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Lasers in Dentistry — Overview Based on FDI Policy Statement

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ABSTRACT

Background: Lasers have become an important adjunct in dentistry, offering minimally invasive approaches for caries removal, endodontic disinfection, periodontal therapy, and prosthetic or orthodontic elements debonding. Despite numerous clinical studies, a comprehensive evidence-based overview linked to the FDI Policy Statement has not yet been provided.

Objective: To critically review the current evidence on the applications of dental lasers across caries management, endodontics, prosthetics, orthodontics, periodontal surgery, and peri-implant therapy, and to discuss their translational and clinical relevance.

Methods: A narrative review was conducted using PubMed, Scopus, and Web of Science databases, integrating original studies, systematic reviews, and consensus statements. Emphasis was placed on mechanisms of action, clinical efficacy, safety, limitations, and future research needs, aligned with international policy frameworks.

Results: Erbium lasers (Er:YAG, Er,Cr:YSGG) demonstrate effective and selective caries ablation, smear layer removal, and improved adhesion. In endodontics, laser-activated irrigation protocols such as photon-induced photoacoustic streaming and shock wave—enhanced emission photoacoustic streaming enhance irrigant penetration and biofilm disruption. In prosthodontics and orthodontics, erbium lasers allow minimally invasive debonding of crowns, veneers, and brackets, preserving underlying structures. In periodontology and peri-implantitis, lasers improve debridement, support regeneration, and enhance wound healing. Photobiomodulation contributes to pain reduction, inflammation control, and tissue repair. However, outcomes vary with wavelength, energy settings, and clinical protocols, underscoring the need for standardization.

Conclusion: Lasers represent valuable adjuncts to conventional dental treatment by enabling minimally invasive procedures, enhancing patient comfort, and promoting biological healing. Current evidence supports their role across multiple specialties, although further high-quality trials are necessary to define standardized protocols.

Clinical Relevance: This review provides clinicians and educators with an evidence-based synthesis of laser applications in dentistry, aligned with the FDI Policy Statement, to support safer, effective, and globally consistent clinical practice.

Introduction

Oral health is increasingly recognized as an essential component of general health and well-being, extending beyond the absence of disease to include physiological, social, and psychological dimensions.[1] Despite this recognition, oral diseases such as dental caries, periodontitis,

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peri-implantitis, and oral cancer remain among the most prevalent global health burdens. Their progression is closely linked to ageing populations, multimorbidity, and persistent challenges in early diagnosis and minimally invasive treatment.[2] As dentistry shifts towards prevention-focused and tissue-preserving care, innovative technologies such as dental lasers have gained prominence. Modern laser systems enable clinicians to perform highly precise procedures with reduced collateral damage, improved patient comfort, and enhanced biological responses. Their integration into routine practice reflects a broader movement towards minimally invasive dentistry supported by evidence-based use of advanced technologies.[1-3]

The adoption of lasers in dentistry must also be viewed through the lens of global professional standards. The FDI Policy Statement on Lasers in Dentistry emphasizes the importance of proper training, safety protocols, and evidence-based selection of wavelength-specific applications. These principles ensure that laser technologies are integrated responsibly and consistently across diverse clinical settings.[4]

This review synthesizes current evidence on diagnostic applications, hard- and soft-tissue procedures, caries management, endodontic therapy, prosthetic and orthodontic debonding, periodontal and peri-implant treatment, and photobiological laser interactions. By aligning scientific data with the FDI guidance framework, the article aims to clarify clinical indications, safety considerations, and future directions for laser use in dentistry (Figure 1).

Lasers used for diagnostics and prevention

Laser-based fluorescence techniques have become an important adjunct in the early diagnosis and prevention of oral diseases. Fluorescence occurs when tissues or microbial metabolites emit light at longer wavelengths after being excited by light of a specific laser wavelength. This phenomenon arises when endogenous or exogenous fluorophores absorb photons and move to a higher energy state. As they return to their ground state, part of the absorbed energy is released as visible or near-infrared light. The emitted signal can be detected and measured, and variations in its intensity or spectral distribution provide diagnostic information about presence of demineralization, bacterial metabolites, or dysplastic tissue changes. On this basis, fluorescence has been successfully applied in several areas of dental practice as a noninvasive tool for the early detection of pathological changes.[5-7] Clinical applications include the detection of incipient caries, candidiasis, bacterial infections, as well as the diagnosis of oral cancer and the delineation of tumour margins.

