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Optical Coherence Tomography (Oct): 6th Generation Periodontal Probe??? A Review

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Abstract: *Optical coherence tomography (OCT) is a non-invasive method of imaging dental microstructure which can potentially evaluate the health of periodontal tissue. This modality of imaging was pioneered at the Lawrence Livermore National Laboratory (Livermore, CA, USA). It provides an 'optical biopsy' of tissue 2–3 mm in depth. Optical coherence tomography is based on optical scattering signatures within tissue structure which can create 3-D, high-resolution, cross-sectional images of biologic structures by scanning a lightly focused light beam across the tissue surface of interest by the use of broadband low-coherent near-infrared (NIR) light sources that provide considerable penetration into tissue without any known detrimental biologic effects. Periodontal tissue contour, sulcular depth and connective tissue attachment are visualised at high resolution using this technology. Because OCT reveals micro-structural detail of the periodontal soft tissues, it can potentially identify active periodontal disease before significant alveolar bone loss occurs. Optical coherence tomography is potentially a more reproducible and reliable method of determining attachment level than traditional probing methods. This article emphasises on the future development of an OCT probe which may be designed with a short focus distance for direct contact imaging, allowing a submillimetre probe to be placed on the tissue surface or even in the pocket space. This paper reviews OCT and its applications in periodontology. Source of data- An online literature search was made using Google Scholar for all the relevant articles that relate OCT applications in Periodontics.*

Keywords: *Optical Coherence Tomography, Periodontal pocket, Periodontal probing*

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I. Introduction

Optical coherence tomography (OCT) is an optical analog of ultrasound imaging that was invented in the early 1990s. Tomographic imaging techniques such as x-ray computed tomography[1], magnetic resonance imaging[2], and ultrasound imaging[3] have found widespread applications in medicine; OCT is one of them. Optical coherence tomography (OCT) utilizes low-coherence interferometric technology (i.e., infrared wavelengths) to acquire reflectance/backscatter data. The cross-sectional images are constructed using Comparison of tissue reflectance to reference light. The resolution of OCT is almost comparable to high magnification optical microscopy with an imaging capability of 1–3 mm depth within tissues, thereby allowing generation of volumetric data (e.g., epidermal thickness) at microscopic resolution. OCT volumetric data allows for three-dimensional construction of tissues, providing a greater understanding of histomorphologic changes than otherwise provided by two-dimensional histology images. Optical coherence tomography provides sections of tissues in a noncontact and noninvasive manner[4]. OCT has been revolutionized in recent years by the development of Fourier-domain (FD) techniques that provide a distinct increase in sensitivity compared with traditional (TD)-OCT[5]. Over the past decade, many functional OCT systems, such as Doppler OCT (DOCT)[6,7], polarization sensitive OCT (PS-OCT)[8,9,10], endoscopic OCT[11,12] and acoustic OCT[13,14], were reported for new biomedical research applications. These functional systems provide not only structure images but also the specific optical characteristics, including blood flow velocity and tissue orientation. Moreover, deeper transmission depth is achieved with combination of fluorescence [15,16]. Indeed, these optional functions promote the efficiency of diagnosis of OCT. The optical sectioning capability of OCT is akin to that of confocal microscopic systems[15,16]. However, although the longitudinal resolution of confocal microscopy depends on the available numerical aperture[17], OCT's resolution is limited only by the coherence length of the light source. Thus, OCT can maintain high depth resolution even when the available aperture is small.

II. Method And Materials

The author searched Google Scholar for articles in the English language literature on Optical Coherence Tomography (OCT) and Periodontics from 1971 to 2019. The search strategy initially employed the key words OCT AND Periodontics. A subsequent search was conducted with each OCT AND Periodontics.

III. Results

A search on Google Scholar yielded almost 2580 results with the key words OCT and Periodontics. Articles selected for discussion consisted mostly of recent systematic reviews and meta-analyses. Several randomized clinical trials were also included.

IV. Types Of Optical Coherence Tomography

Currently, there are two basic types of optical coherence tomography[5]:

1) Time domain optical coherence tomography (TdOCT) and
2) Fourier domain optical coherence tomography (FdOCT).

