MULTIVARIATE BEHAVIORAL RESEARCH
2026, VOL. 61, NO. 1, 35–50

OPEN ACCESS

Application of Laser Technologies in Modern Medical Practice

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ABSTRACT
Modern laser technology has found increasingly widespread application in medical practice over the past decade, thanks to its precision, minimal invasiveness, and high effectiveness. Long-established medical standards are undergoing a revolutionary transformation and rapid development, bringing significant benefits to patients and greatly supporting the work of healthcare professionals. This evolution is redefining treatment protocols and prompting a reassessment of many long-held medical doctrines. This study explores the fundamental principles of laser operation, their types and parameters, as well as their specific applications across various medical specialties—including surgery, dentistry, ophthalmology, dermatology, and aesthetic medicine. Special attention is given to innovative surgical techniques in cardiology, orthopedics, gynecology, urology, gastroenterology, and angiology; tumor removal; new practices in dentistry and ophthalmology; treatment of vascular and pigmented lesions; skin rejuvenation; and more. The study also analyzes the risks, contraindications, and the necessity for an individualized approach when selecting laser therapy. It emphasizes the importance of technological advancement and a multidisciplinary approach in enhancing the safety and effectiveness of laser procedures, as well as the ongoing need for continuous education of specialists in this rapidly evolving field.

KEYWORDS
Laser technology in surgery, laser treatment in medicine, laser endoscopic surgery.

1. Introduction

Laser technology (light amplification by stimulated emission of radiation) is based on the stimulated emission of electromagnetic waves that amplify a beam of light. A laser consists of an energy source, an active medium, a resonator, and an optical waveguide. Lasers are characterized by their monochromaticity (emitting light of a single wavelength) and coherence. Depending on their power, lasers are classified as low-energy and high-energy. Low-energy lasers, with power up to 75 mW, are primarily used in physiotherapy, allowing penetration into tissues to a depth of several millimeters. High-energy lasers are most widely used in surgery due to their precision and ability to reduce intraoperative blood loss. The most commonly used lasers in practice include the He-Ne laser and CO_2 lasers.

In recent decades, laser technology has established itself as one of the most innovative and promising fields in modern medicine. Thanks to its high precision, controlled penetration depth, and potential for minimally invasive interventions, lasers have become an indispensable tool in numerous clinical and aesthetic procedures. From surgical interventions and treatment of dermatological conditions to aesthetic corrections and rejuvenation therapies, the application of laser technology continues to expand, offering new opportunities for improved outcomes and reduced risks for patients.

The development of various types of lasers—CO_2, erbium, diode, Nd:YAG, and others—enables a personalized approach to treatment, tailored to the individual needs and condition of each patient. At the same time, the integration of laser systems into clinical practice requires in-depth knowledge, accurate diagnostics, and a high level of professionalism from medical specialists.

This publication aims to present the current state of laser technology in medicine, with a focus on innovations, trends, and challenges related to its application. Both the clinical benefits and potential risks are analyzed, emphasizing the need for safe and effective practice in this rapidly evolving field.

2. Implementation

Applications in Medicine – As laser technology enters the field of medicine, it offers numerous opportunities for conducting specialized therapies without the need for traditional surgical interventions.

2.1. New trends in the development of laser endoscopic surgery advantages and disadvantages

New generations of surgical robots are successfully entering fields such as surgery and neurosurgery, enabling the execution of complex operative procedures with a level of precision unattainable through conventional surgical methods.

Laser endoscopic surgery is an innovative, minimally invasive surgical procedure that utilizes laser energy for precise tissue ablation and coagulation. It is increasingly applied across a wide range of medical specialties such as angiology, gastroenterology, gynecology, cardiology, oncology, orthopedics, otorhinolaryngology, ophthalmology, dentistry, urology, physiotherapy, phlebology, and others (fig.1). Procedures performed using this method allow for rapid patient recovery and help prevent various complications, such as the need for deep anesthesia, significant blood loss, development of inflammatory processes, and poorly executed sutures completing the operation. Laser-assisted surgeries also save time and resources for medical teams.

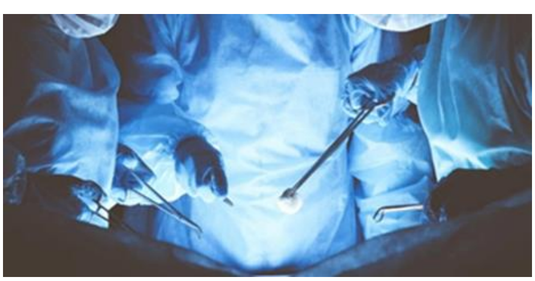

Fig. 1. Group surgeons wearing safety masks perform operation medicine concept

An endoscope is essentially a small, flexible tube equipped with a camera and a light source at its tip, which is inserted into the body through a small surgical incision or a natural opening, depending on the location of the operative field. The laser beam is applied to cut, remove, or coagulate tissue, thereby eliminating the need for traditional surgical techniques and instruments.

This surgical technique is gaining popularity due to its ability to provide highly effective, targeted treatment, significantly reducing the risk of complications and enabling faster recovery. Today, laser endoscopic surgery is increasingly performed using robotic surgical systems, further enhancing precision and control during operative interventions.

Laser-based robotic systems perform minimally invasive operations in hard-to-reach areas, significantly reducing the size of the surgical field. As a result, the risk of complications is minimized, and surrounding tissues, organs, and systems are maximally protected, since the laser removes only the targeted tissue within the operative field without damaging adjacent healthy structures.

