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Optical Coherence Tomography in Dentistry – An Updated Review

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Abstract

Optical Coherence Tomography (OCT) is a new technology for performing high-resolution cross sectional imaging. OCT is analogous to ultrasound imaging, except that it uses light instead of sound. OCT can provide cross sectional images of tissue structure on the micron scale in situ and in real time. It is based on low coherence interferometry, employs near infrared light (long wavelength) which penetrates into the scattering media (e.g.: oral tissues) and capture sub-micrometer resolution. This paper reviews the understanding of the OCT, its basics, systems & setup, uses, limitations with the focus of it as a diagnostic imaging tool for oral lesions.

Keywords: Optical Coherence Tomography, Resolution, Ultrasound, Interferometry, wavelength.

Introduction

Optical coherence tomography (OCT) is an emerging diagnostic method for cross-sectional imaging of internal biological structures. OCT helps visualize differences in tissue optical properties, which include the effects of both optical absorption, and scattering.[1] The general principle of using reflections to create the images is the same for OCT and ultrasound but the methods for detecting these reflections are different. The use of light as the medium in OCT gives it the advantage of being non contact for the patient.[2]

As light is faster than sound, the time delays between reflections from different layers cannot be measured directly, the differences would be on the order of femto seconds, hence, OCT uses low-coherence interferometry to see the time difference corresponding to the distances between structures[3]. Initially, OCT was developed to image the transparent tissue, such as eye, recently it has been used to image non transparent tissues[4]. This added advantage has been utilised in imaging the oral cavity as they have both transparent and non transparent tissues. Moreover, oral cavity is particularly well suited for OCT imaging because they are easily accessible for interrogation by the fibre-optic OCT device. [5]

The non-invasive nature of this imaging modality coupled with (i) a penetration depth of 2–3 mm, (ii) high resolution (5–15μm), real-time image viewing, and (iii) capability for cross sectional as well as 3D tomographic images, provide excellent prerequisites for in vivo oral screening and diagnosis.[6]

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. Later, the in vivo imaging of human dental tissue was presented [7]. The oral cavity consists of three main parts: (1) hard tissue, including tooth and alveolar bone, (2) soft tissue, including mucosa and gingiva tissues, and (3) periodontal tissues [8]. The traditional diagnosis of caries is based on examination using dental exploration and radiographs. The diagnosis of periodontal disease needs the examination of periodontal probes. The poor sensitivity and reliability of periodontal probing make it difficult for dentists to monitor the progression of periodontal destruction and the treatment outcome [9]. Radiography may be the most popular diagnostic tool recently. However, radiography provides only two-dimensional images. The caries or bone structure on the buccal and lingual sides of teeth may be superimposed with tooth structures or normal anatomic structures. The radiation exposure of radiographic techniques is also a great concern. Furthermore, early detection of caries, periodontal disease and oral cancer is quite difficult with clinical examination or radiographs.

OCT may provide a solution to these problems. Dental OCT detects qualitative and quantitative morphological changes of dental hard and soft tissues in vivo. Furthermore, OCT can also be used for early diagnosis of dental diseases, including caries, periodontal disease and oral cancer, because of the excellent spatial resolution. Early detection and treatment can increase the survival rates of teeth and patients. Three-dimensional imaging ability is another advantage of dental OCT. It helps clinicians to locate problems in soft and hard tissues more accurately and rapidly.[10]

This review paper discusses the development of dental OCT. The applications of OCT in dentistry by imaging oral tissue, tooth decay, periodontal disease and oral cancer are also reviewed.

Historical Perspective

The concept of using light and optics to image biological tissues was first proposed by Duguay in 1971[11]. 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 imaging retina, 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. Otis et al in 2000 proposed the OCT imaging for dental applications. Wojtkowski et al., (2001) presented the first in vivo spectral-domain (SD)-OCT scans. In 2002, US Food and Drug Administration (FDA) approved the SD-OCT systems for clinical use[12].

Principle of OCT

Optical coherence tomography and US imaging has most often been compared. OCT and US imaging employ backscattered signals reflected from different layers in the tissue to reconstruct structural images, with the US imaging quantifying sound waves rather than light. The resulting optical coherence tomography image is a 2D representation of the optical reflection in a tissue sample.[13,14]

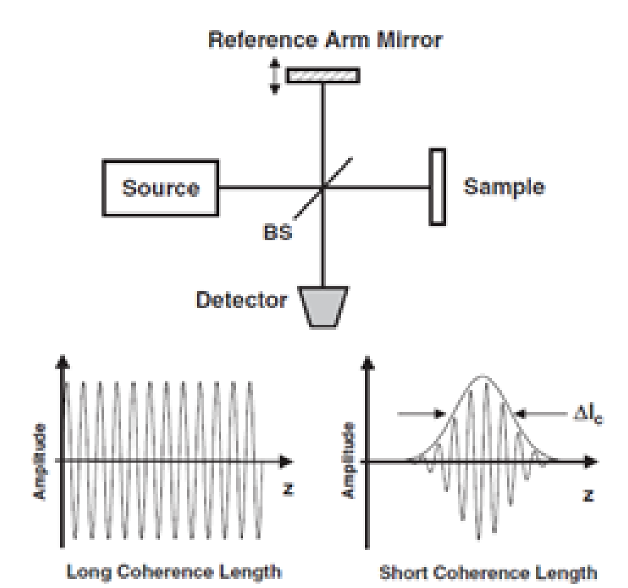


Figure 1. Schematic illustrating the concept of low coherence interferometry. Using a short coherence length light source and a Michelson-type interferometer, interference fringes are observed only when the path lengths of the two interferometer arms are matched to within the coherence length (Δl_c) of the light source.

