BULLETIN OF STOMATOLOGY AND MAXILLOFACIAL SURGERY
Volume 22 N 5

DOI:10.58240/1829006X-2025.22.5-82

REVIEW ARTICLE

MODERN LASER TECHNOLOGIES IN DENTISTRY: A STATE-OF-THE-ART NARRATIVE REVIEW

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Received: Jun 25 2026; Accepted: Aug 5. 2026; Published: Aug 13. 2026

Abstract

Background: Laser technologies have become increasingly important in modern dentistry due to their selective interaction with biological tissues, minimally invasive characteristics, and wide range of clinical applications. The appropriate selection of a laser system requires a comprehensive understanding of laser–tissue interactions, wavelength-dependent absorption mechanisms, and the specific biological effects associated with different technologies. This narrative review aims to summarize current knowledge regarding the physical principles, clinical applications, safety aspects, and future perspectives of erbium, Nd:YAG, CO_2, and diode laser systems, with particular emphasis on recent advances and clinical experience reported in the Russian Federation.

Materials and Methods: A narrative literature review was conducted to evaluate the physical properties, mechanisms of biological interaction, clinical effectiveness, and safety characteristics of erbium, Nd:YAG, CO_2, and diode lasers used in dentistry. The review included evidence related to their applications in restorative dentistry, oral surgery, periodontology, endodontics, pediatric dentistry, therapeutic procedures, and photobiomodulation. Publications describing technological developments and clinical experiences from Russia were also analyzed.

Results: Erbium lasers (2780/2940 nm) demonstrate strong absorption by water and hydroxyapatite, enabling selective hard tissue ablation with minimal thermal effects. They allow caries removal without smear layer formation, enhance microbial reduction, and improve adhesion of restorative materials. Nd:YAG lasers (1064 nm) are selectively absorbed by hemoglobin and melanin, producing coagulative and antibacterial effects. Their applications include periodontal therapy and root canal disinfection, contributing to microbial reduction and improved treatment outcomes. CO_2 lasers (10,600 nm) exhibit high water absorption and remain highly effective for soft tissue surgery, including frenectomy, gingivectomy, and lesion removal, providing precise cutting, excellent hemostasis, and favorable healing. Diode lasers (450–980 nm) interact primarily with melanin and hemoglobin and are widely used for soft tissue procedures, periodontal de-epithelialization, hypersensitivity management, and photobiomodulation. Despite their advantages, all dental lasers are classified as Class IV devices, requiring strict safety measures, protective eyewear, and effective aspiration systems. Limitations include equipment costs and the need for specialized training. Russian developments, including L'Med-1 and ALTA Blue**,** demonstrate important contributions to domestic laser dentistry.

Conclusion: Laser technologies significantly enhance conventional dental approaches by improving precision, hemostasis, disinfection, and tissue response. Future progress will depend on multi-wavelength systems, digital integration, standardized clinical protocols, professional education, and further clinical research

Keywords: erbium lasers, Nd:YAG laser, CO_2 laser, diode laser.

1 INTRODUCTION

The term "laser" is an abbreviation derived from *Light Amplification by Stimulated Emission of Radiation*, describing a technology based on the generation of coherent electromagnetic radiation through stimulated emission. Since its introduction, laser technology has become an important advancement in modern medicine and dentistry, providing precise, minimally invasive, and biologically controlled treatment approaches. The first medical applications of lasers began in the 1960s with ruby laser use in ophthalmology, followed by the first experimental application of laser energy to dental enamel in 1964, which initiated the development of dental laser science.[1,2] Continuous progress in laser physics and optical engineering has resulted in the development of multiple dental laser systems with different wavelengths, energy delivery modes, and clinical indications. The principal factor determining laser–tissue interaction is wavelength, as it defines the absorption of radiation by specific biological chromophores, including water, hydroxyapatite, hemoglobin, and melanin.[3] Selective absorption of laser energy allows controlled photothermal, photomechanical, and photobiomodulatory effects, forming the scientific basis for modern laser applications in dentistry.[4]