Caries detection

Streptococci represent some of the earliest colonizers of both soft and hard oral tissues and are key contributors to the host's oral health status. They are implicated in a wide range of conditions, including dental caries, endodontic and periodontal infections, and have also been linked to oral carcinogenesis. To better investigate these mechanisms, genetically engineered streptococcal strains that express fluorescent proteins have been developed, enabling visualization under microscopy and quantitative assessment of bacterial behaviour in biofilms.[5] Devices such as DIAGNOdent and Diagnopen (Kavo) employ laser fluorescence to identify incipient carious lesions. Healthy enamel and dentin show a characteristic autofluorescence (AF), while demineralized tissues and bacterial products, particularly porphyrins produced by *Streptococcus mutans* and other biofilm-forming bacteria, modify

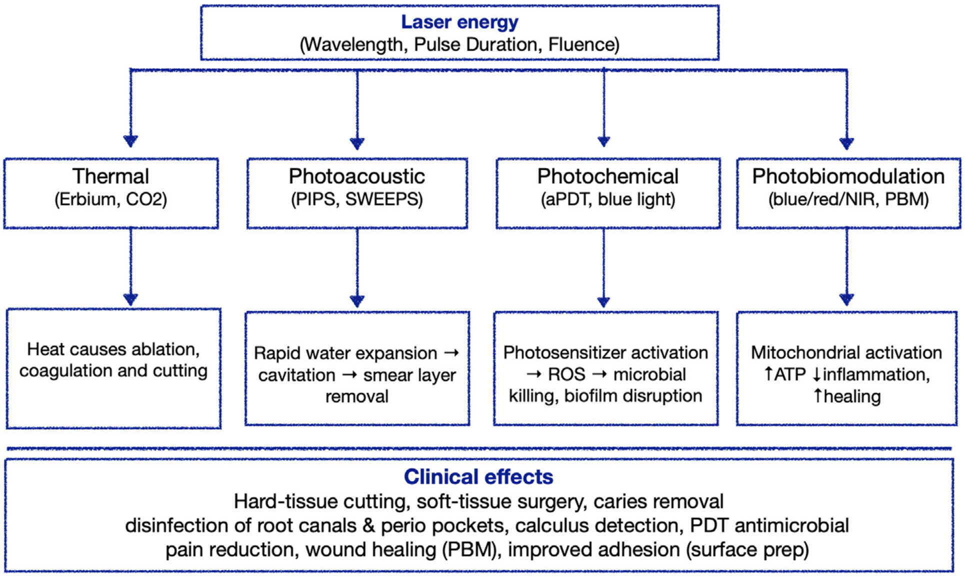

Fig. 1 – Overview of key laser–tissue interaction mechanisms relevant to dentistry. Different wavelengths and pulse modes generate thermal, photoacoustic, photochemical, or photobiomodulatory effects. These interactions underlie clinical applications such as hard-tissue ablation, soft-tissue surgery, canal disinfection, photodynamic antimicrobial therapy, and enhanced wound healing.

fluorescence intensity and spectral distribution, indicating early microbial activity and mineral loss.[6] Clinical studies confirm their diagnostic utility: while VistaCam iX (Dürr Dental) and DIAGNOcam show higher sensitivity, DIAGNOdent (KaVo), remains a highly specific adjunctive tool for detecting early enamel caries and monitoring lesion progression.[7-9] Thus, fluorescence-based diagnostics provide both a microbiological and clinical perspective: engineered fluorescent strains allow deeper experimental insight into biofilm dynamics, while chairside devices translate these principles into practical caries detection, supporting minimally invasive and preventive dentistry.

Periodontal applications

Periodontal accurate detection of subgingival calculus is critical for effective and successful treatment outcomes. Traditional tactile methods with probes and curets are often unreliable, often leaving residual deposits. Laser fluorescence detects subgingival calculus by exploiting the AF of bacterial metabolites, particularly porphyrins, with red laser light around 655 nm wavelength. Early in vitro studies demonstrated that fluorescence induced by red diode laser produced significantly stronger signals from calculus compared with cementum or dentin.[7] These findings were later confirmed in clinical studies, where the same 655 nm diode laser, reporting high sensitivity of 70% and specificity approaching 97%, with an overall accuracy of 82% for detecting subgingival calculus in patients with periodontitis.[10] Comparative studies further demonstrated that laser fluorescence outperforms differential reflectometry in both accuracy and reproducibility (76.2% vs 68.2%), reinforcing its diagnostic potential.[11] Importantly, the method provides real-time numerical feedback, allowing clinicians to localize calculus deposits more objective and reproducible than with tactile probing alone. These results support its use as a diagnostic adjunct in nonsurgical periodontal therapy, where improved detection may enhance scaling and root planing (SRP) outcomes and reduce the need for surgical intervention.

