DOI: https://doi.org/10.17816/uds635366

Innovative Laser Technology in Dentistry

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ABSTRACT

In recent decades, laser technology has been widely used in medicine, particularly in dentistry, resulting in significant advancements in various aspects of clinical practice. Laser technology is becoming increasingly popular due to such characteristics as high accuracy, minimal invasiveness, and wide range of applications. The literature search was performed in the databases PubMed, Scopus, and Web of Science. The analysis included studies published in peer-reviewed journals, which assessed the use of laser technology in dentistry. The latest advancements and trends in the field were reviewed. The role of laser technology in the diagnosis, treatment, and regeneration of dental and periodontal tissues is discussed, as well as various types of lasers used in dentistry and their applications for dental procedures. The review revealed a wide range of laser technology applications in dentistry, including the diagnosis of dental caries, dental tissue preparation, endodontic treatment, periodontology, and esthetic dentistry. Laser technology ensures high accuracy, minimal thermal injury, and improved clinical outcomes compared to conventional treatment options. Laser technology opens up new opportunities in all aspects of dentistry and postoperative care. It improves the efficacy and comfort during various dental procedures. Advancements in this area provide new possibilities for the use of laser technology in dentistry in the future.

Keywords: laser; dental laser; laser diagnosis; treatment of oral pathologies; innovative approaches.

To cite this article

Toumassian MG, Toumassian SG, Satygo EA. Innovative Laser Technology in Dentistry. *Acta Universitatis Dentistriae et Chirurgiae Maxillofacialis*. 2024;2(3):113–122. DOI: https://doi.org/10.17816/uds635366

Received: 23.08.2024 **Accepted:** 05.09.2024 **Published online:** 10.10.2024

DOI: https://doi.org/10.17816/uds635366

Инновационное использование лазера в стоматологии

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АННОТАЦИЯ

За последние десятилетия лазерные технологии получили распространение в медицинской практике, особенно в стоматологии, что привело к существенным изменениям в различных аспектах клинического применения. Рост использования лазеров в стоматологии обусловлен их характеристиками: высокой точностью, минимальной инвазивностью, широкими возможностями применения. Поиск литературы осуществлялся в базах данных PubMed, Scopus, Web of Science. В выборку были включены статьи, опубликованные в рецензируемых журналах и посвященные использованию лазерных технологий в стоматологии. Обзор охватывает последние достижения и тенденции в этой области. Рассматривается роль лазера в диагностике, лечении и регенерации тканей зуба и пародонта, различные типы лазеров, широко используемые в стоматологии, обсуждается их применение в стоматологических процедурах. Обзор выявил широкий спектр применения лазерных технологий в стоматологии, включая диагностику кариеса, препарирование тканей зуба, эндодонтическое лечение, пародонтологию, эстетическую стоматологию. Лазеры обеспечивают высокую точность, минимальное термическое повреждение и улучшенные клинические результаты по сравнению с традиционными методами лечения. Лазерные достижения открыли новые возможности во всех аспектах стоматологии и послеоперационного ухода. Лазеры способны улучшить эффективность и уровень комфорта различных стоматологических процедур. Исследования и разработки в этой области расширяют возможности применения лазерных технологий в стоматологии в будущем.

Ключевые слова: лазер; лазерная стоматология; лазерная диагностика; лечение заболеваний полости рта; инновационные методы.

Как цитировать

Тумасян М.Г., Тумасян С.Г., Сатыго Е.А. Инновационное использование лазера в стоматологии // Университетская стоматология и челюстно-лицевая хирургия. 2024. Т. 2, № 3. С. 113–122. DOI: https://doi.org/10.17816/uds635366

Рукопись получена: 23.08.2024 **Рукопись одобрена:** 05.09.2024 **Опубликована online:** 10.10.2024

ЭКО • ВЕКТОР

INTRODUCTION

Lasers have been widely employed in dentistry since their introduction in the 1960s. The term "laser" is an abbreviation for Light Amplification by Stimulated Emission of Radiation. Thus, a laser can be defined as a device that generates light energy during light intensification by forced emission of electromagnetic radiation [1]. Photons in a laser beam are coherent, with phase amplification (standing wave) by radiation of a certain wavelength (monochromatic radiation). For more than two decades, lasers have been especially effective in dentistry due to the continuous wave mode [2]. Lasers are widely used in dentistry for a variety of procedures [3, 4] due to their simplicity, efficacy, and convenience, as well as other advantages over conventional techniques (such as non-contact action, minimal invasiveness, low systemic toxicity, selective action on abnormal tissues, hemostasis, faster healing, and lower risk of postoperative infections). They can be used for diagnostic tests and work with hard tissues, as well as during surgeries and for the treatment of dental materials [5]. Lasers are used in conservative dentistry, endodontic treatment, periodontology, implantology, dental surgery, and so on [6].