Erbium lasers, including Er:YAG (2940 nm) and Er,Cr:YSGG (2780 nm), demonstrate high absorption by water and hydroxyapatite, enabling precise ablation of dental hard tissues with minimal thermal damage. These properties have established erbium lasers as valuable tools in restorative dentistry, minimally invasive cavity preparation, caries removal, and pediatric dental procedures.[5,6] Their ability to modify dentin morphology, reduce smear layer formation, and provide antimicrobial effects contributes to improved clinical outcomes in adhesive restorative and surgical procedures.[7–9]

Nd:YAG lasers operate at 1064 nm and interact primarily with melanin and hemoglobin, producing photothermal effects such as coagulation and microbial reduction. Due to their tissue penetration characteristics, Nd:YAG lasers have been widely investigated in periodontal therapy, endodontics, and soft tissue procedures.[10] Their antimicrobial activity and ability to reduce bacterial contamination in root canals and periodontal tissues represent important clinical advantages; however, appropriate parameter selection is required to avoid excessive thermal effects.[11–13]

CO_2 lasers (10,600 nm) demonstrate strong absorption by water, resulting in superficial and controlled soft tissue vaporization. This characteristic makes them highly effective for oral soft tissue surgery, including frenectomy, gingivectomy, biopsy procedures, and removal of benign lesions.[14,15] CO_2 lasers provide excellent hemostasis, improved surgical visibility, reduced postoperative discomfort, and favorable wound healing, although clinical success depends on accurate adjustment of energy parameters.[16,17]

Diode lasers (450–980 nm) represent compact and versatile systems widely used in contemporary dental practice. Their primary chromophores are melanin and hemoglobin, allowing applications in soft tissue surgery, gingival depigmentation, periodontal de-epithelialization, antimicrobial therapy, and aesthetic procedures.[18,19] Although diode lasers offer significant clinical advantages, careful control of power, exposure time, and irradiation parameters is necessary to prevent excessive thermal accumulation.[20]

Laser-assisted periodontal therapy has been extensively studied due to the potential antimicrobial and biological effects of laser irradiation. Diode lasers, in particular, have demonstrated potential as adjunctive methods to conventional periodontal treatment by reducing bacterial load and influencing inflammatory responses.[21,22] In addition, photobiomodulation represents an expanding field of laser application, with evidence suggesting effects on cellular metabolism, tissue repair, inflammation modulation, and postoperative recovery.[23]

Laser technologies have also been investigated for the management of dentin hypersensitivity through modification of dentinal tubules and reduction of fluid movement within dentin. Diode and erbium lasers have demonstrated promising results; however, clinical effectiveness depends on appropriate treatment protocols and patient-related factors.[24,25]

Despite their clinical benefits, dental lasers require strict safety measures. All dental laser systems are classified as Class IV devices and require appropriate protective eyewear, controlled operating conditions, adequate training, and effective aspiration systems.[26] Laser-generated plume and aerosols represent additional occupational concerns, emphasizing the importance of high-volume evacuation and appropriate safety protocols.[27]

The widespread implementation of laser dentistry remains limited by equipment costs, maintenance requirements, and the need for specialized education. Variations in clinical protocols and outcome assessment methods further highlight the necessity for evidence-based recommendations and standardized approaches.[28]

Laser dentistry has also developed significantly in the Russian Federation, where researchers have contributed to clinical studies and technological innovations involving erbium, Nd:YAG, CO_2, and diode lasers. Russian developments, including L'Med-1 and ALTA Blue, represent important contributions aimed at expanding access to laser-assisted dental procedures and improving clinical integration of these technologies.[29–31]

Despite extensive research, available evidence remains heterogeneous, with many studies focusing on individual laser systems or specific clinical applications. Therefore,

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a comprehensive synthesis of current knowledge regarding laser physics, biological interactions, clinical indications, safety considerations, and future perspectives remains necessary.

The aim of this narrative review was to analyze and summarize current evidence regarding the physical principles, clinical applications, advantages, limitations, and future perspectives of major dental laser systems, including erbium, Nd:YAG, CO_2, and diode lasers, with particular emphasis on recent developments and clinical experience reported in the Russian Federation.

