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Radiology

OPTICAL COHERENCE TOMOGRAPHY (OCT) - A REVIEW

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ABSTRACT Optical Coherence Tomography (OCT) is a new technology, which gives a 3 dimensional, non-invasive imaging modality which produce high-resolution images of a biological tissues in cross section. OCT is analogous to ultrasound imaging, except that it uses light from broadband laser light source instead of sound. In the year 1991, Huang and co-workers were first introduced OCT which was initially used for retinal imaging. Later in 1998, Colston et al were introduced OCT for dental applications. It can provide images of tissue in situ and in real time. OCT can be used where standard excisional biopsy is hazardous or impossible, to reduce sampling errors associated with excisional biopsy, and to guide interventional procedures. This review article focuses on principle and various applications in dentistry till date.

KEYWORDS : Tomography, laser light

Introduction:
Radiology has evolved leaps and bounds from its initial two dimensional days, each new steps of progress promises better diagnostic properties and minimal invasiveness. Though imaging has some variation due to a difference in angulations and radiographic techniques, but newer modalities of imaging such as Optical coherence tomography (OCT) can overcome those limitations.OCT is a recently described, non-invasive, non-destructive and noncontact technique for obtaining high resolution (<20-μm) cross sectional images of biologic structure. It was initially applied for tomographic imaging of transparent tissue like eye for diagnosis of retinal macular diseases.[1]

Other than eye, OCT can detect qualitative and quantitative morphological changes of hard and soft tissue structure in the oral cavity in vivo. OCT has the potential to detect and diagnose very early stages of demineralization and remineralization, recurrent caries, restorative failures, root canals, periodontal disease, soft tissue dysplasia and precancerous lesions in real time.[2]

Historical background:
The concept of using light and optics to image biological tissues was first proposed by *Duguay* in 1971. *Fujimoto* in 1989 imaged the retina of the eye using OCT. *Huang et al* in 1991 did extensive work on the usage of OCT for retinal imaging, optic nerve head structure and coronary arteries. *Fercher et al* presented the first *in vivo* OCT images in 1993. In 1994, *Carl Zeiss Meditec*, Inc (Dublin, California) patented OCT. The first commercially available OCT, called OCT 1000, was marketed in 1996 and then OCT 2000 in the year 2000. Application of OCT in dentistry has become very popular. The first in vitro images of dental hard and soft tissues in a porcine model were reported in 1998 by Colston et al. They developed a prototype OCT and acquired images of porcine periodontal tissues.[3] *Otis et al* in 2000 proposed the OCT imaging for dental applications. [2]

Principles of OCT:
There are two fundamental optical tomographic techniques as follows- A diffuse optical tomography (DOT) and optical diffraction tomography (ODT). OCT is based on ODT.[4] In the year 2000, Otis et al

developed a dental OCT system which consist of a computer, compact diode light source, photodetector and hand piece that scans a fiber optic cable over the tissue. [2]

An OCT system is an optical technique which utilizes short coherence-length broadband light reflectance to produce high resolution and cross sectional image.[4] Because the reflectance delay times for light are extremely short, determination of delays requires use of **white light Michelson interferometry method**.[2] OCT technology has capabilities for outstanding resolution parameters (1–2 μm resolution has been reported), real-time visualization, and endoscopic access through rigid or flexible fiber-optic probe.[5] OCT utilizes non-invasive light and biomedical optics to provide cross-sectional 'optical biopsy' images of tissue up to 3 mm in depth, measured from the tissue surface. An optical biopsy is defined as a method for imaging tissue pathology without the surgical removal of tissue, while the resultant image correlates well with that of histopathology.[2] For OCT, light is emitted from a broadband laser light source towards a partially reflecting mirror, made up of fiber-optic devicewhich acts as an **optical beam splitter**. This fiber-optic splitter separates the light from low coherence diode into the sample and reference arm of interferometer. This One arm of the resulting light beam is directed towards a reference mirror at a specified distance from the fiber-optic splitter, known as **Reference delay arm**. The other beam is projected towards the biological tissue sample to be examined, known as **Sample arm**. Light directed toward the reference mirror reflects back with a specific time delay which is proportional to the distance traveled, while the reflected light beam from a biological tissue consists of multiple echoes which are determined by the optical reflectivity of structures within the sample. These two reflected light beams (the reference and sample arms) are recombined and propagated to a photo detector. The magnitude of reflective signals is determined by the optical scattering properties of the tissue. Thus, image contrast is determined by the optical properties of the tissue. An inter-ferometric signal is detected when the distance of two reflected arms are matched with coherence length of the source. The light source is coupled with He-Ne laser guidance beam for visualization[5]. (Fig 1)
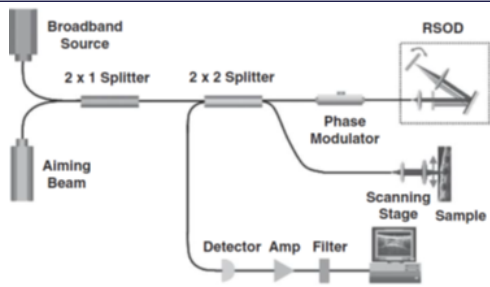
Fig 1- Schematic of optical coherence tomography (OCT) imaging system.