Interferometry is the main principle of OCT. It is an evolving imaging modality that cumulates interferometry with low-coherence light to engender high-resolution tissue imaging. CS in-vivo images were obtained utilizing an OCT contrivance consisting of a Michelson interferometer, light source (1.3 µm broadband), and a handheld fiber optic imaging probe. Image pixel has reached the resolution of 10 µm. Broadband laser light waves are emitted from a source (Ws) and directed toward a beam splitter. One wave from the beam splitter is sent to the tissue sample (Wt) and the other toward a reference mirror (Wr). After the two beams reflect off the reference mirror and tissue sample surfaces at varying depths, they are directed toward the beam splitter, where they merge and together are directed to the photo detector (Wp), which will further analyze the beams (Figure 2). The analyzing interference of the recombined light waves engenders the image. CS images of tissues are constructed in authentic time, at near histologic resolution of 10 mm. The 10 mm resolution of OCT displays depth, thickness, peripheral margins, and histopathological appearances of the tissues in-vivo. Thus, OCT ameliorates on subsisting clinical capabilities, particularly for the identification of biopsy sites for monitoring of lesions, and for screening of a high-risk population. With 1-3 mm of tissue perforation depth, the imaging range of OCT diagnostics is opportune for the oral mucosa. The normal human oral mucosa is very delicate, ranging from 0.2 mm to 1 mm in thickness. Different scanning procedures in OCT imaging are axial scans withal called as A-scan, longitudinal scan or B-scan, En-face scans or T-scans and transverse slice scansl called as C-scan.[12-16]

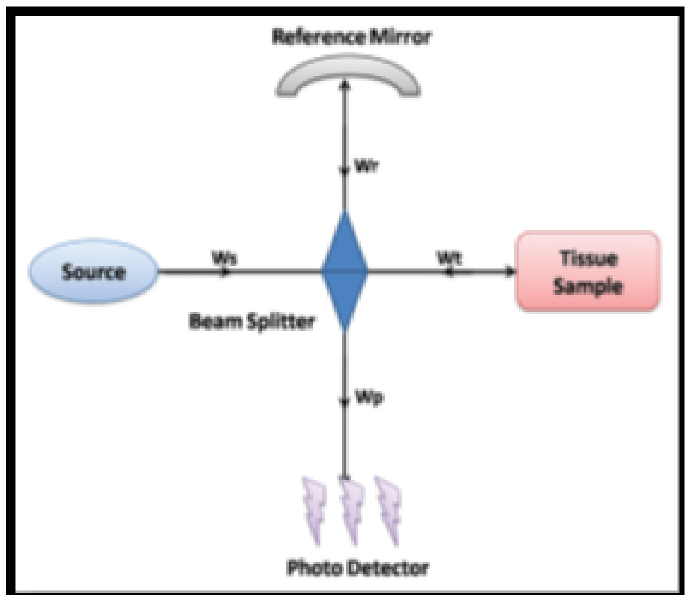


Figure 2

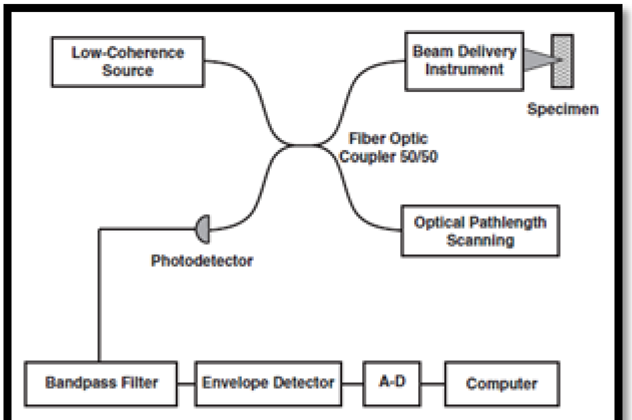


Figure 3. Schematic representation of an OCT system implemented using fiber optics. The Michelson interferometer is implemented using a fiber-optic coupler. Light from the low-coherence source is split and sent to a sample arm with a beam delivery instrument and a reference arm with an optical path length scanner. Reflections from the arms are combined, and the output of the interferometer is detected with a photodiode. The signals are demodulated, processed by a computer, and displayed as an image.

Scanning modes in OCT imaging: 17

There are three main scanning procedures depending on the engine performing the imaging and its application.

A-scan or Axial scan

It measures the depth of the object being scanned. The data obtained is one dimensional.

B-Scan

It is similar to ultrasound B scan. It is actually a collection of different A-Scans, taken linearly across the object and following this in a transverse direction. Thus both depth and lateral aspect of the object can be assessed.

T-Scan or en-face scans

It is produced by a beam which scans the object transversally while maintaining a fixed reference point. This reference point could either be angulated or in a lateral direction. It is the most popular modality to record the occlusion. It accurately records the force exerted, time taken and amount of occlusal surface in contact. This scan helps in determining the length of bite, the time and force with which the teeth occlude.

C-Scan or Coronal scan

It scans in a transverse direction and is actually a collection of many T scans transversally. It is particularly useful in imaging the retina.

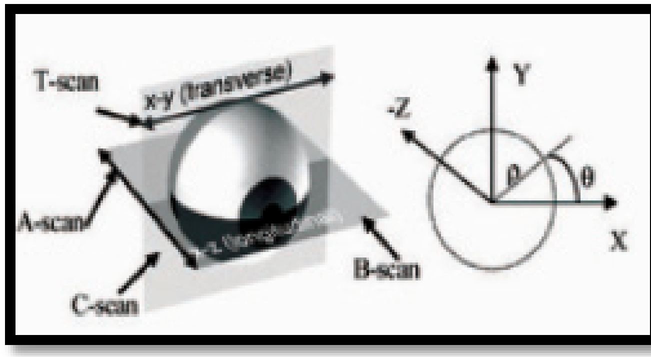


Figure 4: Relative orientation of the axial scan (A-scan), longitudinal slice (B-scan), x-y (transverse) scan (T-scan) and en-face or transverse slice (C-scan).

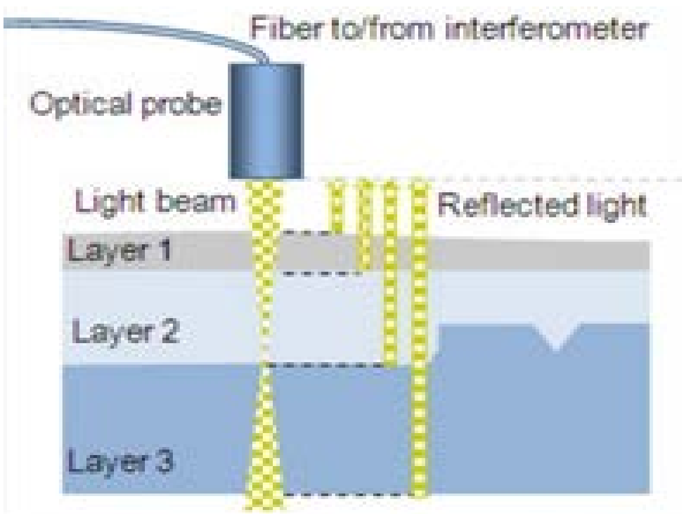
Main Characteristics Of Oct[12-16]

