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# NOVEL BIOPHOTONICS-BASED TECHNIQUES IN DENTAL MEDICINE – A LITERATURE REVIEW

*NOVE TEHNIKE ZASNOVANE NA BIOFOTONICI U DENTALNOJ MEDICINI – PREGLED LITERATURE*

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**Summary**
**Introduction**. Biophotonics deals with interactions between light and biological matter, integrating knowledge of physics, chemistry, engineering, biology, and medicine for solving specific biomedical or life science problems. Due to the ability to provide non-invasive, highly sensitive tissue information and inducing specific localized tissue ablation, biophotonics-based technologies may be of utmost importance in improving dental healthcare. The aim of this review article is to give an overview of contemporary biophotonics-based technologies and their applications in dental research and clinical practice. **Various applications of biophotonics-based technologies.** Biomedical imaging techniques (nonlinear microscopy methods and optical coherence tomography), photo-mechanical methods (digital holographic interferometry, photo-elasticity, digital image correlation, Moiré interferometry), optical spectroscopy techniques (Raman and Fourier transform infrared spectroscopy, Brillouin light scattering spectroscopy), fiber Bragg grating sensors, photodynamic therapy, photo-biostimulation, and femtosecond laser applications are presented in this paper. **Conclusion.** In accordance with the modern tendencies of prevention and timely diagnosis of oral diseases, biophotonics may be considered the leading scientific discipline on the path of progress of dental medicine and technology. Therefore, this paper provides an overview of modern methods based on biophotonics and summarizes their applicability focusing on the field of dental medicine.
**Key words:** Optics and Photonics; Lasers; Microscopy; Optical Imaging; Dentistry; Mouth Diseases

**Sažetak**
**Uvod.** Biofotonika se bavi interakcijom svetlosti sa biološkom materijom, integrišući znanja iz fizike, biologije, hemije, tehnike i medicine za rešavanje određenog biomedicinskog ili prirodnonaučnog problema. Zbog mogućnosti neinvazivnog pružanja visokoosetljivih informacija o tkivu i indukovanja specifične lokalizovane ablacije tkiva, tehnologije zasnovane na biofotonici mogu imati ogromnu vrednost za poboljšanje stomatološke zdravstvene zaštite. Cilj ovog preglednog rada je da se pruži prikaz savremenih tehnologija zasnovanih na biofotonici i njihove primene u stomatološkim istraživanjima i kliničkoj praksi. **Različite primene tehnika zasnovanih na biofotonici**. Tehnike biomedicinskog snimanja (metode nelinearne mikroskopije i optička koherentna tomografija), fotomehaničke metode (digitalna holografska interferometrija, fotoelastičnost, digitalna korelacija slike, Muarova (*Moire*) interferometrija), tehnike optičke spektroskopije (*Raman* i Furijeova (*Fourier*) infracrvena spektroskopija, Briluanova (*Brillouin*) spektroskopija), fiber Bragovi (*Bragg*) senzori, fotodinamička terapija, fotobiostimulacija i primena femtosekundnog lasera predstavljeni su u ovom radu. **Zaključak.** U skladu sa savremenim tendencijama prevencije i pravovremene dijagnostike oralnih oboljenja, biofotonika se može smatrati vodećom naučnom disciplinom na putu napretka dentalne medicine i tehnologije. Stoga, ovaj rad pruža pregled savremenih metoda zasnovanih na biofotonici i rezimira njihovu primenljivost usredsređujući se na oblast dentalne medicine.
**Ključne reči:** optika i fotonika; laseri; mikroskopija; optički imidžing; stomatologija; bolesti usta

## Introduction

Biophotonics, defined as a field of biomedical optics, is a novel interdisciplinary scientific approach, relating to the interaction of light with biological matter [1]. Accordingly, biophotonics integrates physics, chemistry, engineering, biology, and medicine for solving specific biomedical or life science problems [2]. It combines optical methods for studying and manipulating biological specimens at the subcellular, cellular, tissue, and organ levels, while covering biomedical diagnosis, research, and therapy [3]. From a general viewpoint, photonics is defined as "the technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon" [4]. It includes all light-based optical technologies used for information processing and transfer, measurement of changes in physical parameters, as well as physically modifying material characteristics [5]. Ever

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***Abbreviations***

| | |
|---|---|
| 2PEF | – two-photon excited fluorescence |
| SHG | – second harmonic generation |
| DHI | – digital holographic interferometry |
| FTIR | – Fourier transform infrared |
| BLS | – Brillouin light scattering |
| FOS | – fiber optic-based sensors |
| PDT | – photodynamic therapy |

since the first demonstration of lasers in 1960, a concentrated source of monochromatic light, photonics has emerged as an indispensable tool for basic life science research [6].

