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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-bistimulation, 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, integrirajući znanja iz fisike, biologije, hemije, tehnike i medicinе za rešavanje određenog biomedicinskог или природног проблема. Zbog mogućnosti neinvazivnог pružanja višekomponentних informacija o tkivu i indukovanja specifične lokalizovane ablacije tkiva, tehnologije zasnovane na biofotonici mogu imati ogromnu vrednost za poboljšanje stomatološke zdravstvene zaštite. Cilj ovog preglednог rada je da se pruži prikaz savremenih tehnologija zasnovanih na biofotonici i njihove primene u stomatološkim istraživanjima i kliničкоj praksi. Različite primene tehnika zasnovanih na biofotonici. Tehnike biomedicinskог snimanja (metode nelineарне микроскопије и оптичких кохерентних томографија), фотомеханичке методе (релевантног Фурејеовог интерферометрија, фотовискости, интерферометрија, фотореакције спектроскопије (Раман и Фурејеове спектроскопије), фотобистимуляције, и примена фемтосекундног лазера представљени су у овом раду. Закључак. У склопу савремених тенденција прецизности и прорачуне дјагностике биолошког оближње, биофотоника се може смрати водаочном научном дисциплином на путу напредак стоматолошке медицине и технологии. Стога, овај рад пруга предлог савремених метода заснованих на биофотони и резимира њихову премијност у прорачуну усмерених се на област стоматолошке медицине.

Кључне речи: оптика и фотоника; лазери; микроскопија; оптичкие идивизиони; стоматологија; болести уста

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...
since the first demonstration of lasers in 1960, a
concentrated source of monochromatic light, pho-
onics 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 com-
mon oral diseases, as well as the preservation of
tooth tissue as much as possible during treatment
[7]. The potential of biophotonics-based technolo-
gies 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 clini-
cally relevant information much earlier than actual
signs and symptoms of a disease appear indicates
possibility of performing preventive or minimally in-
vasive treatment procedures [10]. The aim of this
review article is to give an overview of contempo-
rary biophotonics-based techniques and their ap-
plications in dental research and clinical practice.

Various applications of biophotonics-based
techniques

Different ways to classify the application of biopho-
onics-based techniques have been suggested, al-
beit 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 Asun-
di [10], with a wide-ranging categorization into re-
search 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 har-
monic generation (SHG), and coherent anti-Stokes
Raman spectroscopy (CARS) are widely used imag-
ing 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 non-
invasive imaging modalities, provide in situ informa-
tion 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 micro-
structure in living tissues is optical coherence tomog-
raphy [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 estab-
lished in dentistry for caries diagnostics, soft tissue
analysis, dental materials investigation, etc. [17–19].

Photo-mechanics

In general, photo-mechanics is a scientific disci-
pline that uses optical methods for studying the me-
chanical response of various structures under an
impact of load [20–22]. It includes several non-de-
structive, highly sensitive (submicron range) tech-
niques 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 interferom-
etry 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 us-
ing a digital camera connected to a computer inter-
faced in DHI, fast and simple recording and recon-
struction 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 distribu-
tion and intensity [28]. However, these models are
made of light-polarizing material, with obvious dif-
culty 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

| Diagnostics/Dijagnostika | Therapy/Terapija | Research/Istraživanje |
|-------------------------|-----------------|----------------------|
| Biomedical imaging     | Photodynamic therapy/Fotodinamička terapija | Photo-mechanics/Fotomehanika |
| Biomedicinski imidžing | 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 gratings 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, femtosec-
ond 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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