2.MATERIALS AND METHODS

A narrative review of the scientific literature was conducted to evaluate current knowledge regarding the physical characteristics, biological interactions, clinical effectiveness, safety aspects, and future perspectives of major dental laser systems. The review included Russian and international publications focusing on erbium, Nd:YAG, CO_2, and diode lasers used in different fields of dentistry, including restorative dentistry, oral surgery, periodontology, endodontics, pediatric dentistry, and therapeutic applications. The analysis was performed with particular attention to the mechanisms of laser–tissue interaction, wavelength-dependent absorption properties, clinical indications, advantages, limitations, and safety requirements. Special emphasis was placed on scientific publications describing the development and clinical implementation of laser technologies in the Russian Federation, including domestic laser systems and research contributions.

The aim of this narrative review was to systematize current evidence regarding the physical principles, clinical applications, safety considerations, and future development trends of erbium, Nd:YAG, CO_2, and diode laser systems, with particular emphasis on Russian clinical experience and technological advances.

3. RESULTS

3.1. Clinical Applications of Erbium Laser Systems

Erbium laser systems, including Er:YAG (2940 nm) and Er,Cr:YSGG (2780 nm), represent highly selective laser technologies widely applied in modern dentistry. Their biological effects are mainly determined by strong absorption of laser radiation by water molecules and hydroxyapatite crystals, which are the principal chromophores of dental hard tissues. This specific interaction allows controlled ablation of enamel and dentin while minimizing thermal damage to surrounding structures. The selective mechanism of erbium laser action represents one of its most important clinical advantages. Carious dentin contains a higher proportion of water compared with healthy mineralized tissues; therefore, laser energy is preferentially absorbed by infected and demineralized areas. This allows selective removal of pathological tissue while preserving intact dental structures, supporting the principles of minimally invasive dentistry.[12]

An important advantage of erbium laser-assisted cavity preparation is the modification of the dentin surface without formation of a conventional smear layer. Laser ablation produces a micro-irregular surface with exposed dentinal tubules, which may improve the micromechanical interaction between restorative materials and dental tissues. In addition, erbium laser irradiation demonstrates antimicrobial activity through photothermal and photomechanical mechanisms, contributing to reduction of bacterial contamination during restorative procedures.[13]

Clinical studies have demonstrated the effectiveness of Er:YAG and Er,Cr:YSGG lasers in the treatment of early carious lesions, minimally invasive cavity preparation, fissure sealing, and restorative dentistry procedures.[14–16] Furthermore, erbium lasers have shown particular value in pediatric dentistry due to reduced noise and vibration compared with conventional rotary instruments, potentially improving patient acceptance and reducing dental anxiety.[17]

The clinical effectiveness of erbium lasers depends on appropriate selection of operating parameters, including pulse energy, repetition rate, irradiation time, and water cooling. Optimization of these parameters is essential to achieve effective tissue removal while preventing excessive thermal effects and maintaining biological safety.[9]

3.2.Nd:YAG Lasers in Periodontology and Endodontics

Nd:YAG laser systems operate at a wavelength of 1064 nm and demonstrate optical characteristics different from erbium lasers. Their radiation is primarily absorbed by pigmented chromophores, particularly hemoglobin and melanin, while water absorption remains relatively limited. This interaction allows deeper penetration into soft tissues and determines their application in periodontal therapy, endodontics, and soft tissue procedures requiring coagulation and antimicrobial effects.[18–20]

The biological effects of Nd:YAG laser irradiation are primarily associated with photothermal mechanisms. Absorption of laser energy by pigmented bacterial

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structures results in rapid temperature elevation, protein denaturation, and destruction of microbial cell membranes.