In contemporary dental practice, the principal priorities are early diagnosis and prevention of common oral diseases, as well as the preservation of tooth tissue as much as possible during treatment [7]. The potential of biophotonics-based technologies to provide noninvasive highly sensitive tissue information and induce specifically localized tissue processing may therefore be of immense value [8, 9]. On the other hand, the ability to identify clinically relevant information much earlier than actual signs and symptoms of a disease appear indicates one of their most beneficial features, due to the possibility of performing preventive or minimally invasive treatment procedures [10]. The aim of this review article is to give an overview of contemporary biophotonics-based techniques and their applications in dental research and clinical practice.

## Various applications of biophotonics-based techniques

Different ways to classify the application of biophotonics-based techniques have been suggested, albeit very few of them in the field of dental medicine [2, 5, 10–12]. The most convenient approach would probably be the one proposed by Kishen and Asundi [10], with a wide-ranging categorization into research and clinical applications, subdivided into diagnostics and therapeutic approaches **(Table 1)**.

*Biomedical imaging techniques*

Nonlinear microscopy methods, such as two-photon excited fluorescence (2PEF), second harmonic generation (SHG), and coherent anti-Stokes Raman spectroscopy (CARS) are widely used imaging techniques for studying a variety of biological materials [9, 13, 14]. Recently introduced in dental research practice for investigating internal tooth tissue structure and caries diagnosis, 2PEF, and SHG as noninvasive imaging modalities, provide in situ information of the examined samples without the need for histological tissue sectioning [15, 16]. Moreover, relying on the intrinsic properties of specimens (2PEF images are generated by excitation of tissue fluorophores, while SHG signal is produced by non-centrosymmetric molecules such as collagen), the use of sample labeling is unnecessary [15]. Also, these research modalities can provide three-dimensional information due to their inherent tomographic capabilities [10].

Another optical imaging technique able to provide high-resolution noninvasive images of internal microstructure in living tissues is optical coherence tomography [17]. Unlike 2PEF and SHG, it performs cross-sectional tomographic imaging in situ and in real-time by measuring back-scattered or back-reflected light [17]. At first, applied in ophthalmology for obtaining corneal and retinal images, it is currently well established in dentistry for caries diagnostics, soft tissue analysis, dental materials investigation, etc. [17–19].

*Photo-mechanics*

In general, photo-mechanics is a scientific discipline that uses optical methods for studying the mechanical response of various structures under an impact of load [20–22]. It includes several non-destructive, highly sensitive (submicron range) techniques such as digital holographic interferometry (DHI), photo-elasticity, digital image correlation, and Moiré interferometry that can provide full-field stress and strain information of specimens in situ [23].

The DHI is a laser optic technique suitable for the submicron measurement of surface deformations in a contactless and non-destructive manner [24]. The basic principle of holographic interferometry considers recording sample images (holograms) at two states, before and after mechanical load, and interference of the resulting holograms visualizing the displacement field of the object [25–27]. By using a digital camera connected to a computer interface in DHI, fast and simple recording and reconstruction of the holographic images in real-time is possible [24]. As for photo-elasticity, it is based on the interference of polarized light transmitted by experimentally loaded models simulating dental structures, providing information on stress distribution and intensity [28]. However, these models are made of light-polarizing material, with obvious difficulty to mimic the variation of biological structure [23]. On the other hand, digital image correlation is a less sensitive method than photo-elasticity, but it is not limited in terms of material and it is easy to use when compared to other optical methods [23].

**Table 1.** Applications of biophotonics-based techniques in dental medicine
***Tabela 1.*** *Primena tehnologija zasnovanih na biofotonici u dentalnoj medicini*

| Diagnostics/*Dijagnostika* | Therapy/*Terapija* | Research/*Istraživanje* |
|---|---|---|
| Biomedical imaging<br>*Biomedicinski imidžing* | Photodynamic therapy/*Fotodinamička terapija* | Photo-mechanics/*Fotomehanika* |
| | Photo-biostimulation/*Fotobiostimulacija* | Optical spectroscopy/*Optička spektroskopija* |
| | Photo-thermal effects/*Foto-termalni efekti* | Fiber optic sensors/*Fiber optički senzori* |

Moiré interferometry is an optical method viable for studying elastic, viscoelastic, and plastic deformations of both isotropic and anisotropic materials [29]. The main advantage of this method is its capability of measuring in-plane deformations (unlike DHI), particularly corresponding to hard tooth tissue functional load [23]. With its high sensitivity, spatial resolution, and clarity, Moiré interferometry is recommended for investigating dental mechanical strain, as well as deformations caused by thermal or hydro (e.g. moisture change, water loss) alterations in tooth tissue [29–31].

*Optical spectroscopy methods*

The interaction of light (electromagnetic radiation) with matter can lead to a variety of phenomena such as absorption, scattering, reflection, and emission, presenting the basis of optical spectroscopy [1, 10]. Considering different regions of the electromagnetic spectrum that can be employed in spectroscopy for the structural analysis of biological material, various experimental techniques have been developed. Ultraviolet-visible spectroscopy, fluorescence spectroscopy, infrared and Raman spectroscopy, as well as Brillouin light scattering spectroscopy are some of the techniques that may be applied in dental research practice [10, 32].

