'Biophotonics' In Dentistry- A Long Way to Go. An Epigrammatic Review

Dr.Ch.Pallavi[1], Dr. B. Lakshmanarao[2], Dr.P.V.Vaibhav[3]
[1]*Senior Lecturer, Dept of Prosthodontics, Anil Neerukonda Institute of Dental Sciences; Visakhapatnam, A.P.*
[2]*Prof & Hod, Dept of Prosthodontics, Lenora Institute of Dental Sciences, Rajahmundry, A.P.*
[3]*Post Graduate Student, Dept of Prosthodontics, Lenora Institute of Dental Sciences, Rajahmundry, A.P.*
Corresponding Author: Dr. B. Lakshmanarao

Abstract - Biophotonics, the interdisciplinary field combining light-based technology with biological applications, has transformed modern dentistry by enabling minimally invasive diagnostics, precise treatments, and enhanced healing processes. The integration of lasers, fluorescence imaging, photodynamic therapy (PDT), and Photobiomodulation (PBM) has significantly improved dental procedures, patient comfort, and clinical outcomes. Photobiomodulation therapy (PBM), formerly known as Low-Level Laser Therapy (LLLT), has shown promising results in reducing postoperative pain, accelerating wound healing, and promoting tissue regeneration in periodontal and implant procedures. Additionally, fluorescence-guided biopsy and AI-assisted imaging systems are paving the way for early oral cancer detection and personalized treatment approaches.

This paper explores the various applications of Biophotonics in dentistry, including hard and soft tissue laser treatments, early caries detection, periodontal therapy, root canal disinfection, oral cancer diagnosis, and implantology. Technologies such as Er:YAG, Er,Cr:YSGG, Nd:YAG, diode, and CO_2 lasers are widely utilized for cavity preparation, soft tissue surgery, bacterial reduction, and bone regeneration. Fluorescence-based optical imaging enhances early detection of dental caries, oral cancer, and microbial infections, while PDT offers a non-invasive approach to eliminating pathogenic biofilms and malignant cells.

Keywords: Biophotonics, Laser Dentistry, Photobiomodulation, Photodynamic Therapy, Optical Imaging, Periodontal Therapy, Oral Cancer Detection, Regenerative Dentistry.

INTRODUCTION

Biophotonics is an interdisciplinary field that involves the study and application of light-based technologies to biological systems. It combines principles from physics, engineering, biology, and medicine to develop optical methods for imaging, detecting, and manipulating biological materials at molecular, cellular, and tissue levels.

Types of Biophotonics and Their Applications

Biophotonics can be classified based on its functional applications in biological and medical sciences. The major types include: [1,2]

1. Imaging Biophotonics

Utilizes optical techniques to visualize biological structures and functions at different scales, from molecules to organs. Key Techniques:

Fluorescence Microscopy – Uses fluorescent markers to image specific cellular components.

Confocal Microscopy – Enhances image resolution by using a spatial pinhole to eliminate out-of-focus light.

Multiphoton Microscopy (MPM) – Uses two-photon excitation for deep-tissue imaging.

Optical Coherence Tomography (OCT) – A non-invasive imaging method used in ophthalmology and dentistry.

Photoacoustic Imaging (PAI) – Combines laser-induced ultrasound for high-resolution imaging.

Applications: Cancer detection (fluorescence-based tumor identification)

2. Therapeutic Biophotonics

Uses light-based methods for medical treatments and interventions. Key Techniques:

Photodynamic Therapy (PDT) – Uses light-activated drugs to treat cancer and infections.

Laser Surgery & Tissue Ablation – Uses high-energy laser beams for precise surgical procedures.

Low-Level Laser Therapy (LLLT) – Stimulates cellular repair and reduces inflammation.

Applications:
Cancer treatment (PDT for skin and esophageal cancer); Laser-assisted dental procedures; Chronic pain relief (LLLT for musculoskeletal conditions) [3,4]

3. Biophotonics in Biosensing & Detection
Optical methods used for detecting and analyzing biological molecules and microorganisms. Key Techniques:
Surface Plasmon Resonance (SPR) – Detects molecular interactions in real time.
Raman Spectroscopy – Identifies chemical composition through light scattering.
Fluorescence-Based Biosensors – Uses fluorescence markers for detecting specific biomolecules.