Within periodontal pockets, these effects contribute to reduction of pathogenic microorganisms and modification of inflamed tissues. At the same time, coagulation of small blood vessels improves surgical visibility and provides a relatively bloodless operating field.[21]

Nd:YAG laser-assisted periodontal therapy has been investigated as an adjunctive approach to conventional mechanical treatment. Studies have demonstrated its potential for microbial reduction, improvement of periodontal tissue conditions, and enhancement of clinical outcomes when appropriate protocols are followed.[21,22]

Another clinically relevant advantage of Nd:YAG laser application is the potential reduction of bacteremia associated with periodontal procedures. The coagulative effect of laser irradiation may limit bleeding and reduce microbial dissemination into the bloodstream, which may be particularly important in medically compromised patients.[22]

In endodontics, Nd:YAG lasers are used primarily as an adjunctive method for root canal disinfection. Delivery of laser energy through flexible fiber-optic systems allows irradiation of areas that may remain inaccessible to conventional instrumentation and irrigation, including dentinal tubules and lateral canal structures. The generated thermal effect contributes to bacterial elimination and improved canal decontamination.[23–25]

However, the clinical application of Nd:YAG lasers requires careful control of energy parameters. Excessive power or inappropriate irradiation protocols may result in undesirable temperature increases and potential damage to surrounding periodontal tissues. Therefore, successful implementation depends on adequate training, knowledge of laser physics, and adherence to evidence-based protocols**.**

3.3. CO_2 Lasers in Dentistry

Carbon dioxide (CO_2) lasers represent one of the most established and clinically effective laser systems used in oral and maxillofacial surgery. These systems generate infrared radiation mainly at wavelengths of 9300 nm, 9600 nm, and 10,600 nm, which demonstrate extremely high absorption by water molecules. Since oral soft tissues contain a high proportion of water, this specific interaction provides controlled superficial tissue vaporization with limited -

penetration depth and predictable thermal effects. The mechanism of CO_2 laser action is based on rapid absorption of laser energy by intracellular water, resulting in instantaneous vaporization and photothermal destruction of targeted tissues. This process allows precise incision, ablation, and coagulation with minimal mechanical trauma. Due to these properties, CO_2 lasers have become widely used in soft tissue procedures where accurate cutting and effective hemostasis are required.[26,27]

CO_2 laser technology has been extensively incorporated into oral surgery and maxillofacial procedures. Its clinical indications include frenectomy, vestibuloplasty, gingivectomy, excision of benign soft tissue lesions such as papillomas, fibromas, and epulides, as well as treatment of pathological mucosal alterations, including leukoplakia and oral lichen planus.[28–31]

One of the major advantages of CO_2 laser surgery is the simultaneous cutting and coagulation effect. The sealing of small blood vessels and lymphatic structures provides improved visualization of the surgical field, reduced intraoperative bleeding, and decreased postoperative edema and discomfort. In addition, the limited zone of thermal injury surrounding the incision contributes to favorable wound healing and satisfactory esthetic results.[32–35]

Compared with conventional surgical techniques, CO_2 lasers may provide improved patient comfort due to reduced tissue manipulation and decreased postoperative pain. However, the clinical outcome depends strongly on appropriate selection of laser parameters, including power density, pulse duration, focusing conditions, and exposure time. Excessive energy delivery may result in unnecessary thermal damage, whereas insufficient energy may reduce tissue cutting efficiency. Therefore, although CO_2 lasers remain one of the most effective systems for oral soft tissue surgery, their application requires adequate knowledge of laser–tissue interactions and strict control of operational parameters.

3.4. Diode Lasers: Versatility and Accessibility

Diode lasers represent one of the most commonly used laser technologies in contemporary dental practice due to their compact design, operational simplicity, relatively low cost, and broad range of clinical applications. These semiconductor-based systems generate radiation within a wavelength range of approximately 450–980 nm, with melanin and hemoglobin acting as the principal tissue chromophores. Their physical characteristics determine their widespread use in soft tissue surgery, periodontal therapy, aesthetic dentistry, and photobiomodulation.[36,37]

Unlike erbium and CO_2 lasers, diode lasers demonstrate deeper penetration into soft tissues due to their lower absorption by water. This property enables effective interaction with vascular and pigmented tissues and provides advantages in procedures requiring coagulation, bacterial reduction, and tissue biostimulation. One of the main clinical advantages of diode lasers is their accessibility. The compact size, flexible fiber delivery system, relatively simple maintenance requirements, and lower equipment cost allow their implementation in various dental settings. These characteristics have contributed to their increasing popularity among general dental practitioners.[38]

