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Review

Optical Coherence Tomography in Early Caries Detection: Review

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Abstract

Optical coherence tomography (OCT) enables monitoring and quantifying the demineralization process within dental structures, which aids in early detection of dental caries. By utilizing non-invasive and non-ionizing radiation, OCT captures high resolution optical images at faster acquisition rates. This technique is based on low coherence interferometry that can provide three-dimensional images. This review focuses on the principles of OCT and its application in early caries detection. Numerous *in vitro* and *in vivo* studies have revealed the efficiency of this powerful tool to detect incipient lesions. Further research is recommended to validate the clinical usefulness of this emerging diagnostic aid.

Keywords: *Optical coherence tomography; demineralization; incipient lesion; caries; interferometry*.

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INTRODUCTION

Dental caries, a multifactorial microbial infectious disease is commonly encountered in dentistry resulting in the localized dissolution and destruction of dental calcified tissue [1,2]. Wide clinical studies reveal that the disease states range from incipient, subsurface changes to advanced stage with loss of the enamel and significant dentin involvement [3,4]. Identification of dental caries, understanding the disease progression plays an important role in prevention and treatment of the condition. On early detection of carious lesions, remineralization strategies can be applied to arrest or reverse the process. The prognosis of this treatment depends upon accurate monitoring and detection of the lesions [5]. Failure to detect early dental caries, leads to poor results and outcomes for remineralisation procedures.

Routine techniques such as visual and tactile methods are unable to help in detection of caries in its early stage. Routine radiographs have poor sensitivity in early carious lesion detection since the demineralization is minimal and hence do not provide enough contrast [6]. Advanced radiology like CBCT requires expertise to use the tools to detect dental caries. To overcome such limitations, newer detection methods that allow early lesions to be quantified are studied. This enables a system to monitor caries progression or resolution by remineralisation. This paper reviews briefly on the basics and application of OCT in early caries detection.

Optical Coherence Tomography

OCT is a promising non-invasive and non-destructive imaging. High resolution (10-30µm) morphologic depth images can be obtained with this device. OCT is comparable to ultrasound but uses light waves rather than sound waves. However, OCT provides image resolution higher in magnitude than ultrasound methods.

The technique is based on coherent back-scattered light and works on the principle of white light Michelson interferometry [7]. The system comprises a Michelson interferometer connected to a handpiece that creates a tomographic scan. A fiber-optic splitter divides the low-coherence diode's light beam into the interferometer's sample and reference arms. The backscattered light from the sample arm and reflections from the reference mirror bounce off each other, are mixed, and are then absorbed by the detector [8].The reflected pattern creates an interference pattern which generates a depth profile at a single point along the laser trajectory (Figure 1) Moreover, a changing optical delay within the reference arm with a filtering reflect working of known speed, the pivotal positions of the reflected signals can be gotten and measured. The size of the reflected light is decided by the optical scattering properties of the tissues. The signals are allotted a gray scale and the pivotal signals are serially shown creating an OCT picture of intrigued. This 2 – dimensional representation of OCT pictures of tissue can be seen in genuine time and stored digitally [9].

Principles of OCT

a. **Time domain OCT (Td-OCT)**

The time domain (TD-OCT) theory underpinned the original OCT technology. Here, the laser beam within the Michelson interferometer is separated into 2 parts by a beam splitter. The split beam takes after a reference path that incorporates reflections from the reference reflect and different layers inside a sample. Due to the light's broadband nature, impedances between the beams can only be seen when the reference and test arms' optical path lengths are equal to or less than the light's coherence length. The pictures obtained are observed as an arrangement of dark and bright borders, when the path distinction lies inside the coherence length of the light source [7].

b. **Fourier domain / Spectral domain OCT/ Spatially Encoded frequency Domain OCT**

In this configuration, the reference arm's optical path length stays constant while the interference pattern is divided into its frequency components and measured with the help of a spectrometer. Advantage of this method includes increased acquisition rate, possibility to separate dependence on axial resolution.

c. **Full Field OCT/ En-face OCT**

This type of OCT is based on white-light interference microscopy. It provides high resolution images in three dimensions using halogen lamps instead of laser beams. The images obtained are in the en-face /transverse orientation, where the interferometric images are recorded by CCD camera.

d. **Polarization – Sensitive OCT (PS-OCT)**

This type of OCT is capable of providing high resolution images by tissues exhibiting special characteristics called "Birefringence". When a light ray passes through certain anisotropic materials, it splits into two phenomena known as birefringence or double refraction. Sound/carious enamel or dentin structures are highly transparent and birefringent resulting in high resolution images. As a result of demineralisation due to carious processes, changes in the optical properties of enamel and dentin are markedly observed. Such changes enable the early detection and characterization of lesions in OCT technique.

e. **Swept Source OCT (SS-OCT)**

Swept source OCT technique provides a faster image acquisition. SS-OCT uses a tunable laser that sweeps the wavelength over a certain range. This kind of OCT can scan through the range of relevant frequencies and the reflected beam can be detected by a single photodetector. Advantage of this OCT includes faster scan speed, higher scan density and improved finer transverse resolutions.