- The wavelengths utilized in OCT imaging lies within 600 to 2,000 nm, where the main constituents of the tissue, water, pigments exhibit low absorption
- To achieve high depth resolution, the optical spectrum line width should be wider and the coherence length should be smaller
- A strict phase relationship is required between the interfering waves for interference to take place. This is best achieved by single scattered photons rather than multiple photons because, as the number of photons increases, the event loses the phase information
- Photodetection at the interferometer output involves multiplication of the two optical waves, therefore, the weak signal in the object arm, backscattered or transmitted through the tissue, is amplified by the strong signal in the reference arm.
- This explains the higher sensitivity of OCT when compared with confocal microscopy, which for instance in skin can produce images only to a depth of 0.5 mm

- OCT is built around a confocal microscope, hence, the transverse resolution is determined by diffraction

Dental OCT imaging is considered safer as the power of the source in the assuming 8 hours of continuous exposure, when compared it is thousand times less than the current systems falls far below the American National Standards Institute (ANSI) standard for tissue damage.

- The ANSI threshold for skin damage using a source with a 1.3 mm wavelength is 96 mW, criterion.
- Live subsurface images at near-microscopic resolution.
- Instant, direct imaging of tissue morphology.
- No preparation of the sample or subject.
- No contact with the patient
- No ionizing radiation



A low-coherence light beam from an optical probe scans through a multilayer film. Note: the emitted and reflected light actually travels along the same axis (collinear scanning).

Figure 5

Table 1 shows a comparison between dental OCT and other dental diagnostic methods used today.[19-24]

Radiography	1. Low cost 2.Broad measurement range	1. Radiative 2.Poor spatial resolution 3. Only 2-D image
Dental-CT	1.Broad measurement range 2. 3-D image reconstruction	1.No real-time image 2. Radiative 3.Poor spatial resolution
Intraoral Digital camera	1. Low cost 2.Non-radiative	1. Only surface information
Periodontal probe	1. Low cost 2.Broad measurement range	1.Low sensitivity 2. No image 3. Invasive
OCT	1. High spatial resolution 2.Real-time image 3. 3-D image reconstruction is available	1.Limited penetration depth and scanning range
Raman spectroscopy	1.High sensitivity 2.Responses to mineral and chemical concentrations	1.In vitro measurement 2. Expensive 3. No image
Laser fluorescence spectrometer	1.Real time detection 2.Responses to bacteria and chemical concentrations	1.Lack of diagnostic consistency 2.No image

Types of OCT[18]

There are two main types of OCT

- Time Domain OCT (TDOCT)
- Spectral Domain OCT (SDOCT)
- Functional OCT
- Sensitive OCT
- Polarisation Sensitive OCT
- Differential Absorption OCT
- Doppler OCT
- En-Face OCT or Full-Field OCT

Applications of Dental OCT

Early OCT studies focused mainly on the topics of dental soft and hard tissue morphology because of the limitation of system size and light source manufacture technology. Nowadays, OCT is not only an "imaging tool" but also an important and non-invasive method could be applied in advanced diagnosis problems such as tooth decay, periodontal disease and oral cancer. The use of OCT in dentistry is further simplified with the introduction of handy dental probes where diagnosis can be done on the chair side.[25,26]

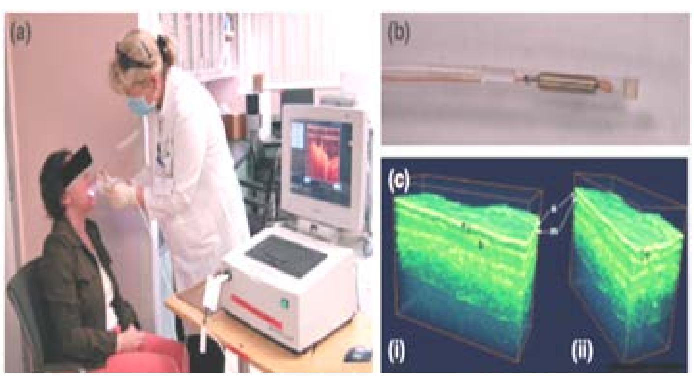


Figure 6: (**a**) Intra-oral imaging using the Imalux™ OCT system (Imalux Corp., Cleveland, OH, USA). (**b**) Photograph of intra-oral fiberoptic probe (Reproduced with permission: Jun Zhang and Zhongping Chen for 3D imaging). (**c**) In the 3D reconstructed OCT images of healthy hamster cheek pouch mucosa, the surface squamous keratinized epithelium, and underlying submucosa and muscle layer are clearly visible (A: Anterior view; B: Lateral view; e: epithelium; b: basement membrane; m: mucosa). From: Jung WG, Zhang J, Chung JR, Wilder-Smith P, Brenner M, Nelson JS, Chen Z (2005). Advances in oral cancer detection using optical coherence tomography**.**

Figure 7: Handheld probe for oral OCT

Normal tooth structure

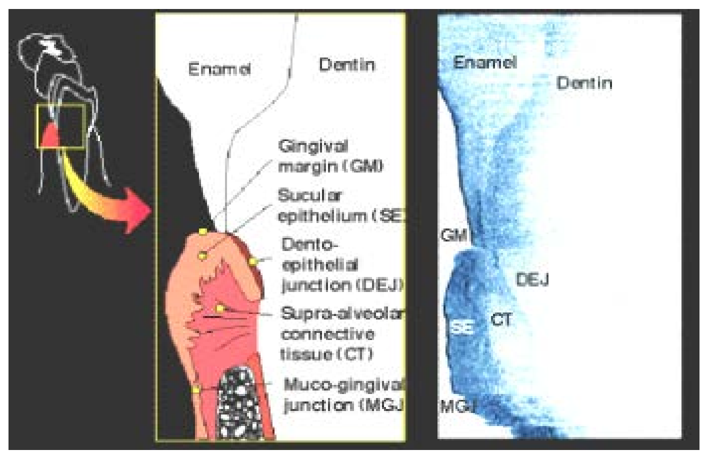


Figure 8: Reprinted from: Optical Engineering Laboratory, 2001 [27]

In general, there are different types of clinical scenarios wherein OCT could have important applications.

1. Dental X-rays considerably underestimate caries lesion size and are not sensitive enough. By the time a lesion is visible on radiographs, the demineralization has extended to or beyond the middle third of the dentin.