Short coherence length broadband light reflectance is used as a light source, RSOD- acts as a reference mirror

The OCT image thus obtained is a two-dimensional representation of the optical reflections of tissue in cross-section and the images can be viewed in real time and can be stored in a digital format.[2]

Scanning Procedures in OCT Imaging:
There are three main scanning procedures depending on the engine performing the imaging and its application.

1. *A-scan or Axial scan:* It measures the depth of the tissue being scanned which is determined by optical reflectance of the tissue. The data obtained is one dimensional.[2]
2. *B-Scan:* B-scan or longitudinal scan is similar to ultrasound B scan. It is generated by collection of many single axial scans linearly across the tissue and following these scans in transverse positions. In this scan both depth and lateral axis of the object can be assessed.
3. *T-Scan:* T-scan or En-face scan is produced by transversally scanning the beam over the target and subsequently maintaining a fixed reference point.[2]
4. *C-Scan:* It scans in a transverse direction which is actually a collection of many T scans transversally. Usually applied for retinal imaging.

Types of OCT: There are several types of OCT such as,
• Time Domain OCT (TDOCT)
• Spectral Domain OCT (SDOCT)
• Functional OCT
• Sensitive OCT
• Polarization Sensitive OCT
• Differential Absorption OCT
• Doppler OCT
• En-Face OCT or Full-Field OCT

OCT works on the principle of Michelson or Mach-Zehnder interferometer.[2] Depending on the type of OCT used, the signal is captured by a photodiode (PD) or charge-coupled device (CCD). The signal may undergo two types of interference-Non-constructive and constructive. Non-constructive occurs when the optical pathlength (OPL) of light reflected by the reference and sample is same. Constructive interference occurs when OPL between the light reflected by the reference and sample is in multiples of wavelength.[3]

Time domain OCT (TD-OCT): The path length of the reference arm is scanned in time. It was the first OCT used in dentistry. Interference is only achieved when the **optical path difference (OPD)** lies within the coherence length of the light source. Applications such as, evaluation of indirect dental restorations, apical micro leakage after laser – assisted endodontic treatment, monitoring the periodontal ligament changes induced by orthodontic forces and orthodontic interfaces.[2]

Spectral domain OCT (SD-OCT): Here, spectrum at the output of low coherence interferometer is measured. It can be divided into Swept source (SS-OCT) and camera based. By this method, we can measure all depths of soft tissues in one measurement. Thus it has an advantage of improving imaging speed as well as signal to noise ratio.[2]

Functional OCT: In this type, the signals obtained from functional changes of the tissue or the organ involved, which usually precede morphological changes and thereby it is helpful for early diagnosis.