These procedures are performed with minimal blood loss, and the use of laser-assisted "sutures" to close the surgical wound allows for significantly faster recovery compared to traditional surgical interventions. [1-9]

Among the major advantages of laser endoscopic surgery over traditional surgical methods are:

• Greater precision – the laser does not damage surrounding tissues, as it targets a clearly defined operative field. This significantly reduces the risk of side effects and complications.

• Reduced operative field – thanks to its precise targeting of a specific area, the size of the operative field is significantly minimized, which in turn reduces the size of postoperative wounds and scars and accelerates their healing time.

• Minimally invasive – since the procedure is performed through smaller incisions, blood loss is significantly reduced, leading to faster recovery for patients after the intervention.

Several types of lasers are used in endoscopic surgery, including:

• Carbon dioxide (CO_2) laser

• Neodymium-doped yttrium aluminum garnet (Nd:YAG) laser

• Erbium-doped yttrium aluminum garnet (Er:YAG) laser

The choice of a specific type of laser depends on the particular surgical procedure and the type of tissue being treated, and is made with consideration of the respective advantages and limitations of each laser system.

Laser endoscopic surgery also has certain disadvantages that must be considered when planning its use:

• Not always suitable for all types of surgeries or for every patient, as there is always a risk of complications;

• Potential for unintended tissue damage due to scattering or reflection of the laser beam from nearby structures in the operative field – safety measures must be taken, and the surgical field must be precisely defined;

• Risk of thermal injury to tissues caused by excessive heat, especially in sensitive areas such as the brain, eyes, or mucous membranes – precise control of exposure time and laser power is required;

• High cost of the equipment and the need for additional training of medical teams, which limits access to this technology in some healthcare facilities.

2.2. Risks and Complications After Laser Treatment

The widespread use of laser treatment is highly effective and gentle for patients. When all procedures are performed according to pre-established protocols, the risk of complications is minimal. To ensure this, planned interventions are preceded by a detailed examination, and all potential risks and benefits are assessed and discussed with the patient. Safe recovery is planned in combination with a set of measures aimed at reducing some of the risks associated with the procedures:

• Adequate pre-procedural preparation: This often includes the discontinuation of intense physical activity, dietary adjustments, and temporary cessation of certain medications.

• Post-procedural preventive measures: Depending on the type of laser treatment applied, various recovery measures are recommended, such as avoiding direct sunlight without protection, temporarily refraining from certain cosmetic procedures, taking prescribed medications, and avoiding heavy physical exertion.

• Contraindications: In some cases, laser use is contraindicated or must be applied with caution. These include immunocompromised patients with severe immunosuppression, individuals with autoimmune diseases, patients who have undergone radiation therapy in the facial area followed by facial laser therapy, pregnant and breastfeeding women, patients with darker skin undergoing localized dermatological laser treatment, and individuals prone to keloid formation.

• Post-procedural risks: Depending on the type of treatment performed, complications may occasionally occur, such as redness, pain, swelling, itching, changes in skin pigmentation, and in some cases, the development of secondary infections.

3. New Treds Of Applications Of Laser Technology In Surgery

Among the latest trends in laser endoscopic surgery are:

The use of new laser wavelengths and operating modes. For example, in the treatment of prostate cancer, infrared lasers are used because they penetrate deeper into tissues and are therefore applied in surgical practices, unlike picosecond lasers, which are most effective in dermatological treatments.

• The use of fluorescence imaging, which enhances visualization of the treated structures and is successfully applied in oncology. This involves the use of fluorescent dyes injected into the body and activated by a laser during surgery, allowing the surgeon to see tissue structures more clearly [10].

• The use of robotic systems, which provide greater precision in performing laser ablation. These systems enable sub-millimeter accuracy through pre-programmed procedures, helping to avoid damage to surrounding tissues and increasing the success rate of complex interventions. Robotic systems also offer the best visualization of the surgical field.

• Imaging through Optical Coherence Tomography (OCT) provides the best real-time visualization during procedures, giving surgeons optimal visibility of the surgical field and guiding the laser beam precisely during the operation, which significantly improves surgical outcomes [11, 12].

The significant impact of laser endoscopic surgery on medical practice is accompanied by several challenges, such as the need to improve surgeons' qualifications for safe use of laser technology due to its technical requirements, as well as ensuring the safety of medical teams and patients.

Another important trend is the use of increasingly advanced laser technologies. Optical fibers are being used more frequently for precise delivery of laser energy through endoscopes with significantly miniaturized sizes, applicable in a wide range of procedures such as coagulation, tissue ablation, and cutting.

Despite its many advantages, laser endoscopic surgery also has some potential drawbacks and limitations. In certain procedures, the use of lasers may carry risks such as accidental organ perforation or thermal damage to surrounding tissues.

Nevertheless, the use of laser-assisted surgery is expanding not only in endoscopic procedures but also in open surgery.

4. Applications Of Laser Technology In Surgery Across Different Medical Areas

4.1. Application in Angiology and Phlebology

Lasers are widely used in the fields of angiology and phlebology [13].

Reports on the application of laser technology in phlebology date back to 1981, when a dye laser with a wavelength of 577 nm was used to treat damaged microvessels.

In 1983, Endovenous Laser Obliteration (EVLO) was introduced into practice. This method is based on the selective absorption of laser energy with a specific wavelength by various tissue components, leading to their selective destruction. It enabled selective coagulation and microvascular hemostasis through intravascular exposure to laser radiation [10].