2. Tooth cracks have been a diagnostic challenge because of the difficulty in locating the fracture lines of an

incomplete fracture. Early detection and diagnosis are important to limit crack growth.

3. Clinical assessments of margin quality for intraoral restorations are routinely carried out in dental practice; however, the replacement of existing restorations and the decisions related to treatment planning are very subjective

In Caries Diagnosis: [28]

Caries is an important dental care issue. Caries has high prevalence and wide distribution among ages. The World Health Organization (WHO) revealed that dental caries is still a major public health problem globally and major public health problem in most high-income countries. The enamel displays powerful birefringence and there is anisotropic propagation of light via dentinal tubules. Baumgartner et al. presented the first polarization resolved images of dental caries. Wang et al. measured the birefringence in dentin and enamel and suggested that the enamel rods acted as waveguides [46]. PS-OCT is suitable for the detection of secondary caries, because the scattering properties of restorative materials and dental hard tissue have marked differences.

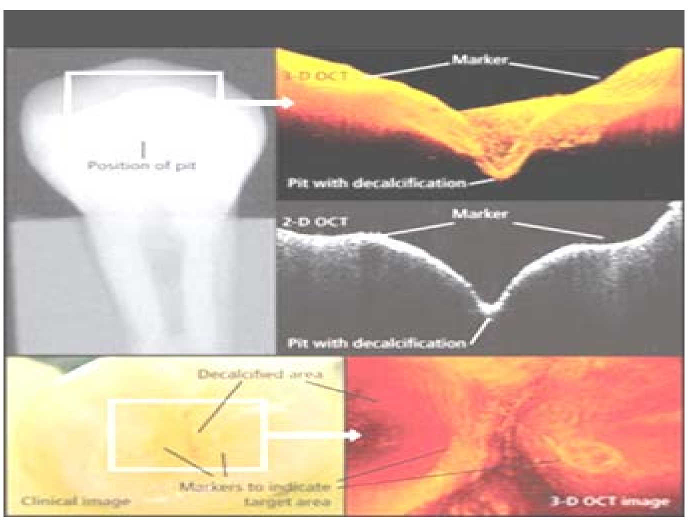


Figure 9

Presently, diagnoses of carious lesions are mainly through visual and radiographic examination. Unfortunately, the former does not detect the non-cavitated lesions, whereas the latter known for its high sensitivity and specificity for diagnosing primary caries are highly invasive and less reliable in the detection of early caries.

In such instances, OCT appears to be a promising technique by providing information about the extent of the carious lesion and it can also differentiate between stain, enamel dysplasia and active decay. Moreover, OCT can image through water, saliva and plaque and can record microstructural changes underneath any materials for marginal integrity, bonding interphase, structural fractures, voids and early stages of demineralization beneath occlusal sealants or orthodontic composite brackets.

OCT imaging can be helpful in determining the progression of decay and the treatment outcome by having a vital role in evaluation of remineralization of the tooth following fluoride application or in case of arrested caries. This is based on the hypotheses that the restoration of mineral volume would result in a measurable decrease in the depth-resolved reflectivity. Jones and Fried in 2006 conducted a study to test the above stated hypotheses by measuring the optical changes in artificially caries induced and remineralized human tooth specimens using PS-OCT. The authors concluded that the mineral volume changes before and after remineralization can be measured accurately on the basis of the optical reflectivity of the lesion.

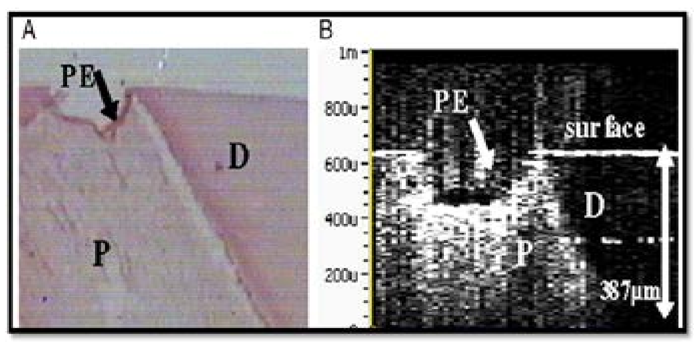


Figure 10: Site of pulp exposure. (A) Histologic cross-section of pulp exposure. (B) The pulp and dentin were

clearly delineated in the OCT image (P: pulp; D: dentin; PE: pulp exposure)

Endodontics:[29]

In case of root canal therapy, understanding the complexity of the root canals plays a vital role in its outcome. The OCT outsmarts conventional endoscopes through its small diameter and increased flexibility of the probe. In addition, OCT imaging does not require dry root canal and they provide a characterised microscopic detailed image through the surrounding root canal circumferential from dentin to cementum. Such measurements are capable of indicating the exact thickness of the dentinal wall and can aid in determination of minimal dentin thickness to prevent root canal over preparation and possible perforation of canal walls.

Intraoperatively, OCT imaging of root canals can indicate uncleaned fins, transportation of the canals, hidden accessory canals and measurement of the apex. Shemesh et al in 2007 evaluated OCT's ability to image root canal walls following endodontic preparation and correlated these images to histological sections. The authors concluded that OCT was reliable for imaging root canals and the dentinal wall in a nondestructive manner.

Determining the presence of vertical root fractures pose a challenge to the clinician and a threat to the tooth's prognosis, both during root canal therapy and postoperatively. Diagnosis of such fractures is difficult and mostly subjective, involving direct visualisation, bite tests, staining, transillumination, probing and radiographs. Radiographs are limited and can reveal a vertical root fracture only if the X-ray beam is parallel to the line of fracture. A controlled blind OCT endodontic study concluded that OCT is a valuable tool for imaging and identifying vertical root fractures and detecting the fracture's location along the root.