Polarization Sensitive OCT (PS-OCT): OCT is capable of coherence detection of polarization states from the backscattered signal. Therefore more information can be obtained by polarization sensitive OCT (PS-OCT) by enhancing the detection power of OCT.[6]

Differential absorption OCT: In this modality, two light emitting diodes with different wavelength are used. Among the light-emitting diodes, one emitting in a vibrational absorption band of the chemical compound of interest and the other emitting just outside this band, are used as sources at the input of the interferometer. By this modality, we can distinguish lipid and water inclusions in a scattering material.[7]

Doppler OCT (DOCT): This modality was introduced to visualize and quantify blood flow. Nowadays phase-sensitive detection techniques are most widely used to determine blood velocity and blood flow from tissues. Doppler OCT has the potential to improve our abilities to diagnose and monitor ocular vascular diseases.[8]

En-face OCT: This is an emerging imaging technique derived from spectral domain **OCT**. It produces frontal sections of retinal layers, also called "C-scan **OCT.** This produces transverse images of retinal and choroidal layers at any specified depth. It provides an extensive overview of pathological structures in a single image.[9]

Dental applications of OCT:
In dentistry, OCT is used to support diagnosis, treatment planning and patient education. It provides a localized, digital image in real time. By this advance modality, we can evaluate the margins of oral lesions, detect caries or tooth fractures, and support the diagnosis of periodontal disease. It is also useful in measuring caries preparations for restorations created by computer-aided design/computer-aided manufacturing (CAD/CAM) technology.

Initially OCT was developed to image the transparent tissue like eye; recently it has been used for transparent as well as non-transparent tissues. The oral cavity is ideal for OCT imaging as it has both nontransparent and transparent tissues. Also it is easily accessible for interrogation by the fiber optic OCT device. Applications of OCT in dental practice are as follows:

• **CARIES DIAGNOSIS-** Human tooth consists of primarily enamel, dentin, and pulp which do not show strong X-ray contrast. With the help of OCT B-scan (2D image), we can find the corresponding anatomic dental structure(Fig 1).[6] OCT provides the capability for early detection of demineralization (fig 2)[10]. OCT can predict the boundaries of the carious lesion and can also distinguish between active lesion, enamel dysplasia and stain. OCT can be very helpful in evaluation of tooth remineralization after application of fluoride or arrested caries and thus can be help in assessing the decay progression as well as it can predict the outcome of treatment.
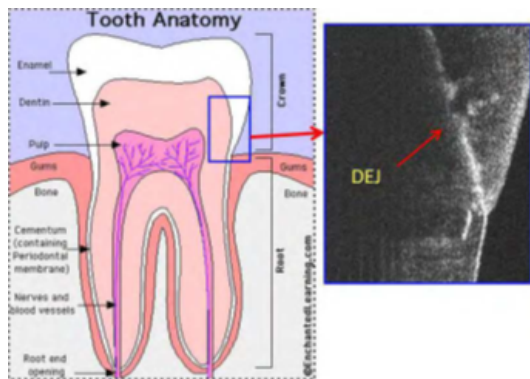

Fig 1-OCT B-scan (2D image), we can find the corresponding anatomic dental structure
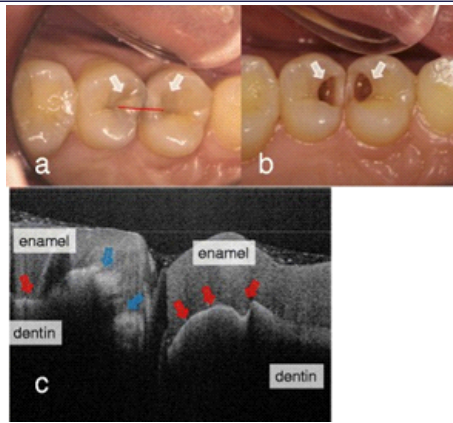
Fig 2- Dental caries with respect to first and second premolars. Swept-source(SS-OCT) image was performed, showing "Bright Zone" indicates the increased light scattering in porus demineralized tissue(Blue arrow) and a strong refelection penetration along DE junction suggestive of cavitated lesion(Red arrow).

