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REVIEW

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Applications of lasers and advanced technologies in periodontics, caries removal, and soft tissue surgery: A comprehensive review

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ABSTRACT

Laser technology has emerged as an important advancement in contemporary dentistry, enabling minimally invasive approaches for the management of periodontal diseases, dental caries, and various oral soft-tissue conditions. Over the past two decades, multiple laser systems including diode, CO_2, Er:YAG, Er,Cr:YSGG, and Nd:YAG have been integrated into dental practice because of their ability to provide precise tissue removal, effective bacterial reduction, and improved postoperative outcomes. Despite increasing clinical adoption, the literature presents variations in reported clinical efficiency, treatment protocols, and long-term outcomes, indicating the need for a comprehensive synthesis of available evidence.

The objective of this review is to evaluate the applications of lasers and emerging technological advancements in periodontics, caries removal, and soft tissue oral surgeries, while examining the biological mechanisms, clinical advantages, and limitations. Procedures such as laser-assisted periodontal therapy, gingival depigmentation, caries excavation, and soft-tissue surgical interventions including frenectomy and gingivectomy are studied predominantly.

This review analyses findings from peer-reviewed clinical studies, systematic reviews, and experimental investigations published in recent years. The analysis presents that laser-assisted therapy can improve haemostasis, reduce postoperative discomfort, and enhance patient acceptance compared with conventional mechanical approaches. However, variability in clinical protocols, equipment costs, and the requirement for specialized training remain important barriers to widespread usage.

Emerging technologies such as photodynamic therapy, artificial intelligence-assisted diagnostics, and laser-guided regenerative procedures indicate a growing integration of advanced technologies in dental practice. Continued clinical research and technological refinement are essential to establish standardized protocols and optimize the long-term therapeutic potential of laser-assisted dental treatments.

KEY WORDS

Laser technology; Caries removal; Laser-assisted periodontal therapy; Gingival depigmentation; Laser fluorescence

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Introduction

Periodontal diseases, dental caries, and oral soft tissue lesions represent some of the most prevalent conditions encountered in clinical dental practice. Conventional management of these conditions depends primarily on mechanical instrumentation, including scaling and root planning, rotary instruments for caries excavation, and scalpel-based surgical procedures [1]. Although these techniques are clinically effective, they are associated with certain limitations such as mechanical trauma to surrounding tissues, intraoperative bleeding, postoperative discomfort, and patient anxiety related to vibration and noise generated by rotary instruments [2].

Laser technology has been progressively incorporated into dental practice as an alternative to conventional treatment modalities. Dental lasers generate monochromatic and coherent light energy that interacts with biological tissues through absorption and photothermal effects [3]. The clinical effect of a laser system depends on its wavelength, power settings, and the optical characteristics of the target tissue. Different laser systems, including diode, carbon dioxide (CO_2), neodymium-doped yttrium aluminum garnet (Nd:YAG), erbium-doped yttrium aluminum garnet (Er:YAG), and erbium, chromium-doped yttrium scandium gallium garnet (Er,Cr:YSGG), have been used for both hard and soft tissue procedures in dentistry [4].

In periodontology, lasers have been investigated for procedures such as periodontal pocket decontamination, removal of inflamed epithelial lining, gingival depigmentation, and adjunctive antimicrobial therapy [5]. Laser irradiation can reduce the microbial load within periodontal pockets and may facilitate removal of diseased epithelial tissue without extensive mechanical trauma. Certain treatment protocols, such as the Laser-Assisted New Attachment Procedure (LANAP), have been proposed as minimally invasive approaches for the management of chronic periodontitis [6].

These are also applied in conservative dentistry for the removal of dental caries. Erbium lasers, particularly Er:YAG and Er,Cr:YSGG, have demonstrated the capacity to ablate demineralized dental hard tissues through thermomechanical processes involving water absorption within the tooth structure [7]. These lasers allow selective removal of infected dentin while preserving sound tooth structure. Laser-based

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cavity preparation may also reduce the smear layer and provide a bactericidal effect within the prepared cavity. These characteristics have generated interest in the use of lasers as an alternative to conventional rotary instruments [8].

Soft tissue oral surgical procedures represent another important area of laser application. Diode, CO_2, and Nd:YAG lasers have been used for gingivectomy, frenectomy, crown lengthening, and excision of benign oral lesions. The use of lasers in these procedures allows simultaneous incision and coagulation of tissues, which may reduce intraoperative bleeding and improve visualization of the surgical field [9,10].