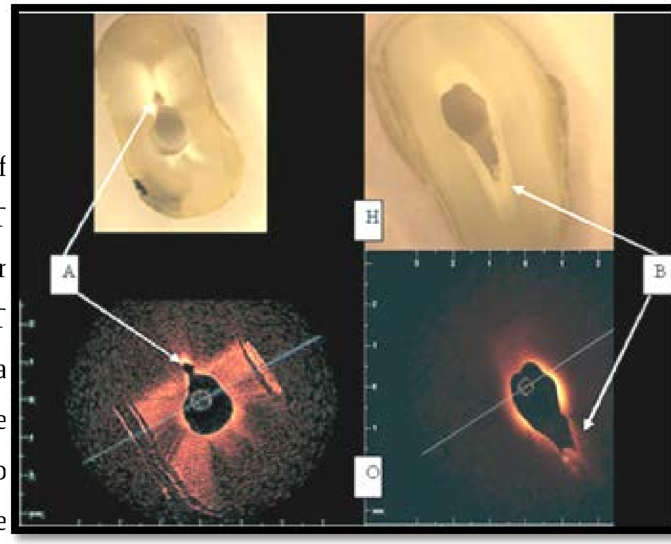


Figure 11: Oval canals and uncleaned fins at 7 mm from the apex revealed by histology (H) and optical coherence tomography (O). Oval canals (A) and canal fins (B).

Fracture lines in tooth

Fracture lines (FL) in enamel, zoom (occlusal overloaded anterior tooth, with a normal crown morphology): 18 degree in air if 18 degrees, this is not zoom, for the review you should give the size in mm

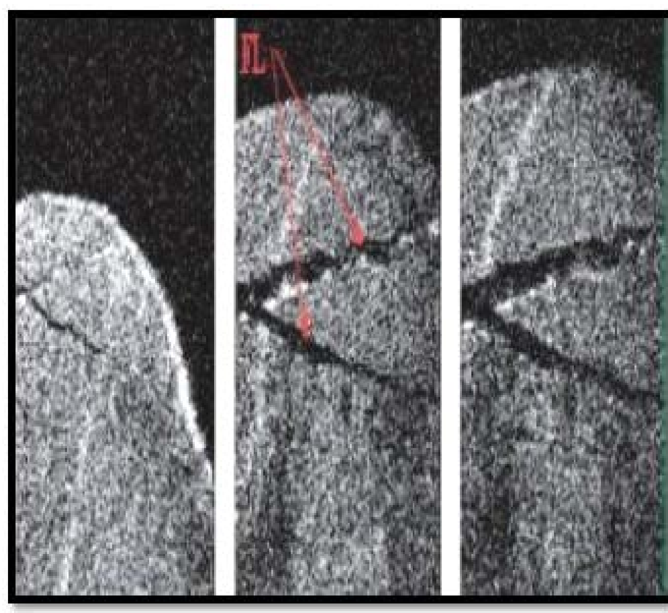


Figure 12: Reprinted from :Carmen Todea1, 2010

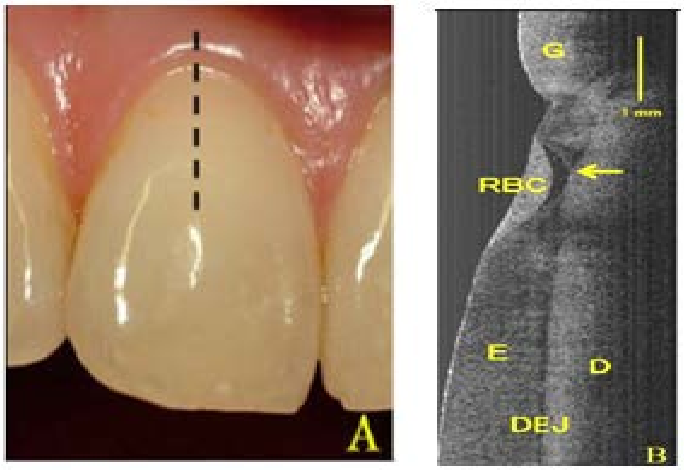


Figure 13: Photogragh (A) and SS-OCT image (B) of Class V restoration in the central incisor. Arrow shows microleakage formation beneath resin material (G: gingival; RBC: resin based composite; E: enamel; D: dentin; DEJ: dental enamel junction)

Periodontics:[30]

The microanatomy of periodontium and its soft tissue density does not allow routine imaging. Hence, the current periodontal diagnosis is completely based on clinical examination and evaluation of alveolar bony changes which are seen only after the progression of the disease. Otis et al in 1998 evaluated the accuracy of OCT for taking in vitro images of periodontal structures using an animal model. The authors found that the OCT images were comparable with the histopathology. However, the observations were limited because of the poor signal-to noise ratios associated with the bulk optics used. The images produced were thus merely topographical maps corresponding to characteristic reflections from the interface between tissue and air.

With the promising observations noted in the previous study Otis et al in 1998 performed a study with porcine mandibles using two prototypes dental OCT systems (an 850 nm wavelength, 700 mW system with a relatively low numerical aperture of 0.03 and a 1,310 nm wavelength, 140 mW system with a higher numerical aperture of 0.20). The images obtained through OCT were correlated with histological sections and clinical probing. The authors observed that the images generated using the 1,310 nm wavelength systems were significantly better as compared with those images obtained from 850 nm system. The authors opined that the improvement in the image quality of 1,310 nm wavelength system was primarily due to the two-fold increase in its imaging depth and also due to its larger numerical aperture.

The authors concluded that the OCT can provide excellent images of the periodontal soft tissue attachment, contour, thickness and depth of the periodontal pockets in vitro. At the outset, the authors hypothesized that another important mechanism that can improve the quality of the OCT image is the composition of tissue that is imaged. Hence, it is likely that in vivo OCT images will have improved contrast when compared to the nonvital specimens used in the present study. This is based on the theory proposed by Brezinski et al that the strong contrast between cardiac muscle and adjacent adipose tissue on OCT images found in his study may be attributable to their water content. Similarly, it is conceivable that sulcular fluid will enhance contrast for imaging periodontal tissues in vivo. Variations in the tissue fluid resulting from periodontal diseases may provide differences in contrast important for clinical imaging.

To evaluate the efficacy of OCT in vivo imaging of periodontium, Otis et al in 2000 performed a study among healthy adults with no clinical evidence of gingivitis or periodontal disease. The dental OCT system consisted of 140 µW, 1,310 nm superluminescent diode light source which can detect up to 70 femtowatts of reflected light. It has an imaging depth of approximately 3 mm, with an image acquisition time of 45 seconds. The authors concluded that the in vivo dental OCT images clearly depicted periodontal tissue contour, sulcular depth and connective tissue attachment. In addition, the authors stated that as OCT reveals microstructural detail of the periodontal soft tissues, it offers the potential for identifying active periodontal disease before significant alveolar bone loss occurs.