In 1997, a study was presented on the optical properties of blood when exposed to laser radiation with wavelengths ranging from 400 to 2500 nm. The absorption of energy by different optical components of blood (hemoglobin and water) was examined. The wavelengths with maximum absorption by the various blood components were identified. These findings form the basis of all Endovenous Laser Ablation (EVLA) lasers. In 1998–1999, diode lasers with a wavelength of 810 nm were used for EVLA, as described in reports [14], and the method was named Endovenous Laser Therapy (EVLT) [15].

In 2001, data were summarized on delivering laser energy to the great saphenous vein (GSV) via intravascular injection using a laser fiber and a diode laser with a wavelength of 810 nm. One-year follow-up of patients showed 100% vein obliteration.

The process of thrombotic occlusion following thermal application of laser radiation was described in 2002. The mechanism of EVLA [14] is based on the indirect effect of thermal energy on the vessel wall following the absorption of light energy by hemoglobin (Fig.2). As a result of the thermal effect, vapor bubbles form in the blood, their volume correlating with the laser beam's power. These bubbles damage the endothelium of the venous wall. In the studied case, the maximum penetration depth of the laser beam (wavelength 940 nm) through blood was 0.3 mm. The study concluded that laser radiation, due to its complete absorption by hemoglobin, does not damage the endothelium.

Fig 2 Portable-Leg-Varicose-Veins-Laser-Evla

In 2008, angiologists reported results from the elimination of perforating veins using EVLO. A 100% obliteration rate was reported for 67 perforating veins. In 90% of cases, an energy flow of 50J achieved complete obliteration in treated patients.

In 2009, phlebologists tested a new type of optical fiber called JACKET (Fig.3). These fibers allow for even distribution of laser energy around the vessel due to their spherical working tip. The advantage of this type of fiber is that it does not require the use of catheters for vessel insertion. Results from a clinical study comparing the effectiveness of radiofrequency ablation and EVLA with the JACKET catheter were presented.

The conclusion was that there were no significant differences in procedure duration, postoperative recovery time, or complications. At the same time, the cost was significantly lower than that of EVLO consumables [16].

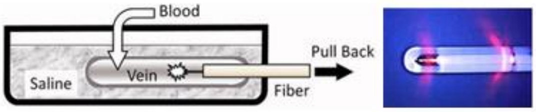

Fig.3 JACET tool [16]

4.2. Application in Gastroenterology

In the 1990s, laser technologies entered the field of gastroenterology (for surgical interventions on the esophagus, stomach, colon, in cases of acute gastrointestinal bleeding treated endoscopically, for the extrahepatic bile ducts and abdominal parenchymal organs, as well as for lymphangiomas, hemangiomas, hemorrhoids, and others). High-energy lasers, instruments, and staplers were used. New methods for surgical interventions were introduced, including the creation of a laser mechanical suture with an adjustable compression period on the tissues (Fig.4) . Techniques for laser "welded" anastomoses of hollow organs in the gastrointestinal tract were tested. Methods were developed for stopping acute gastrointestinal bleeding using CO_2, YAG-neodymium, and argon lasers through endoscopic surgery. Laser methods became widely used for the removal of polyps, villous tumors of the stomach, and for the recanalization of the esophagus and colon in cases of stenosing tumors of these organs [17-19].

Fig. 4 A gastroenterologist performs a gastroscopy or colonoscopy using a probe

4.3. Application in Gynecology

Laser endoscopic surgery is increasingly used in gynecology [20, 21], offering precise, minimally invasive, and often bloodless solutions for a variety of conditions. Here are some of its main applications:

Pelvic surgeries – Laser technology is used in laparoscopic procedures for the removal of cysts, fibroids, endometriosis, and adhesions, achieving minimal damage to surrounding tissues.

Interventions on the cervix and vagina – Lasers are used to treat cervical dysplasia, condylomas, polyps, and other benign lesions.

Ovarian ablation – In cases of polycystic ovary syndrome (PCOS), laser ablation can be used to restore ovulation.

Laser removal of adhesions – Particularly effective in women with chronic pelvic pain or following inflammatory diseases.

Laser vaginal therapy – Modern systems such as Fotona and MonaLisa Touch are used for:

• Treatment of stress urinary incontinence (IncontiLase)
• Vaginal relaxation (IntimaLase)
• Pelvic organ prolapse (ProlapLase)
• Vaginal atrophy during menopause (RenovaLase) – painless, incision-free, and with no recovery time required.

The main advantages of using laser technology in gynecology are:

• Minimal tissue trauma – the laser allows for extremely precise cutting and coagulation, which preserves healthy tissues.
• Bloodless procedures – laser energy coagulates blood vessels during the incision.
• Lower risk of infections – due to the less invasive nature and the sterile properties of laser energy.
• Faster recovery – patients recover more quickly and often do not require hospitalization.
• Less pain after the procedure – thanks to the gentle nature of the laser intervention [20, 21].

4.4. Application in Dermatology and Cosmetology

Laser technology is widely used in dermatology for treating a variety of skin conditions, including[22-24]:

• Neurodermatitis, urticaria, acne, vitiligo, rosacea, herpes zoster
• Nail mycosis, wart removal, scar treatment
• Hair loss and alopecia (treatment and prevention)
• Skin rejuvenation and anti-aging procedures

• In dermatologic plastic surgery, lasers are clinically applied for: Benign and malignant skin tumors, Hypertrophic and keloid scars, Vascular and pigmented lesions, Cosmetic defects

Types of Lasers in Aesthetic Dermatology

Ablative Lasers (Resurfacing)

• Use high-energy beams to vaporize the outer skin layers.
• Stimulate collagen production during healing, resulting in smoother, firmer, and younger-looking skin.
• Effective for deep wrinkles and skin texture improvement.
• Drawbacks: Long recovery time (weeks to months), higher risk of side effects.
• Types: Er:YAG and CO_2 lasers.