Beyond bacteria implicated in caries and periodontal disease, fungi such as *Candida* spp. can also be identified through laser-induced AF. Selected strains of *Candida* emit characteristic red-orange fluorescence under violet light laser excitation (405 nm), attributed to endogenous porphyrin-like compounds within the fungal cells. Recent studies demonstrated the diagnostic promise of this approach for rapid, noninvasive detection of candidiasis, which is particularly relevant in immunocompromised and denture-wearing populations.[12]

Oral cancer and potentially malignant disorders

AF imaging devices such as VELscope are increasingly used to assist in the visualization of dysplastic and malignant lesions. Normal mucosa emits a green AF, whereas dysplastic or cancerous tissue demonstrates fluorescence loss due to stromal changes, collagen breakdown, and increased haemoglobin absorption, helping clinicians highlight suspect fields that are less conspicuous under white light (IL).[13] AF can improve lesion conspicuity in oral potentially malignant disorders, and may aid biopsy site selection, especially for less-experienced examiners.[13-15] In a prospective screening study of high-risk patients, combining AF with conventional IL examination improved agreement for biopsy indication decisions (κ = 0.88 with AF+IL vs κ = 0.78 with IL alone) and led to the detection of additional leukoplakias.[15] However, diagnostic accuracy remains variable. Cross-sectional studies have reported sensitivities of 80% to 90% specificities below 50%, reflecting a high false-positive rate.[16,17]

A prospective study using quantitative VELscope methods demonstrated that objective AF analysis improved specificity to over 80% when distinguishing high-risk from low-risk potentially malignant disorders, though sensitivity decreased compared with subjective assessment.[17] Contemporary reviews confirmed that AF should be regarded primarily as a visibility aid and biopsy-site selection tool, not a diagnostic substitute, with biopsy remaining essential for definitive diagnosis.[18] Clinical use is further complicated by confounded such as inflammation, vascularity, keratosis, or fungal colonization, leading to false positives. Findings must therefore be interpreted in full clinical context and, where possible, supported by objective metrics or imaging analysis before biopsy.[5-17]

Collectively, fluorescence-based laser applications extend across cariology, periodontology, mycology, and oncology. They offer minimally invasive, objective, real-time, and reproducible insights into early pathological changes, supporting preventive and conservative approaches. While their adjunctive value is well established, further refinement, particularly in quantitative analysis and specificity enhancement, is required to optimize integration into routine evidence-based care.

Lasers for soft and hard tissue applications

Lasers have become integral to many restorative, endodontic, periodontal, surgical, and prosthetic procedures, where they function either as stand-alone tools or as adjuncts to conventional techniques. Their clinical value depends on wavelength-specific interactions with dental hard tissues, soft tissues, biomaterials, and microorganisms, which must be understood to ensure effective and safe treatment (Table).

Caries treatment and enhance adhesion

The therapeutic use of lasers in cariology reflects the principles of minimally invasive dentistry, where selective removal of diseased tissue is prioritized while preserving sound structures.[19] Among currently available systems, the erbium family, including Er:YAG (2.940 nm) and Er,Cr:YSGG (2.780 nm), is particularly effective for ablating enamel, dentin, and carious tissues due to strong absorption in water and hydroxyapatite.[19,20] An additional advantage is that carious dentin contains more water and less mineral than healthy, intact dental tissue, which makes it more susceptible to erbium laser ablation. The higher water content enhances absorption of laser energy, leading to preferential removal of diseased tissue while preserving surrounding sound structures.[20,21] When erbium family laser energy is delivered

Table – Overview of dental laser systems, wavelengths, clinical applications, and safety considerations.

Laser type	Wavelength	Clinical applications	Key advantages	Notes/safety
Er:YAG	2940 nm	Hard and soft tissue surgery, periodontal debridement, implant decontamination, caries removal, debonding, aesthetics	Selective ablation, minimal thermal damage, extremely shallow penetration	Water spray essential to prevent thermal rise; plume evacuation recommended
Er,Cr:YSGG	2780 nm	Hard and soft tissue surgery, periodontal debridement, caries removal, debonding, aesthetics	Selective ablation, minimal thermal damage, shallow penetration	Water spray essential; avoid dry firing
CO_2 (10.6 μm)	10,600 nm	Soft tissue surgery, frenectomies, aesthetic procedures	Excellent haemostasis, very shallow penetration ($\sim$20-30 μm)	Surface thermal effect only; plume evacuation required; avoid contact with hard tissue (risk of carbonization)
CO_2 (9.3 μm – Solea)	9300 nm	Hard tissue ablation (caries removal), soft tissue cutting, periodontal procedures	Fast and efficient hard-tissue ablation, strong hydroxyapatite absorption	Must use manufacturer-specified settings; minimal thermal penetration, but plume evacuation essential
Nd:YAG	1064 nm	LANAP, soft-tissue coagulation, deep tissue disinfection, pigmentation removal	Deep penetration (2-4 mm), strong coagulation	High risk of deep heating; use controlled pulse settings; plume evacuation required; eye protection critical
Diode (810-980 nm)	810-980 nm	Soft-tissue surgery, periodontal pockets, PBM, aPDT activation	Compact, affordable, highly versatile	Highly absorbed by melanin/haemoglobin → risk of carbonization; avoid reflective surfaces
Blue diode	445 nm	Soft-tissue surgery, antimicrobial applications, gingivectomy, bacterial reduction	Strong haemostasis; high absorption by haemoglobin → precise cutting	Requires careful parameter control to avoid carbonization; limited penetration
PBM lasers	630-700 nm (red), 780-950 nm (NIR)	Wound healing, pain reduction, implant stability, mucositis, nerve repair	Noninvasive, strong evidence in healing and analgesia	Must follow biphasic dose-response (Arndt–Schulz law); near-infrared penetrates deeper
PDT/aPDT	630-660 nm (phenothiazine, 805-810 nm (ICG)	Periodontitis, peri-implantitis, endodontic disinfection, halitosis, OLP	Strong targeted antimicrobial effect; reduces inflammation	Wavelength must match photosensitizer; ensure adequate preirradiation time