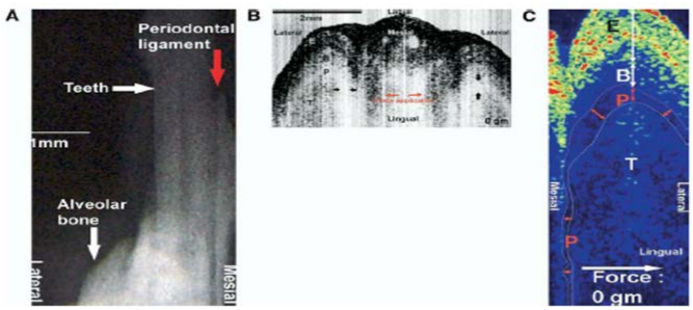


Figure 14: Images of a periodontal ligament. (A) Radiograph. (B) OCT. (C) Logging OCT images; the boundary of each tissue can be identified more clearly.

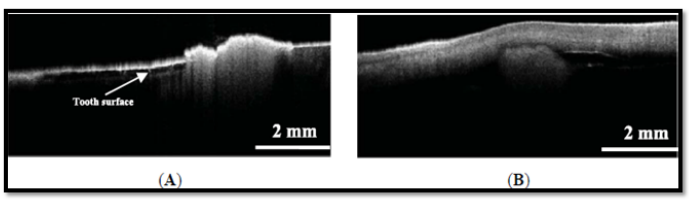


Figure 15: OCT image of subgingival calculus. (A) Subgingival calculus without coverage of gingiva. (B) Subgingival calculus covered with gingival.

Prosthodontics:[31]

The dental prosthesis are integrated of various materials which are bridged or bonded together, such as acrylics, ceramics, polymers, composites and metals. They are liable to fracture due to a variation in their physical and mechanical properties and masticatory load. Currently, several methods are employed for evaluation of the micro leakage, such as bacterial penetration, fluid transport, clarification and penetration of radioisotopes, electrochemical methods and gas chromatography. However, none of them are found be effective and can be considered standard.

Sinuescu et al in 2008 performed a study to evaluate the capability of OCT in detection and analysis of possible fractures in several fixed partial dentures using two single mode directional couplers with a super luminescent diode as the source at 1,300 nm employing enface scanning procedure. Here, the image acquisition was done by obtaining both C-scans as well as B-scan images. The resultant images showed voids of different sizes and shapes between the material interfaces at different depths.

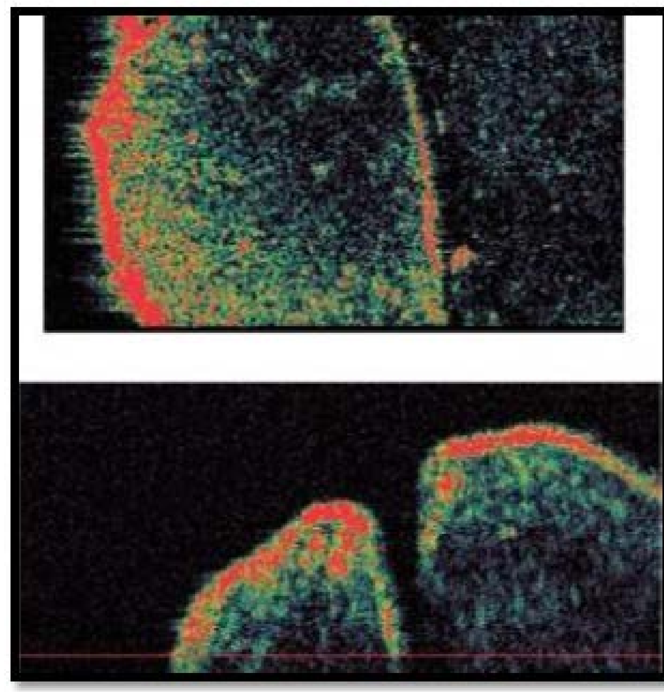


Figure 16: Marginal adaptation of an empress veneer on the proximal area

Orthodontics

Can be used for evaluating the demineralized white lesions surrounding orthodontic brackets, and for determining tooth movement under light orthodontic forces. OCT investigation provides information on the microleakage of the bracket's bonding , gaps are also assessed along the bracket base. A lack of adhesive material on the side of the bracket can be seen too.

Uses in the soft tissue pathologies:[32]

Oral mucosa : To operate OCT imaging of oral mucosa, a compact, dual wavelength, fiber-based superluminescent diodes operating at 830 nm (Dl=25 nm) and 1280 nm (Dl =50 nm) served as the short coherent length light source, producing 1.5 mW and 0.5 mW powers to the object respectively. The indepth resolution of the OCT scanner was 13 microns (830 nm) and 17 microns(1280 nm).

1. Masticatory Mucosa (gingival and hard palate mucosa)

A characteristic feature of keratinized regions in the oral cavity is the presence of relatively high connective tissue papillae projecting into the overlying epithelium. The 200 µm thick region beneath the squamous epithelium is the lamina propria (LP). The papillae of the LP within the epithelium contain strong

bundles of collagen fibers which are tightly interlaced and woven into the periosteum45 (bone covering tissue).

In the OCT scan, a distinct boundary between the LP and the periosteum is visible. The total depth of OCT imaging in the gingival mucosa is 600-650µm.

2. Lining Mucosa (alveolar, soft palate, labial, and buccal mucosa, as well as the mucosa of the mouth floor and the ventral surface of the tongue)

In OCT image of vestibular alveolar mucosa, the epithelium (EP) is seen as a straight, transparent layer ~150 µm in thickness. The LP, seen as the brightly backscattering (500 µm thick) strip in the OCT scan, is a fibrous connective tissue structure and is separated from the EP by a basement membrane. It also contains muscle fibers and blood vessels which weakly backscatter and appear as dark structures in the scan above the darker, bony attachment.

3. Specialized Mucosa (lips, dorsum of the tongue)

OCT images of those parts where the epithelium evidences high keratinisation (marginal gingiva, vermillion border of the lip, buccal zona intermedia, dorsal surface of the tongue, hard palate) substantially differ from images of those parts where EP evidences low or no keratinization in its normal state (alveolar mucosa, labial mucosa, floor of the mouth, and soft palate). Keratinization may reduce the contrast and makes it difficult to distinguish the lamina propria and submucosa from EP. OCT imaging also reveals blood vessels and glands in LP and submucosa because their optical properties differ significantly from their environment (fibrous connective tissue).