Non-Ablative Lasers

• Target the dermis without damaging the epidermis.
• Used for photorejuvenation, treating fine lines, pigmentation, and vascular lesions.
• Advantages: Minimal downtime, lower risk of complications.
• Drawbacks: Less dramatic results, requiring multiple sessions.

Fractional Lasers (Fractional Photothermolysis)

• Treat microscopic zones of skin, leaving surrounding tissue intact.
• Faster healing with results similar to ablative lasers but fewer side effects.
• Effective for: Facial and periorbital wrinkles, Sun-damaged and aging skin, Pigmented lesions and acne scars, Improving skin elasticity, texture, and tone
• Typically requires 1–3 sessions spaced 3–4 weeks apart.
• Mild discomfort (burning sensation), redness for up to 7 days, occasional swelling.
• Post-treatment care includes sun protection (SPF 30+) and hydration.

Cosmetology Applications

Laser technologies are also used in the beauty industry for:

• Scar and stretch mark correction
• Vitiligo treatment
• Teeth whitening
• Tattoo removal
• Laser hair removal
• Transdermal delivery of micro-molecules for rejuvenation
• Percutaneous Laser Coagulation

Percutaneous Laser Coagulation

The successful use of lasers in treating facial telangiectasias forms the basis for the method used to treat reticular varicose veins in the legs. Sclerotherapy is difficult to apply for vessels with a diameter smaller than 1 mm and carries unwanted side effects such as hyperpigmentation and epidermal necrosis.

For the treatment of large and deep vessels, lasers with lower hemoglobin absorption and reduced skin scattering are used. This allows for homogeneous heating and sclerosis, following the principle of selective photothermolysis. Suitable lasers for this purpose operate in the infrared range: Alexandrite (755 nm), diode lasers (810, 940, 970 nm), and Nd:YAG (1064 nm). Oxyhemoglobin absorbs weakly at 755 and 1064 nm, and selective photothermolysis at these wavelengths may be accompanied by thermal damage to the skin. Therefore, the role of Alexandrite and Nd:YAG lasers is mostly supportive.

The most suitable lasers for selective sclerosis of vessels up to 1.5 mm in diameter are diode lasers in the 810–970 nm range. In this range, dispersion is very low, and oxyhemoglobin absorption is relatively low, allowing uniform heating across the vessel's cross-section.

For superficial vessels up to 0.5 mm in diameter, especially on the face, yellow-green lasers (532 nm), Alexandrite, and Nd:YAG lasers are the most effective and safest.

For vessels larger than 1.5 mm, microsclerotherapy is the most effective method. For the largest veins in the lower limbs, diode lasers in the 800–1000 nm range are the most effective.

4.5. Application in Cardiac Surgery

The application of laser technology in clinical cardiac surgery is rapidly evolving and includes both invasive and non-invasive procedures [11]. The main areas of development are:

Endoscopic and Minimally Invasive Cardiac Surgery

Laser technology is used in procedures involving heart valves, correction of atrial septal defects, biopsies, and tumor removal [25].

These interventions are performed through small incisions using an endoscope and laser instruments, which:

• reduce surgical trauma,
• shorten hospital stays,

• accelerate recovery,

• and improve cosmetic outcomes.

Excimer Laser Atherectomy

This technique is used to remove calcified plaques and restenosis in coronary and peripheral vessels.

The excimer laser (308 nm UV) does not burn tissue but breaks it down through photoablation, making it extremely precise and safe.

It is suitable for:

• Chronic total occlusions

• Transmyocardial revascularization

• Complex in-stent lesions

• Peripheral arterial disease (PAD)

• Removal of pacemaker and defibrillator leads

Advantages of Laser Technology in Cardiology:

• Minimal thermal trauma

• High precision when working with vessels and implants

• Improved safety in complex cases

• Shorter recovery time

• Suitable for patients with contraindications to traditional methods

4.6. Application in Neurosurgery

The application of laser technology in neurosurgery is an innovative and rapidly developing field that offers new possibilities for treating complex brain and spinal conditions with high precision and minimal invasiveness [26, 27, 28]. The main areas include:

Laser Interstitial Thermal Therapy (LITT)

• Used for the treatment of brain tumors, epileptogenic zones, metastases, gliomas, and recurrent lesions.

• The procedure involves inserting a thin laser catheter into the brain under MRI guidance, which heats and destroys the pathological tissue.

Advantages: minimally invasive, suitable for patients who are not candidates for open surgery, short hospital stay

Laser Discectomy

• Applied in cases of herniated discs and degenerative spinal diseases.

• The laser is used to vaporize part of the intervertebral disc, relieving pressure on the nerves.

Advantages: bloodless procedure, performed on an outpatient basis, fast recovery

Laser Ablation for Epilepsy

• Used for thermal destruction of epileptogenic foci, especially in deep brain structures such as the hippocampus.

• Suitable for patients with medication-resistant epilepsy.

General Advantages of Laser Neurosurgery:

• High precision when working with delicate brain structures

• Minimal trauma to surrounding tissues

• Lower risk of infections and complications

• Shorter hospital stay and recovery period

• Enables treatment of hard-to-reach lesions

4.7. Application in Neurology and Physiotherapy

Laser technology is increasingly becoming part of modern medicine for the treatment of certain neurological conditions such as neuralgia, plexitis, neuritis and radiculitis.