Despite the increasing use of lasers in dentistry, the clinical evidence regarding their effectiveness remains variable. Several clinical trials and systematic reviews have reported improvements in parameters such as probing depth reduction, bacterial load reduction, and patient comfort following laser-assisted procedures [11]. However, other studies have reported outcomes comparable to conventional mechanical approaches. Differences in laser type, irradiation parameters, treatment protocols, and study design contribute to heterogeneity in reported outcomes. In addition, the high cost of laser equipment and the requirement for specialized operator training continue to limit widespread adoption of these technologies in routine clinical practice [12,13].

The objective of this review is to evaluate the current clinical applications of laser technology in periodontics, dental caries management, and oral soft tissue surgical procedures. The review aims to examine the mechanisms of laser–tissue interaction, assess reported clinical outcomes, and compare the effectiveness of laser-assisted procedures with conventional treatment methods.

Review Methodology

A structured literature review was conducted to evaluate the clinical applications of laser technology in periodontics, caries removal, and oral soft tissue surgical procedures. The review aimed to synthesize current scientific evidence regarding the mechanisms of laser-tissue interaction, clinical outcomes, advantages, and limitations associated with the use of dental lasers.

Literature search strategy

A comprehensive literature search was performed using multiple electronic databases to identify relevant studies. The primary databases included PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar. These databases were selected because they index a large proportion of peer-reviewed biomedical and dental research articles. The search strategy was designed to identify studies evaluating the use of laser technologies in periodontal therapy, caries management, and oral soft tissue surgical procedures. The literature search focused primarily on studies published between 2015 and 2024 to ensure that the review reflects current technological developments and recent clinical evidence.

Search keywords

A combination of Medical Subject Headings (MeSH) terms and free-text keywords was used to retrieve relevant publications. The search terms were combined using Boolean operators such as AND and OR to refine the results. The primary keywords used in the search strategy included dental lasers, laser dentistry, laser therapy in periodontics, laser-assisted periodontal therapy, laser-assisted new attachment procedure, laser caries removal, soft tissue laser surgery and others.

Study selection process

The study selection process was performed in two stages. In the first stage, titles and abstracts of all retrieved articles were screened to determine their relevance to the topic of the review. In the second stage, the full text of the articles was reviewed. Studies that fulfilled the inclusion criteria and provided relevant clinical or experimental data were included in the final analysis.

Inclusion criteria

- Peer-reviewed scientific articles published in indexed dental journals.
- Clinical trials, randomized controlled trials, cohort studies, observational studies, and systematic reviews evaluating laser-assisted dental treatments.
- Studies reporting clinical outcomes, including parameters.

Exclusion criteria

- Studies not related to dental applications of laser technology.
- Studies involving animal models or laboratory experiments without clinical evidence.
- Articles lacking clear methodology, clinical outcome data, or statistical analysis.
- Duplicate publications or studies with data manipulations.

Data analysis and synthesis

The findings from the selected studies were analyzed using a qualitative synthesis approach. Due to heterogeneity in study design, treatment protocols, and outcome measures, quantitative meta-analysis was not performed. Instead, the results of the included studies were compared to identify common trends, differences in treatment outcomes, and areas of disagreement within literature. The review also examined the role of emerging technologies such as photodynamic therapy and artificial intelligence-based diagnostic systems in laser-assisted dental treatment.

Lasers in Periodontics

Periodontal diseases are inflammatory conditions involving the support structures of the teeth. The primary objective of periodontal therapy is the elimination of pathogenic microbial biofilm and calculus to control inflammation and prevent further periodontal tissue destruction. Conventional non-surgical periodontal treatment mainly involves scaling and root planning (SRP), which removes plaque and calculus from the tooth surface. But complete removal of deep periodontal pockets may be challenging due to complex root morphology, furcation involvement, and bacterial colonization within periodontal tissues. So, laser-assisted therapy has been considered as an alternative to improve bacterial reduction and enhance periodontal tissue response [14-16].