Applications:
Early disease detection (SPR in medical diagnostics); Pathogen identification in food safety; Blood glucose monitoring in diabetes [5,6]

4. Neurobiophotonics
Optical techniques used to study and manipulate neural activities in the brain. Key Techniques:
Optogenetics – Uses genetically modified light-sensitive proteins to control neurons.
Two-Photon Microscopy – Enables deep-brain imaging with minimal damage.
Functional Near-Infrared Spectroscopy (fNIRS) – Measures brain activity through hemodynamic responses.

Applications:
Studying neurodegenerative diseases (Alzheimer's, Parkinson's); Brain-computer interfaces ;Understanding memory and behavior through optogenetics [7,8]

5. Environmental and Agricultural Biophotonics
Application of biophotonics in monitoring environmental conditions and agricultural processes. Key Techniques:
Hyperspectral Imaging – Captures data across multiple wavelengths to detect plant health.
Optical Sensors for Water Quality – Detects contaminants and microorganisms in water.
Laser-Induced Breakdown Spectroscopy (LIBS) – Analyzes soil composition through laser ablation.

Applications:
Monitoring crop diseases ; Assessing water contamination; Precision farming through optical sensors [9,10]
Biophotonics is a rapidly expanding field with applications in medicine, neuroscience, environmental science, and agriculture. The ongoing integration of AI, nanotechnology, and quantum photonics will further revolutionize its potential.

Applications of Biophotonics in Dentistry
Biophotonics is revolutionizing dentistry by providing advanced diagnostic, therapeutic, and surgical solutions. Optical technologies such as laser dentistry, optical coherence tomography (OCT), fluorescence imaging, and photodynamic therapy (PDT) have improved precision, minimized invasiveness, and enhanced treatment outcomes. Below is a detailed exploration of biophotonic applications in dentistry, along with references.

1. Optical Imaging in Dental Diagnostics
Biophotonics enables non-invasive and real-time imaging of dental tissues, allowing early detection of oral diseases.
A. Optical Coherence Tomography (OCT)
OCT provides high-resolution, cross-sectional imaging of dental tissues, helping in early detection of:
Caries (Tooth Decay): Detects enamel demineralization before it becomes clinically visible.
Periodontal Disease: Visualizes gingival and periodontal ligament changes.
Periapical Lesions: Assists in endodontic diagnosis.
Cracked Teeth: Identifies microfractures in enamel and dentin. [11,12]

B. Fluorescence-Based Diagnostics
Utilizes natural or induced fluorescence to detect:
Dental caries: Devices like DIAGNOdent (KaVo) use laser fluorescence to detect early lesions.
Oral cancers and precancerous lesions: Autofluorescence imaging helps identify malignant tissues.

Bacterial biofilms and plaque: Specific fluorescence wavelengths highlight microbial activity. [13,14]

2. Laser Dentistry for Hard and Soft Tissue Applications
Lasers are one of the most significant biophotonic advancements in dentistry.
A. Laser-Assisted Hard Tissue Applications
Caries Removal & Cavity Preparation: Er:YAG and Er,Cr:YSGG lasers remove decay and prepare cavities without requiring anesthesia.
Enamel and Dentin Surface Modification: Laser irradiation can enhance adhesion for restorations.
Tooth Whitening: Lasers activate bleaching agents for faster results with minimal sensitivity. [15]

B. Laser-Assisted Soft Tissue Applications
Periodontal Therapy: Lasers like Nd:YAG, Er:YAG, and diode lasers are used for:
Non-surgical gingival pocket decontamination
Gingivectomy and frenectomy
Accelerated wound healing
Oral Surgery: Laser frenectomy, biopsy, and excisions minimize bleeding and discomfort.
Treatment of Oral Lesions: Photobiomodulation helps in healing aphthous ulcers, herpes labialis, and mucositis. [16]

3. Photodynamic Therapy (PDT) in Dentistry
PDT is a minimally invasive approach using a photosensitizer, light, and oxygen to destroy harmful bacteria or cancerous cells.