in short pulses, water molecules within carious enamel and dentin undergo rapid microexplosive vaporization. This photothermal-photoacoustic interaction disrupts the surrounding mineral matrix, selectively ablating demineralized tissues while minimizing collateral damage. As a result, laser cavity preparation can be performed with reduced vibration and noise compared to rotary instruments, which is particularly advantageous in anxious and paediatric patients.[19-23]

In addition to erbium systems, short-pulsed CO_2 laser, particularly at 9.300 nm (Solea, Convergent Dental), have been developed for hard tissue applications, demonstrating efficient caries removal, cavity preparation, and reduced need for anesthesia.[24,25] CO_2 lasers (9.300 and 10.600 nm) can also increase enamel resistance to demineralization through structural and chemical modifications of the surface layer.[24,25] When combined with silver diamine fluoride, CO_2 irradiation significantly enhanced resistance to enamel and dentin demineralization in vitro.[25,26] Similarly, Er:YAG pretreatment has been shown to reduce susceptibility to demineralization and improve fluoride uptake in dentin.[20,27] Preventive protocols have also been explored for root caries[28-30] and an initial enamel lesions,[31] supporting the role of laser irradiation in caries control strategies. Lasers can further assist caries-related diagnostics through laser Doppler flowmetry, which measures pulpal blood flow and provides an objective adjunct for assessing pulp vitality when conventional sensibility tests are inconclusive.[32]

Erbium laser irradiation also modifies enamel and dentin surface morphology, producing microretentive patterns and reducing the smear layer.[22] This facilitates resin infiltration and micromechanical bonding, though results vary depending on laser parameters. Some studies confirm laser conditioning as a valuable adjunct to acid etching,[23] while others report inconsistent improvements in bond strength, emphasizing the need for standardized protocols.[33,34] Experimental studies confirmed that Er:YAG pretreatment exposes open dentinal tubules and improves shear bond strength, where orthodontic brackets bonded better to laser-treated enamel to untreated surfaces[34] In primary dentin, Er:YAG laser irradiation has also been reported to increase microtensile bond strength and facilitate adhesive penetration,[35] while Er,Cr:YSGG pretreatment demonstrated comparable improvements in bonding performance and adhesive penetration, particularly when combined with antioxidant application[36]

Recent meta-analyses indicate that erbium laser conditioning can maintain or even enhance immediate and long-term bonding compared with traditional bur preparation, especially when universal adhesives are used.[37] Overall, erbium and CO_2 lasers support minimally invasive caries management while improving adhesion and offering additional preventive benefits.[38]

Endodontic therapy

The goal of endodontic treatment is to eliminate infection and achieve hermetic sealing of the root canal system. Persistent infection however, remains a major challenge due to the complexity of root canal anatomy and the resilience of biofilms, with *Enterococcus faecalis* being one of the most frequently associated pathogens.[39-42] Conventional irrigation with sodium hypochlorite (NaOCl) is effective against planktonic bacteria but limited in its penetration into dentinal tubules and lateral canals, and at higher concentrations it poses cytotoxic risks. These limitations have prompted the development of laser-assisted protocols to enhance disinfection, irrigant activation, and, in selected cases, regenerative vital-pulp procedures.

Erbium family lasers are highly absorbed in water and, therefore, well-suited for irrigant activation. Protocols such as photon-induced photoacoustic streaming and shock wave –enhanced emission photoacoustic streaming create vapor bubbles, cavitation, and secondary shock waves that enhance irrigant flow and penetration into dentinal tubules, lateral canals, and the apical region.[43] Systematic reviews confirm that erbium-based laser-activated irrigation achieves superior smear layer removal and bacterial reduction compared with syringe or ultrasonic techniques, while avoiding harmful thermal effects.[43] Other wavelengths have also been explored. Nd:YAG and Nd:YAP lasers act primarily via photothermal absorption by pigmented bacterial chromophores, leading to biofilm disruption and bacterial killing.[44,45] Nd:YAP irradiation combined with NaOCl has been shown to significantly reduce *E. faecalis* penetration into dentin compared with irrigants alone.[46] Diode lasers (810-980 nm) exhibit comparable bactericidal activity and are valued for their ease of clinical use, although their potential for irrigant activation is limited.[42]