STUDY AIM. To review modern applications of lasers in dentistry, including the role of lasers in the diagnosis, treatment, and regeneration of dental and periodontal tissues, various types of lasers used in dentistry, and their use during dental treatment procedures.

MATERIALS AND METHODS

The review was based on a search of relevant Russian and international literature in the leading scientific databases PubMed, Scopus, and Web of Science. The review included original studies, review articles, and case reports. Relevant articles were identified using the following search terms: laser dentistry, dental laser, laser application in dentistry, laser therapy in dentistry, innovative laser technology in dentistry, laser classification, etc. Peer-reviewed articles were included. The review allowed identifying the key areas of laser application in dentistry and assessing the efficacy and safety of laser technology, as well as the prospects for laser dentistry development in the near future.

RESULTS AND DISCUSSION

Classification of lasers

Lasers in dentistry can be classified by the active medium, which includes solid-state, diode, gas, and semiconductor lasers. Moreover, they can be classified by wavelength, which includes erbium lasers, neodymium-doped yttrium aluminum garnet (Nd:YAG) lasers, carbon dioxide (CO_2) lasers, and argon lasers. Lasers can also be classified by their application: for example, there are soft tissue lasers for procedures such as gum contouring and hard tissue lasers for cavity preparation and tooth ablation. Furthermore, lasers can be classified by damage to the skin or eyes after prolonged exposure. In complex cases, combinations of different wavelengths ensure the high efficacy of dental treatment [7].

In dentistry, laser radiation is generated using a variety of substances such as erbium, carbon dioxide, and neodymium. Moreover, various combinations are used, such as yttrium aluminium garnet (YAG) and yttrium scandium gallium garnet (YSGG), as well as excimer, argon, and diode lasers. Each of them emits light of a specific wavelength [8]. Table 1 presents the classification of lasers according to their wavelength and the effect on target tissues.

Lasers as a diagnostic tool

Dental probing, the conventional method of diagnosing dental caries, can damage the enamel and cause caries. Diode lasers, such as the KaVo-Diagnodent (KaVo, Germany) with a wavelength of 655 nm, can be used as an alternative diagnosis method. These lasers enable early detection of dental caries by laser-induced fluorescence. Dental cavities emit a stronger fluorescence, making it possible to accurately determine their location. Moreover, this method allows for the monitoring of hard tooth tissue demineralization and remineralization, as well as the detection of interproximal and occlusal lesions under fillings and fissure sealants in the interdental space.

Laser Doppler flowmetry, which is based on the Doppler effect, is a modern additional tool for diagnosing microcirculatory disorders in periodontal tissues. A flowmeter can probe the examined area by reflecting laser radiation emitted by blood cells, particularly red blood cells [11]. This method allows assessing the vascular permeability in periodontal tissues and detecting early tissue ischemia, which may result from abnormal dentition (crowding) or orthodontic treatment. Tissue ischemia is caused by microcirculatory disorders, which result in inadequate oxygen supply and, eventually, periodontal tissue damage [12]. Moreover, this method enables assessing the revascularization of damaged teeth. He-Ne and GaAlA diode lasers are used, with a low power of 1 or 2 mW [13].

Advancements in laser-induced fluorescence technologies have resulted in a new diagnostic tool: Raman spectroscopy [14]. Raman spectroscopy identifies organic molecules using inelastic light scattering spectra. It is one of the most precise analytical procedures for organic and inorganic compounds. Raman radiation can be used to assess both healthy and damaged teeth; it allows determining the degree of hard tissue mineralization or demineralization.

Table 1. Wavelength of applied laser radiation and the target tissue

Таблица 1. Длина волны используемого лазерного излучения и ткань, на которую оно направлено

Laser type	Wavelength, nm Pulse mode	Chromophores used	Target tissue
Diode laser	850–1064	Pigment Hemoglobin Melanin	
Neodymium-doped yttrium aluminum garnet (Nd:YAG) laser	1064	Pigment Hemoglobin Melanin	Gum, mucous membranes
Erbium laser (Er:YAG)	2940	Water Hydroxyapatite	 Enamel, dentin, bone
Solid-state lasers (Er, Cr:YSGG)	2860	Water Hydroxyapatite	Gum, mucous membranes Enamel, dentin, bone
Carbon dioxide (CO_2)	10 640	Water	Gum, mucous membranes Enamel, dentin, bone

Advantages of lasers in dentistry

Unlike conventional surgical techniques, laser treatment of blood and lymphatic tumors of the oral cavity and vermilion ensures effective healing without anatomical changes [18]. The tissue biopotential of specific laser wavelengths ensures successful ablation of painful areas of the mucosa in lichenoid diseases [19]. Laser light can effectively disinfect infected areas of the oral cavity and successfully treat viral tumors [20]. Moreover, lasers offer numerous advantages in orthopedic surgery. Laser treatment does not require postsurgical sutures, thus preventing deformation of surgical sites and preserving the length of the vestibular system. In patients with removable dentures, laser treatment of tumors or gingival hyperplasia also does not require wound suturing, thus preserving (and in some cases extending) the length of the vestibular system, which is critical for denture stability and fixation [21].