Time Domain OCT

- The Michelson interferometer splits the light from the broadband source into two paths, the reference and sample arms.
- The interference signal between the reflected reference wave and the backscattered sample wave is then recorded.
- The axial optical sectioning ability of the technique is inversely proportional to its optical bandwidth.
- Transverse scanning of the sample is achieved via rotation of a sample arm galvonometer mirror.
- In order to measure the time delays of light echoes coming from different structures within the eye, the position of the reference mirror is changed so that the time delay of the reference light pulse is adjusted accordingly

Fourier/Spectral domain OCT

- In FD-OCT, the detector arm of the Michelson interferometer uses a spectrometer instead a single detector.
- The spectrometer measures spectral modulations produced by interference between the sample and reference reflections.
- No physical scanning of the reference mirror is required; thus, FD-OCT can be much faster than TDOCT.
- The simultaneous detection of reflections from a broad range of depths is much more efficient than TD-OCT, in which signals from various depths are scanned sequentially.
- FD-OCT is also fast enough for sequential image frames to track the pulsation of blood vessels during the cardiac cycle.

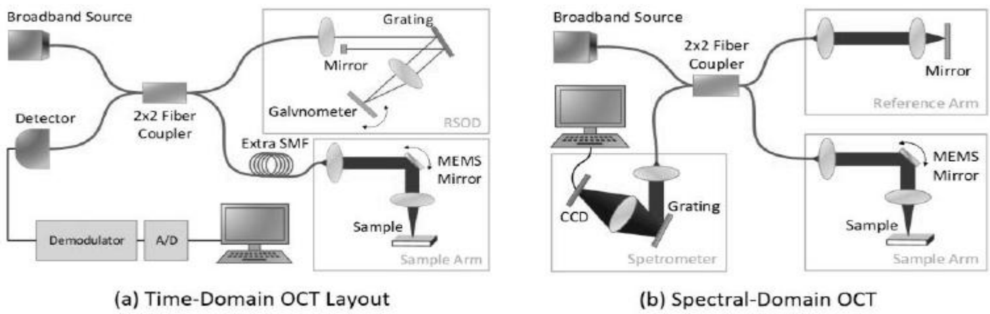

Figure 1:- Types of OCT

The former technique was developed in 1991 by the group of researchers from the Massachusetts Institute of Technology in the United States[18] for use in ophthalmic diagnosis. It can produce tomographic images of relatively low quality, resulting from long time of measurement, but it does not allow for three-dimensional imaging of objects[19]. Modern optical tomography with detection in the frequency domain (Fourier domain optical coherence tomography) reduces the capture time by more than a hundred times.

The electric signal resulting from detection of spectra of interfering beams is called the signal of spectral bands. 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.

Two methods of practical realization of this type of detection are used[5]. The first is spectral optical coherence tomography (SOCT). The other method is optical Fourier domain imaging (OFDI) or swept source OCT [4]. The common elements, used in both methods (SOCT and OFDI), are fixed reference mirrors (as opposed to time domain OCT). This improves mechanical stability of the system. In OFDI, an ordinary photodetector is used instead of a spectrometer, because the applied fast tunable laser generates light of a narrow spectral line individually for each wavelength.

The recently advanced SS-OCT uses a short cavity swept laser with a tunable wavelength of operation instead of the diode laser used in spectral-domain OCT[20]. The SS-OCT has improved image penetration using a wavelength of 1050 nm and has an axial resolution of 5.3 μm and an axial scan rate of 100,000 scans per second. The 12 × 9 mm scan comprises 256 B scans each comprising 512 A scans with a total acquisition time of 1.3 s [21] SS-OCT also provides the capability of a wide field up to 12 × 12 mm images[22]. SS-OCT enables clear simultaneous visualization of the vitreous and the posterior precortical vitreous pockets and the choroid and the sclera.

V. History Of The Oct Original Founders

The development of OCT preceded 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 led to the discovery of X-radiation which turned out to be a fundamental discovery which is still used in medicine today[5]. Another milestone was the development of the first computed tomography (CT) device by Godfrey Newbold Hounsfield in 1967. The concept of tomography refers to a method that provides images showing sections of the tested structure. The first CT scanner initiated rapid development of medical imaging techniques. A common feature of different types of CT devices is noninvasive imaging of tissue structures and internal organs, as well as their functional parameters. The desire to minimize invasiveness of methods such as biopsy or exploratory surgery, which are painful and may cause deterioration in the patient's condition, was an impetus for the improvement of computed tomography equipment. As a result, completely new technologies were developed, such as magnetic resonance imaging (MRI), ultrasonography (USG), positron emission tomography (PET), single photon emission computed tomography (SPECT), and the latest and more widely used optical coherence tomography (OCT)[5].