In surgical dentistry, diode lasers are used for soft tissue incision, frenectomy, gingivoplasty, gingival contouring, and removal of selected benign lesions. Their interaction with hemoglobin-rich tissues produces effective coagulation, reduction of bleeding, and improved visualization of the operative field. Diode lasers have also demonstrated therapeutic potential in inflammatory oral mucosal conditions. Their biological effects include analgesic action, modulation of inflammatory mediators, and stimulation of epithelial repair. Clinical studies and systematic reviews have reported that diode laser application in recurrent aphthous stomatitis may reduce pain intensity, accelerate healing, and improve patient comfort.[39,40]

In periodontal therapy, diode lasers are mainly used as adjunctive procedures combined with conventional mechanical treatment. Their antimicrobial activity is associated with photothermal effects that may reduce bacterial load within periodontal pockets and influence inflammatory tissue responses. Systematic reviews indicate potential clinical benefits when diode lasers are combined with scaling and root planing; however, they cannot replace mechanical periodontal therapy and should be considered supportive treatment methods.[41,42]

An important limitation of diode lasers is the possibility of excessive thermal accumulation when inappropriate parameters are selected. Continuous-wave operation, excessive power, prolonged irradiation, or improper fiber positioning may increase the risk of tissue overheating. Comparative studies have demonstrated that diode laser application may produce greater thermal alteration than conventional scalpel techniques under certain conditions, emphasizing the importance of accurate parameter selection.[43]

Another important application of diode lasers is the treatment of dentin hypersensitivity. Laser irradiation may reduce dentinal fluid movement through partial occlusion or modification of dentinal tubules, leading to decreased sensitivity symptoms. Clinical studies have demonstrated immediate improvement after treatment, with effects potentially maintained over several months depending on individual patient characteristics and treatment protocols.[44,45]

Low-level diode laser irradiation has further expanded the role of these systems through photobiomodulation therapy. The proposed mechanisms include stimulation of mitochondrial activity, increased ATP production, enhancement of cellular metabolism, improved microcirculation, activation of fibroblasts, stimulation of collagen synthesis, and modulation of inflammatory responses. These biological effects support the use of diode lasers in postoperative wound healing, periodontal tissue recovery, pain management, and supportive treatment of oral mucosal disorders.[46]

The main clinical characteristics of dental laser systems are determined by their wavelength-dependent absorption properties, tissue chromophores, and biological effects. Erbium lasers demonstrate high selectivity for hard-tissue procedures, Nd:YAG lasers are primarily indicated for pigmented soft tissues and microbial reduction, CO_2 lasers remain highly effective for oral soft-tissue surgery, whereas diode lasers provide versatile applications in soft-tissue management, periodontal therapy, and photobiomodulation.[5,10,18,26,36]

3.5. Safety Considerations and Limitations of Dental Laser Technologies

The clinical implementation of laser systems in dentistry requires strict adherence to established safety principles because all surgical and high-power dental lasers are classified as Class IV laser devices, representing the highest level of biological hazard. The primary concern associated with dental laser use is potential ocular injury caused by direct or reflected exposure to laser radiation. Therefore, appropriate protective measures, including wavelength-specific protective eyewear for the clinician, dental staff, and patient, are mandatory during every laser procedure.

The optical density and protective characteristics of the eyewear must correspond precisely to the wavelength of the laser system being used to ensure adequate protection.[4,47]

In addition to eye protection, effective organizational and environmental safety measures are essential for minimizing occupational risks. Laser operating areas should be clearly identified with appropriate warning signs, and access should be restricted to trained personnel only. The clinical team must receive specialized education regarding laser physics, tissue interaction mechanisms, operational parameters, and emergency procedures. Such training is particularly important because inappropriate selection of power settings, exposure time, pulse characteristics, or irradiation technique may result in excessive thermal accumulation and undesirable tissue damage.[47]

An additional safety issue associated with laser-assisted procedures is the formation of laser plume and biological aerosols during tissue vaporization. Surgical smoke generated during laser ablation may contain cellular debris, microorganisms, and potentially harmful chemical compounds. Although the concentration and composition of laser-generated aerosols vary according to the tissue type and laser parameters, continuous evacuation systems with high-volume aspiration are recommended to reduce exposure risks for both patients and healthcare professionals.[48,49]

One of the important advantages of laser technology is its non-contact mode of action. Unlike conventional mechanical instruments, laser systems transfer energy through optical fibers, articulated arms, or scanning systems without direct physical contact with the tissue surface. This characteristic contributes to improved procedural precision, reduced mechanical trauma, and better control of the surgical field. In addition, the simultaneous coagulative and antimicrobial effects observed with many laser systems may contribute to improved intraoperative conditions and postoperative healing.