Mechanism of laser-tissue interaction

The therapeutic effect of lasers in periodontal treatment is based on photothermal and photomechanical interactions

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between laser energy and biological tissues. Different laser systems demonstrate selective absorption depending on their wavelength and the optical properties of the target tissue [17]. Pigmented bacteria, hemoglobin, and melanin show greater absorption for certain wavelengths, particularly in the case of diode and Nd:YAG lasers. This property enables selective destruction of pigmented periodontal pathogens located within periodontal layers [18].

Erbium lasers such as Er:YAG and Er,Cr:YSGG exhibit strong absorption in water and hydroxyapatite, allowing effective removal of dental calculus and contaminated root surface deposits. These lasers can facilitate root surface removal while producing minimal thermal damage when appropriate parameters are used. Also, laser irradiation can disrupt bacterial cell walls and reduce the overall microbial load within periodontal layers [19] (Table 1).

Table 1. Classification of lasers used in dentistry based on active medium and wavelength.

Laser Type	Active Medium	Wavelength (nm)	Spectral Region
Excimer Lasers	Argon Fluoride (ArF)	193	Ultraviolet
	Xenon Chloride (XeCl)	308	Ultraviolet
Gas Laser	Argon	488	Blue
		514	Blue-Green
	Helium–Neon (HeNe)	637	Red
	Carbon dioxide (CO_2)	10,600	Infrared
Diode Lasers	Indium Gallium Arsenide Phosphide (InGaAsP)	655	Red
	Gallium Aluminium Arsenide (GaAlAs)	670–830	Red–Infrared
	Gallium Arsenide (GaAs)	840	Infrared
	Indium Gallium Arsenide (InGaAs)	980	Infrared
Solid-State Lasers	Frequency-doubled Alexandrite	377	Ultraviolet
	Potassium Titanyl Phosphate (KTP)	532	Green
	Neodymium:YAG (Nd:YAG)	1064	Infrared
	Holmium:YAG (Ho:YAG)	2100	Infrared
	Erbium Chromium:YSGG (Er,Cr:YSGG)	2780	Infrared
	Erbium:YSGG (Er:YSGG)	2790	Infrared
	Erbium:YAG (Er:YAG)	2940	Infrared

Laser-Assisted Periodontal Therapy

Several clinical studies have evaluated the use of lasers with conventional scaling and root planning. Laser irradiation may assist in the removal of inflamed pocket epithelium, promote coagulation, and provide localized antimicrobial effects. Diode and Nd:YAG lasers are commonly used for soft tissue decontamination due to their affinity for pigmented tissues and hemoglobin. The Laser-Assisted New Attachment Procedure (LANAP) is one of the most widely discussed laser-based periodontal treatment protocols. This technique utilizes Nd:YAG laser irradiation to selectively remove diseased pocket epithelium while preserving connective tissue structures. Following laser irradiation, scaling and root planning are performed to remove calculus and contaminated root surfaces [20,21].

Gingival depigmentation

Melanin pigmentation of the gingiva is a physiological condition that may present aesthetic concerns in certain patients. Laser-assisted depigmentation procedures have been performed using diode, Nd:YAG, and Er:YAG laser systems. The laser energy selectively targets melanin-containing epithelial cells, resulting in removal of the pigmented epithelial layer [22].

Photodynamic therapy

Photodynamic therapy (PDT) has been studied as an alternative antimicrobial approach in periodontal treatment. This method involves the application of a photosensitizing agent, such as methylene blue or toluidine blue, followed by irradiation with low-level laser light of a specific wavelength. Activation of the photosensitizer leads to the generation of reactive oxygen species that induce oxidative damage to bacterial cell structures. Several clinical trials have examined the use of photodynamic therapy with scaling and root planning. Some studies have reported reductions in periodontal pathogens and limited improvements in clinical parameters [23,24].

Laser-Assisted Caries Removal

Dental caries is a biofilm-mediated disease characterized by progressive demineralization of enamel and dentin caused by acids produced during bacterial metabolism. Traditional caries management involves mechanical removal of infected tooth structure using rotary instruments followed by restoration of the prepared cavity. Although this method is effective, the use of rotary instruments may cause patient discomfort due to vibration, noise, and thermal effects. For these reasons, laser-assisted caries removal has been used as an alternative method

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for minimally invasive cavity preparation [25] (Figure 1).

