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Optical detection in dentistry

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Abstract
Medical imaging is the basis of effective medical diagnosis it is dynamically developing branch of biomedical engineering. Optical coherence tomography is a non-invasive, non-radiative optical diagnostic tool based on interferometers. Polarization imaging is an inexpensive approach for detecting dental hard tissue diseases and has the potential for application in diagnosis.

Keywords: Optical coherence tomography, transillumination, fiber optics, magnifications

Introduction
Its development started after an accidental discovery of *Wilhelm Conrad Roentgen*, a professor of physics, who in 1895 observed little fluorescence during his research on electrical discharges and cathode rays. The method of optical coherence tomography using interferometry with partially coherent light was first presented in 1991 at the Institute of Technology of the University of Massachusetts [1].
Optical coherence tomography was first reported by Fujimoto *et al.* in 1991. It is an optical imaging technique that enables cross-sectional imaging of microstructures of tissue in situ, can provide "*optical biopsy*" without the need for excision and processing of specimens as in conventional biopsy and histopathology. It is an interferometer-based system with a low coherence length broadband light source. By using a low-coherence broadband near-infrared light source, it is possible to obtain excellent spatial resolution (~20 μm) images [2].
Device consists of coupled hardware components containing the software and five basic modules: a partially coherent light source, an imaging apparatus, a measurement head, a module of data processing, and image generation as well as a computer control system. The computer control system controls the entire *Optical coherence tomography* scanner. It enables to control scanning and synchronize the operation of all components. Imaging is possible by measuring the intensity and time delay of the "echo" of the reflected or backscattered light. The method of imaging is analogous to ultrasonography. The basis of optical tomography is the phenomenon of interference of two partially coherent light beams coming from a single source - the reference beam and the probe beam. Biological objects, such as tissues and organs, are for light waves, the centres with nonuniform distribution of a refractive index. The analysis of interference signal enables to locate the points at which the refractive index changes. These points are situated along the direction of propagation of the probe beam.
There are two basic types of optical coherence tomography: Time domain optical coherence tomography and Fourier domain optical coherence tomography. Optical coherence tomography enables the study of objects that are partially transparent for light from the near infrared range. In the OCT scanner the information about the location of scattering (reflecting) layers along the sample beam is contained in the modulation frequency of the light intensity measured as a function of frequency. The electric signal resulting from detection of spectra of interfering beams is called the signal of spectral bands [1].
A *dental implant* is essentially a substitute for a natural root and commonly it is a screw. Each implant is placed into a socket drilled. The implant can be screwed into position. The main aim during installation of any implant is to achieve immediate close contact with the surrounding bone. This creates an initial stability. The stability of implant is enhanced by further growth of bone into microscopic roughness on the implant surface [3].
Failure of a dental implant is often related to failure to osseointegrate correctly. Optical Coherent Tomography is a proper technique to obtain the image of the contact tissue-metal

screw. OCT images are useful to evaluate optical properties of bone tissues. To study the quality of the contact between tissue and metal screw high resolution image of the investigated area is required. Optical microscopy is a useful imagistic method because is low cost, short time and non-special preparation requirements. Scanning electron microscopy gives much higher resolution images with specific *disadvantages*: expensive equipment, time consuming, dried samples, prepared samples, skilled people. Both techniques can supply very nice images but only of the visible free surface. They cannot show the contact quality, because the surface of the metal is below the tissue growth on the screw. A competitive and non-invasive method is Optical Coherent Tomography, it is a proper technique to obtain the image of the contact. The most important feature of it is the possibility to see under the free surface of tissue [4].

Optical Coherence Tomography has been used to produce images of dental tissues. Fourier Domain Optical Coherence Tomography (FD-OCT) achieves greater sensitivity and higher image speeds than Time Domain-OCT. The most effective approach to do FD-OCT is to keep the single photodetector and to use a swept light source instead of superluminescent diode. The great advantage of the swept source technique is the simplicity of the interferometer. It has the capacity to give 3-D image of the tissue at the implant sites for in-vitro investigations [3].

The most common way to *detect oral mucosal disease* is by visual inspection of the suspect tissue. However, the human eye is not optimized for this task because the perceived spectrum of light is divided into three channels, all of which have overlapping spectral sensitivity curves. *Abnormalities in the oral cavity* are optimally perceived when the excitation is in the long wave ultraviolet (UVA) band. Positive green autofluorescence emissions arise from the cytokeratins which are found in normal oral mucosal epithelial cells, when tissues are exposed to violet and blue light.

