a sunburn, burning is felt, lasting up to 2-3 hours. If necessary, local anesthesia is used. The skin remains slightly red for up to 7 days, which is a sign of deep recovery. Sometimes swelling is observed, passing in 2-3 days.

In the recovery process, the following is observed: (**darkening** of the skin, which persists for 3-14 days, and depends on the depth of the laser treatment, **intense peeling** - the newly formed skin replaces the burned one. The use of moisturizers is recommended, it is extremely important to provide **sun protection** - to use sunscreens with a minimum of SPF30, both during the healing phase and months after).

In rare cases, hyper- or hypopigmentation (transient), allergic reactions are observed because of using some medicated creams. The fractional laser system is combined with botulinum toxin, hyaluronic acid, IPL, and other techniques. Thanks to this state-of-the-art Microspot fractional laser technology, skin looks younger, smoother, and firmer.

III. CONCLUSION

From the observed therapeutic effects, laser technologies and phototherapy are emerging as leading methods of treatment and prevention in modern medical practice. The future development of laser technology will be seriously advocated in medical practice, and for this reason it is good to observe all serious trends in the field of its improvement.

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