Light-based technologies in dentistry: Biophotonic principles and clinical integration (Review)

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Received May 15, 2026; Accepted July 9, 2026

DOI: 10.3892/wasj.2026.497

Abstract. Biophotonics has emerged as a transformative interdisciplinary field that integrates optical science with biological systems to enhance diagnostic and therapeutic capabilities in dentistry. Conventional diagnostic methods often detect oral diseases at advanced stages, whereas biophotonic technologies enable real-time, non-invasive and high-resolution assessments at the molecular and cellular levels. The present narrative review provides a comprehensive overview of the fundamental principles of light-tissue interactions and their clinical translation in dentistry. Key biophotonic modalities, including fluorescence imaging, optical coherence tomography, Raman spectroscopy, laser-based therapies, photodynamic therapy and photobiomodulation, are discussed with respect to their mechanisms, applications, advantages and limitations. The present review further discusses their roles across major dental specialties, such as periodontology, endodontics, restorative dentistry, orthodontics, paediatric dentistry and oral oncology. Recent advancements highlight the integration of artificial intelligence, nanotechnology and multimodal imaging systems, enabling improved diagnostic accuracy, targeted therapy and personalized treatment planning. Despite these advantages, challenges, such as limited tissue penetration, high costs, the lack of standardization, and regulatory constraints continue to restrict widespread clinical adoption. Biophotonics represents a paradigm shift toward minimally invasive, precision-based dentistry. Continued research, technological innovation and clinical validation are essential to facilitate its transition into routine dental practice and to improve overall oral healthcare outcomes.

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Key words: biophotonics, dentistry, photodynamic therapy, laser dentistry, fluorescence imaging, oral diagnostics, minimally invasive dentistry

Contents

1. Introduction

Dentistry has undergone substantial technological advancement, leading to the development of innovative diagnostic and therapeutic approaches. Biophotonics has emerged as an interdisciplinary field that integrates optical science with biological systems to facilitate the detection, monitoring and treatment of disease. Biophotonics technologies enable non-invasive imaging, molecular characterization and targeted therapeutic interventions at cellular and tissue levels. They provide significant advantages over conventional approaches by providing real-time information, enhanced precision and reduced patient morbidity (1,2). Traditionally, oral diseases such as caries, periodontitis, peri-implantitis, oral lichen planus and oral cancer have been viewed primarily as a function of bacterial plaque, the host immune response, and changes in the structure of the enamel, dentin, periodontium and mucosa (1). Endodontic assistance primarily involves a somewhat visual-tactile examination via visual-tactile means, radiographs and histopathology or tissue examination; however, these methods usually only identify the pathology after it has progressed to an advanced stage. Although therapeutic interventions may be effective, they often involve invasive procedures, radiation exposure or a long period of recovery once an individual has undergone treatment. Biophotonics achieves these goals, however, by using the properties of light-matter interactions to provide for real-time, specific molecular (diagnosing and/or treating) therapies without radiation (3).

Using various photochemical, photothermal, photomechanical and photoionization effects, rapid, sensitive, specific, low-cost and non-invasive methods have been developed. The development of biophotonics has its roots in Einstein's theory of photons and the first ruby laser in 1960, which was introduced into dentistry for early hard-tissue research in 1964 (4). The challenge of thermal injury from CO_2 lasers was overcome by the introduction of short-pulsed infrared systems using Er:YAG (2.94 μm) and Er,Cr:YSGG (2.78 μm) laser configurations in the 1980s and 1990s, which allowed for very precise ablation and minimal collateral damage (5,6).

Recent advances in biophotonics have expanded the scope of dental diagnostics and therapeutics by enabling the improved visualization of tissue changes, enhanced microbial detection and more targeted treatment strategies. The synergistic association emerging between biophotonics and artificial intelligence (AI), quantum-enhanced imaging and advanced nanomaterials also enhances the likelihood that biophotonics will enable predictive, personalized and preventative oral healthcare solutions (7). While there have been some established advances in biophotonics, it continues to face a number of the same challenges that it has historically faced, e.g., limited penetration depth into highly scattering tissues, high costs associated with biophotonics devices, biophotonics device dependency and regulatory barriers regarding newly developed biophotonics devices (8). These deficiencies in future progress emphasize the need for increased research, standardization and translational efforts across the spectrum of oral healthcare, particularly in economically disadvantaged communities/areas where equal access is a priority.