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[18]. The first in vivo measurements of the section of the human retina were made two years later in Vienna[23]. The first commercial optical tomography device was produced in 1996 by Zeiss-Humphrey[24].

•David Huang, MD, PhD student at Harvard-MIT 1991: 1st scientific description of OCT[18].
•David Huang, MD, PhD student at Harvard MIT conceived the idea of OCT while working with Dr. James Fujimoto, PhD.
•Eric Swanson, MS built the 1st OCT at the Lincoln laboratory of MIT.
•Carmen Puliafito, MD -> Formed startup company: Advanced Diagnostics

VI. Principle of Optical Coherence Tomography.

• Interferometry is the technique of superimposing (interfering) two or more waves, to detect differences between them.
•Interferometry works because two waves with the same frequency that have the same phase will add each other while two waves that have opposite phase will subtract.
•Light from a source is directed onto a partially reflecting mirror and is split into a reference and a measurement beam.
•The measurement beam reflected from the specimen with different time delays according to its internal microstructure.
•The light in the reference beam is reflected from a reference mirror at a variable distance which produces a variable time delay. The light from the specimen, consisting of multiple echoes, and the light from the reference mirror, consisting of a single echo at a known delay are combined and detected.

VII. Working Of Optical Coherence Tomography

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. OCT is a modular device which consists of coupled hardware components like 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[5]. The light source used in the device determines its axial resolution and penetration depth of the light beam. The OCT imaging apparatus module is the central element of the system. Biological objects, such as tissues and organs, are for light waves, the centres with non - uniform 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. The graph of reflected wave power density as a function of the position of the reflective point, which is the source of the wave, is called an

A-scan. B scans give sagittal scans of the object and C scans—lateral scanning images at a constant depth. Combination of measurement results lying in one plane (numerous parallel directions of the probe beam) creates a two-dimensional image of the section of the test object[25].

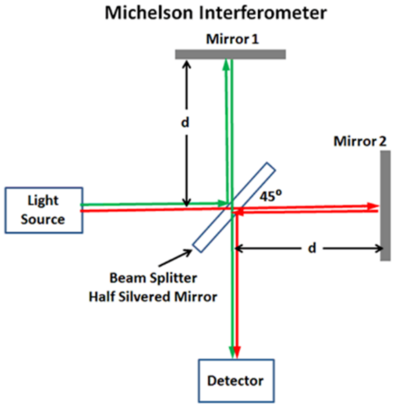

Figure 2:- Michelson Interferometer

The localization of the boundaries of layers with different refractive indices, that is, determination of the waveform of refractive index changes as a function of light beam penetration depth is carried out by interferometric distance measurement systems. It uses the property of light waves, which is the ability to overlap. This property is dependent on coherence of light. There are two types of light coherence: spatial—defining the phase correlation between wave sequences generated by different points of the light source and time—defining the phase correlation of wave sequences emitted by a single point of the light source at different points in time[26]. The time consistency of light is examined using the Michelson interferometer[27]. The schematic diagram of the operation of the Michelson interferometer is shown in Figure 2. The light wave incident on the semi-transparent mirror BS (beam splitter) splits into two beams. The light source (LS) changing its direction into perpendicular after passing through BS is reflected by the movable mirror M1, again passes through BS, without changing its direction, and reaches the screen D (detector). The second beam formed by the passage of the primary beam through BS without changing its direction is reflected by the fixed mirror M2, then passes through BS changing the direction into perpendicular, and falls on screen D. The beam incident on the screen forms an interference image[5]. The OCT imaging apparatus module is the central element of the system. This may be any measuring device capable of measuring the reflected or backscattered light with high sensitivity and resolution. Instruments that enable lossless signal transmission are also indispensable. Other elements of the OCT system are the measuring head and the system for bringing the probe beam to the test structure. They take different forms, depending on the field of medicine for which they are intended. The computer control system controls the entire OCT scanner. It enables to control scanning the reference arm of the interferometer and synchronize the operation of all components. Moreover, it allows for communication between the apparatus and the image processing block as well as the display of measurement results in real time.