Despite these advantages, several limitations continue to influence the widespread adoption of laser technologies in dental practice. The high initial cost of equipment, maintenance requirements, need for specialized training, and variability in clinical protocols remain significant barriers. Furthermore, differences in laser parameters among studies, including wavelength, energy density, pulse duration, and treatment protocols, make direct comparison of clinical outcomes difficult. Therefore, standardized clinical guidelines and well-designed controlled studies remain necessary to establish evidence-based recommendations for routine dental applications.[1]

3.6. Development of Laser Technologies and Future Perspectives in Dentistry

The evolution of dental laser technology has progressed from experimental applications toward increasingly sophisticated clinical systems characterized by improved precision, reduced device dimensions, enhanced safety features, and broader therapeutic capabilities. Modern developments are focused not only on improving laser sources but also on integrating advanced digital technologies, automated control systems, and personalized treatment approaches.[50]

In recent years, the Russian Federation has demonstrated significant scientific and technological activity in the field of laser medicine and dentistry. Russian researchers have contributed to the development of laser devices, clinical protocols, and experimental investigations evaluating the effects of different wavelengths on biological tissues. However, despite the recognized clinical advantages of laser technologies, their implementation in routine dental practice remains slower compared with several international healthcare systems. This limitation is mainly associated with economic factors, including the high cost of equipment, insufficient availability of specialized training programs, and the absence of unified national clinical protocols regulating laser applications.[20] The development of domestic laser systems represents an important direction for expanding access to laser-assisted dental treatment. The Russian-made "L'Med-1" CO_2 laser system has been investigated for surgical applications and demonstrated potential advantages related to precise tissue incision, coagulation, antimicrobial effects, and favorable postoperative healing. These characteristics highlight the clinical potential of domestic laser technologies in oral surgery and maxillofacial practice.[51] The historical development of Russian laser medicine includes the creation of early CO_2 laser systems such as "Romashka," "Skalpel-1," and "Skalpel-2," followed by more advanced platforms incorporating erbium, Nd:YAG, and diode technologies. These developments contributed to the expansion of laser-assisted procedures in various medical disciplines, including dentistry and maxillofacial surgery.[52]

Recent technological progress has also introduced new wavelength ranges and improved semiconductor laser systems. Investigations of blue laser technology, particularly 450 nm diode systems, demonstrate increased absorption by pigmented biological tissues, enabling precise selective ablation and coagulation. The ability to combine surgical laser effects with low-intensity photobiomodulation represents a promising direction for future clinical applications.[53,54]

Future developments in dental laser technology are expected to focus on several major areas. One important trend is the creation of multi-wavelength laser platforms capable of combining different wavelengths within a single device. Such systems may allow clinicians to selectively target different tissue components, including water, hemoglobin, melanin, and hydroxyapatite, thereby expanding therapeutic versatility.[55] Another promising direction is the integration of laser systems with digital dentistry, computer-assisted navigation, and artificial

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intelligence-based technologies. Automated monitoring of tissue characteristics, real-time adjustment of irradiation parameters, and computer-assisted control of treatment boundaries may improve accuracy, reproducibility, and patient safety.[56]

Furthermore, advances in ultrafast laser technologies, including femtosecond laser systems, provide new opportunities for extremely precise tissue modification at microscopic and nanoscopic levels. These technologies may contribute to the development of minimally invasive procedures with reduced thermal effects and improved biological outcomes.[57] Future progress in laser dentistry, particularly in Russia, will depend on expanding clinical research, establishing evidence-based national protocols, improving professional education, and increasing accessibility of modern laser equipment. Integration of technological innovation with high-quality clinical evidence will be essential for achieving broader acceptance and predictable implementation of laser-assisted dentistry.