The aim of the present narrative review was to provide a broad overview through a discussion of the core ideas, present-day practices, diagnosis and treatment methods, and the clinical relevance. The present review seeks to connect current science with future prospects in terms of progress in photonics-based precision oral healthcare that will be non-invasive, patient-centred and accessible to all.

2. Literature search methods

A well-structured search of the existing literature was carried out across the PubMed, Scopus, Web of Science and Google Scholar databases. The search strategy used combinations of the following key words: Biophotonic dentistry, optical coherence tomography (OCT), Biophotonic laser therapy for periodontitis, photodynamic therapy (PDT) for oral cancer, Raman spectroscopy for dental caries, nanobioscience/mechanics in Biophotonic dentistry, AI in dental imaging, and nanomaterials (2000-2026). The search results included clinical trials/observational studies/molecular-level studies/reviews/market reports; editorials/non-peer-reviewed materials/irrelevant articles were excluded. The titles and abstracts were independently screened by two authors (ST. and SUN), followed by full-text assessments. Data extraction focused on biophotonic mechanisms, diagnostic applications, therapeutic modalities, clinical outcomes, emerging technologies and translational implications in dentistry.

3. Evolution and classification of biophotonics

In 1964, biophotonics made their way into the field of dentistry with hard tissue studies (4,6). Early CO_2 lasers caused the carbonization of hard tissues and were replaced by short-pulsed infrared systems (Er:YAG 2.94 μm, Er,Cr:YSGG 2.78 μm) in the 1980s and early 1990s due to the improved ability to perform precise ablative procedures (5,6).

The modern classification system categorizes biophotonics based on their methods of interaction (photochemical, photothermal, photomechanical and photoionization) and on their wavelength (visible=400-700 nm; near-infrared therapeutic window) (3).

Biophotonics can be further divided into three categories: Bioimaging, biosensing and photonic therapy, all of which are particularly relevant to both periodontal and restorative treatment in dentistry (1,2).

4. Biophotonic components, light-tissue interactions and host responses

Biophotonic systems in dentistry employ light-based technologies, such as lasers and light-emitting diodes (LEDs) together with optical delivery and detection units to interact with oral tissues (3). Following exposure to biological tissues, light may undergo absorption, scattering, reflection, or fluorescence depending on the optical characteristics of the target site. These interactions produce various photonic effects, including photochemical, photothermal, photomechanical, and photoionization responses, which form the basis of several modern diagnostic and therapeutic dental applications (3,7).

As illustrated in Fig. 1, light-induced tissue interactions can trigger multiple cellular and molecular responses, including reactive oxygen species (ROS) formation, enhanced mitochondrial activity, fibroblast proliferation, collagen remodelling and antimicrobial effects. Collectively, these biological responses contribute to improved wound healing, periodontal regeneration, osseointegration, inflammation control and minimally invasive management of oral diseases Fig. 1 illustrates the fundamental principles of light-tissue interactions that underpin biophotonic applications in dentistry. When light from lasers or LEDs is transmitted to oral tissues by optical systems, it undergoes absorption, scattering, reflection, and fluorescence depending on composition of tissues and optical properties (3). These interactions lead to various biological effects, such as photochemical, photothermal, photomechanical and photobiomodulatory, which form basis of several diagnostic and therapeutic modalities (3,9). Clinically, these mechanisms help in antimicrobial activity, inflammation control, wound healing, periodontal regeneration and enhanced osseointegration. Fig. 1 highlights how a single optical stimulus can generate distinct biological responses depending on wavelength, energy density, and tissue characteristics, thereby enabling diverse applications across multiple dental specialties (9,10).