Applications of PDT in Dentistry:
Periodontal Disease Treatment: PDT is effective in reducing periodontal pathogens in deep pockets.
Root Canal Disinfection: PDT ensures complete eradication of bacteria, preventing reinfection.
Oral Cancer Therapy: PDT selectively destroys malignant tissues while sparing healthy cells.
Treatment of Drug-Resistant Oral Infections: Effective against oral candidiasis, peri-implantitis, and biofilm-associated infections. [17,18]

4. Biophotonics in Prosthodontics and Restorative Dentistry
Biophotonic technologies improve accuracy, efficiency, and longevity of prosthetic and restorative treatments.

A. Digital Optical Impressions & CAD/CAM Integration
Optical scanners use biophotonics to take precise 3D impressions without traditional impression materials.
CAD/CAM systems ensure precise fabrication of crowns, bridges, and dentures.

B. Laser-Assisted Implantology
Peri-implantitis management: Lasers help in decontaminating implant surfaces.
Soft tissue management: Improves healing and aesthetics around implants.
Osseointegration enhancement: Certain lasers promote bone regeneration around implants. [19,20]

5. Biophotonics in Regenerative Dentistry
Light-based technologies enhance tissue healing and regeneration.
A. Photobiomodulation (PBM) Therapy
Accelerates wound healing after dental surgery.
Reduces pain and inflammation in TMJ disorders.
Stimulates bone healing in fractures and implants.

B. Stem Cell Activation for Dental Tissue Regeneration
Biophotonics plays a role in activating stem cells to regenerate dental pulp, bone, and periodontal tissue. [21,22]
Biophotonics is transforming dentistry by enhancing diagnostic accuracy, treatment effectiveness, and patient comfort. Technologies like OCT, fluorescence imaging, lasers, PDT, and photobiomodulation are increasingly used in preventive, restorative, prosthodontic, periodontal, and surgical dentistry. Continued research in AI-driven biophotonics, nanophotonics, and quantum optics will further revolutionize dental care.

Integration of Biophotonics Technologies in Various Dental Specialties
Biophotonics integrates advanced optical technologies into different fields of dentistry, improving diagnostics, treatment precision, and patient outcomes. Below is a detailed breakdown of key biophotonic technologies and their applications in different dental specialties, along with references.
1. Optical Coherence Tomography (OCT) in Dentistry

OCT is a non-invasive, high-resolution imaging technique that uses near-infrared light to produce cross-sectional images of dental tissues.
Applications in Dental Specialties
A. Endodontics
Detects root fractures and cracks before conventional radiographs.
Helps in pulpal vitality assessment without invasive tests.
Evaluates root canal morphology and treatment success.

B. Periodontology
Identifies early-stage periodontal disease by assessing gingival thickness and attachment loss.
Detects subgingival calculus and biofilm deposits.

C. Prosthodontics
Assesses marginal fit and adaptation of crowns, bridges, and veneers. Monitors implant osseointegration. [23]

2. Laser Technology in Dentistry
Lasers deliver highly focused light energy to cut, shape, or remove tissues with minimal pain and bleeding.
Applications in Dental Specialties
A. Restorative Dentistry & Operative Dentistry
Er:YAG and Er,Cr:YSGG lasers replace drills for caries removal and cavity preparation.
Enhances bonding and adhesion of restorative materials.

B. Periodontology
Nd:YAG and diode lasers perform gingival pocket disinfection and laser-assisted new attachment procedure (LANAP).
Used in gingivectomy and frenectomy with minimal bleeding.

C. Endodontics
Laser-activated irrigation (PIPS, SWEEPS) enhances root canal disinfection.
Helps in apicoectomy and periapical lesion management.

D. Oral & Maxillofacial Surgery
CO_2 and diode lasers are used for soft tissue excisions, biopsy, and frenectomy.
Lasers accelerate wound healing and reduce postoperative pain. [24]

3. Fluorescence-Based Imaging in Dentistry
Fluorescence-based devices detect changes in dental tissues and biofilms by analyzing their autofluorescence properties.
Applications in Dental Specialties
A. Caries Detection
DIAGNOdent (KaVo) and QLF (Quantitative Light Fluorescence) detect early demineralization.
Fluorescence imaging identifies secondary caries under restorations.

B. Oral Cancer Screening
VELscope (autofluorescence imaging) detects precancerous and malignant lesions in the oral mucosa.