Beyond their bactericidal effects, Er:YAG lasers also contribute to improving the substrate for obturation. By disrupting biofilms, removing the smear layer, and opening dentinal tubules, they facilitate deeper sealer penetration and potentially improve adhesion.[47,48] High-speed visualization studies demonstrated that short-pulsed Er:YAG laser energy induces explosive vapor and cavitation within irrigants, generating dynamic streaming forces that extend into complex canal geometries.[49] Subsequent efficacy studies confirmed that this mechanism significantly enhances debris and smear-layer removal compared with syringe irrigation, including in canal irregularities and the apical third.[50]

Together, these findings position laser-assisted endodontic disinfection and irrigation as promising adjuncts to conventional protocols, improving biofilm eradication, smear layer removal, and substrate conditioning for predictable endodontic outcomes. In parallel, lasers are gaining importance in vital pulp preservation. Both CO_2 and Er:YAG lasers have been shown to sterilize exposure sites, provide effective haemostasis, and stimulate reparative dentinogenesis.[51] In addition, low-level photobiomodulation (PBM) appears to modulate inflammation and promote pulp healing, suggesting an adjunctive role in regenerative endodontic strategies.[51] Thus, lasers contribute not only to improved disinfection and cleaning but also to biological preservation and repair within endodontic therapy.

Ceramic prosthetics and orthodontics unit removal

Ceramic and CAD/CAM restorations are widely adopted in contemporary prosthodontics due to their aesthetics and biomechanical performance, yet their brittle nature and susceptibility to fatigue and fracture continue to pose clinical challenge.[52,53] The removal of ceramic restorations and orthodontic appliances is particularly demanding, as conventional rotary instruments risk damaging underlying tooth structures and are time-consuming. Recent studies highlight erbium family lasers (Er:YAG 2940 nm and Er,Cr:YSGG 2780 nm) as minimally invasive alternatives for debonding due to their ability to selectively weaken the adhesive interface without excessive heat transfer. This enables selective debonding while preserving the integrity of the restoration and abutment.[54-63]

Clinical and laboratory studies confirm that erbium lasers allow safe removal of lithium disilicate and zirconia crowns, veneers, and implant-retained prostheses without damaging the underlying tooth, implant, or restoration.[54-60] In a retrospective clinical analysis, Deeb et al[55,61] showed that erbium laser-assisted removal of ceramic restorations was predictable and clinically practical, reducing chairside time compared with rotary instruments. Scoping and in vitro studies further confirmed that erbium lasers preserve ceramic restorations for potential reuse, while rotary burs typically destroy them.[54,58,60,61]

Retrieval of cement-retained crowns from titanium or zirconia abutments is traditionally challenging, often requiring destructive rotary instrumentation. Grzech-Leśniak et al and Elkharashi et al demonstrated that Er:YAG lasers efficiently debond lithium disilicate and zirconia crowns from both titanium and zirconia abutments, with significantly shorter debonding times for resin-modified glass ionomer vs composite resin cements. Importantly, temperature increases remained within safe biological limits (<6°C), avoiding risks to peri-implant tissues and osseointegration.[57,62] For orthodontic, studies have showed that Er:YAG irradiation allowed safe removal of ceramic and metallic brackets with minimal temperature rise and no enamel damage,[54,55,58,60] and more recent work has confirmed efficient debonding of orthodontic aligner attachments.[63]

From the patient perspective, implant and ceramic restorations are increasingly accepted due to their aesthetics, longevity, and minimally invasive protocols. However, concerns remain regarding cost and retrievability in case of biological or technical complications. Surveys show that awareness of implant-supported prosthetics is rising, but patient education remains essential.[64-66] Laser-assisted retrieval techniques directly address these concerns by enabling conservative, repeatable debonding when complications occur. Overall, erbium lasers provide a safe, efficient, and conservative option for removing ceramic crowns, veneers, implant-supported restorations, fibre posts, and orthodontic units, while preserving both restorations and underlying structure.[54-63]

Bone remodelling, crown lengthening, open flap procedure

The clinical use of lasers in periodontal and surgical procedures aims to achieve precise ablation with minimal collateral damage, effective haemostasis, and improved wound healing. Among available systems, Er:YAG (2940 nm) and Er, Cr:YSGG (2780 nm) lasers demonstrate strong affinity for water and hydroxyapatite, making them effective for both soft and hard tissue management. Their energy is absorbed by interstitial water, inducing rapid microexplosive vaporization that selectively removes tissue while minimizing thermal damage to adjacent structures.[67,68] Recent advancements, such as Quantum Square Pulse (QSP) technology, further enhance this precision. QSP short pulses reduce vibrational effects and debris shielding, improving ablation efficiency and producing sharp, well-defined margins with lower thermal load compared to conventional pulse modes. This is particularly advantageous in procedures requiring controlled bone reshaping, such as crown lengthening and osseous recontouring, where tissue preservation and accuracy are critical.