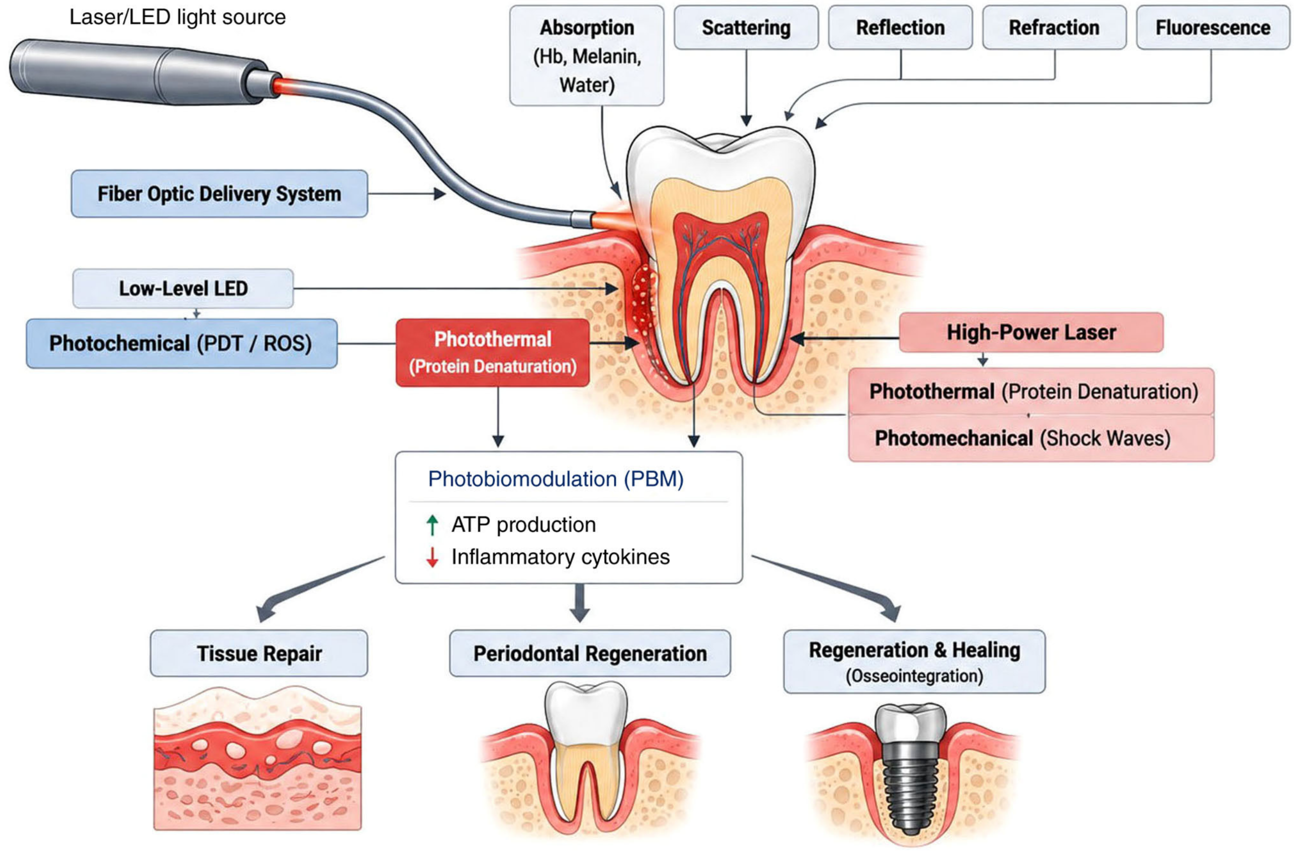

Figure 1. Mechanisms of light-tissue interaction and host responses in dental biophotonics. LED, light-emitting diode; PDT, photodynamic therapy; ROS, reactive oxygen species.

5. Biophotonic modalities: Mechanisms, dental implications and clinical translation

Clinically, dentistry is being transformed through biophotonics by bringing cutting-edge light science into an integrated system of detection, treatment and management of oral diseases (7). Imaging techniques, such as fluorescence imaging use autofluorescence to visualize early caries, demineralization and oral cancer so that these conditions can be managed with minimal invasiveness (11-13).