C. Plaque & Biofilm Assessment
Fluorescent plaque disclosing solutions highlight bacterial accumulation.
Useful in periodontal maintenance therapy. [25]

4. Photodynamic Therapy (PDT) in Dentistry
PDT combines a photosensitizing agent, light source, and oxygen to selectively destroy bacteria and malignant cells.
Applications in Dental Specialties
A. Periodontology
Kills periodontal pathogens in deep pockets.
Alternative to antibiotics in periodontal therapy.

B. Endodontics
Disinfects root canals more effectively than conventional irrigation.
Helps in treating apical periodontitis.

C. Oral Medicine & Oral Oncology
Used for oral leukoplakia and early-stage squamous cell carcinoma.
Treats drug-resistant oral infections (candidiasis, peri-implantitis, biofilms). [26]

5. Biophotonics in Prosthodontics & Implant Dentistry
A. Optical Scanners & CAD/CAM Integration
Digital optical scanners create precise 3D impressions.
CAD/CAM technology improves fit and accuracy of restorations.

B. Laser-Assisted Implantology
Decontaminates implant surfaces to prevent peri-implantitis.
Promotes osseointegration and tissue healing.

C. Biophotonics in Denture & Material Evaluation
Optical methods assess biocompatibility and wear resistance of prosthetic materials. [27]

6. Photobiomodulation (PBM) Therapy in Dentistry
PBM uses low-level lasers (LLLT) or LEDs to stimulate cellular repair and reduce inflammation.
Applications in Dental Specialties
Pain relief in temporomandibular disorders (TMD).
Speeds healing in oral ulcers and post-extraction wounds.
Stimulates bone regeneration in periodontal and implant therapy. [28]

Biophotonics Therapy: Indications, Uses, and Applications
Biophotonics Therapy
Biophotonics therapy refers to the therapeutic application of light-based technologies in medicine and dentistry. It involves photodynamic therapy (PDT), photobiomodulation therapy (PBM), laser therapy, and fluorescence-guided treatments. These therapies modulate biological processes, reduce inflammation, stimulate tissue regeneration, and destroy pathogens or malignant cells.

Types of Biophotonics Therapy
A. Photobiomodulation Therapy (PBM) / Low-Level Laser Therapy (LLLT)
Uses low-power lasers or LEDs to stimulate cellular repair, reduce inflammation, and accelerate healing.
Works by modulating mitochondrial activity and enhancing ATP production.

B. Photodynamic Therapy (PDT)
Combines photosensitizing agents, light, and oxygen to destroy bacteria, cancer cells, or inflammatory tissues.
Produces reactive oxygen species (ROS) to kill pathogens selectively.

C. Laser Therapy
Uses high-energy focused light to perform surgical, therapeutic, and analgesic procedures.
Commonly used lasers: Nd:YAG, Er:YAG, Diode, CO_2, and Er,Cr:YSGG lasers.

D. Fluorescence-Guided Therapy
Uses fluorescence imaging to detect and treat oral cancer, bacterial biofilms, and tissue pathologies.

Indications of Biophotonics Therapy
A. General Medical Indications [19,22]
Chronic Pain Management (e.g., arthritis, fibromyalgia, neuropathy); * Wound Healing (diabetic ulcers, burns, surgical wounds); Cancer Therapy (PDT for skin and oral cancers); Infection Control (antimicrobial PDT for resistant bacteria); Neurotherapy (stroke recovery, traumatic brain injury, Parkinson's disease)

B. Dental Indications
Oral Cancer Treatment (PDT for leukoplakia, squamous cell carcinoma); Periodontal Disease (PBM & PDT reduce inflammation and biofilms); Tooth Sensitivity (LLLT blocks pain transmission); TMJ Disorders (PBM relaxes muscles and reduces joint pain); Postoperative Healing (PBM reduces swelling, pain, and healing time); Root Canal Therapy (PDT enhances root canal disinfection); Implantology (Laser therapy accelerates osseointegration) [29]

Uses and Applications of Biophotonics Therapy in Dentistry
A. Periodontology (Gum Disease Therapy)
Laser-Assisted Periodontal Therapy: Nd:YAG and diode lasers remove infected gingival tissue and biofilms. PDT for Periodontitis: Photosensitizers (e.g., methylene blue) + laser light eliminate anaerobic bacteria in periodontal pockets.
PBM for Tissue Regeneration: Stimulates angiogenesis and fibroblast activity for faster healing. [30]

