Optical Coherence Tomography in Early Diagnosis of Oral Diseases

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Abstract. OCT is a potential diagnostic tool for the early diagnosis of oral diseases. The overall burden of oral diseases is high globally, and screening and early detection can prevent a high incidence of dental caries, periodontal diseases, and oral cancer. Advances in miniature hand-held optic devices and the birefringence property of enamel with the anisotropic property of dentin allow the use of OCT in early caries detection. The varied histology of oral cavity tissue raises limitations in its use. However, with advances in nanoparticles, OCTA, dual-axi, andT and integration of AI, OCT promises to be the standardized diagnostic tool in the future.

Keywords: Optical coherence tomography, principles, oral diseases, early oral lesions, dental caries, periodontal diseases, oral cancer, premalignant lesions

1 Introduction

The World Health Organization (WHO) estimates that more than 3.5 billion people around the globe suffer from one or other form of oral diseases, the most common being dental caries, periodontal diseases and oral cancer. Socio-economic factors apart, the increasing impact of commercial advertisements in promoting detrimental habits like alcohol and smoking, poor dietary and life style choices, has continued to increase the global burden [1]. Most of the dental care providers are private practices or private enterprises, resulting in an increased cost in services which again serves as a detriment to seek dental care. Prevention and early detection of oral diseases is the primary approach; however, the lack of funding in dental health research and proper instrumentalization in surveillance tools is an important major factor for the increased burden of oral diseases globally. According to the Global Oral Health Status Report, the prevalence of dental diseases, periodontal disease, and oral cancer was 18%, 20.3%, and 23.4%, respectively, of

S. P. Vijayaragavan et al. (eds.), *Proceedings of the Global Conference on Sustainable Energy Systems, Smart Electronics and Intelligent Computing (GCSESEIC 2025)*, Advances in Engineering Research 297,
https://doi.org/10.2991/978-94-6239-654-8_9

the globaloverload. Oral cancers present at advanced stages result in high mortality. The early detection of premalignant lesions will significantly reduce the burden. Screening by visual examination, vital staining, brush biops, andd biopsy (invasive method) are traditional methods. Medical imaging by optical coherence tomography (OCT) is a non-invasive method which can be used inside the body cavity using a fibre-optic device and a harmless light source to provide morphological details at 0.5μm resolution. OCT allows the clinician to identify the region of interest (ROI) by real-time tissue architecture visualization, reducing the sampling error and in identifying tumor margins intraoperatively, reducing the wait time considerably [2].

2 Optical Coherence Tomography

OCT imaging is based on the principle of low-coherence interferometry. A near-infrared light ray is focused on the tissue, and the measured delay in the back-reflected rays reveals the depth of the tissue structure where the reflection has taken place. The delay cannot be directly measured. An interferometer is used to split the light from the source into two: one directed at the sample and the other directed at the reference arm placed at known arm length.It then combines the light reflected from the two paths at the interferometer [3]. Coherent waves are superimposed, and their electromagnetic fields amplitudes either add, cancel or meet conditions in between based on the uniqueness of the structure/tissue in the path of the light.This forms the basis of A-scan. Material scattering is measured as a function of depth. The beam is scanned laterally across the sample to obtain a cross-sectional image or a B- scan. The Time domain-OCT (TD-OCT) modulated the reference length for each depth. The second-generation is the more efficient Fourier domain OCT (FD-OCT)/Frequency-domain OCT uses spectral information to generate A-scan. The intensity variation rate at different frequencies determines the depth of the reflecting tissue layer governed by Nyquist theorem. The maximum sensitivity occurs at zero delay difference point because of the finite size of the pixels. The spectrometer-based FD-OCT (SD-OCT) replaces the point detector using a spectrometer which different wavelengths into a line image recorded by a high-speed camera to form spectral interferograms. A super luminescent diode is used because of its high bandwidth and power output [4]. The Swept source OCT (SS-OCT) uses rapidly tuneable lasers to sweep a narrow line width over a broad range of wavelengths. Each wavelength is measured by an ultrafast separates (>100 kHz) high-speed photodetector with Analog Digital (AD) conversion in GHz. Fourier transformation is required to extract the information as functions of depth positions with the mirror term rejected in the final image of the A-scan.(6) OCT angiography (OCTA) images neovascularization and vascular flow by reflecting the erythrocyte movements in the blood vessel in repeated OCT B-scans at the same position. Dual axis OCT uses an off-axis beam to collect multiple forward scattered electrons for deep surface morphology [5].