In dental surgery, diode lasers are considered the best option due to their wide range of applications, high reliability, and intuitive control. A diode laser with a wavelength of 810 nm can significantly improve the outcomes of surgical treatment in patients with various oral and maxillofacial pathologies, including precancer conditions, tumors, and inflammations [22, 23].

Clinical and immunological evidence suggests that laser therapy activates the body's local defense mechanisms by stimulating secretory, humoral, and cell factors. Moreover, the analysis of peripheral white blood cell populations shows the absence of inflammation, intoxication, and immunodeficiency following laser treatment [24].

According to research findings, diode lasers in combination therapy of periodontal inflammation improve quality of life due to decreased intensity of pain, absence of functional limitations, short rehabilitation and recovery period, and much shorter treatment duration [25, 26].

Laser treatment of hard tooth tissues (enamel and dentin)

Lasers can remove infected and softened dentin in dental caries just as well as dental drills. However, Er:YAG lasers ensure a lower vibration exposure. They provide effective and safe removal of dental caries and cavity preparation, preserving the tooth structure without increasing the temperature around the nerve. Moreover, they can safely remove defective composite restorations and cement [27].

A strong fluorescent signal of bacterial porphyrins in dental calculus allows for the effective use of Er:YAG lasers for scaling. These lasers effectively eliminate bacteria, including pathogens of periodontal disease such as *Porphyromonas gingivalis* and *Actinobacillus actinomycetemcomitans* [28].

In 1999, YSGG lasers were approved for the treatment of class I–V cavities and removal of dental caries; shortly thereafter, they were also approved for these procedures in children. Moreover, the majority of hard tissue procedures do not require injection anesthesia, as a laser acts on the cell level and suppresses the pain response.

YSGG lasers provide high-precision treatment of pits and fissures on the occlusal surfaces of molars, promoting the development of micro- and minimally invasive dentistry [29].

Lasers have recently become widely used for the prevention of dental caries on sub-ablation levels, where the energy is sufficient for changes in enamel structure but insufficient for tissue ablation. In the early 1980s, it was discovered that laser radiation can alter the structure of surface enamel tissues. An interaction between a laser and the enamel on sub-ablation levels results in a rapid increase in surface temperature from 100°C to 1,600°C, causing alterations in tissue structure [30].

Laser radiation interacts with water and hydroxyapatite, which are enamel chromophores. Following radiation exposure, the water content in the enamel decreases, especially around hydroxyapatite crystals, reducing tissue permeability, which includes the entry of acids produced by dental caries bacteria. Moreover, radiation alters the chemical composition of hydroxyapatite, increasing the amounts of calcium and phosphate while decreasing the amount of carbonate. These alterations improve the chemical stability of hydroxyapatite, increasing its crystallinity and improving the structural properties of the enamel [31].

Lasers have demonstrated additional advantages *in vitro*, such as increased fluorine uptake by the enamel and improved sealant fixation when used in combination with an acid gel for enamel pit and fissure etching [32].

Lasers increase the efficacy of endodontic treatment by emitting radiation that effectively disinfects the endodontic system and removes debris and smear layers form the root canal. Lasers emit heat, which provides high bactericidal activity, resulting in the evaporation of water, which is found in large amounts in bacterial cells. This destroys the bacterial cell wall and eventually disrupts the osmotic equilibrium, leading to cell death. Dentinal tubules have a small diameter, limiting antiseptic liquid penetration to a depth of 100 nm, while microorganisms can enter dentin to a depth of up to 700 nm. Lasers can solve this problem, as their penetrating capacity exceeds these limitations [8, 33].