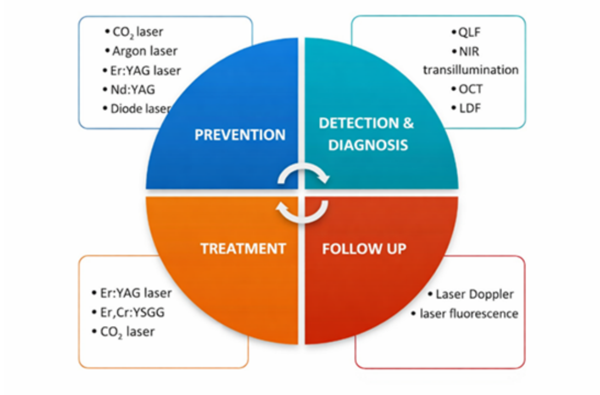

Figure 1. Overview of different wavelengths applications in caries management.

Mechanism of laser-mediated hard tissue removal

Laser systems used for hard tissue procedures primarily include erbium-based lasers, particularly Er:YAG and Er,Cr:YSGG. The wavelengths demonstrate strong absorption in water and hydroxyapatite. When laser energy is delivered to the tooth surface, rapid absorption by water molecules within the enamel and dentin produces micro-explosions that result in removal of the mineralized tissue. This thermomechanical process allows removal of carious tooth structure. Laser-mediated removal also produces a roughened surface morphology and removes the smear layer that is generated during rotary instrumentation. The absence of a smear layer may improve adhesion between the tooth surface and restorative materials [26].

Clinical applications

Several clinical studies have reported that erbium lasers are capable of selectively removing demineralized dentin while preserving healthy tooth structure. This selective removal supports the minimally invasive dentistry, which highlights conservation of healthy enamel and dentin. Another advantage reported in clinical investigations is the reduction in patient discomfort during cavity preparation. As laser systems operate without direct contact with the tooth surface, they generate less vibration and noise compared with rotary instruments. As a result, laser treatment may reduce anxiety and improve patient experience, particularly in paediatric patients [27,28].

Laser Fluorescence for Caries Detection

Along with tissue removal, laser technology has also been incorporated into diagnostic devices for early detection of dental caries. Laser fluorescence systems utilize specific wavelengths to stimulate fluorescence from bacterial metabolites present in demineralized tooth structure. The intensity of the emitted fluorescence is measured and converted into numerical values that correspond to the degree of mineral loss. These allow non-invasive detection of early carious lesions and help clinicians in monitoring lesion progression over time [29] (Table 2).

Table 2. DIAGNOdent pen score interpretation for dental caries detection.

	Score	Output
	0-12	Healthy Tissue
Occlusal Surfaces	13-24	Demineralized Enamel
	>25	Dentine involved
	0-7	Healthy Tissue
Approximal Surfaces	8–15	Demineralized Enamel
	≥16	Dentine involved

Clinical limitations

Despite the advantages of laser-assisted caries removal, certain limitations remain. The cost of laser equipment is considerably higher than that of traditional rotary instruments, which may limit the availability in routine clinical practice. Also, cavity preparation using lasers may require longer treatment time compared with high-speed burs in certain clinical situations. Proper training and knowledge of laser parameters are also necessary to avoid excessive heat generation and potential damage to surrounding tissues [30].

Lasers in Soft Tissue Oral Surgery

Laser technology has also been incorporated into oral soft tissue surgical procedures because of its ability to provide precise tissue incision, effective haemostasis, and improved intraoperative visibility. Soft tissue lasers are widely used in periodontal and oral surgical procedures including gingivectomy, crown lengthening, frenectomy, and excision of benign oral lesions. Compared with conventional scalpel-based techniques, laser-assisted surgery may reduce intraoperative bleeding, and postoperative discomfort [31].

Mechanism of laser-soft tissue interaction

Different laser systems exhibit selective absorption based on their wavelength, which determines their suitability for specific clinical applications. Diode and Nd:YAG lasers demonstrate strong absorption in pigmented tissues and haemoglobin, making them effective for procedures involving vascular soft tissues. CO_2 lasers absorbed by water, are suitable for superficial soft tissue removal and surgical incision. Laser irradiation produces thermal effects that result in tissue vaporization and coagulation. During surgical procedures, this effect enables simultaneous cutting and haemostasis, which improves visibility. The coagulative effect of laser energy also reduces the risk of intraoperative bleeding and may limit postoperative edema [32].