OCT provides 'optical biopsy' capabilities with a resolution between 5 and 15 μm to diagnose internal defects, cracks and bone loss (14). Molecular specificity is achieved using Raman spectroscopy to analyse biofilm and mineral content. Lasers (Er:YAG, diode, Nd:YAG, and CO_2) allow for precision ablation for soft tissue surgery and decontamination with haemostasis. PDT generates ROS to kill bacteria/viruses and to provide targeted anticancer therapy (15).

Photobiomodulation (PBM) enhances mitochondrial activity to accelerate healing, alleviate pain and facilitate osseointegration (9). The majority of these technologies will not be used in isolation; therefore, multimodal combinations will become the norm (e.g., fluorescence-guided PDT and OCT-monitored laser therapy), as they reflect care that is centred on the patient. A comparative overview of major biophotonic modalities, including their mechanisms and clinical implications, is presented in Table I. To contextualize the clinical value of the modalities summarized in Tables I, II provides a comparative analysis with traditional approaches commonly used in dentistry. This highlights potential of biophotonics to overcome key limitations of conventional methods.

6. Biophotonics applications across major branches of dentistry

Management of periodontology and peri-implant disease. Er:YAG and diode lasers provide the selective ablation of inflamed tissue and bacterial decontamination with excellent haemostasis (10,16). PDT, which uses photosensitizers activated by red/near-infrared light, generates ROS to eliminate persistent pathogens in deep pockets (17,18). PBM enhances mitochondrial function, reduces the levels of pro-inflammatory cytokines and accelerates fibroblast activity to improve attachment gain and osseointegration (19). OCT and fluorescence imaging enable the real-time monitoring of bone loss and pocket depth without radiation (20). Although these technologies have demonstrated promising clinical outcomes, variability in treatment protocols and limited long-term evidence continue to restrict widespread standardization and adoption.

Endodontics. OCT can be used to obtain high-resolution, radiation-free 'optical biopsies' to map complex anatomy, detect microcracks and assess apical pathology or restoration integrity (14,21). Laser-assisted irrigation (e.g., Er,Cr:YSGG) and PDT improve biofilm disruption and bacterial reduction in

Table I. Core biophotonic modalities in dentistry (10,50).

Modality	Mechanism	Primary dental applications	Clinical advantages	Main limitations
Fluorescence Imaging	Autofluorescence	Early caries, oral cancer screening	Rapid, non-invasive	Surface-limited
OCT	Interferometry	Restoration/root canal assessment, bone loss	High-resolution, radiation-free	Cost, equipment size
Raman Spectroscopy	Vibrational scattering	Biofilm/mineral analysis	Molecular specificity	Signal weakness, time
Lasers (Er:YAG, diode, etc.)	Photothermal ablation	Caries removal, soft-tissue surgery, decontamination	Precision, haemostasis	Learning curve, thermal risk
PDT	ROS generation	Antimicrobial, anticancer	Targeted, antibiotic-sparing	Photosensitizer side-effects
PBM	Mitochondrial stimulation	Pain relief, healing acceleration	Non-invasive, safe	Dose optimization needed

The modalities summarized in the table demonstrate that biophotonic technologies can provide complementary diagnostic and therapeutic capabilities that are difficult to achieve using conventional approaches alone. While OCT and fluorescence imaging support early disease detection, therapeutic modalities, such as PDT and PBM facilitate minimally invasive management and tissue regeneration. However, variability in clinical protocols and equipment costs continue to limit widespread implementation, highlighting the need for standardized clinical guidelines and further validation studies. OCT, optical coherence tomography; PDT, photodynamic therapy; PBM, photobiomodulation.

dentinal tubules (22,23). PBM promotes periapical healing and reduces post-treatment pain through enhanced cellular energy production. However, the complete and predictable disinfection of complex root canal systems remains challenging, and the additional clinical benefit of adjunctive biophotonic therapies over conventional chemomechanical preparation remains a subject of ongoing investigation (24,25).