In physiotherapy, the heat generated by laser energy absorbed by tissues is used to treat various physiological conditions. Laser therapy enhances blood flow and stimulates microcirculation in the treated area, which in turn increases cellular metabolism, provides anti-inflammatory and analgesic effects, and reduces tissue swelling.

Laser procedures are increasingly used in the treatment of inflammatory and degenerative musculoskeletal disorders (arthritis, arthrosis, tendovaginitis), as well as in post-traumatic recovery and comprehensive physiotherapeutic programs.

In physiotherapy, low-level lasers therapy (LLLT) is widely used. LLLT [29] which is also known as phototherapy or photobiomodulation (Fig.5) involves the use of photons in non-thermal irradiation to alter the biological activity of treated tissues.

This technology uses:

• Coherent light sources (lasers),

• Non-coherent sources (LEDs or filtered lamps),

• Or a combination of both.

These stimulate stem cells, aiding tissue regeneration and healing. Even at low doses, laser irradiation increases the proliferation of fibroblasts, lymphocytes, keratinocytes, and endothelial cells.

The mechanism is based on photostimulation of mitochondria, where photons are absorbed by mitochondrial chromophores. This increases reactive oxygen species, activates signaling pathways, and regulates transcription factors, leading to the production of growth factors.

LLLT also:

• Enhances collagen synthesis
• Promotes neovascularization
• Stimulates angiogenesis, aiding the healing of acute and chronic wounds

Fig.5 Phototherapy tool [30]

Therapeutic Effects of Photobiomodulation:

• Stimulates endorphin production
• Increases cellular metabolism
• Promotes cell growth and regeneration
• Triggers anti-inflammatory responses
• Stimulates nerve function
• Reduces edema
• Decreases bradykinin and histamine production
• Reduces fibrous tissue formation
• Stimulates long-term nitric oxide production

Photobiological Effects:

Primary effect: Interaction between photons and mitochondria, converting light energy into chemical energy, regulating cellular activity.

Secondary effect: Tissue-level responses such as protein synthesis, cell proliferation, degranulation, increased growth factor production, myofibroblast contraction, and neurotransmitter modulation.

Combined Therapy:In biomedical LLLT, the goal is cellular regeneration. It stimulates detoxification pathways, helping eliminate harmful metabolic byproducts such as viruses, bacteria, and foreign antigens.

4.8. Application in Nephrology and Urology

In nephrology [31], lasers are now used in daily clinical practice, playing a key role in the treatment of urolithiasis (kidney stone disease) by breaking down certain types of stones.

In urology, laser technologies are actively used in surgical procedures for prostate conditions (including partial removal in cases of prostatitis), tumor diseases, and more. In modern medical practice, laser technologies are increasingly replacing traditional conservative surgical methods in favor of minimally invasive, endoscopic techniques [32. 33].

For the removal of soft tissue benign and malignant lesions, green lasers, diode lasers, holmium lasers, and thulium lasers are widely used. For stone fragmentation, the holmium laser is the primary tool [34].

The thulium laser generates high-energy, short light pulses at high frequency, as well as continuous wave (CW) laser emission. It is used in enucleation procedures. Thulium lasers are applied in:

• Prostate vaporization (enucleation)
• Tumor surgery without carbonization
• Stone fragmentation with minimal damage to surrounding tissues

A key advantage of fiber-thulium technology is the significantly reduced size of the module, allowing integration into various devices. This fiber-laser technology enables the use of increasingly thin endoscopic fibers in surgical practice. However, a major limitation that reduces their effectiveness is the restricted average optical power output (up to 8 W).

4.9. Application in Oncology

The application of laser technology in oncology [35-42] is of great importance for modern cancer diagnosis and treatment. Lasers are widely used in the treatment of tumors, polyps, and precancerous lesions. Various methods are applied, such as tumor irradiation, focused beam coagulation, and others, with the goal of destroying, removing, or significantly reducing the size of the tumor.

Thanks to their precision, controlled energy, and ability to selectively target tissues, lasers are used in several key areas:

Laser Surgery

• Used for removing tumors in hard-to-reach areas such as the vocal cords, bladder, cervix, and others [35-37].

• Allows for bloodless interventions with minimal damage to surrounding healthy tissues.

• Suitable for both benign and malignant tumors, especially in early stages [38.41].

Photodynamic Therapy (PDT)

• Combines photosensitizing agents with laser light to selectively destroy cancer cells.

• Used in the treatment of skin cancer, esophageal cancer, lung cancer, and bladder cancer [39.40].

• Advantages: minimal toxicity, tissue-sparing, and suitable for repeated applications.

Diagnostics and Biopsy

• Lasers are used for targeted biopsy and visualization of tumor structures through fluorescence imaging.

• In some cases, laser technology can detect circulating tumor cells in the blood with up to 1000 times greater sensitivity than standard methods.

Laser Ablation

• Used for thermal destruction of tumor tissue, especially in the brain, liver, and prostate.

• Laser Interstitial Thermal Therapy (LITT) is performed under MRI guidance.

Studies have examined the morphological features of photodestruction in certain tumors, and optimal parameters for photodynamic tumor destruction have been developed through experiments.

Professor E. F. Stranadko [42] applied photodynamic therapy methods in clinical practice, pioneering the treatment of malignant tumors with external localization (skin, early-stage breast cancer, oropharyngeal cancer, and tumors in difficult-to-access locations).