Table 1: Periodontology Studies done with OCT.[37]

Number	Reference number	Author	Title	Significance
(1)	38	Gladkova et al.	Evaluation of oral mucosa collagen condition with cross-polarization optical coherence tomography	The OCT signal SD in cross-polarized images reflects two boundary conditions of collagen disorganization, namely, loss of fibre properties at active inflammation which attenuates the signal and fibrosis that occurs due to synthesis of a new remodeled collagen which amplifies the OCT signal.
(2)	39	Weber et al.	Towards a bimodal proximity sensor for in situ neurovascular bundle detection during dental implant surgery	The proximity to the neurovascular bundle can be tracked in real time in the range of a few millimeters with NIR signals, after which higher resolution imaging OCT to provide finer ranging in the submillimeter distances.
(3)	40	Kikuchi et al.	Evaluation of the marginal fit at implant-abutment interface by optical	OCT appeared as an effective tool for evaluating the misfit of implant-abutment under thin layers of soft tissue.

			coherence tomography	
(4)	41	Mota et al.	Non-invasive periodontal probing through Fourier-domain optical coherence tomography	Regarding the ability of the two OCT systems to visualize periodontal structures, the system operating at 1325 nm shows a better performance, owing to a longer central wavelength that allows deeper tissue penetration. The results with the system at 930 nm can also be used, but some features could not be observed due to its lower penetration depth in the tissue.
(5)	42	Boadi et al.	Imaging of 3D tissue-engineered models of oral cancer using 890 and 1300 nm optical coherence tomography	890 nm OCT retains some of its known advantages of higher contrast between anatomical tissue layers when used to observe dysplastic and malignant 3D oral mucosa constructs. However, 1300 nm OCT is confirmed to possess a greater ability to image the full thickness of the model epithelia, and in particular, it is more suited to imaging through the keratinized layer.
(6)	43	Sanda et al.	The effectiveness of optical coherence tomography for evaluating peri-implant tissue: a pilot study	Cement remnants at the submucosal area can be detected in some cases, which can be helpful in preventing peri-implant diseases. Still, though there are some restrictions to its application, OCT could have potential as an effective diagnostic instrument in the field of implant dentistry as well.
(7)	44	Damodaran et al.	Non-invasive detection of periodontal loss of attachment using optical coherence tomography	The conventional time domain OCT system acquisition speed is limited by the speed of the mechanical scanning system. In order to overcome this issue, a novel electro-optic-based scanning system is proposed and demonstrated.
(8)	45	Fernandes et al.	Monitoring the gingival regeneration after aesthetic surgery with optical coherence tomography	OCT is an efficient method in the evaluation of regeneration gingival.
(9)	46	Augustine et al.	Optical coherence tomography in oral cancer detection	OCT can pinpoint epithelial changes; this imaging tool has sought potential broad applications in other mucosal lesions such as vesiculobullous and vascular lesions. The possibility of this application for bone-related disease imaging is an interesting research prospect. Future research should focus on the suitable wavelength of the light source of OCT for better observation of oral diseases. Faster and higher resolution OCT systems may replace the need for biopsies in many situations in the near future.
(10)	47	Negrutiu et al.	Assessment of dental plaque by optoelectronic method.	The biofilm network was dramatically destroyed after the professional dental cleaning. OCT noninvasive methods can act as a valuable tool for the 3D characterization of dental biofilms.
(11)	48	Fernandes et al.	In vivo assessment of periodontal structures and measurement of gingival sulcus with optical coherence tomography: a pilot study	OCT has the potential to be a reliable tool for in vivo periodontal tissues evaluation and for reproducible sulcus depth measurements in healthy sites. Further technological advances are required to reduce the procedure time and promote evaluation of posterior oral regions.
(12)	49	Salehi et al.	Characterization of human oral tissues based on quantitative analysis of optical coherence tomography images	These OCT features can reliably differentiate between a range of hard and soft tissues and could be extremely valuable in assisting dentists for in vivo evaluation of oral tissues and early detection of pathologic changes in the tissues.
(13)	50	Englund et al.	Assessing the dynamic biofilm removal of sulfonated phenolics using CP-OCT	This novel CP-OCT flow cell assay has the potential to examine rapid interactions between antibiofilm agents and tooth like surfaces.
(14)	51	Bordin et al.	Optical coherence technology detects early signs of peri-implant mucositis in the minipig model	Development of clinical applications of OCT imaging for early diagnosis of mucositis could lead to therapeutic interventions to reduce one of the causes of implant failure.