Restorative and aesthetic dentistry. Fluorescent imaging and Raman spectroscopy are useful in identifying early caries, demineralization and biofilm composition at the molecular level, which play a critical role in the minimally invasive treatment of diseases (11,26). Er:YAG lasers provide selective caries removal with minimum damage to hard dental tissues while improving the marginal adaptation (27). Bleaching activated by laser accelerates whitening, while reducing sensitivity. OCT provides information about the restoration interfaces and secondary caries without intrusive probe placement. The advantages include the comfort of the patient and the conservation of healthy tooth structure (28). However, the interpretation of optical signals is subject to numerous factors, for example the type of the tooth, any discolorations present, as well as the type of material used (28,29).

Orthodontics. Biophotonics primarily supports adjunctive pain control and tissue remodelling during tooth movement. Low-level PBM (using diode lasers or LEDs in the red/near-infrared range) modulates cytokine release to accelerate alignment and intrusion, while alleviating discomfort following arch wire changes or separator placement (30). Orthodontically induced root resorption may be reduced by implementing more effective treatment techniques (e.g., 850 nm or greater light wavelength and adequate fluence) (31). However, the reported effects of PBM on the rate of orthodontic tooth movement remain inconsistent across studies. While some clinical studies have reported accelerated alignment and reduced treatment duration following PBM application, others have found minimal or no significant effect on tooth movement. These discrepancies have been attributed to differences in wavelength selection, energy density, irradiation protocols, treatment frequency, and study methodologies (28-30).

Paediatric dentistry. Child-friendly, minimally invasive techniques are paramount, and biophotonics aligns well by reducing fear, anaesthesia needs and trauma. PDT provides effective antimicrobial action against caries pathogens and in pulp therapy without generating resistance (15,32). Lasers (e.g., Er:YAG for the removal of caries and soft-tissue procedures, such as frenectomy) provide painless, bloodless interventions (27,33). Fluorescence aids the screening of early caries in uncooperative children (11,12). PBM controls post procedure inflammation and pain. These methods support the preservation of primary teeth and behaviour management, with clinical reports showing good outcomes in high-caries-risk or special-needs patients (25). However, despite these advantages, the evidence base in paediatric populations remains comparatively limited, and further well-designed clinical studies are required to establish standardized protocols and long-term safety outcomes.

Oral medicine, pathology and oncology. Biophotonics facilitates the non-invasive screening and targeted therapy for mucosal lesions and malignancies. Autofluorescence and OCT enable the early visualization of dysplasia, lichen planus,

Table II. Comparison between conventional dental approaches and biophotonic techniques, including their advantages and limitations (1,7,29).

Application/ specialty focus	Traditional approach	Biophotonic approach	Key advantages of biophotonics	Persistent challenges of biophotonics
Detection of early caries	Visual-tactile + bitewing radiographs	Fluorescence imaging/ QLF/Raman spectroscopy	Radiation-free, detects incipient lesions, guides remineralization	Surface-limited depth, operator variability
Periodontal/peri-implant decontamination and pocket management	Scaling and root planing ± systemic antibiotics	PDT/Er:YAG or diode lasers/PBM	Targeted ROS, antibiotic-sparing, enhanced pocket reduction and regeneration	Photosensitizer effects, parameter optimization needed
Root canal anatomy and disinfection	Radiographs + chemical irrigants	OCT 'optical biopsy'/ laser-assisted irrigation/PDT	High-resolution (5-15 μm), no radiation, improved tubule disinfection	Equipment cost/ size, limited deep access
Soft-tissue procedures (gingivectomy, frenectomy, biopsy)	Scalpel/electrosurgery	Diode/Nd:YAG/ Er:YAG/CO_2 lasers	Precision, haemostasis, reduced pain/ swelling/bleeding, faster healing	Thermal risk if misused, learning curve
Oral mucosal lesion/cancer screening and margins	Visual + incisional biopsy + histopathology	Autofluorescence/ OCT/Raman spectroscopy	Non-invasive early dysplasia detection, real-time molecular margins	Signal weakness (Raman), penetration in thick tissues
Post-surgical/ post-procedure healing and pain management	Analgesics, anti-inflammatories	Photobiomodulation (PBM)	Mitochondrial ATP boost, cytokine reduction, accelerated regeneration	Dose/protocol variability
Restorative cavity preparation and bleaching	Mechanical burs/ chemical bleaching	Er:YAG/Er,Cr YSGG lasers/laser-activated bleaching	Selective ablation, no vibration/noise, better adaptation, reduced sensitivity	Slower speed in bulk removal, higher device cost
Overall accessibility and economics	Low initial cost, widespread availability	High upfront device and training cost	Potential long-term savings (fewer complications/ retreatments)	Limited adoption in LMICs/ resource poor settings