Research has also focused on the development, clinical testing, and application of second-generation photosensitizers, photoactive drugs, and metal-based compounds for photodynamic therapy.

Methods are being developed for targeted delivery of photosensitizers to ensure selective accumulation in tumor tissues.

Advantages of Laser Oncology:

• High precision and control
• Minimally invasive
• Fewer side effects
• Suitable for patients with contraindications to chemotherapy or radiotherapy
• Can be combined with other therapies

4.10. Application in Orthopedics

The application of laser technology in orthopedics has significantly expanded in recent years [43, 44], thanks to its ability to provide precise, minimally invasive, and tissue-sparing interventions for various traumatic conditions and diseases of the musculoskeletal system. The main areas of application in modern practice include:

Laser Surgery for Joint and Bone Disorders is applied in arthroscopic procedures for the treatment of:

• Meniscal injuries
• Chondromalacia
• Synovitis
• Osteochondral defects

Laser technology allows for precise cutting, coagulation and ablation of tissues with minimal damage to surrounding structures.

Laser Therapy for Pain and Inflammation. Here, Low-level laser therapy (LLLT) is applied in clinically proven cases for the treatment of:

• Pain relief in arthritis, bursitis, tendinitis
• Stimulation of regeneration in muscle and tendon injuries
• Reduction of inflammation and swelling

Laser Osteosynthesis and Regeneration

• In experimental and clinical settings, laser stimulation of osteoblasts is used to accelerate bone regeneration.

• Also applied in cases of delayed fracture healing or pseudoarthrosis.

Laser Discectomy for Spinal Conditions

In cases of herniated discs, laser nucleoplasty is used—a minimally invasive procedure in which part of the disc is vaporized using a laser to relieve pressure on the nerves.

Advantages of Laser Technology in Orthopedics:

• Minimal tissue trauma
• Faster recovery
• Less postoperative pain

• Lower risk of infection
• Possibility for outpatient treatment

4.11. Application in Otorhinolaryngology

The application of laser surgery in otorhinolaryngology [45, 46] continues to expand and evolve, with 2025 seeing increased interest in minimally invasive techniques and the integration of laser technologies into routine clinical practice. Below is a summary of the key points:

Main Areas of Application

Laryngology

• Treatment of benign and malignant lesions of the vocal cords (papillomas, polyps, carcinomas).
• Phonosurgery with CO_2 laser to improve vocal function.

Rhinology

• Laser reduction of hypertrophic nasal turbinates.
• Treatment of chronic rhinitis and nasal polyps.
• Endoscopic laser surgery of the sinuses.

Otology

• Precision work in stapedoplasty and other microsurgical interventions of the middle ear.

Head and Neck Oncology

• Transoral laser microsurgery (TLM) for tumors of the pharynx and larynx.
• Less invasive alternative to open surgeries.

Advantages of Laser Surgery

• Precision and control – minimal damage to surrounding tissues.
• Bloodless field – coagulation of vessels during cutting.
• Faster recovery – less pain and swelling.
• Outpatient procedures – possibility of performing without hospitalization.

Limitations

• Requires specialized training and equipment.
• Risk of thermal damage if used improperly.
• Higher initial investment for equipment.

4.12. Application in Ophthalmology

Laser surgery has revolutionized ophthalmology [47-51] by offering precise, effective, and minimally invasive methods for treating a wide range of eye diseases. Laser technologies have a significant impact in ophthalmology; they are applied in modern practice for reduced visual acuity, astigmatism, and for the treatment of certain retinal diseases and some forms of glaucoma.

Main Areas of Application in Ophthalmic Laser Surgery:

Refractive Errors

• LASIK and PRK – correction of myopia, hyperopia, and astigmatism by reshaping the cornea.

Glaucoma

• Selective Laser Trabeculoplasty (SLT) – improves the outflow of intraocular fluid and reduces intraocular pressure.
• Laser Iridotomy – used in angle-closure glaucoma.

Diabetic Retinopathy

• Photocoagulation – this method uses a special laser to create micro-burns on the retina, stopping the growth of new blood vessels. It has the highest potential and can reduce the risk of blindness by up to 90%.
• Vitrectomy – a surgical procedure to remove the vitreous gel from the center of the eye, mainly used in cases of retinal detachment or hemorrhage.
• In cases of macular edema, two treatment options are available:
• Focal photocoagulation, which slows fluid leakage in the macula.
• Intravitreal injections of drugs that block VEGF (vascular endothelial growth factor), which stimulates the growth of new blood vessels and plays a key role in the development of retinopathy.

Retinal Tears and Detachments

• Argon Laser – creates a seal around the tear area, preventing progression.

Age-Related Macular Degeneration (AMD)

• Photodynamic Therapy (PDT) – destroys abnormal blood vessels in the macula.

Secondary Cataract

• YAG Laser Capsulotomy – removes clouding that occurs after intraocular lens implantation.

Advantages of using laser technologies in Ophthalmology

• High precision and selectivity.
• Minimal trauma and fast recovery.
• Possibility for outpatient treatment.

Limitations

• Requires specialized equipment and training.

• Risk of retinal damage if misused.

• Not suitable for all patients and conditions.

Types of Lasers Used in Ophthalmology

Laser procedures are bloodless, and tissue recovery is fast and efficient. With the help of a computer, the eye is scanned in 3D (Fig.6), providing reliable information about the unique shape of the eye and the stage of the disease. The laser is configured to the appropriate mode based on the patient's individual characteristics, and the laser beam performs incisions in seconds—without the surgeon physically touching the patient. The level of precision is incomparable to invasive surgery, making this method ideal for procedures in this field of medical practice.