B. Endodontics (Root Canal Therapy & Disinfection)
PDT for Root Canal Therapy: Eradicates Enterococcus faecalis and biofilms in infected canals.
Laser-Assisted Irrigation (PIPS & SWEEPS): Uses Er:YAG lasers to enhance root canal cleansing and disinfection. [18]

C. Oral & Maxillofacial Surgery (Soft Tissue Healing & Pain Management)

PBM Therapy: Reduces post-extraction pain and swelling.
Laser-Assisted Excision: CO_2 and diode lasers are used for biopsies, frenectomy, and lesion removal. [28]

D. Prosthodontics & Implantology
PBM for Osseointegration: Stimulates bone formation around implants.
Laser Decontamination of Implant Surfaces: Prevents peri-implantitis and implant failure.
Schwarz, F., et al. (2009). "Laser application in implant dentistry: A review", Lasers in Medical Science, 24(6), 849-860.

E. Oral Cancer Therapy
PDT for Malignant Lesions: Selectively destroys dysplastic and cancerous cells.
Fluorescence-Guided Biopsy: Enhances early detection of oral cancers. [14]

Advantages of Biophotonics Therapy
Minimally Invasive: Reduces need for surgery; Selective Targeting: Destroys pathogens/cancer cells without harming healthy tissue; Faster Healing: Stimulates tissue repair and regeneration; Pain-Free & Anesthesia-Free: Useful in pediatric and geriatric patients; Reduced Postoperative Complications: Less swelling, bleeding, and infection.

Future of Biophotonics Therapy in Dentistry
Nanophotonics: Integration of nanoparticles for targeted drug delivery in oral infections.
AI-Guided Optical Diagnostics: Enhances accuracy in caries, cancer, and periodontal disease detection.
3D Bioprinting with Light-Based Tissue Engineering: Aims to regrow dental pulp, enamel, and bone. [22]

Laser Biophotonics in Dentistry
Laser Biophotonics in dentistry refers to the application of laser technology for diagnostics, treatment, and biostimulation of oral tissues. It integrates light-based technologies to enhance precision, efficiency, and patient comfort in various dental procedures. Lasers in dentistry work based on photothermal, photomechanical, and photochemical interactions with biological tissues. The primary types of lasers used include:
High-Power Lasers (for cutting, ablation, coagulation); Low-Level Lasers (LLLT) / Photobiomodulation (PBM) (for healing, pain relief, and tissue regeneration).

Types of Dental Lasers Based on Wavelength and Application
1.Laser Type Wavelength (nm) Primary Use in Dentistry
2.Er:YAG (Erbium: Yttrium-Aluminum-Garnet) 2,940 nm Hard & Soft Tissue Cutting, Cavity Preparation
3.Er,Cr:YSGG (Erbium, Chromium:Yttrium-Scandium-Gallium-Garnet) 2,780 nm Cavity Preparation, Bone Surgery, Gingivectomy
4.Nd:YAG (Neodymium:YAG) 1,064 nm Periodontal Therapy, Deep Tissue Penetration
5.Diode Laser 810-980 nm Soft Tissue Surgery, Bacterial Reduction, Biostimulation
6.CO_2 Laser 10,600 nm Soft Tissue Ablation, Hemostasis [28]

Indications of Laser Biophotonics in Dentistry
A. Hard Tissue Applications
Caries detection & removal (Er:YAG, Er,Cr:YSGG); Enamel etching before bonding (Er:YAG); Dentin hypersensitivity treatment (Diode, Nd:YAG, Er:YAG); Root canal disinfection (Diode, Nd:YAG)

B. Soft Tissue Applications
Gingival contouring & frenectomy (Diode, CO_2, Nd:YAG); Periodontal pocket decontamination (Diode, Nd:YAG); Biopsy & excision of lesions (CO_2, Diode); Oral ulcer treatment (Low-Level Laser Therapy - LLLT)

C. Regenerative & Therapeutic Applications
Accelerating wound healing (Photobiomodulation - PBM);TMJ pain relief (LLLT, PBM); Stimulating bone growth after implant placement (PBM) [30]

Uses & Applications of Laser Biophotonics in Dentistry
A. Restorative Dentistry & Caries Management
Laser Caries Detection: Fluorescence-based devices like DIAGNOdent (655 nm diode laser) detect early demineralization.