Compared with conventional approaches, biophotonic technologies offer substantial advantages including earlier disease detection, reduced invasiveness, improved patient comfort, and enhanced therapeutic precision. However, these benefits must be balanced against challenges such as equipment costs, operator training requirements, limited accessibility, and variability in clinical protocols. Future cost-effectiveness studies and multicentre clinical trials are necessary before widespread implementation can be recommended. OCT, optical coherence tomography; PDT, photodynamic therapy; PBM, photobiomodulation.

or cancer margins (13,34). Raman spectroscopy provides molecular fingerprinting of suspicious tissues (35). PDT results in the selective destruction of precancerous/cancerous cells and resistant biofilms with minimal collateral damage (36,37). PBM is guideline-recommended for preventing radiation-induced oral mucositis. This branch benefits from high diagnostic specificity and antibiotic-sparing effects (38). However, despite encouraging diagnostic performance reported in a number of studies (33-35), histopathological examination remains the gold standard for definitive diagnosis, and further large-scale clinical validation is required prior to widespread clinical adoption.

7. Emerging biophotonic technologies in oral health

The introduction of AI provides real-time decision support for data analysis, while deep learning enables the use of

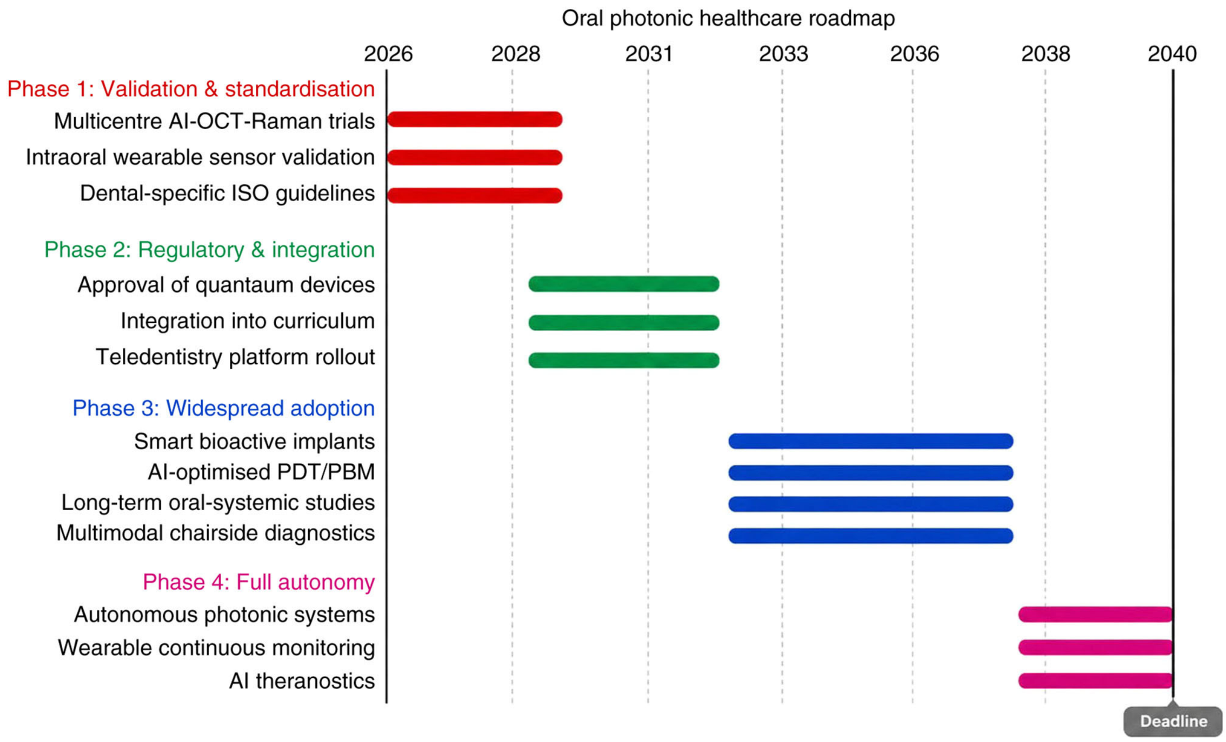

Figure 2. Emerging biophotonic technologies and future directions in dentistry, including integration of AI, nanotechnology, multimodal imaging, and personalized therapeutic approaches. AI, artificial intelligence; OCT, optical coherence tomography; PDT, photodynamic therapy; PBM, photobiomodulation.

fluorescence/OCT/Raman spectra to estimate caries development and oral cancer outer limits with >95% specificity (7,39).

Multimodal AI will allow for capable explainable diagnostics in the oral health field (39). With the ability of AI to evaluate hyperspectral imaging modalities, risk categorization for periodontitis/peri-implantitis can be performed chair-side and thereby improved for high-risk patients. Data privacy and bias are challenges, but federated learning can help expedite the use of AI (39,40).

The application of quantum biophotonics allows for subshot-noise sensitivity and deeper penetration. The use of entangled photons may allow clinicians to achieve subcellular resolution in periodontal tissues or identify malignancies earlier than previously possible. NIR-II quantum dots allow for toxicity-free imaging of cm-scale bone regeneration via non-invasive imaging; thus, preclinical studies may support the use of optical biopsy as a diagnostic tool. Nanomaterials are expected to improve targeted therapies (41).