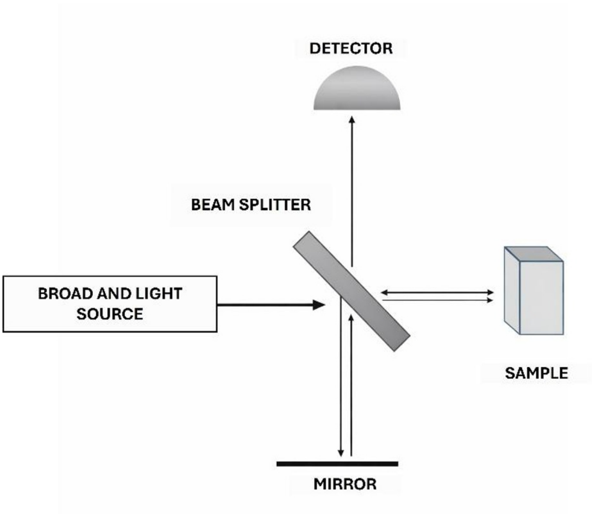

Fig. 1. Principle of OCT

The Fig.1 shows the principle of OCT. Light from the broadband source is split into two, one directed to the sample and the other to the reference arm. The reflected light is then recombined at the interferometer with superimposing coherent waves. The amplitude of the electromagnetic field adds, cancels, or meets conditions in between [6].

AI-enhanced OCT enables the detection of suspicious lesions and reduces operator variability. The advances i-heldd held detectors with Micro electromechanical systems (MEMS) can be used inside the body cavities has overcome the difficulties in access and convenience with use in endoscopes, cath, ands and needle biopsy. The size, design, and grip are designed in accordance with various specialties, with dentists preferring tube like model with endoscope heads. Photonic crystals and microcavities further scale the optical MEMS. Gold, silver, silicon and hybridnanoparticles enhance scattering andare being researched for increased contrast in OCT images and to track cellular uptake and migration in magnetomotive OCT application [7].

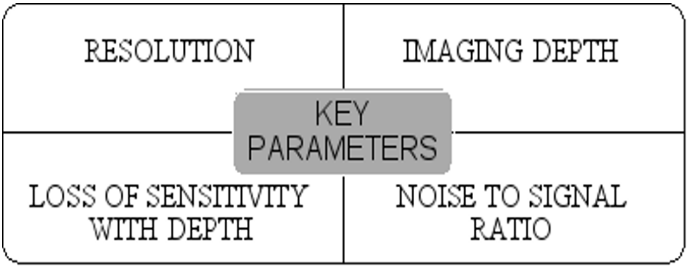

Fig. 2. Key parameters in OCT imaging

Fig. 2. shows the Key parameters in OCT imaging . The maximum scan angle θ_{max} determines the field view. Signal to noise ratio (SNR) is the height of the signal to the image noise. Sensitivity merits the performance of the OCT and is determined as the minimum reflectance detected to achieve SNR of 1. It is the ability of the OCT to determine the faintest back reflection by the sample.

3 OCT and existing diagnostic tools in dentistry

Various diagnostic tools in dentistry include visual examination, radiographs, surgical biopsy, brush biopsy, vital staining, VizilLite, salivary diagnostics, and various optical and imaging systems. Surveillance with biopsy and surgical resection are the current approaches for early cancer detection. Fig. 3. shows the resolution of various diagnostic tools. Epithelial and stromal changes alter the distribution of tissue fluorophores by directly affecting the tissue fluorescence directly visible to the eye when stimulated with intense light (blue light, 400-460nm) by devices based on tissue autofluorescence like the Velscope system. Studies combining spectroscopy with polarized light, tissue fluorescence and microscopy are underway. LED-based probes, Raman spectrometer, laser spectrometers (caries detection) are under investigations [8].

	RESOLUTION
OCT	1-15μm
Ultrasound	80-120 μm
MRI	80-300 μm
Fluoroscopy	100-200μm

Fig. 3. Resolution of various diagnostic tools

Radiograph	Low cost, 2D image, poor resolution, radiation
CT	3D, no real-time imaging, radiation, poor spatial resolution
Intraoral camera	Surface characteristics, low cost, no radiation
Periodontal probe	Broad measurement range, low cost, invasive, no image, low sensitivity
OCT	Real-time image, low penetration depth, high spatial resolution, can construct 3D images from 2D images

Fig. 4. Comparison of OCT with other routine methods

OCT is a non-invasive real-time imaging approach that is well received by patients on viewing the imaging shown to them. Fig. 4.Comparison of OCT with other routine methods. It lies between ultrasound and optical microscopy in terms of resolution. Superior to radiographs in sensitivity, OCT allows qualitative and quantitative analysis of the tooth structure in caries. However, it has a marginally higher false-positive rate, indicating the initial lesions as moderate. When early lesions are detected, the clinician must use a conservative approach. OCT produces images interpret of the tooth microstructure from the surface to the pulp. The device scans all surfaces for caries, detects demineralization at early stages and remaining dentin caries after excavation. It is not affected by plaque or calculus, as with other techniques. A 3D representation can be computed from the 2D scans, and lesions can be monitored over time by comparing them with previous scans [9].