Malignant and potentially malignant condition:[33,34]

OCT can perceive early transmutations in malignant and premalignant changes like loss of epithelial stratification, hyperkeratosis, epithelial down growth, disruption of the basement membrane.

Accounting for 96% of all oral cancers, squamous cell carcinoma (SCC) is usually preceded by dysplasia presenting as white epithelial lesions on the oral mucosa (leucoplakia). Dysplastic lesions in the form of erythroplakias carry a risk of malignant conversion of 90%19. Tumour detection is complicated by a tendency toward field cancerization, leading to multi centric lesions. This high-resolution optical technique permits minimally invasive imaging of near-surface abnormalities in complex tissues, having a penetration depth of 1-2 mm. This permits in vivo noninvasive imaging of the macroscopic characteristics of epithelial and subepithelial structures, including: depth and thickness, histopatological appearance and peripheral margins. Oral mucosa is very thin, ranging from 0,2 to 1 mm.

In a study of Wilder-Smith, 50 patients were evaluated, examined and photographed with white or red intra-oral lesions. The imaging was carried out along the long axis at the center of each lesion using either a fiber optic high-resolution 3D OCT probe with a scan length of up to 10 mm or a commercially available 2D probe with a scan length of 2 mm Niris TM OCT imaging system by Imalux (Cleveland, OH). Contra lateral healthy tissues were scanned in a similar fashion. The acquisition required approximately 5-180 seconds per 3D scanning and 1,5 seconds for 2D scanning, totalling less than 15 minutes for each patient.

In the OCT images, epithelium, lamina propria, and basement membrane are clearly visible.

The OCT image of a dysplastic lesion parallels histopathological status, showing epithelial thickening, loss of stratification in lower epithelial strata, epithelial down growth, and loss of epithelial stratification as compared to healthy oral mucosa. The epithelium is highly variable in thickness, with areas of erosion and invasion into the sub epithelial layers. The basement membrane is not visible as a coherent landmark. OCT image is rapid, unproblematic and well received by all patients.

In another study of 97 patients utilizing OCT imaging to detect neoplasia in the oral cavity by Tsai et al. in 2009, their results revealed that the an important criteria for high-grade dysplasia/carcinoma in-situ was the lack of a layered structural pattern. Diagnosis predicated by this method for dysplastic/malignant versus benign/reactive conditions achieved a sensitivity and specificity of 83% and 98%, respectively, and by 0.76 as an inter-observer accident value. Their study concluded that OCT, had high sensitivity and specificity along with a good inter-observer acquiescent, is a promising imaging modality for non-invasive evaluation of tissue sites, suspected with high-grade dysplasia or/ and cancer.**8** Lee et al. in 2009 had diagnosed the OSMF with OCT. Compared with the conventional method of quantifying maximum mouth opening, the utilization of the proposed OCT scanning results can be a more accurate technique for OSF diagnosis.

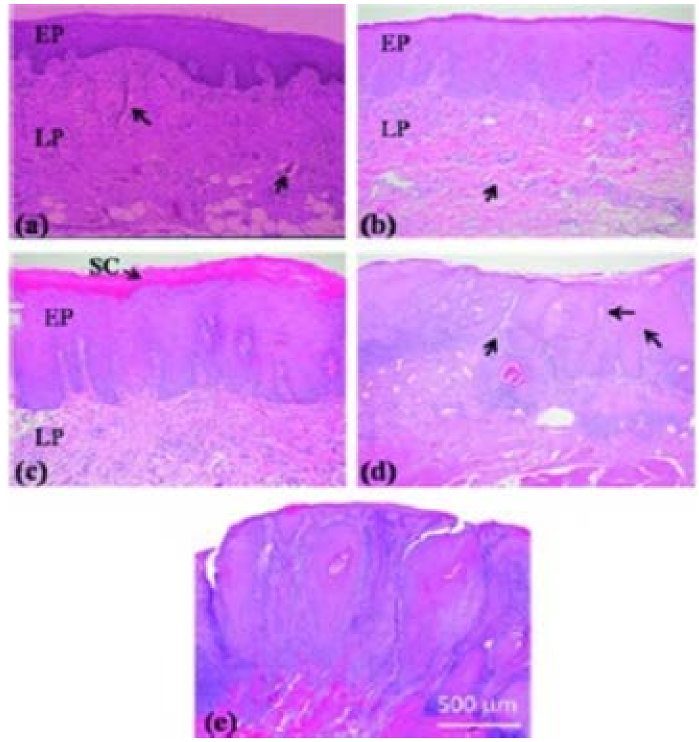


Figure 17: Histological images of the (a) normal, (b) MiD, (c) MoD, (d) ES-SCC, and (e) WD-SCC samples

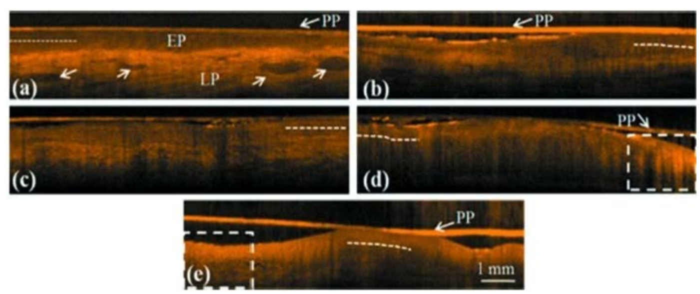


Figure 18. SS-OCT scanned images of the (a) normal control and biopsied oral (b) MiD, (c) MoD, (d) ES-SCC, and (e) WD-SCC lesions. Their histological images were shown in Figure 17(a–e)

Cancer therapy-induced mucositis: [35]

OCT has manifestated its benefit in the detection of transmutations in cancer therapy-induced mucositis. Oropharyngeal mucositis occurs in 30-75% of chemotherapy patients, 75% of patients receiving a hematopoietic cell transplant, and basically all the patients experiencing head and neck radiation therapy in doses of >5000 cGy. It is very arduous to prognosticate the exact onset and rigor of mucositis which can cause arduousness in treatment. OCT can detect early vicissitudes in mucositis which will ameliorate the aversion and treatment effect.