Cavity Preparation & Hard Tissue Ablation: Er:YAG & Er,Cr:YSGG lasers remove decayed enamel/dentin with minimal heat and no vibration.
Desensitization of Exposed Dentin: Nd:YAG, diode, and Er:YAG lasers occlude dentinal tubules. [31]

B. Periodontology (Gum Disease Therapy)
Laser-Assisted Periodontal Therapy (LAPT): Diode & Nd:YAG lasers perform gingival curettage, sulcular debridement, and bacterial elimination.
Laser-Assisted New Attachment Procedure (LANAP): Nd:YAG laser promotes new tissue attachment and bone regeneration.
Peri-implantitis Management: Lasers disinfect implant surfaces without damaging them. [20]

C. Endodontics (Root Canal Therapy)
Laser-Activated Irrigation (PIPS, SWEEPS): Er:YAG lasers enhance root canal disinfection.
PDT for Root Canal Disinfection: Photosensitizer + diode laser destroys resistant bacteria (Enterococcus faecalis). [32]

D. Oral & Maxillofacial Surgery
Laser Biopsy & Soft Tissue Excision: CO_2 and diode lasers provide bloodless, precise cuts.
TMJ Pain Management: LLLT/PBM therapy reduces muscle pain and inflammation. [33]

E. Prosthodontics & Implantology
Laser Gingival Troughing Before Impressions: Diode lasers remove excess gingival tissue for precise impressions.
Osseointegration Acceleration: PBM stimulates bone healing around implants. [34]

F. Oral Cancer Therapy & Photodynamic Therapy (PDT)
Oral Precancer & Cancer Treatment: PDT using a photosensitizer + laser light selectively destroys dysplastic and malignant cells.
Fluorescence-Guided Biopsy: Autofluorescence imaging detects early-stage oral cancer. [14]

CONCLUSION

Biophotonics has revolutionized modern dentistry by integrating light-based technologies for enhanced diagnostics, treatment precision, and tissue healing. The application of lasers, photodynamic therapy (PDT), photobiomodulation (PBM), and fluorescence imaging has led to minimally invasive, highly efficient, and patient-friendly dental procedures.Lasers such as Er:YAG, Nd:YAG, diode, and CO_2 have significantly improved cavity preparation, periodontal therapy, root canal disinfection, and soft tissue surgery, reducing pain, bleeding, and healing time. Optical imaging and fluorescence-based diagnostics allow for early detection of caries, microbial infections, and oral cancer, improving prognosis and treatment outcomes. Additionally, photobiomodulation therapy (PBM) has demonstrated its potential in reducing inflammation, accelerating wound healing, and promoting tissue regeneration.
As nanophotonics, artificial intelligence, and regenerative biophotonics continue to advance, the future of dentistry will see even more precise, personalized, and efficient treatment modalities. The integration of smart optical sensors, AI-assisted diagnostics, and advanced laser technologies will further optimize patient care, making Biophotonics a cornerstone of next-generation dental practice.In conclusion, Biophotonics is transforming dentistry into a more precise, comfortable, and biologically adaptive field, ensuring better patient outcomes and sustainable clinical advancements. Continued research and innovation in this field will further expand its applications and effectiveness in dental healthcare.

REFERENCE

[1] Drexler, W., & Fujimoto, J. G. (2008). Optical Coherence Tomography: Technology and Applications. Springer.
[2] Helmchen, F., & Denk, W. (2005). "Deep tissue two-photon microscopy", Nature Methods, 2(12), 932–940.
[3] Dolmans, D. E. J. G. J., Fukumura, D., & Jain, R. K. (2003). "Photodynamic therapy for cancer", Nature Reviews Cancer, 3(5), 380–387.
[4] Anders, J. J., et al. (2015). "Low-level light/laser therapy versus photobiomodulation therapy", Photomedicine and Laser Surgery, 33(4), 183–184.
[5] Homola, J. (2008). "Surface plasmon resonance sensors for detection of chemical and biological species", Chemical Reviews, 108(2), 462–493.