(15)	52	Kim et al.	Improved accuracy in periodontal pocket depth measurement using optical coherence tomography	OCT was able to visualize periodontal pockets and show attachment loss. By calculating the calibration factor to determine the accurate axial resolution, quantitative standards for measuring periodontal pocket depth can be established regardless of the position of periodontal pocket in the OCT image.
(16)	53	Chen et al.	Quantifying dental biofilm growth using cross-polarization optical coherence tomography	CP-OCT has the ability to non-destructively monitor biofilm growth and elucidate the growth characteristics of these microcosms on different dental material compositions. CP-OCT was able to quantify the mass of the biofilm by measuring the overall depth-resolved scattering of the biofilm.
(17)	54	Adegun et al.	Quantitative analysis of optical coherence tomography and histopathology images of normal and dysplastic oral mucosal tissues	Quantitative differentiation of normal and dysplastic lesions using OCT offers a noninvasive objective approach for localizing the most representative site to biopsy, particularly in oral lesions with similar clinical features.
(18)	55	Adegun et al.	Quantitative optical coherence tomography of fluid-filled oral mucosal lesions	The differentiation of normal and fluid-filled areas using individual SID values yielded both a sensitivity and specificity of approximately 80%. OCT complemented by SID analysis provides a potential in vivo clinical tool that would enable non - invasive objective visualization of the oral mucosa.

VIII. Discussion

Periodontal Diseases (PD) is chronic multi factorial conditions, characterized by the destruction of periodontal tissues. Periodontal health depends on the balanced relationship between the dental biofilm and the immune inflammatory response of the host[28]. Traditionally, PD diagnosis is performed through clinical examination to detect signs of inflammation, presence of supragingival and subgingival calculus, as well as evaluation of clinical insertion and loss of bone through periodontal probing. Despite the low cost, wide use and acceptance in the scientific and clinical environment, traditional periodontal probing is prone to errors during its execution, in addition to not identifying PD in the subclinical phase[29]. The search for an early diagnosis method, as well as the monitoring of periodontal tissues with greater precision and sensitivity allied to non-invasiveness, has triggered interest in the use of alternative techniques such as OCT[30,31,32].

In a study by Mota et al. 2015[30] where Five fresh porcine jaws were sectioned and Two- and three-dimensional OCT images of the tooth/gingiva interface were performed, and measurements of the gingival structures were obtained; they concluded that through image analysis, it is possible to identify the free gingiva and the attached gingiva, the calculus deposition over tooth surfaces, and the subgingival calculus that enables the enlargement of the gingival sulcus. In addition, the gingival thickness and the gingival sulcus depth can be non-invasively measured, varying from 0.8 to 4 mm.

Also in a similar study by Fernandes et al. 2017[31,32], where 445 sites of 23 periodontally healthy individuals were measured by 3 instruments: North Carolina manual probe, Florida automated probe and OCT at 1325 nm. they concluded that OCT is suitable for in vivo humans imaging of the microscopic appearance of gingival sulcus and nearby tissues without any adverse side effects, artifacts or staining procedures. In another study by the same author Fernandes et al. 2018[32] in another study where 14 patients aged 18-65 years old diagnosed with periodontal disease were evaluated prior and after treatment, and a total of 147 labial sites from 49 anterior teeth were analyzed. Preliminary results were already reported[32,33]. They concluded that from the longitudinal study clearly point out to the importance of using optical coherence tomography in the identification of periodontal structures in follow-up of treatments.

However, it presents with some technical limitations, such as light penetration depth and scan window lower than the size of the pockets, OCT presents advantages as non - invasiveness, possibility of 2D and 3D images in real time, which can be assessed at distance by experts, providing a real case for telemedicine[32]. The technique is efficient in monitoring not only periodontal disease, but has also applications in other niches in dentistry, both in soft and hard tissue, as well as dental materials[34]. Particularly to PD, manual periodontal probes have evolved to minimize errors and operator manipulation, and are currently in their fifth generation[35]. When one associates the advantages of OCT as a non - invasive method associated to appearance of low cost OCT systems[36] there arises one question whether it holds a future and would replace current periodontal probing method thus hoping for the addition of OCT as 6th generation of periodontal probes.

IX. Conclusion

OCT is a current promising diagnostic technologies that can be used to revolutionize periodontal examination. However more in-vitro and in-vivo studies should be carried out in this aspect to take advantage of the excellent diagnostic imaging properties of OCT.

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