4 OCT in dentistry

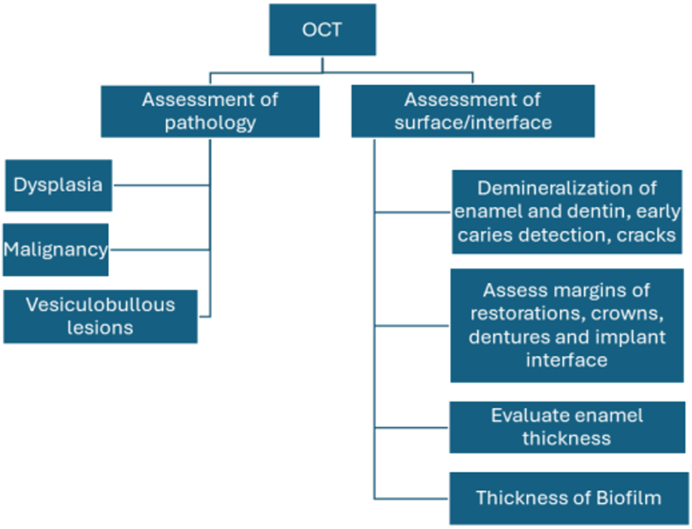

Fig. 5. OCT as a diagnostic tool for early detection of oral diseases

Fig. 5 shows the OCT as a diagnostic tool for early detection of oral diseases Diagnostic tools are used in dentistry to assess underlying pathological changes or assess changes in the surface of the oral tissues. Changes in the connective tissue with the destruction of collagen bundles or formation of new collagen bundles and remodelling give altered OCT signals. Disorganized collagen bundles present in inflamed tissue will diminish the signal while newly formed collagen fibres amplify the signal. This helps in screening dysplasia, vesiculobullous lesions, and malignancy. NIR-OCT with wavelength of 890nm can evaluate the dysplastic changes effectively. A wavelength of 1300 enables deeper penetration into the keratinised tissues. Table 1 shows the OCT interpretation in OPMD and oral cancer. Nanoparticle-enhanced contrasts can be obtained to recognise premalignant and early malignant changes from malignancy. OCT has shown 80% specificity in recognising fluid filled lesions and could serve as a diagnostic tool in identifying vesiculobullous lesions. Periodontitis is a chronic oral disease with a prevalence of 50% in the world population. OCT can be used to detect the development of early peri-implant mucositis, residual cement in the mucosa, implant-abutment fix, and proximity to neurovascular bundle. Fig.6. shows the Frictional keratosis. The differences in the refractive index of enamel, dentin, cementum, gingiva, and calculus can enable OCT can help in identifying early periodontal diseases and remodelling of periodontal tissues in orthodontic movement [10].

Table 1. OCT interpretation in OPMD and oral cancer

FEATURE	OCT IMAGE INTERPRETATION
Basic structure	Distinct epithelium and lamina propria with a distinct thin bright line representing the keratin layer, absent in non-keratinized mucosa, Homogenous structure
Basement Membrane	Intact basement membrane is observed in normal, benign and dysplastic lesion
Rete pegs	Shadow extensions from the epithelium with the same signal intensity
Hyperplasia	Slight increase in epithelium thickness
Frictional keratosis	Hyper-reflective signal due to an increase in the thickness of keratin layer
Severe dysplasia and carcinoma-in-situ	Hypo-reflective layer due to disorganised tissue differentiation
Invasive carcinoma	Hypo-reflective keratin layer or no keratin layer due to ulceration
Prominent blood vessels	A central hypo-echoic shadow between two hyper-echoic lines is seen
Minor salivary gland duct	Tiny, tortuous, signal-free cavities