Use of VistaCam intraoral cameras

The use of near-infrared reflection (NIRR) for the diagnosis of approximal caries in posterior teeth has recently become the focus of growing interest. Fluorescence-technology based VistaCam iX and VistaCam iX HD cameras (Dürr Dental, Germany) have been developed for this purpose. These cameras are multifunctional: they have attachments for intraoral images (Cam), optimal 120x magnification images (Macro), diagnosis of caries of proximal tooth surfaces (Proxi), and diagnosis of caries and dental plaque (Proof) [34]. The device has two infrared emitting diodes with a wavelength of 850 nm, a power output of 6 mW, and a light spot of 7 × 9 mm to illuminate adjacent portions of two teeth. A semiconductor sensor is installed between the infrared emitting diodes to record reflected light. After that, a digital image is made and displayed on the monitor in a black-and-white mode, using imaging software DBSWIN or VistaSoft (Dürr Dental, Germany) [35].

Ahrari et al. found that the Proxi attachment of the VistaCam iX system had high sensitivity for detecting early approximal caries in permanent posterior teeth; however, its use was associated with a significant number of false positive results and a very low specificity [36]. Thus, NIRR is not suitable for the detection of approximal surfaces without caries. Overall, NIRR showed low accuracy in the detection of approximal caries. When detecting approximal caries in permanent posterior teeth, laser-induced fluorescence outperformed NIRR in terms of diagnostic accuracy. However, the authors concluded that VistaCam iX Proxi cannot be considered suitable for the diagnosis of approximal caries.

Use of quantitative light-induced fluorescence

Quantitative light-induced fluorescence (QLF) is widely used in dentistry to assess the enamel state during various procedures. It allows for a quick, objective assessment of oral hygiene, as well as monitoring of enamel demineralization and remineralization over time without damaging the enamel. QLF provides dentists and dental hygienists with new opportunities by ensuring early detection of pathologies, enamel assessment, dental plaque detection without staining, detection of hidden caries, tooth cracks, and dental calculus, and assessment of oral hygiene [37]. According to Lytkina and Zeibert [38], QLF is a more informative approach to the diagnosis of dental caries than conventional techniques (visual examination and probing). QLF increased the detection rate of dental caries by 17%.

Lasers in the treatment of oral mucosa and temporomandibular joint dysfunction

Tiunova and Lyubomirsky [39] presented data on laser treatment of oral mucosa. The study showed that the use of a diode laser with a wavelength of 810 nm for laser thermoablation, in combination with a collagen-based product in the postoperative period, during combination treatment of verrucous leukoplakia provided good clinical outcomes: complaints resolved, and epithelialization was observed during follow-up examination.

Puzin et al. [40] performed treatment in 175 patients with temporomandibular joint dysfunction. Pain is one of the primary symptoms of this disorder; in some cases, it is accompanied by jaw popping or limited jaw movement. The treatment included orthopedic therapy, drug therapy, and physiotherapy approaches, such as laser diagnosis and helium-neon laser therapy. This combination therapy effectively decreased the severity of pain and promoted masseter muscle recovery. Moreover, the helium-neon laser allowed the detection of trigger points and provided effective treatment of myofascial pain.

CONCLUSION

The use of lasers in dentistry is an effective, modern approach to the treatment of oral pathologies. Laser therapy offers numerous advantages, including no bleeding, minimum pain and discomfort, fast tissue healing, and no risk of infection. Lasers provide a highly accurate and mild impact on affected areas while preserving healthy tissues.

Laser technologies in clinical dentistry are highly advanced and offer the potential for further development. Laser-induced photochemical reactions have a wide range of potential applications, including effects on specific pathogens and cells. The wide use of lasers will dramatically change treatment planning in dentistry in the near future. This technology has changed the approach to dentistry by improving comfort and efficacy of treatment, as well as by providing quick results and increasing the predictability of treatment outcomes.

ADDITIONAL INFORMATION

Authors' contribution. Thereby, all authors made a substantial contribution to the conception of the study, acquisition, analysis, interpretation of data for the work, drafting and revising the article, final approval of the version to be published and agree to be accountable for all aspects of the study. The contribution of each author: M.G. Toumassian — gas chromatography–mass spectrometry, data analysis, writing the main part of the text; S.G. Toumassian — experimental design, collecting and preparation of samples, writing the main part of the text; E.A. Satygo — preparation of samples.

Competing interests. The authors declare that they have no competing interests.

Funding source. This study was not supported by any external sources of funding.

ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. Все авторы внесли существенный вклад в разработку концепции, проведение исследования и подготовку статьи, прочли и одобрили финальную версию перед публикацией. Личный вклад каждого автора: М.Г. Тумасян — хроматографическое исследование, анализ полученных данных, написание текста; С.Г. Тумасян — концепция и дизайн исследования, сбор и обработка материалов, написание текста; Е.А. Сатыго — обработка материалов.

Конфликт интересов. Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

Источник финансирования. Авторы заявляют об отсутствии внешнего финансирования при проведении исследования.

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DOI: https://doi.org/10.17816/uds635366