In periodontology, minimally invasive open flap surgery supported by erbium lasers has shown favourable outcomes. In periodontology, minimally invasive flap surgery combined with erbium lasers has demonstrated favourable outcomes. A recent multicentre randomized controlled trial comparing Er, Cr:YSGG-assisted flap procedures with the minimally invasive surgical technique in intrabony defects reported comparable or superior improvements in probing depth (PD) reduction and clinical attachment gain, with reduced morbidity and favourable patient-centred outcomes over 12 months.[69] Long-term follow-up studies support these findings: a 5-year evaluation of Er:YAG-assisted periodontal surgery showed stable improvements in clinical attachment levels (CALs) and reduced PDs, confirming the durability of laser-assisted approaches.[70] A systematic review and meta-analysis further concluded that laser-assisted open flap debridement yields greater improvements in periodontal parameters compared with conventional methods, although heterogeneity in protocols remains a limitation.[71]

Beyond regenerative procedures, lasers are increasingly used in mucogingival and aesthetic surgery. For instance, a randomized controlled clinical study comparing CO_2 lasers with conventional scalpels in lip repositioning for excessive gingival display reported effective and predictable outcomes with reduced intraoperative bleeding and postoperative discomfort.[72] Systematic reviews also indicate that erbium laser–assisted crown lengthening, whether flapless or flap-based, provides comparable clinical results to conventional surgery, while improving haemostasis and patient comfort.[73] Collectively, evidence supports erbium and CO_2 lasers as valuable adjuncts in regenerative and aesthetic periodontal surgery, complementing established protocols such as guided tissue regeneration.[74]

Beyond periodontal applications, erbium lasers are also used in bone remodelling and oral-maxillofacial procedures. Their ability to ablate both soft tissue and bone with minimal thermal necrosis offers an advantage in reshaping alveolar bone, sinus floor elevation, or managing osseous defects. Early reports also indicate utility in managing medication-related osteonecrosis of the jaws, where early laser-assisted surgical management achieved favourable healing and symptom control.[75,76] In oral surgery, erbium lasers have been applied to third molar removal. A meta-analysis found that their use significantly reduced postoperative pain, oedema, and trismus compared with conventional rotary methods,[77] while recent guidance stresses the importance of minimally invasive technologies – including lasers – for safer and more predictable outcomes in third molar surgery.[78] Taken together, these data highlight erbium laser systems, particularly in QSP mode, as precise and minimally invasive tools for crown lengthening, open flap surgery, bone remodelling, and dentoalveolar procedures.[69,71,77,78]

Periodontitis and periimplantitis therapy

Periodontitis and peri-implantitis are chronic inflammatory diseases of microbial origin, but they affect distinct anatomical structures. Both conditions are characterized by progressive loss of supporting tissues, which, if untreated, ultimately leads to tooth or implant loss.[79] Periodontitis is initiated by dysbiotic bacterial biofilm, and its progression is largely determined by the host immune-inflammatory response. Overproduction of proinflammatory cytokines (IL-1β, TNF-α), increased oxidative stress, and imbalance in the RANKL/OPG pathway accelerate tissue destruction and alveolar bone resorption.[80,81] Peri-implantitis, although also triggered by biofilm, is strongly influenced by implant-related local factors such as surface roughness, corrosion by products (eg, titanium particles), prosthetic design, and reduced width of keratinized mucosa.[82] According to the BIND (Biofilm-Mediated Inflammation and Bone Dysregulation) model, peri-implantitis develops when the balance between biofilm control, immune regulation, and bone remodelling is disrupted, leading to progressive bone loss and soft tissue inflammation.[80,83]

Periodontitis is among the most prevalent chronic diseases globally, affecting up to 50% of adults to varying degrees,[84] whereas peri-implantitis affects between 8.9% and 45% of implant patients, with prevalence strongly dependent on diagnostic thresholds and the population studied.[85-87] For periodontitis, SRP remains the cornerstone on nonsurgical treatment. Adjunctive use of Er:YAG and Er,Cr:YSGG lasers have shown comparable or superior outcomes to SRP alone in reducing PD, improving CAL, and decreasing bleeding on probing, especially in deep pockets (≥7 mm) and in systemically compromised patients.[88-90] Randomized controlled trials have also demonstrated immunomodulatory effects of erbium lasers, including increased IL-10 and decreased MMP-13 levels.[91] Systematic reviews confirm noninferiority or even superiority of Er:YAG-assisted therapy compared to minimally invasive surgical techniques, with the additional benefit of improved patient comfort,[92] and LANAP (Laser-Assisted New Attachment Procedure) has been validated as a regenerative approach with both histologic and clinical evidence.[89]