Raman and Fourier transform infrared (FTIR) spectroscopy are complementary research techniques most frequently used for non-destructive imaging of hard dental tissues and studying dental materials' chemical composition, especially the degree of conversion (DC) [33, 34]. It is commonly perceived that the main advantage of Raman spectroscopy compared to FTIR is its ability to provide a material examination in their native state, but the recent advances in FTIR spectroscopy also allow sample analysis with minimal preparation [34]. In contemporary dental research practice, FTIR has proved to be a useful technique for rapid and precise investigation of chemical structural properties of natural and synthetic materials at the molecular scale [34–37]. On the other hand, the use of Raman spectroscopy has significantly increased due to the advances in instrumentation and technique (e.g. implementation of miniature fiber optical probes) [38–40]. By expanding its field of application into oral hard and soft tissue pathology diagnosis, as well as identification of oral microbial flora, Raman spectroscopy can be considered an important diagnostic tool in the early detection and prognosis of oral diseases [33].

Brillouin light scattering spectroscopy (BLS) measures spectral changes of coherent incident light caused by its interaction with inherent density fluctuations of matter [32]. The frequency shift and linewidth of spectra are linked to the stiffness and viscosity of the material. Unlike standard mechanical tests, BLS is non-invasive and non-destructive. Recently, researchers have performed the first study of hard dental tissues and materials using BLS [16, 32]. By measuring different Brillouin frequency shifts and linewidths of spectra in healthy and decayed dentinal samples, BLS showed the potential to be used as a micro-precise diagnostic laser-based tool in dental medicine to differentiate healthy dentin from a carious lesion, as well as to examine tissue-material interfaces precisely and non-destructively [16, 32]. Based on the research outcomes, a fiber-optic diagnostic tool with a microscopic precision based on BLS could be developed for in situ clinical use in dental practice.

*Fiber optic sensors*

Optical fibers offer the advantage of adaptability of light beam manipulation providing an optical passage for illuminating inaccessible areas, or for using high-energy laser beams at a specific location for tissue cutting [10]. The progress from conventional sensors to fiber optic-based sensors (FOS), provided a highly sensitive, safe, rapid, and minimally invasive diagnostic method [41]. Being a suitable method for real-time assessment of local temperature and tooth biomechanical behavior, as well as for measurement of dental material polymerization kinetics, fiber Bragg grating sensors seem to be the most convenient and appealing type of FOS in dental medicine [42, 43].

*Therapeutic applications*

Photodynamic therapy (PDT) is a relatively new treatment modality, still in the early stage of development within the field of dental medicine [44]. Defined as "the light-induced inactivation of cells, microorganisms or molecules" [45], PDT provides an alternative treatment of elimination of malignant cells or pathogenic microorganisms, while overcoming the problems of bacterial, fungal, and viral resistance. However, PDT has a few disadvantages, such as a period of consequent skin photosensitivity due to the accumulation of photosensitizing agents in the target tissue, and a limited ability to penetrate deep tissues [44]. Although having a few limitations, PDT with its non-invasive approach and non-resistant broad-ranging spectrum of action against pathogens can be considered a promising therapeutic tool in dentistry [44].

Photo-biostimulation or low-level laser therapy is another non-invasive treatment modality used in several fields of contemporary dental practice [46–48]. By using low-powered laser light biological interaction is induced, in particular reduction of pain mediators and inflammatory cells leading to an acceleration of pain relief and healing [49]. In the field of orthodontics, it was found that intraoral application of low-level laser therapy reduced the treatment time, supposedly by increasing cellular metabolic activity and favoring bone remodeling [46]. Moreover, photo-biostimulation can be used to reduce pain severity and duration, as well as swelling after dental implant surgery [49].

With the recent introduction of high power and high repetition rate femtosecond lasers significant progress towards precise and effective tooth tissue ablation was achieved, compared to cavity preparation using a conventional erbium laser [8]. Utilizing proper laser parameters for efficient dental ablation, femtosecond lasers cause no collateral thermo-mechanical damage to the surrounding tooth tissue, whereas beneficial tooth surface roughness is achieved [8, 50]. Therefore, based on "cold" tooth tissue ablation and machining precision at the submicron and nano levels, femtosecond laser may become an advanced alternative laser system for tooth cavity preparation [50].

## Conclusion

Bearing in mind constant efforts to accomplish prevention and early diagnosis of oral diseases, as well as non-invasive treatment measures in modern dental practice, biophotonics should be the leading scientific discipline to provide advancements in dental medicine and technology. In the light of such trends, this paper has provided an overview of contemporary biophotonics-based techniques and summarized their applicability focusing on the field of dental medicine.

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