MXenes and upconverting nanoparticles can be used for PDT in deep pockets. Biomaterial scaffolds are biodegradable and promote regenerative processes, while allowing for monitoring (42). Graphene (hybrid) nanomaterials can also be used to create bioactive, light-activated (through antibacterial processes) implants. Intraoral SERS patch devices can be used to continuously monitor the presence of biomarkers in a patient, while also providing real-time monitoring. In summary, dentists can use combination platforms (OCT + Raman + photoacoustic), as well as other wearable tele-dentistry devices (43,44).

These align with the biophotonics roadmap, emphasizing label-free specificity and scalability, although costs and regulation remain hurdles.

8. Future directions

Light is evolving from a diagnostic tool to a therapeutic precision instrument, necessitating a paradigm shift. Future research needs to prioritize the following: i) The application of non-invasive photonic biomarkers (i.e., salivary OCT/Raman assays) for use on the chair-side, risk assessments and the longitudinal tracking of the progression of chronic periodontal disease and the recurrence of oral cancer (44-46). ii) Integrating omics (photonic, metagenomic and AI) to map the virome-bacteriome present within periodontal lesions (1). iii) The development of novel theranostics (quantum dots, MXene nanoparticles and CRISPR-directed photonic activation for use in PDT and photobiomodulation) that allow for precision PDT/PBM application in periodontal pockets and/or peri-implant sites with the instant release of therapeutic agents (3,43). iv) Utilizing wearable intraoral sensors and teledentistry to provide personalized care in real-time, especially for underserved populations (44). v) Conducting standardized clinical trials and developing regulatory pathways for quantum and AI biophotonic devices to be translated into routine clinical practice expeditiously.

Proposed roadmap for clinical translation (2030-2040). The following roadmap represents a conceptual and forward-looking framework based on current technological trends and emerging research directions. It should not be interpreted as a definitive prediction of future clinical adoption timelines: i) 2026-2028: Multicentre validation trials of AI-OCT-Raman systems, intraoral wearable sensors and the development of dental-specific standardization guidelines. ii) 2029-2032: Regulatory approval of quantum-enhanced and nanomaterial devices; integration into dental school and teledentistry. iii) 2033-2037: Widespread adoption of smart implants and AI-optimized PBM/PDT along with long-term outcome studies linking oral photonic monitoring to systemic health. iv) 2038-2040: Fully autonomous photonic systems for predictive oral healthcare along global equitable access programmes.