Ultraviolet (UVA), blue and green light causes visible green-yellow *fluorescence* in healthy enamel. Enamel fluorescence does not depend on the colour of the tooth. Dentine has a distribution spectrum which is similar to that of enamel. Reduced fluorescence from dental hard tissue indicate the presence of early forms of mineral loss from dental caries or dental erosion, or subsurface porosity. These lesions can then be arrested or reversed using remineralizing therapies. The underlying process used with UVA systems, is that when excited by UVA and violet light, carious enamel appears dark compared to yellow-green luminescent sound enamel. Such negative fluorescence has been shown to detect more demineralized pre-cavitated enamel areas than a conventional visual examination.

The *fluorescence method* can also be used to assess cleaning techniques for teeth as well as dental appliances, since residual deposits of mature plaque and calculus appear as red fluorescing areas. The maturity of dental plaque, rather than the presence of particular cariogenic streptococci, is the basis for the red fluorescence. The same wavelengths give red emissions from infected carious dentine in cavity preparations, indicating the presence of bacteria thus guiding caries removal [5].

Dental enamel constitutes the outer layer of a crown of teeth and grows nearly parallel. This unique nanostructure makes enamel possess *birefringence properties*. The tooth surface exhibits an optical birefringence property, which means that the intensity response of the reflected light changes with a different polarization orientation of the incident light. It has been reported that the observed enamel birefringence is the sum of the intrinsic (related to hydroxyapatite crystals and with negative sign) and the form (related to non-mineral volumes and with positive sign) birefringence. When a polarized light is emitted on a tooth, the polarization state of the backscatter light from the infected part is expected to differ from the uninfected part because of the nanostructural changes arising from dental hard tissue diseases. By observing the polarization states images, a lesion can be distinguished quantitatively. *Polarized light microscopy* and *Polarization sensitive optical coherence tomography* have been used to investigate the birefringence characteristics of the tooth and to monitor the progress of dental caries as well as remineralization and demineralization processes. All the dental hard tissue diseases exhibit higher diattenuation and overall lower linear retardance when compared to the normal tissue whereas the changes of depolarization are not significant. Infected area has lower linear retardance than the healthy part because of the damage of the enamel nanostructure, which leads to the loss of its birefringence properties. In contrast to the linear retardance, the diattenuation images exhibit a high signal-to-noise ratio and have higher capability to identify the infected area [6].

Minimally invasive dentistry calls for the development of a diagnostic technique for *carious lesions* in the earliest stages of the disease. *Transillumination* is a method based on optic fibre technology whereby a tooth is targeted by high-intensity white light emanating from a hand-held device. Tissue with caries, being more porous than healthy tissue, absorbs far more light enabling us to observe that the surrounding tissue is whiter and more opaque, whereas the lesion appears darker because carious lesions disperse visible light. This method may be used on any dental surface of the patient, particularly in interproximal lesions of anterior teeth, as in this case, the bucco-lingual enamel thickness is lower than in posterior teeth. The light is propagated towards the tooth by way of optic fibres and has the sufficient intensity to pass through the dental structure to reach areas difficult to view with the naked eye, the light transmitted passes through the tooth and becomes a detectable signal read by a computer; it is then instantaneously displayed on a screen [7].

Fiber optics (optical fiber) refers to flexible, thin cylindrical fibers of high-optical-quality glass or plastic. The theory of fiber optics is based on a single optical fiber that consists of glass or plastic material with an outer cladding of a lower index of refraction material. Since the fiber core has a higher refractive index, light rays are reflected back into the core. This phenomenon is based on *Snell's Law* and is called *Total Internal Reflection* (TIR). Individual fibers are grouped together to form a fiber optic bundle. Fiber optics have been used in dentistry for adjunctive illumination of other devices such as handpieces and ultrasonic scalers, as well as attached to magnifying loupes [8].

Optical fiber started with the creation of "optical transmit" by *French Chappe siblings*. In 1880, *Alexander Graham Bell* concocted his 'Photophone', which transmitted a voice motion on a light emission. *Ringer* centered daylight with a mirror and after that talked into an instrument that vibrated the mirror. *William Wheeling*, in 1880, protected a technique for light exchange called "funneling light. In the late 1970s and mid-1980s, phone organizations started to utilize strands broadly to revamp their correspondences framework **[9]**.