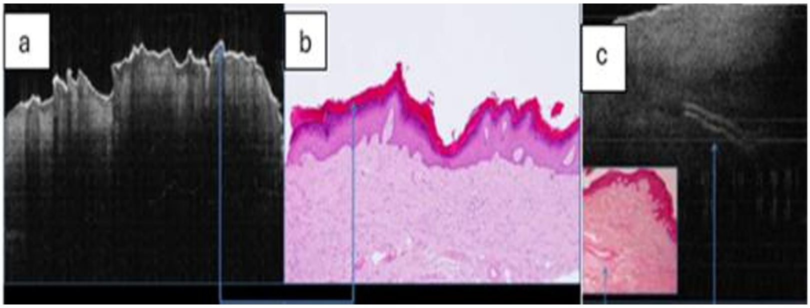

Fig. 6. Frictional keratosis (a, b) Hyper-reflective signal corresponding to an increase in the thickness of keratin layer; Blood vessel (c) central hypo-echoic shadow flanked by two hyper-echoic lines

Source: Hamdoon, Z., Jerjes, W., Al-Delayme, R. et al. Structural validation of oral mucosal tissue using optical coherence tomography. Head Neck Oncol 4, 29 (2012). https://doi.org/10.1186/1758-3284-4-29

Dental caries is a global health concern among school children. Enamel birefringence and the ability of anisotropic light waves to propagate within the dentinal tubules make OCT vital in identifying early caries lesions, monitoring the progression, effectiveness of the restoration and fluoride treatment. The scattering properties of restorative materials and dentin enable the detection of secondary caries underlying the restoration. NIR OCT imaging detect different characteristics in cracks in enamel and dentin. The microleakage under restorations have been calculate very close to the actual size. SS OCT provides better 3D reconstruction of vertical root fractures compared to CBCT or radiographs.OCT aids in identifying challenging anatomical pulp canal and non-carious tooth surface loss.

5 Result and Discussion

The results of Optical Coherence Tomography (OCT) in the early detection of oral diseases were assessed on the basis of the results that were reported in the past published clinical and experimental experiments. OCT had better spatial resolution of between 1 and 15 000 mm as compared to other traditional imaging modalities, which are ultrasound, MRI, fluoroscopy, and radiography. This high resolution made it possible to visualize the epithelial thickness, basement membrane integrity, collagen organization and microstructural alterations related to dysplasia and malignancy in detail. According to several studies, OCT has been reported to have high sensitivity in the detection of early oral lesions such as premalignant lesions and early stage oral cancer. OCT demonstrated about

80 percent specificity in the detection of fluid-filled and vesiculobullous lesions and proved to be effective in distinguishing between normal tissue and dysplastic and malignant tissue changes on the basis of variation in signal intensity and tissue structure. In comparison with conventional diagnostic techniques like visual examination, radiographs, and biopsy, OCT offered real time and non-invasive imaging with low patient discomfort. OCT also showed better failure in identifying early caries in the teeth, demineralization of the enamel, periodontal tissue alteration, and residual caries under the restorations. The possibility of coming up with three-dimensional reconstruction of two-dimensional scans also improved lesion tracking and longitudinal evaluation. Fig 7 shows the comparison of Traditional Diagnostic Methods and the Proposed Machine Learning Framework

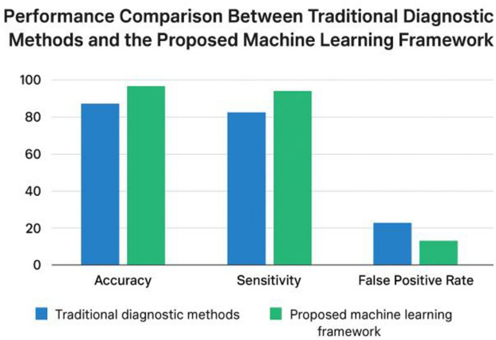

Fig. 7. Comparison of Traditional Diagnostic Methods and the Proposed Machine Learning Framework

5.1 Discussion

The findings show that OCT has a great diagnostic benefit compared to conventional methods of detecting oral diseases. The traditional methods of visual inspection and radiography have disadvantages in low sensitivity, two-dimensionality, and the impossibility to trace microscopic alterations at an early stage. Conversely, OCT provides high-resolution cross-sectional images, which allow detecting pathological changes at an early stage before clinical manifestations occur. The combination of AI-enhanced OCT also increases the reliability of the diagnosis by eliminating the dependence of the operator and improving the accuracy of recognizing lesions. Collagen disorganization, epithelial thickening and basement membrane disruption, which are important indicators of dysplasia and malignancy, are more reliably identified using OCT as compared to the traditional methods.