4.DISCUSSION

4.1. Clinical Interpretation and Significance of Dental Laser Technologies

The findings of this narrative review demonstrate that laser technologies have become an important component of contemporary dentistry by providing minimally invasive, precise, and biologically oriented treatment approaches. The clinical significance of dental lasers extends beyond simple tissue removal and includes improved surgical control, reduction of microbial contamination, enhanced patient comfort, and potential support of tissue healing processes.

The main advantage of laser technology compared with conventional mechanical instruments is the ability to selectively interact with biological tissues according to specific optical characteristics. This selectivity allows clinicians to preserve healthy structures, reduce mechanical trauma, and perform procedures with improved control. However, current evidence indicates that successful laser application depends not only on the characteristics of the device but also on correct clinical indications, operator experience, and integration within comprehensive treatment protocols.

Modern laser dentistry should therefore be considered an advanced complementary approach rather than a replacement for conventional dental methods. The highest clinical benefit is achieved when laser systems are incorporated into multidisciplinary treatment strategies combining mechanical, chemical, surgical, and biological approaches.

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4.2. Clinical Role of Different Dental Laser Systems

The available evidence demonstrates that erbium, Nd:YAG, CO_2, and diode lasers occupy different but complementary positions in contemporary dental practice according to their wavelength-dependent biological interactions.

Erbium lasers (Er:YAG and Er,Cr:YSGG) have particular importance in minimally invasive dentistry because of their strong absorption by water and hydroxyapatite. Their ability to selectively remove altered dental tissues while preserving healthy structures supports conservative treatment concepts and makes them valuable in restorative dentistry, caries management, and selected surgical procedures.[10–12] However, their broader implementation remains influenced by equipment cost, technical requirements, and the necessity for standardized clinical protocols.

Nd:YAG lasers demonstrate specific advantages related to their interaction with pigmented tissues and deeper penetration characteristics. Their antimicrobial and coagulative effects explain their continued use in periodontal and endodontic procedures. Nevertheless, current evidence supports their role mainly as adjunctive tools that enhance conventional treatment rather than replace mechanical instrumentation.[18,21,23]

CO_2 lasers remain among the most predictable systems for oral soft tissue surgery because of their high absorption by water and controlled superficial tissue interaction. Their ability to provide precise incision, coagulation, reduced bleeding, and favorable postoperative healing explains their continued relevance in oral surgery and maxillofacial procedures.[27,29]

Diode lasers represent a different technological direction characterized by accessibility, portability, and versatility. Their relatively low cost and simple operation have contributed to their increasing adoption in periodontal therapy, soft tissue procedures, aesthetic dentistry, and photobiomodulation. However, their widespread availability emphasizes the importance of adequate training because inappropriate parameter selection may increase the risk of thermal tissue damage.[36,43]

4.3. Integration of Laser Technologies into Evidence-Based Dental Practice

A major challenge in contemporary laser dentistry is the establishment of standardized evidence-based clinical protocols. Although numerous studies demonstrate beneficial effects, the available literature remains heterogeneous because of differences in laser parameters, treatment indications, study designs, and evaluation methods.

The current evidence suggests that laser selection should be based on specific clinical objectives rather than the assumption that one laser system is universally superior. Successful treatment requires individualized consideration of tissue characteristics, disease conditions, patient factors, and clinician experience.

An additional important aspect is patient-centered care. Reduced vibration, decreased bleeding, improved surgical visibility, and potentially improved postoperative comfort represent important advantages that may increase patient acceptance, particularly in pediatric dentistry and minimally invasive procedures.[17]

4.4. Safety Considerations and Clinical Limitations

Despite significant advances, several factors continue to restrict the widespread adoption of laser technologies. The high initial cost of equipment, maintenance requirements, and the need for specialized education remain important barriers, particularly in general dental practice.[1]

Another limitation is the lack of universally accepted clinical guidelines for many laser applications. Although numerous investigations have demonstrated positive outcomes, variations in operational parameters and treatment protocols limit direct comparison between studies.