OCT systems can acquire *A-scans/axial* scan images. The images obtained here are by focusing the laser beam to a point on the sample and combining the reflected light with the reference. Image gives a clear representation of the depth of the tissue. *B-scans/longitudinal* scan images are acquired by combining many single axial scans linearly across the tissue and in transverse positions. Images will show both depth axis and lateral axis. *En-face images/C-images* are made by combining many transverse slices. Acquisition of images in the above-mentioned ways helps in a three-dimensional representation of the structure [7].

How relevant is OCT in early caries detection?

OCT can provide high resolution images of those tissues (like enamel and dentin) which exhibit light - polarization properties. The crystalline scatterers within the tooth matrix are anisotropic and birefringent in nature, resulting in tooth imaging [10]. Application of OCT within the field of dentistry was performed by Colston et al in 1998. It supports exact representation of enamel and dentin structures. Their investigation led to the advancement of a novel dental OCT framework that consisted of a sample arm and scanning optics inside a handpiece instrument [11]. This system had a lateral resolution of 50µm, with a total lateral scan distance of 12mm using a laser beam of wavelength 1,310nm.

Thereafter, various studies were encouraged in imaging dental hard tissues using OCT. In 2001, from the university of Texas, Amaechi et al performed studies dealing with the methodology of OCT [12]. An in-vitro study in 2003, involved the quantitative comparison of OCT with QLF [13]. A study in 2004, described the comparison of OCT with transverse microradiography in the determination of mineral loss in caries affected tooth [14]. The authors used an OCT system, which had a wavelength of 850nm and optical source width of 16 µm.

Further experiments described the efficacy of PS-OCT in detecting early dental lesions. *Fried et al*, in 2002 elaborated that PS-OCT was suitable in demonstration of enamel demineralisation [15]. In a study by *Yasushi Shimada*, 3D OCT showed A higher specificity and accuracy in detecting dentinal proximal caries than digital dental radiography which was corroborated by histological study [16]. OCT techniques are also capable of detecting microstructural changes for voids, fractures, marginal integrity and early stages of demineralisation beneath restorative sealants or orthodontic brackets [17]. PS-OCT technique has a higher image acquisition rate and resolution compared to other techniques.

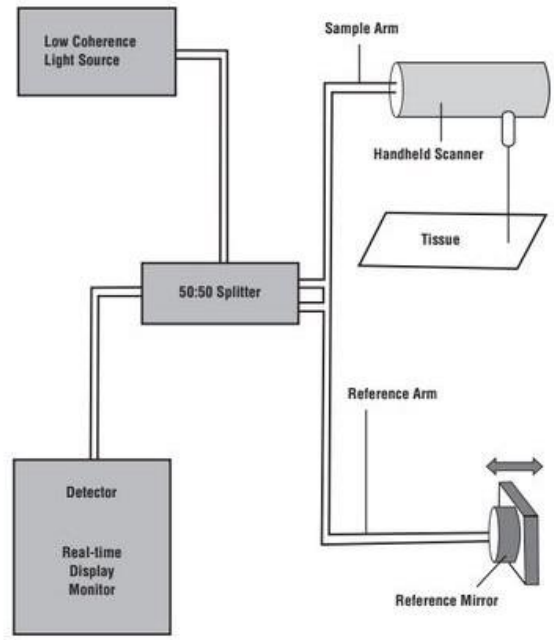

Figure 1: Principle of OCT

Clinical trials on caries research using OCT have been attempted. In vivo study, by *Feldchtein et al*. presented high resolution images of dental enamel, dentin and restorations [18]. Studies by *Wang et al*, also elaborated on the birefringent property of enamel and dentin [19]. OCT also plays a critical role in the evaluation of remineralization of the tooth with fluoride application. It helps in determining the progression of decay and its treatment outcome [20]. Recent study by *Xing et al* has shown the efficiency of detection of non cavitated proximal caries with cross-polarized optical coherence tomography (CP-OCT) and found the coronal plane to be superior to the horizontal plane. This is critical as detecting non-cavitated proximal caries clinically due to the presence of adjacent teeth is challenging [21]. Erdelyi et al. explored the abilities of OCT in optimizing X-ray units imaging. By implementing optimal protocols, low radiation doses can be achieved. It also aids in providing a qualitative image [22].

CONCLUSION

The OCT, a recent imaging technique for detection and analysis of early dental caries, enables in quantifying the demineralised state of dental structures. Detailed knowledge regarding lesion location, lesion depth, surface characteristics, defects such as cracks and fissures are known in OCT images. OCT can be used routinely to screen for early lesions, to assess the caries process, to determine the remineralization treatment and to motivate the patients. Investigations with the OCT system, would be a vital tool for dentists and researchers. Imaging process provides information in various aspects such as in rectangular, transversal and axial directions thus allowing proper diagnosis. Thus, activity of caries lesions can be assessed followed by providing effective treatment. Usage of a tool, with high sensitivity and specificity, will be a promising adjunct to assist dental professionals and researchers in decision – making and treatment planning.

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