OCT has limitations associated with depth of penetration, as well as fluctuating tissue refractive indices in the oral cavity, despite having its benefits. Nevertheless, overcoming such difficulties is likely to be achieved through the development of longer-wavelength sources, nanoparticle-enhanced contrast, OCT angiography and deep learning integration. In general, the results prove OCT as a potential adjunctive diagnostic measure of early detection, monitoring, and management of oral diseases. Non-invasive nature, a possibility to provide real-time images, and an ability to be used in conjunction with AI-based analysis makes OCT one of the possible standard diagnostic modalities in the dental and oral oncology practice of the future.

6 Limitations and challenges in the oral cavity

The limited penetration depth by the near-infrared rays restricts the imaging to the epithelium, enamel surface, and oral biofilm. Longer wavelengths of >1300nm may be required without escalating the equipment cost. The center wavelength of 1550nm is good for dental hard tissues but cannot be used for soft tissues as it might be absorbed by blood. Hence, the system seems more appropriate for use as a diagnostic tool for hard tissues. The dental lesions are measured in centimeters, and multiple images need to be taken for larger lesions which becomes a tedious procedure to the dentist and uncomfortable for the patient. Moreover, apart from restorations, sealants, and implants, the oral cavity has hard and soft tissues of variable histological structure (enamel, dentin, pulp, cementum, tongue, gingiva, alveolar bone, and buccal mucosa) of varied refractive indices) and thickness.This may cause alteration in the penetration, scattering, and absorption of light, which may alter the image formation and interpretation.

7 Conclusion

The non-invasive approach and ability to provide cross-sectional images makes OCT a feasible diagnostic tool for early detection of oral diseases. Patients become more compliant with dental procedures as biopsy after imaging. The availability of portable hand-held miniature optic devices can make OCT apart from routine dental clinic setup for diagnostic imaging. Integrating AI, radiomics, and teledentistry, Dental OCT promises to be the standardized diagnostic tool of the future.

References

1. Jain, N., Dutt, U., Radenkov, I., Jain, S.: WHO's global oral health status report: Actions, discussion, and implementation. In: Oral Diseases, vol. 30, no. 2, pp. 73–79 (2024)
2. Chauhan, N., Paul, S., Bhadauria, U. S., Purohit, B. M., Duggal, R., Priya, H.: Oral health surveillance system in India: Need and proposal. In: National Board Examination Journal of Medical Sciences, vol. 2, no. 9, pp. 888–895 (2024)
3. Janjua, O. S., Jeelani, W., Khan, M. I., Qureshi, S. M., Shaikh, M. S., Zafar, M. S. et al.: Use of optical coherence tomography in dentistry. In: International Journal of Dentistry, vol. 2023, article 4179210 (2023)
4. Aumann, S., Donner, S., Fischer, J., Müller, F.: Optical coherence tomography (OCT): Principle and technical realization. In: Bille, J. F. (ed.) High-Resolution Imaging in Microscopy and Ophthalmology: New Frontiers in Biomedical Optics, pp. 59–85, Springer International Publishing, Cham (2019)
5. Jelly, E. T., Zhao, Y., Chu, K. K. et al.: Deep imaging with 1.3 μm dual-axis optical coherence tomography and an enhanced depth of focus. In: Biomedical Optics Express, vol. 12, no. 12, pp. 7689–7702 (2021)
6. Author(s) Unknown: The role of AI-enhanced optical coherence tomography in the early detection and treatment of gastrointestinal cancers. In: Review Article (2024)
7. Daneshpour Moghadam, S., Maris, B., Mokhtari, A., Daffara, C., Fiorini, P.: OCT in oncology and precision medicine: From nanoparticles to advanced technologies and artificial intelligence. In: Bioengineering, vol. 12, no. 6, pp. 650 (2025)
8. Hwang, I. K., Kim, S. Y., Kim, T. I.: Optical coherence tomography for assessing the severity of dental caries: An in vitro validation study. In: Dentistry Journal, vol. 13, no. 11, pp. 543 (2025)
9. Jerjes, W., Stevenson, H., Ramsay, D., Hamdoon, Z.: Enhancing oral cancer detection: A systematic review of the diagnostic accuracy and future integration of optical coherence tomography with artificial intelligence. In: Journal of Clinical Medicine, vol. 13, no. 19, pp. 5822 (2024)
10. Aumann, S., Donner, S., Fischer, J., Müller, F.: Optical coherence tomography (OCT): Principle and technical realization. In: Bille, J. F. (ed.) High-Resolution Imaging in Microscopy and Ophthalmology: New Frontiers in Biomedical Optics, pp. 59–85, Springer International Publishing, Cham (2019)