Kawakami–Wrong et al. 2007 had done study in which five patients receiving neoadjuvant chemotherapy for primary breast cancer, oral mucositis, and OCT was used to clinically assessed and imaged. Imaging was scored utilizing a novel imaging-predicated scoring system. Oral mucositis assessment scale was used as the gold standard for conventional clinical assessment. Patients were evaluated on 0, 2, 4, 7, and 11 days after beginning the chemotherapy. One blinded investigator viewed the OCT images. The findings in the study were: Transmutation in epithelial thickness and subepithelial tissue integrity (beginning on 2**nd** day), loss of continuity of surface keratinized layer (beginning on 4**th** day), and loss of epithelial integrity (beginning on 4**th** day). Higher scores were obtained for imaging data compared to clinical scores earlier in treatment, suggesting the higher sensitivity of imaging-predicated diagnostic scoring to early mucositis change than the clinical scoring system. Imaging and clinical scores converged, after establishing the mucositis. OCT identified oral changes induced by chemotherapy prior to their clinical manifestation, and the proposed scoring system for oral mucositis was validated for the semi quantification of mucositis change

Muanza et al. in 2005 performed a study in murine radiation-induced mucositis models. The study concluded that OCT can be subsidiary for both qualitative and quantitative assessments of acute mucosal damages. There were predominant transmutation in the mucosa detected by the OCT images afore visible macroscopic manifestations, like ulcers became ostensible.

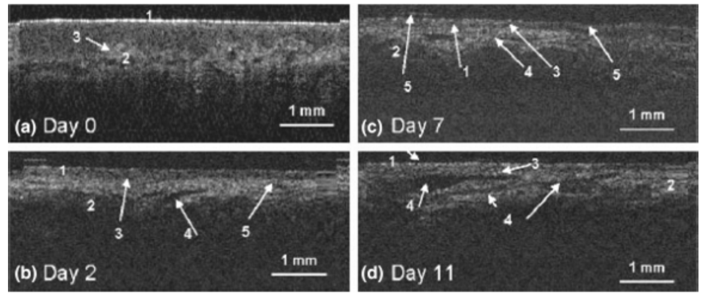


Figure 19

In vivo optical coherence tomography (OCT) images throughout the development of oral mucositis: OCT images of ventral surface of tongue before (**a**), after 2 days (**b**), after 7 days (**c**) and after 11 days (**d**) of chemotherapy. In (**a**), smooth stratified squamous epithelium (1) is visible, separated from the submucosa (2) by the basement membrane (3). Cumulative diagnostic imaging score is 0. In (**b**), epithelium is thinner by 50%, surface is still intact, although directly below the surface some breakdown is apparent (5). Subepithelial tissues just below the basement membrane show some disruption. At this point, the patient was totally asymptomatic. Cumulative diagnostic imaging score is 2. Further epithelial atrophy is seen after 7 and 11 days (**c, d**), with infiltrate around the basement membrane and disruption of the adjacent epithelial and subepithelial tissues (4), and breakdown of the epithelial surface (5). Cumulative diagnostic imaging score for (**c**) is 3 and for (**d**) is 5. From Kawakami-Wong et al (2007)

Oral vascular malformation [36,37]

Ozawa et al. 2009 detected the two cases of vascular malformation, one with a capillary-venous malformation of the lower lip whereas the other with a reddish mass on the buccal mucosa. In these cases, OCT images correlated well with histological structures, revealing well demarcated capillary vessel lumina and endothelial lining. Cognizance of the size, area, and the border of the vascular lesions can be secondary for the diagnosis and cull of surgical treatment, particularly for vascular anomalies, and hemangiomas in the oromaxillofacial region.

Mucocutaneous lesions

Certain skin disorder can be detected by OCT, like lichen planus, pemphigus, pemphigoid etc. However, it requires a specific intentness for skin disorders whose incidence is furthermore higher in the oral cavity .

Forsea et al. had done studies of 3 patients with psoriasis and came to surmise that OCT showed typical thickening of the epidermis, with epidermal protrusion into the dermis, vigorous hyperkeratosis as a more tenebrous superficial band.

Forsea et al. had detected sarcoidosis with OCT, showed hypo-dense confluent rounded structures in the dermis corresponding on the histopathology exam to granulomatous infiltrates.

Temporo-Mandibular Joint Disc:[38]

The micro structure of temporomandibular disc by using OCT was investigated by Marcauteanu and Colab. Two different OCT systems were used: an Enface (TDOCT) system working at 1300nm (C-scan and B scan mode) and a spectral OCT system (a FDOCT) system, working at 840nm (B scan mode). The OCT investigation of the temporomandibular joint discs revealed a homogeneous microstructure. The longer wavelength of the FDOCT offers a higher penetration depth (2.5mm in air), which is important for the analysis of temporomandibular joint.

Implantology: [39]

OCT images provide quantitative information regarding micro-structural architecture, including the character of the gingiva as well as that of the implant and the soft tissue relationships. More importantly, OCT identifies the earliest signs of inflammation that are so minimal that clinical examination is unlikely to detect. OCT imaging offers the exciting potential to detect peri-implantitis before significant osseous destruction occurs. Several histological animal studies have shown that gingival connective tissue forms a scar-like fibrous connective tissue adjacent to titanium implant surfaces, while peri-implantitis is characterised by a disorganised connective tissue containing more vascular elements. The preliminary data demonstrate that in OCT images of healthy implant sites, collagen appears well organised and its birefringent nature produces a characteristic high OCT signal intensity. OCT images of soft tissue surrounding failing implants are characterised by linear signal deficits, low-intensity collagen signals, and pronounced increases in vascular elements. OCT will improve clinical evaluation of peri-implant soft tissues and will provide significant advantages over existing diagnostic procedures.

OCT can produce two- or three-dimensional images depicting the topography of the implant sulcus and the relationship of implants soft tissue interfaces. A fiberoptic clinical OCT system was used to obtain large size, 12 mm occlusal-apical OCT images.

The advantage of OCT compared to non-optical imaging modalities are its:[40]

- High depth and transversal solution
- Contact-free and non-invasive operation, and the possibility to create
- Function dependent image contrast
- OCT uses light for imaging of tissues hence patient is not exposed to ionizing radition
- OCT helps in early diagnosis of oral diseases
- OCT helps in real time monitoring of both hard and soft tissues.
- It has excellent resolution and penetration depth and hence can image the normal and abnormal changes in the oral mucosa.
- T scan can be for occlusal mapping and help in recording the pattern of occlusion.

The disadvantage of OCT are:[41]

- OCT has limited penetration depth in scattering media.
- The scanning range of OCT is usually several millimeters; hence many pictures would be needed to scan an entire lesion
- OCT takes a longer time to acquire the image.
- Artifacts are produced due to tissue birefringence.

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