The integration of AI, nanotechnology and advanced multimodal imaging systems in biophotonics is illustrated in Fig. 2. Fig. 2 presents a conceptual roadmap for the future integration of emerging biophotonic technologies into dental practice. The proposed framework outlines a progressive transition from validation and standardization of advanced photonic systems to regulatory approval, widespread clinical adoption, and eventually autonomous photonic healthcare platforms. The roadmap highlights the anticipated role of artificial intelligence, multimodal imaging, nanotechnology-based therapeutics, smart bioactive implants, and wearable biosensors in supporting precision dentistry. These technologies have the potential to improve diagnostic accuracy, enable personalized treatment planning, and facilitate continuous monitoring of oral health. However, the projected timeline should be interpreted cautiously, as successful implementation will depend on clinical validation, cost-effectiveness, regulatory approval, ethical considerations, and long-term safety data.

9. Clinical integration, implementation and challenges

The first step towards the successful clinical development of biophotonic technologies is to demonstrate biological plausibility and validity of diagnosis. However, integration into practice does not depend only on technical performance, but also on clinician training, treatment protocols, reimbursement and regulation. Further analyses of cost-effectiveness are warranted to justify large-scale adoption (47).

Implementation in clinical practices continues to face various challenges. Chairside devices should be compatible with existing workflows so that the treatment time is not excessively increased. Moreover, these devices demand proper training so that the diagnostic output is well understood and interpreted by the practitioners. Furthermore, the high acquisition and maintenance costs of advanced modalities may restrict adoption, mainly in resource-constrained settings.

Additional challenges exist in rural and low-resource environments. The use of portable fluorescence-based diagnostic systems, teledentistry and simplified diagnostic procedures can make access easier and ensure the early detection of diseases of concern among vulnerable groups of individuals. In comparison with more advanced technologies, portable fluorescence devices may be a better option when it comes to application in low-resource environments, since they do not require too much investment in the infrastructure, and their use is relatively easy. The combination of portable fluorescence diagnostic systems with community dental health systems can perform early screening and referral actions in vulnerable groups of individuals (48).

Regulatory considerations are particularly critical for diagnostic systems assisted by AI and emerging multimodal imaging platforms, as they require rigorous validation of safety, reproducibility and clinical utility prior to routine use (40).

Educational preparedness represents an additional challenge. The use of biophotonic technologies is accompanied by the requirement of sufficient understanding of optical diagnostics, interpretation of images, as well as digital workflow. That is why it is reasonable to incorporate the educational program with these biophotonic technologies into dental studies. Moreover, variability in clinical protocols remains an issue, which requires standardization and multicenter validation. The effective utilization of biophotonic technologies requires competency in optical diagnostics, image interpretation and digital workflows, highlighting the need for integration into dental curricula and continuing professional education (49).

10. Conclusion

Technical advancements in biophotonics have expanded the understanding of diagnostics and treatment in dentistry beyond what is currently possible with standard techniques. Future enhancements using AI, quantum technology, intelligent nanomaterials and wearable devices will create precise preventive and person-specific treatment protocols for dental patients that will support their overall health and well-being. The roadmap provided in the present review addresses a number of the challenges that need to be overcome by the dental profession to accelerate the translation of biophotonics into clinical practice, improve the quality of care for patients and establish biophotonics as one of the cornerstones of dentistry in the 21st century. Additionally, the present review presents a timely, structured opportunity for dental researchers and practitioners to achieve this paradigm shift.

Acknowledgements

Not applicable.

Funding

No funding was received.

Availability of data and materials

Not applicable.

Authors' contributions

ST and SUN were involved in the conceptualization of the present review, as well as in data curation, in the literature search, the evaluation of studies from the literature for inclusion in the review, project administration, validation, visualization and in the writing of the original draft, and in the writing, reviewing and editing of the manuscript. ST, SUN, MM and SK were involved in the conceptualization of the present review, in data curation, investigation, in the literature search, in project administration, validation and study supervision. All authors have read and approved the final manuscript. Data authentication is not applicable.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Use of artificial intelligence tools

During the preparation of this work, AI tools (Rubriq) were used to improve the readability and language of the manuscript or to generate images, and subsequently, the authors revised and edited the content produced by the AI tools as necessary, taking full responsibility for the ultimate content of the present manuscript.

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