Fig 6. Eye diagnostic procedure in progress

Among the most effective lasers used in the treatment of diabetic retinopathy are femtosecond lasers, which offer several advantages over conventional cataract surgery.

The most widely used is the micropulse or yellow laser, operating at a unique wavelength of 577 nm, which is not absorbed by the macular pigment. This protects against vision damage in case of accidental error or misadjustment by the ophthalmologist. This laser works over 10 times faster than the standard green laser and is much gentler on the retina. When operating in subthreshold mode (about 50% below minimum power), the yellow laser does not destroy cells but stimulates them at a biochemical level. The effect of the procedures is typically observed between the 6th and 8th week of therapy, with a gradual reduction in retinal swelling. Laser procedures can also be performed using the classic green laser with a wavelength of 532 nm. However, it is not suitable in cases of macular edema, and its action can affect not only pathological but also surrounding tissues. This is why treatment with this type of laser may sometimes result in scotomas (dark spots in the visual field).

Fig.7. Ophthalmological practice with Laser for curing DR

In modern ophthalmic practice, combined lasers are most commonly used, such as those from the Eye Lite system (Fig. 7), which combine a diode and dual-frequency YAG laser. Diode emission is highly efficient and has a lower thermal effect. The dual-frequency YAG laser converts light from 1064 nm to 532 nm using a KTP crystal. This laser allows for longer use compared to standard diode or argon lasers.

The clinical effect of the combination laser is similar to that of the argon laser, but with the advantage of a 532–514 nm wavelength. Its application is much safer due to significantly lower absorption by the xanthophyll pigment of the macula. However, it shows increased absorption by hemoglobin and oxyhemoglobin, so it is not recommended for treating large hemorrhagic areas. The latest modern lasers are from the Pascal system, which allows for the creation of a group of coagulates in a specific pattern with a single shot.

4.13. Application in Dentistry

Laser technology is increasingly used in modern dentistry (Fig.8) and is becoming a permanent part of new treatment trends. In the near future, it may even replace traditional treatment methods [52-58]. Laser techniques offer precise, painless, and minimally invasive solutions for a wide range of dental procedures. They also provide significant advantages when working with children, highly traumatized, or hypersensitive patients.

Fig. 8. Modern dental practices based on laser technologies

Main Areas of Laser Application in Dentistry are:

Soft Tissue Procedures

• Gingivectomy and gingivoplasty – shaping and removing excess gingival tissue.

• Frenulotomy – cutting a short frenulum of the tongue or lip.

• Periodontitis treatment – disinfection and reduction of periodontal pockets.

• Biopsies and lesion removal – precise and bloodless excision of benign formations.

• Soft tissue surgery – including removal of fibromas, papillomas, etc.

Hard Tissue Procedures

• Caries removal – painless and often without the need for anesthesia.

• Tooth preparation for fillings – with minimal damage to healthy tissue.

• Endodontic treatment – disinfection of root canals.

• Treatment of tooth sensitivity – by sealing dentinal tubules.

• Teeth whitening – activation of whitening agents with laser light.

Most Common Types of Dental Lasers Used in Practice

• High-energy lasers such as Nd:YAG, Erbium, CO_2 are used for treating hard dental tissues (removal of carious tissue). They are suitable for easily accessible, superficial caries. Results are comparable to those achieved with ultrasonic (piezo) techniques, which are effective for deep and hard-to-reach caries. The main component in the equipment is a laser diode, activated by electric current. The diode emits monochromatic light, which is focused, defocused, and transmitted via flexible optical fibers. The light is invisible and emits non-ionizing thermal radiation, which does not cause changes in cellular DNA. The laser is usually air-cooled.

• High-energy laser systems are suitable for treating: abscesses, adenomas, aphthae, biopsies, biostimulation, teeth whitening, periodontal pocket curettage, desensitization of sensitive dental tissues, drainage, epulis, excision, fibroma, fistulas, frenectomies, gingivectomies, gingivoplasty, hemangiomas, hemostasis, herpes, hyperplasia, implant exposure, incisions, root canal sterilization, pulp coagulation, mucocele, operculectomy, papilloma, peri-implantitis, sulcus retraction, sulcus sterilization, fistulous tracts, vestibuloplasty.

• Diode lasers are also high-energy lasers with wavelengths ranging from 700–1100 nm, allowing painless, bloodless coagulation and vaporization of soft tissues. This enables nearly all surgical interventions on soft tissues in the oral cavity, such as gingivotomy, biopsies, frenulotomy, and periodontal treatment.

• Nd:YAG laser is successfully used for treating dental calculus and periodontal pockets.

• CO_2 laser is used in oral surgery and cosmetic procedures.

• Photodynamic laser has a powerful bactericidal effect, especially effective in treating periodontal diseases.

Key Advantages of Laser Technology in Dental Practice

• Minimally invasive: Laser procedures are usually significantly less painful and require smaller incisions, reducing the need for stitches in oral surgery. Laser technology promotes faster healing and reduces patient discomfort.

• Precise and controlled: Dentists can target specific areas with maximum precision, minimizing damage to surrounding healthy tissue.

• Reduced bleeding: Lasers promote blood clotting, reducing bleeding during and after procedures.

• Minimal anesthesia: In many cases, local anesthesia is not necessary, making dental visits more comfortable for patients.

• Faster healing: Laser treatments provide faster healing due to reduced tissue trauma.

• Reduced risk of infection: Lasers have a sterilizing effect, lowering the risk of postoperative infections.