Near Infrared Imaging serves as a valuable diagnostic aid in the early detection of interproximal caries. The near infrared (NIR) is the region of the electromagnetic spectrum between

0.7 to 2.0 micrometers (µm). Enamel is transparent to NIRI due to the reduced scattering co-efficient of light, allowing it to pass through its entire thickness and present as a dark area, whereas the dentin appears bright due to the scattering effect of light caused by the orientation of the dentinal tubules, any interferences/pathological lesions/ areas of demineralization appear as bright areas in a NIRI image due to the increased scattering within the region. Optical methods have the advantage that they do not use ionizing radiation, thus these procedures can be used as often as desired to monitor caries. NIRI is an effective tool in aiding the diagnosis and monitoring early stages of interproximal caries. It is non-invasive by nature, can be used as frequently as required to monitor the patient's oral health and provide the patient with chairside education, which enables patients to appreciate and understand the finer details associated with their oral health. [10]

Identification of *cracked teeth* may occur by visual inspection with the unaided eye, although many times diagnostic tests must be used to detect the crack. Removal of restorations and revisualization may be necessary, although most cracks occur in teeth with no or minimal restorations; because the crack with its potential to harbor bacteria and bacterial byproducts may have not completely extended to the pulp. The pulpal diagnosis for a tooth with a crack could be normal, reversible pulpitis, irreversible pulpitis or necrosis. This can be very confusing from the clinical and research perspectives.

Transillumination is the detection method that provides the most information, and easily and graphically represents whether a crack is present. It is based on a *law of physics, namely that a beam of light will continue to penetrate through a substance until is meets a space, after which the light beam is reflected.* This results in a light and a dark area of the tooth separated by the fracture line [11].

A necessary attribute in modern dentistry for clinical work is a high level of visual acuity, especially for near vision. A common way to achieve better vision is to effectively magnify the area of interest. *Worschech CC et al*. said that improved lighting, coupled with magnification, provides a clear distinction between surfaces that may look similar in color or texture under traditional working conditions.

Magnifications for microsurgery was introduced to medicine during the late 19th century. *Carl Nylen*, father of microsurgery, in 1921 first used a binocular microscope for ear surgery. The pioneers in dentistry were *Apotheker and Jako*, who first introduced the use of microscope in dental procedures in 1978.

Magnification systems

The concept of magnification-enhanced dentistry incorporates the use of two types of optical magnification systems: a) Loupes b) Surgical operating microscope.

Loupes the most common magnification system used in dentistry is the magnification loupes. Primarily, loupes consist of two monocular microscopes, with side-by-side lenses, angled to focus on an object to form magnified images with stereoscopic properties that are created by the use of convergent lens systems.

Simple loupes: Simple loupes consist of a pair of single, positive, side-by-side meniscus lenses. Each lens has two refracting surfaces, with one occurring as light enters the lens and the other when it leaves. Main advantage is cost effective. Disadvantages are primitive with limited capabilities and are highly subjected to spherical and chromatic aberrations, which distort the image of the object.

Compound loupes or telescopic loupes: Compound loupes or telescopic loupes consist of multiple lenses with intervening air spaces, thus allowing adjustment of magnification, working distance (WD), and depth of field without increase in size or weight.

Prism loupes: Prism loupes are optically most advanced. They produce better magnification, larger fields of view, wider depths of field, and longer working distance. *Surgical operating microscope* in dentistry, are designed on *Galilean principles*. They incorporate the use of magnifying loupes in combination with a magnification changer and a binocular viewing system so that it employs parallel binoculars for protection against eye strain and fatigue. They also incorporate fully coated optics and achromatic lenses, with high resolution and good contrast stereoscopic vision. Surgical microscopes use *coaxial fiber-optic illumination*. This type of light produces an adjustable, bright, uniformly illuminated, circular spot of light that is parallel to the optical viewing axis, due to its shadow-free light, visualization of pathologies, documentation, motion videography, and management of all dental and surgical procedures can be effectively performed under unobstructed vision [12].

A major advantage of optical diagnostic methods is that they use non-ionizing radiation, and can therefore be used with safety at high frequency, unlike dental X-rays. They are simple, painless and noninvasive, and can also be used in situations where radiographs are contra-indicated, such as with pregnant women. The optical polarization imaging system for oral medicine is noninvasive and nonradioactive. In recent years advancements in engineering tools have introduced digital devices for use as supplemental aids for diagnosis of dental pathologies enabling dentists to add to their diagnostic armamentarium.

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