Gingivectomy and crown lengthening

Gingivectomy and crown lengthening procedures are commonly performed to manage gingival overgrowth, improve periodontal health, and facilitate restorative treatment. Laser-assisted gingivectomy can be performed using diode, Nd:YAG, or CO_2 laser systems. The laser allows controlled removal of

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gingival tissue with minimal mechanical trauma. Because laser energy simultaneously coagulates small blood vessels, intraoperative bleeding is significantly reduced compared with conventional scalpel surgery. Several clinical studies have reported that laser-assisted gingivectomy is associated with reduced postoperative pain and improved patient comfort [33].

Excision of benign oral lesions

Laser systems are also used for the excision of benign oral soft tissue lesions including fibromas, papillomas, mucoceles, and vascular lesions. The precise cutting ability of lasers allows controlled removal of pathological tissue while minimizing damage to surrounding structures. Also, the bactericidal properties of laser irradiation may reduce the risk of postoperative infection [34].

Auxiliary Technology in Laser Dentistry

Recent innovations in dental technology have expanded the laser application scopes beyond traditional surgical and therapeutic procedures. Several auxiliary technologies have been integrated with laser systems to improve diagnostic accuracy, treatment precision, and clinical outcomes in dental practice. These developments include photodynamic therapy, laser-based diagnostic systems, artificial intelligence-assisted imaging, and optical diagnostic techniques [35].

Photodynamic therapy

PDT is a light-activated antimicrobial treatment that has been referred to as supportive measures in periodontal and peri-implant disease management. Several clinical investigations have reported reductions in periodontal pathogens and improvements in clinical parameters such as bleeding on probing and probing depth. However, other studies have shown limited additional benefits when compared with mechanical therapy. Variability in treatment protocols, photosensitizer concentration, and irradiation parameters contributes to inconsistent outcomes across different clinical studies [36].

Laser-based diagnostic systems

Laser fluorescence systems are commonly used for the detection of early carious lesions. These systems utilize laser light to induce fluorescence from bacterial metabolites and altered tooth structure present in demineralized enamel and dentin. The emitted fluorescence signal is measured and converted into numerical values that correspond to the degree of mineral loss within the tooth. These systems are also useful for monitoring injury progression and evaluating the effectiveness of preventive treatment strategies [37].

Optical diagnostic technology

- Quantitative light-induced fluorescence (QLF) is a method that measures changes in fluorescence patterns of dental enamel associated with mineral loss. This technique allows visualization and quantification of early enamel demineralization [38].
- Near-infrared transillumination (NIR) is another diagnostic technique that uses near-infrared light to detect early carious injuries without ionizing radiation. Changes in light scattering within demineralized enamel allow identification of early injuries that may not be detected using traditional diagnostic methods [39].
- Optical coherence tomography (OCT) is an imaging technique that produces high-resolution cross-sectional images of dental tissues using reflected light waves. OCT allows non-invasive evaluation of enamel and dentin structure and may assist in the early detection of dental caries and structural defects [40].
- Laser Doppler flowmetry (LDF) is used to assess pulpal blood flow and evaluate pulp vitality. This technique measures the Doppler shift produced when laser light interacts with moving red blood cells within pulpal microcirculation [41].

Discussion

The use of laser technology into dental practice has generated considerable interest due to its potential to improve precision, reduce tissue trauma, and enhance patient comfort during clinical procedures. Multiple studies have evaluated the application of different laser systems in periodontal therapy, caries management, and soft tissue surgery. While several investigations report favorable clinical outcomes, the available literature also highlights limitations and inconsistencies that requires critical evaluation [42].

In periodontal therapy, lasers have primarily been used as substitutes for traditional scaling and root planning. Certain clinical studies have demonstrated that laser-assisted treatment may contribute to additional reductions in probing depth and improvements in clinical treatment. These effects have been attached to the bactericidal properties of laser irradiation, and the ability of certain wavelengths to remove epithelium and reduce microbial contamination. Furthermore, laser energy may help coagulation and localized tissue sterilization within periodontal layers, which could potentially enhance the healing response [43].