In peri-implantitis, conventional mechanical decontamination methods show limited efficacy on rough implant surfaces.[93] Er:YAG lasers effectively remove biofilm and calculus without damaging titanium implant surfaces, with clinical studies reporting improvements in PD and CAL.[92] Nd:YAG lasers offering deeper soft tissue penetration, coagulation, and host-modulating properties, are often employed in combination protocols.[88,94,95] Diode lasers and antimicrobial photodynamic therapy (aPDT) provide additional antimicrobial effects and have demonstrated clinical benefit as adjunctive methods.[96-98] Nevertheless, considerable heterogeneity in laser parameters (wavelength, power setting, exposure duration, number of treatment sessions) hinders the development of standardized treatment guidelines.[99,100] Structurally, teeth benefit from a periodontal ligament and robust vascular supply, whereas implants lack these features, leading to faster disease progression and reduced healing potential in peri-implantitis.[85,101] Consequently, mechanical therapy alone is often sufficient in periodontitis, while peri-implantitis usually requires adjunctive approaches such erbium, Nd:YAG lasers or aPDT to achieve effective decontamination.[99,102,103] Overall, current evidence supports the use of lasers as adjuncts – rather than replacements – for mechanical therapy in both periodontitis and peri-implantitis, with greatest benefits observed in deep, complex defects and in patients with compromised healing capacity.

Laser based on photobiological interactions

Photobiomodulation

PBM, formerly referred to as low-level laser therapy, is an emerging adjunctive modality in dentistry that uses low-power red (630-700 nm), near-infrared (780-1100 nm), and, in specific applications, blue light (400-470 nm) to stimulate cellular activity, modulate inflammation, and support antimicrobial effects.[104]

The primary photoacceptor for red and near-infrared light is cytochrome c oxidase in the mitochondrial respiratory chain. Absorption of photons enhances ATP production, modulation of reactive oxygen species (ROS), release of nitric oxide and triggers nitric oxide release (↓IL-1β, ↓TNF-α, ↑TGF-β, ↑IL-10). These events regulate the balance of pro- and anti-inflammatory cytokines, promoting tissue repair through enhanced fibroblast and osteoblast activity, angiogenesis, and collagen synthesis.[104,105] In contrast, blue light (400-470 nm) primarily interacts with flavoproteins and bacterial porphyrins, producing singlet oxygen and ROS. This mechanism contributes to antimicrobial effects against cariogenic and periodontal pathogens and is increasingly explored in biofilm reduction protocols and as an adjunct in PDT.[106]

PBM has been successfully used in oral surgery, where it has shown significant benefits in pain reduction and wound healing after surgical procedures. Randomized clinical trials in paediatric extractions and third-molar surgery have shown that PBM (typically 660-980 nm) improves socket epithelialization, reduces pain and swelling, and enhances functional recovery.[107,108] PBM also accelerates bone remodelling by upregulating osteogenic markers such as osteocalcin and Runx2 and by increasing trabecular bone density. Systematic reviews confirmed that GaAlAs lasers in the near-infrared spectrum (808-980 nm) promote angiogenesis, osteoblast proliferation, and early bone maturation.[104,109] Clinical data further demonstrated improved alveolar bone preservation after tooth extraction when PBM is combined with erbium and Nd:YAG lasers,[110] as well as better peri-implant soft-tissue healing and primary stability following implant placement.[111,112]

A recent systematic review of 18 randomized controlled trials (771 patients) reported that PBM (660-810 nm, 3-12 J/cm^2) reduced postoperative pain by 30% to 55%, accelerated re-epithelialization, decreased proinflammatory cytokines (TNF-α, IL-6), and increased VEGF expression, leading to better vascularization and fewer complications such as wound dehiscence and infections.[106] PBM is therefore a safe, noninvasive, and effective supportive therapy in dentistry, especially in oral surgery, implantology, paediatric dentistry, and periodontology. The strongest evidence supports its use in reducing pain and accelerating wound and bone healing. However, heterogeneity in applied parameters highlights the need for standardized protocols, with the most effective outcomes reported for 660 to 810 nm, 3 to 12 J/cm^2, applied in multiple sessions.[104,106,109]

Photodynamic therapy

PDT, also termed aPDT, combines a photosensitizer (PS), a specific wavelength of light, and oxygen to generate ROS that destroy microbial cells. The most widely used PS in dentistry are phenothiazine derivatives such as methylene blue and toluidine blue O (absorption peaks 630-660 nm), as well as indocyanine green (peak absorption ~805-810 nm).[113,114] Upon light activation, the PS shifts to an excited triplet state, transferring energy to oxygen molecules via Type I (free radical) or Type II (singlet oxygen) reactions. This results in oxidative damage to bacterial membranes, proteins, and nucleic acids, leading to cell death.[113]

In nonsurgical periodontology, PDT has been extensively studied as an adjunct to SRP. Evidence shows that it can significantly reduce periodontal pathogens such as *Aggregatibacter actinomycetemcomitans*, *Porphyromonas gingivalis*, and *Tannerella forsythia*, with multiple PDT applications after SRP lading to greater reductions in bleeding on probing and microbial load compared to SRP alone.[115] Systematic reviews report that PDT provides additional short-term benefits in PD reduction and clinical attachment gain, particularly in residual or deep periodontal pockets and in systemically compromised patients.[116,117] PDT has also been evaluated for peri-implantitis, endodontic infections, and halitosis, for example in edentulous elderly denture wearers, PDT of the tongue significantly reduced hydrogen sulphide levels and maintained normal breath for up to 7 days, outperforming tongue scraping.[118]