• Application in pediatric dental care: Due to comfort, relatively painless application, and good results, pediatric dentistry is one of the areas expected to develop dynamically in the near future [8,9].

Limitations

• High cost of equipment.

• Requires specialized training.

• Not all procedures can be performed on every patient.

5. New Trends And Techniques In Laser Endoscopic Surgery

The modern development of laser endoscopic surgery is based on the use of ultrafast lasers, which enable extremely precise tissue incisions with minimal damage to surrounding structures. Laser technology is also used in combination with other advanced technologies such as ultrasound and radiofrequency ablation, offering improved precision and better outcomes, especially in the treatment of oncological diseases.

We have already highlighted the significant impact of laser endoscopic techniques and laser surgical practices in key areas of medicine where precision is critical. Now, we will outline the latest trends and techniques in their application in medical practice:

5.1. Thulium Laser

The thulium laser is a new technology that has gained popularity in recent years. It is a versatile laser with a wavelength of 2.0 µm, allowing efficient tissue absorption with minimal thermal damage. It is used in various endoscopic procedures, including:

• Prostate surgery
• Bladder tumor resection
• Treatment of urethral strictures

5.2. Robotic Laser Endoscopy

This technique allows for enhanced precision during surgical interventions. The robotic arm, controlled by the surgeon, directs the laser with high accuracy to the tissue, reducing the risk of damage to surrounding structures (Fig.9). It is mainly used in:

• Gastrointestinal surgery
• Gynecological surgery
• Urological surgery

Fig. 9: Stomach surgery – medical procedure with surgical intervention in an operating room.

5.3. Fractional Laser Ablation

A technique that uses small laser beams to ablate tissue. It allows for precise removal of damaged tissue without affecting surrounding areas. It is used for:

• Treating esophageal strictures
• Removing colon polyps

5.4. Advanced Imaging Technologies

The use of high-resolution cameras and three-dimensional (3D) imaging systems (Fig.10) provides better visualization of the surgical field, allowing for more accurate surgical interventions.

Fig. 10: 3D X-ray endoscopy removing a colon polyp with a wire loop.

5.5. Laser Lithotripsy

A standard endoscopic procedure that uses laser energy to break up kidney and urinary tract stones. The most commonly used laser is the holmium laser with a wavelength of 2.1 µm.

5.6. Laser Tumor Ablation: A minimally invasive technique for destroying tumor tissue using laser energy. The most commonly used lasers are the CO_2 laser and the Nd:YAG laser. It is applied to tumors of the:

• Lungs
• Liver
• Brain

5.7. Laser-Assisted Hysteroscopy

A minimally invasive procedure using a laser fiber to remove pathological tissue with reduced bleeding and faster recovery. It is used to treat gynecological conditions such as:

• Uterine fibroids
• Endometrial polyps

5.8. Confocal Laser Endomicroscopy (CLE)

A new endoscopic technique that provides high-resolution real-time imaging of tissues. It uses a laser to generate a fluorescent signal, which is captured by a specialized microscope attached to the endoscope. CLE improves diagnostic accuracy and guides surgical resection.

5.9. Transoral Laser Microsurgery (TLM)

A minimally invasive technique for removing tumors in the oral cavity and larynx. It allows for precise excision with minimal damage to surrounding tissues. Particularly useful for tumors in hard-to-reach areas.

5.10. Transoral Robotic Surgery (TORS)

A minimally invasive technique for treating head and neck tumors. A robot directs the laser through the mouth and throat to remove tumors. Advantages include:

- Faster recovery
- Significantly fewer side effects compared to traditional surgery

5.11. Laser-Assisted Transurethral Resection of the Prostate (Laser-TURP)

Used to treat benign prostatic hyperplasia (BPH). The laser removes excess tissue causing urinary symptoms. Advantages:

- Less bleeding
- Shorter hospital stay
- Faster recovery

Fig. 11 Endoscopic procedure with laser submucosal dissection.

5.12. Endoscopic Submucosal Dissection (ESD)

Used to remove early-stage gastrointestinal tumors without the need for open surgery (Fig.11). The laser precisely cuts through the mucosal and submucosal layers of the digestive tract. Advantages:

- Less invasive alternative to traditional surgery
- Shorter hospital stay
- Fewer complications

Even vaccine delivery is being revolutionized with laser technology, replacing traditional injection methods by implanting subcutaneous microparticles that release the active substance over time.

6. Conclusion

Laser endoscopic surgery represents a significant breakthrough in the development of minimally invasive surgery. Its advantages—such as reduced pain, shorter hospital stays, faster recovery, and minimal damage to surrounding tissues—make it a valuable tool in modern medical practice.

The observed therapeutic effects of laser technologies and phototherapy establish these methods as leading approaches in both the treatment and prevention of various diseases. The integration of robotic assistance, advanced imaging systems, and ultrafast lasers expands the scope of application and enhances the precision and safety of procedures.

Despite existing challenges—such as the high cost of equipment and the need for specialized training—laser endoscopic surgery continues to be the focus of intensive scientific research and technological innovation. The future development of new laser systems with varying wavelengths and pulse durations is expected to contribute to its even broader application across different medical specialties.

Acknowledgments: The author express their gratitude for the funding under Project No. BG16RFPR002-1.014-0006 "National Center of Excellence in Mechatronics and Clean Technologies", funded by the "Research, Innovation and Digitalization for Smart Transformation" Program 2021-2027, co-financed by the European Union through the European Regional Development Fund for Research Excellence for the realization of the article.

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