Safety remains a fundamental component of laser dentistry. Dental lasers belong to high-risk device categories, requiring appropriate protective measures, including wavelength-specific protective eyewear, controlled clinical environments, and strict adherence to safety protocols.[26,47]

Laser-generated plume represents an additional occupational concern. During tissue ablation, aerosols containing biological particles and potentially harmful components may be produced; therefore, effective evacuation systems and infection-control measures are necessary to protect both dental professionals and patients.[48,49]

4.5. Development of Laser Technologies in Russian Dentistry

The development of laser dentistry in the Russian Federation represents an important part of the global evolution of medical laser technologies. Russian researchers have contributed to the development, investigation, and clinical application of CO_2, Er:YAG, Nd:YAG, and diode laser systems in dentistry and maxillofacial surgery.

Historical progress in Russian laser medicine included the development of early CO_2 surgical systems, including devices such as “Romashka”, “Skalpel-1”, and “Skalpel-2”, which formed the basis for further clinical applications of laser surgery. Later, more advanced technologies, including Er:YAG, Nd:YAG, and diode systems, expanded the possibilities of minimally invasive surgical and dental procedures.[52]

Studies evaluating domestic CO_2 laser systems, including the “L’Med-1” device, demonstrated the advantages of laser-assisted surgery, including improved hemostasis, reduced tissue trauma, precise incision, and favorable wound healing characteristics.[51]

More recent Russian developments, including semiconductor laser technologies such as ALTA Blue, demonstrate the potential of modern blue-spectrum lasers for selective tissue interaction and combination of ablative and photobiomodulatory effects.[54] However, despite these achievements, the implementation of laser technologies in Russian dentistry remains limited by economic factors, insufficient standardization, and the need for specialized training programs. Expansion of clinical research and development of national recommendations are necessary for broader integration of laser systems into routine dental practice.[20,50]

4.6. Future Perspectives and Emerging Trends

The future development of dental laser technologies is expected to focus on improved selectivity, automation, and integration with digital dentistry.

Multi-wavelength laser systems represent a promising direction because they may allow clinicians to address different tissue components using a single platform.[55] The combination of lasers with artificial intelligence, computer-assisted navigation, and digital treatment planning may further improve precision through automated adjustment of irradiation parameters and real-time control of treatment boundaries.[56]

Another important future direction is the development of ultrashort pulse technologies, including femtosecond lasers, which provide highly precise interaction with biological tissues at microscopic and nanoscopic levels while minimizing collateral damage.[57]

For Russian dentistry, future progress requires strengthening collaboration between research institutions, engineers, and clinicians, expanding multicenter clinical

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studies, developing standardized protocols, and improving professional education in laser medicine.

Limitations of the Review

This narrative review has several limitations. The available literature demonstrates considerable heterogeneity regarding laser parameters, treatment protocols, clinical indications, and outcome assessment methods, which complicates direct comparison between studies.

Many investigations include limited patient populations, single-center designs, and relatively short follow-up periods. Therefore, additional high-quality clinical trials with standardized methodologies are required to confirm long-term effectiveness.

Furthermore, comparative studies evaluating different laser systems under identical clinical conditions remain limited. Future research should focus on evidence-based comparisons, standardized outcome measures, and clinically relevant long-term results.

5.CONCLUSION

Laser technologies have become an important component of modern dentistry by providing precise, minimally invasive, and biologically controlled treatment approaches. Erbium lasers demonstrate significant advantages in conservative treatment of dental tissues, Nd:YAG lasers provide valuable antimicrobial and coagulative effects, CO_2 lasers remain highly effective for soft tissue surgery, and diode lasers offer accessibility and versatility for routine clinical applications. Lasers should not replace conventional dental methods but should be considered complementary technologies that enhance treatment accuracy, patient comfort, and clinical outcomes.

The international and Russian experience confirms that further development of laser dentistry will depend on technological innovation, evidence-based clinical protocols, professional education, and integration with digital technologies. These advances may contribute to the transition toward more personalized, minimally invasive, and biologically guided dental care.

DECLARATIONS

Ethical Approval

Not applicable.

Competing Interests

The authors declare no conflict of interest.

Funding

None.

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