However, the range of these advantages remain a debatable matter. Several systematic reviews and randomized clinical trials have reported that the clinical improvements observed following laser-assisted periodontal therapy are not superior to those achieved with traditional treatment. In many cases, the difference between laser-assisted and traditional therapy have been statistically insignificant. Variations in laser wavelength, energy settings, treatment protocols, and operator experience contribute to heterogeneity in clinical outcomes across different studies. Consequently, the regular use of lasers as a replacement for traditional periodontal therapy remains controversial [44].

The Laser-Assisted New Attachment Procedure (LANAP) has been proposed as a minimally invasive alternative to periodontal flap surgery. Some clinical investigations have reported improvements in periodontal parameters, including reductions in pocket depth and radiographic evidence of bone fill following LANAP treatment. These findings suggest that laser-assisted procedures may support periodontal regeneration in certain cases. But the current evidence supporting LANAP is limited by small sample sizes, lack of long-term follow-up, and methodological variability among studies. As a result, the long-term predictability and reproducibility of this technique require further investigation [45,46].

Laser-assisted caries removal has also been evaluated as an alternative to traditional instrumentation. Erbium-based lasers are capable of selectively removing demineralized dental tissues while preserving healthy enamel and dentin. Also, laser

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cavity preparation is often associated with reduced noise and vibration, which may improve patient acceptance and decrease dental anxiety [47].

Limitations and Future Directions

One of the major limitations is the variability in clinical outcomes reported in literature. Differences in laser wavelength, power settings, irradiation duration, and treatment protocols contribute to inconsistencies in the results of laser-assisted procedures. These inconsistencies make it difficult to register structured clinical guidelines regarding the use of laser systems in dental practice [48].

The cost of laser equipment also presents a major limitation to widespread adoption. Dental laser units require substantial financial investment for purchase, maintenance, and calibration. Also, clinicians often require specialized training programs to ensure safe and effective use of these devices. These factors may limit the availability of laser-assisted procedures in many dental practices, particularly in smaller clinical settings [49].

Future developments in laser dentistry are likely to focus on improving treatment efficiency and expanding clinical applications. Developments in laser technology may lead to compact, cost-effective, and user-friendly systems that can be easily incorporated into routine dental practice. Improvements in wavelength optimization and energy delivery may also enhance the selectivity of laser-tissue interaction, thereby reducing the risk of thermal damage while improving therapeutic outcomes [50].

The integration of laser technology with digital diagnostic tools represents a promising direction. Artificial intelligence-based diagnostic systems and advanced imaging techniques may assist clinicians in identifying early disease changes and selecting appropriate laser parameters for individual patients. In addition, emerging research is exploring the use of laser-assisted therapies in combination with regenerative techniques such as biomaterials, growth factors, and tissue engineering approaches to support periodontal regeneration [51].

Conclusion

This review evaluated the clinical applications of laser technology in periodontics, caries management, and oral soft tissue surgical procedures. The available studies indicated that laser technology provides several advantages due to their ability to deliver controlled energy to biological tissues with high precision. Different laser systems demonstrate specific clinical utility depending on their wavelength and interaction with oral tissues. Under periodontal therapy, laser-assisted procedures have shown potential benefits in reducing microbial load within periodontal layers and facilitating removal of inflamed epithelial tissue. When used as a replacement to conventional scaling and root planning, lasers may contribute to improved periodontal decontamination and favorable tissue response. In caries management, erbium-based lasers have demonstrated the ability to selectively remove demineralized enamel and dentin while preserving healthy tooth structure, supporting the principles of minimally invasive dentistry. In addition, laser-assisted soft tissue surgical procedures such as gingivectomy, frenectomy, and excision of benign oral lesions have demonstrated improved haemostasis, enhanced surgical visibility, and reduced postoperative discomfort in several clinical studies. Overall, the review presents that laser technology acts as a major alternative in modern dental practice and has expanded the therapeutic options available for the management of periodontal diseases, dental caries, and oral soft tissue conditions. Future research should focus on well-designed randomized clinical trials with larger patient populations and extended follow-up periods to strengthen the current evidence. Further investigations should also evaluate the integration of laser therapy with regenerative approaches in periodontal treatment, including the use of biomaterials, growth factors, and tissue engineering strategies. In addition, development in digital technologies, including artificial intelligence-assisted diagnostics and image-guided treatment planning, may improve the precision and clinical effectiveness of laser-assisted dental procedures. These developments will contribute to the continued growth of laser technology in dental care.

Disclosure Statement

The author does not have conflict of interest in this research.

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