[6] Kneipp, K., et al. (1997). "Single molecule detection using surface-enhanced Raman scattering (SERS)", Physical Review Letters, 78(9), 1667–1670.
[7] Boyden, E. S., et al. (2005). "Millisecond-timescale, genetically targeted optical control of neural activity", Nature Neuroscience, 8(9), 1263–1268.
[8] Scholkmann, F., et al. (2014). "A review on continuous-wave functional near-infrared spectroscopy and imaging instrumentation and methodology", NeuroImage, 85, 6–27.
[9] Mahlein, A. K. (2016). "Plant disease detection by imaging sensors–parallels and specific demands for precision agriculture and plant phenotyping", Plant Disease, 100(2), 241–251.
[10] Giardino, C., et al. (2019). "Application of optical remote sensing in water quality assessment", Remote Sensing of Environment, 235, 111408.
[11] Colston, B. W., et al. (1998). "Dental OCT imaging: A novel technology for caries detection", Lasers in Surgery and Medicine, 22(5), 257-266.
[12] Sinescu, C., et al. (2008). "Quality assessment of dental treatments using optical coherence tomography", Journal of Biomedical Optics, 13(5), 054065.
[13] Pretty, I. A. (2006). "Caries detection and diagnosis: Novel technologies", Journal of Dentistry, 34(10), 727-739.
[14] Lane, P. M., et al. (2006). "Autofluorescence-based oral cancer detection", Journal of Biomedical Optics, 11(3), 034010.
[15] Gutknecht, N., et al. (2005). "Comparison of laser and drill in dental caries treatment", Lasers in Medical Science, 20(1), 21-26.
[16] Cobb, C. M. (2006). "Lasers in periodontics: A review of the literature", Journal of Periodontology, 77(4), 545-564.
[17] Meisel, P., & Kocher, T. (2005). "Photodynamic therapy for periodontal diseases: State of the art", Journal of Clinical Periodontology, 32(10), 957-973.
[18] Konopka, K., & Goslinski, T. (2007). "Photodynamic therapy in dentistry", Journal of Dental Research, 86(8), 694-707.
[19] Janda, M., et al. (2007). "CAD/CAM dental restorations: An overview", International Journal of Computerized Dentistry, 10(2), 177-192.
[20] Schwarz, F., et al. (2009). "Laser application in implant dentistry: A review", Lasers in Medical Science, 24(6), 849-860.
[21] Parker, S. (2011). "Low-level laser therapy for dentinal hypersensitivity", Evidence-Based Dentistry, 12(1), 6-7.
[22] Arany, P. R., et al. (2014). "Photoactivation of dental stem cells", Science Translational Medicine, 6(238), 238ra69.
[23] Colston, B. W., et al. (1998). "Dental OCT imaging: A novel technology for caries detection", Lasers in Surgery and Medicine, 22(5), 257-266.
[24] Gutknecht, N., et al. (2005). "Comparison of laser and drill in dental caries treatment", Lasers in Medical Science, 20(1), 21-26.
[25] Pretty, I. A. (2006). "Caries detection and diagnosis: Novel technologies", Journal of Dentistry, 34(10), 727-739.
[26] Meisel, P., & Kocher, T. (2005). "Photodynamic therapy for periodontal diseases: State of the art", Journal of Clinical Periodontology, 32(10), 957-973.
[27] Janda, M., et al. (2007). "CAD/CAM dental restorations: An overview", International Journal of Computerized Dentistry, 10(2), 177-192.
[28] Parker, S. (2011). "Low-level laser therapy for dentinal hypersensitivity", Evidence-Based Dentistry, 12(1), 6-7.
[29] Hamblin, M. R. (2017). "Mechanisms and applications of photobiomodulation in human health", FASEB Journal, 31(2), 596-610.
[30] Cobb, C. M. (2006). "Lasers in periodontics: A review of the literature", Journal of Periodontology, 77(4), 545-564.
[31] Hibst, R., & Keller, U. (1989). "Experimental studies of the application of the Er:YAG laser on dental hard substances", Lasers in Surgery and Medicine, 9(4), 338-344.
[32] George, R., & Walsh, L. J. (2011). "Performance assessment of laser-assisted endodontic treatment", Journal of Endodontics, 37(6), 823-827.
[33] Bjordal, J. M., et al. (2003). "A systematic review of laser therapy in temporomandibular disorders", Journal of Oral Rehabilitation, 30(5), 336-345.
[34] Mello, A. C., et al. (2016). "Effects of low-level laser therapy on osseointegration: A literature review", Photomedicine and Laser Surgery, 34(11), 500-508.