Beyond periodontal therapy, PDT has been investigated in oral lichen planus and oral candidiasis. Randomized controlled trials using methylene blue or 5-ALA have shown significant reductions in oral lichen planus lesion size and symptoms, with outcomes comparable or superior to topical corticosteroids, and split-mouth designs report higher remission rates with PDT.[119,121] PDT appears to downregulate inflammatory mediators and modulate local immune responses, supporting lesion resolution.[122] In denture-related stomatitis, PDT has demonstrated antifungal efficacy through direct damage to *Candida* biofilms, and can be more effective than nystatin in preventing recurrence, with outcomes comparable to fluconazole; combination protocols with antifungal agents show synergistic effects.[123,124] Overall, PDT is a safe, minimally invasive adjunct that avoids antibiotic-resistance issues and can be repeated without cumulative toxicity. Its strongest evidence supports use in residual periodontal pockets, systemically compromised patients, halitosis in denture wearers, and selected oral mucosal diseases, although standardized protocols and long-term multicentre trials are still needed.[114,115,117,119-124]

Education and safety

The safe and effective use of lasers in dentistry requires structured education, clinical training, and continuous professional development. Clinical outcomes and patient safety are strongly dependent on the operator's understanding of laser-tissue interactions (photothermal, photomechanical, photochemical, and photobiomodulatory) and on appropriate wavelength selection for the target tissue, for example Er:YAG for hard tissues, Nd:YAG or diode lasers for pigmented soft tissues, PBM in the red or near-infrared range, and PDT with specific photosensitizers. Key energy parameters such as power, fluence, pulse duration, and frequency must be carefully controlled, since inappropriate settings may reduce efficacy or cause tissue damage. Professional bodies such as the World Association for Laser Therapy (WALT), the American Dental Association (ADA), the American Academy of Pediatric Dentistry (AAPD), the Australian Dental Association (ADA Australia), the World Dental Federation (FDI), and the World Health Organization (WHO) emphasize that only practitioners with certified training should incorporate lasers into routine clinical care, and that training should include both didactic education in physics, tissue optics, and safety, as well as supervised hands-on practice.[125-129]

Laser safety aims to minimize risks for both patients and operators and relies on several essential measures. Protective eyewear is mandatory for all individuals in the operatory, with filters specific to the wavelength of the laser in use. The clinical environment must be controlled through clear signage ('laser in use'), restricted access to treatment rooms, and elimination of reflective surfaces. Safe equipment handling requires regular calibration and maintenance as well as the use of manufacturer-approved settings and accessories, including fibres, tips, and handpieces. Smoke evacuation systems are recommended to reduce inhalation of laser plume, which may contain viral or bacterial particles. Tissue cooling is particularly important with hard-tissue lasers such as Er:YAG or Er,Cr:YSGG to avoid thermal injury. Finally, accurate documentation of treatment parameters, including exposure time and treatment sites, must be included in the patient record.[125] High-power lasers (CO_2, Nd:YAG, Er:YAG, Er,Cr:YSGG, high-power diodes) carry the greatest risk of thermal necrosis, carbonization, and potential damage to pulp or bone if applied improperly, whereas PBM devices are generally safe but require attention to dose to avoid the biphasic response in which excessively high doses inhibit cellular activity or become cytotoxic. In PDT and aPDT, most risks relate to photosensitizers, which may cause transient staining, photosensitivity, or rare allergic reactions.[125-128]

Clinical and ethical aspects are equally important in the integration of lasers into dental practice. Patients must provide informed consent after clear explanation of potential benefits, risks, and alternatives. The use of lasers should remain evidence-based and aligned with current guidelines, avoiding overstatement of benefits. Special attention is required when treating vulnerable groups such as pregnant women, immunocompromised individuals, or oncology patients; although PBM is generally regarded as safe in oncology, its use should follow the latest evidence and careful clinical judgment. Ongoing professional education, including workshops and review of updated protocols, is essential to keep pace with rapid technological developments.[125,126] With certified training, adherence to international guidelines, and rigorous safety measures, lasers can be integrated as powerful, safe, and patient-friendly tools in modern dentistry.[125,129]

Relevance to the FDI policy statement

The findings summarized in this review align with the key recommendations of the FDI Policy Statement: Lasers in Dentistry, which advocates for evidence-based, safe, and appropriately trained use of laser technologies in clinical practice. By reflecting these principles – particularly those related to education, safety, and responsible clinical application – this overview supports global harmonization of laser dentistry and reinforces the importance of integrating policy guidance with scientific evidence to promote effective, predictable, and patient-centred outcomes.

Author contributions

K.G.-L.: the conception and design of the study, or acquisition of data, or analysis and interpretation of data, drafting the article or revising it critically for important intellectual content, final approval of the version to be submitted.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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