- **ENDODONTICS-** OCT imaging canbe done in wet canal and gives detailedmicroscopic images from cementum todentin. Such measurements are capable ofindicating the exact thickness of the dentinalwall and can aid in determination ofminimal dentin thickness to prevent rootcanal over preparation and possible perforation of canal walls.Intra-operatively,OCT imaging of root canals canindicate fins, transportation of thecanals, hidden accessory canals and measurement of the apex (Fig 3).[11]
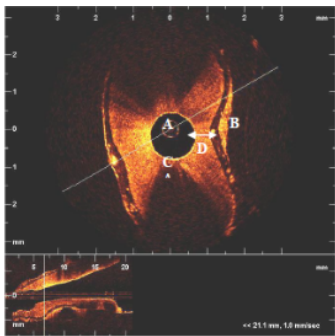

Fig 3- OCT demonstrates a prepared canal (A), Cementum (B), dentinal tubules(C), and risk zone (D).

- **Periodontal disease:** OCTcan provide excellent images of theperiodontal soft tissue attachment, contour, thickness and depth of the periodontalpockets *in vitro*.It is conceivable thatsulcular fluid will enhance contrast forimaging periodontal tissues *In vivo*.**Otis L et al.** concluded that the *In vivo* dental OCTimages clearly depicted periodontal tissuecontour, sulcular depth and connective tissueattachment. In addition, the authors statedthat as OCT reveals micro structural detailof the periodontal soft tissues and to identify active periodontaldisease before significant alveolar bone lossoccurs (Fig 4)[12].
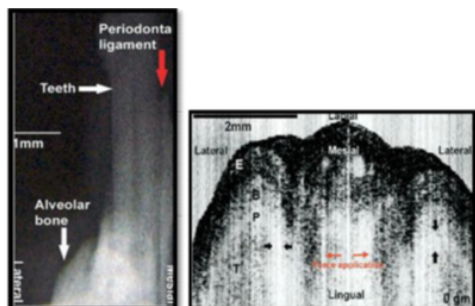

Fig 4- OCT images of a periodontal ligament

- **Prosthodontics:** The ability of OCT to detect and analyzeprobable fractures in fixed partial dentureshas been evaluated by different studies.Here, the image acquisition was done byobtaining both C-scans as well as B-scanimages. The resultant images showed voidsof different sizes and shapes between thematerial interfaces at different depths.

- **Detection of Malignancy**: OCTis found to be promising as it is minimallyinvasive, all cross-sectional imaging of tissuescan be constructed in real time.OCT is a valuable tool in the assessment of surgical margins. Tumor-involved margins can be identified by architectural changes and increase in epithelial layer thickness on the OCT image (Fig-5).The authorsconcluded that the diagnostic sensitivity andspecificity for differentiating betweenmalignant versus non-malignant lesions are 100% and 96%.
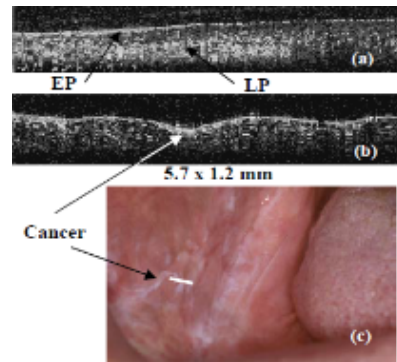

Fig 5 OCT scanned image for oral cancer

- **In evaluation of mucosal changes:** OCT can assess tissue damage at the time of radiation therapy, in real time

- **Implantology:** OCT imaging may detectperi-implantitis before significant osseousdestruction. It can provide evaluation of soft tissues around theimplant and also helps invisualizing the implant sulcus in two andthree dimensions as well as provides valuableinformation about the implant soft tissue interrelationship.[3]

Advantages:
1. High depth and transversal solution.
2. Contact-free and non-invasive operation.
3. Possibility to create Function dependent image contrast.
4. No radiation hazards.
5. OCT helps in early diagnosis of oral diseases.
6. OCT helps in real time monitoring of both hard and soft tissues.
7. Excellent resolution and penetration depth and hence can image the normal and abnormal changes in the oral mucosa.

Disadvantage:
1. Limited penetration depth inscattering media.
2. The scanning range of OCT is usuallyseveral millimeters; hence many pictureswould be needed to scan an entirelesion.
3. OCT takes a longer time to acquire theimage.

Conclusion:
As a general conclusion, it represents a valuable modality for investigation and assessment of oral hard and soft tissues. However, the unique capabilitiesof OCT imaging suggest that it has the potential to have a significant impact on the diagnosis and clinical management of many diseases.

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