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Optical Coherence Tomography in Dentistry: Diagnostic Applications for Materials, Hard and Soft Tissues

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Abstract

The conventional approach to identifying abnormalities in the hard and soft tissues of the oral cavity commences with a visual examination by a skilled dentist, followed by other medical assessments, such as radiographic imaging and/or histological investigation. The diagnosis of oral hard and soft tissues is largely hindered by insufficient visual access, the low specificity of diagnostic methods, and/or the limited feasibility of routine screening for early changes. Thus, noninvasive diagnosis of oral tissue has the potential to improve the accuracy of oral screening. In this context, advanced imaging modalities such as optical coherence tomography (OCT) have emerged as promising tools for noninvasive, high-resolution assessment of oral tissues.

This chapter examines recent developments in the application of OCT within dentistry, emphasizing its increasing significance as a noninvasive, high-resolution diagnostic modality. OCT facilitates real-time, cross-sectional imaging of dental hard tissues, restorative materials, soft tissues, and alveolar bone, providing essential insights into both biological and material structures. The discussion addresses key clinical and research applications, including early detection and monitoring of dental caries, analysis of tooth microstructure, evaluation of tooth–restoration interfaces, and characterization of dental materials. Additional applications encompass imaging of soft tissue and periodontal structures, as well as assessment of bone morphology and healing processes. The chapter also outlines the advantages and current limitations of OCT in dental practice, and considers emerging technologies and future prospects for broader clinical integration.

Keywords: Optical coherence Tomography, diagnostic imaging, biofilm, dental caries, dental restoration, periodontium, crestal bone, oral cancer, dysplasia, optical biopsy

1. Introduction

Diagnostic imaging plays a critical role in both medicine and dentistry. Over the past several decades, the development of noninvasive diagnostic methods with minimal or no side effects has been a primary focus. Since the early 21st century, imaging has shifted from two-dimensional to three-dimensional (3D) modalities, including Cone Beam Computed Tomography (CBCT), 3D ultrasound, and 3D photography [1].

Optical Coherence Tomography provides non-invasive subsurface imaging with high spatial resolution. Initially, OCT was developed as an interferometric technique employing low- or partially coherent light sources and time-domain gating to achieve high depth resolution. Lateral scanning enables two-dimensional or three-dimensional tomographic imaging. The evolution of OCT instrumentation has progressed through several distinct phases, including the transition from free-space to fiber-based systems and from intensity-based imaging to polarization-sensitive, Doppler, and spectroscopic modalities. The introduction of Fourier domain OCT (FD-OCT) in the twenty-first century significantly enhanced the technology, increasing sensitivity by up to 100-fold and facilitating the development of high-speed scanning systems. FD-OCT is now commonly implemented with spectrometers or tunable lasers. OCT is currently regarded as a broadband imaging technique rather than solely a low-coherence interferometric method. High data acquisition speeds and the absence of motion artifact degradation have enabled real-time, three-dimensional imaging for clinical diagnosis. Following decades of rapid research and development, OCT has emerged as a leading in vivo biomedical imaging modality [2].

Optical coherence tomography enables the acquisition of “optical biopsies,” providing structural information about biological tissue at a resolution comparable to histology without the need for sample extraction [1,3]. OCT instruments use near-infrared (NIR) light, typically in the 850-1310 nm range, to generate cross-sectional images of tissue samples by detecting backscattered photons. Due to the high computational demands for image reconstruction, recent research has focused on advancing OCT imaging to improve the efficiency of data acquisition and processing [4]. Efforts to address challenges posed by bulky equipment and restricted access to closed cavities have led to significant advancements in both detector technology and OCT light sources [4]. Recent advancements in miniaturizing OCT instrumentation include the development of handheld OCT devices and integration into endoscopes, catheters, and biopsy needles, thereby broadening clinical healthcare applications [1,5].

Although OCT was initially developed for ophthalmology, it has since been applied in cardiology, oncology, dermatology, and other medical fields. In dental practice, OCT is utilized to assess fractures and cracks in composite resins, detect adhesive failures in indirect restorations, and evaluate the tooth-restoration interface. These applications may facilitate the noninvasive identification of secondary caries [6].

Early-stage demineralization can be identified in OCT images by detecting regions with increased light scattering. The identification is possible due to OCT's high sensitivity to subtle changes in optical properties. This sensitivity enables the detection of carious lesions prior to their clinical or radiographic manifestation, thereby establishing OCT as a valuable tool in preventive dentistry [7,8]. New OCT implementations have led to the creation of unique modalities with benefits for dental applications. Thus, swept-source OCT (SS-OCT) offers faster image acquisition and improved depth penetration, while polarization-sensitive OCT provides stronger contrast for detecting tissue birefringence, making it beneficial for enamel demineralization [9,10]. Cross-polarization OCT (CP-OCT) reduces surface reflections and improves the visualization of the subsurface features [11].

These new OCT implementations have expanded their use in dental diagnostics, enabling more accurate and thorough assessment of pathology [7].

Because OCT employs low-power infrared light and doesn't need contact with the sample, it is entirely non-invasive and avoids radiation exposure for patients—unlike X-ray techniques. Nonetheless, OCT offers significantly better image resolution, with typical axial resolution values reported of 8 μm and state-of-the-art values of 2 μm for both axial and lateral resolutions [12]

2. Development of OCT in the dental field

In 1998, researchers at the Laboratory of Medical Technology in Livermore, California, and the University of Connecticut used OCT instrumentation for the first time in dentistry. They developed an oral OCT prototype and demonstrated its in vivo capabilities. The device could scan hard tissues to a depth of 3 mm and soft tissues to 1.5 mm [13]. In the same year, Feldchtein et al. [14] proposed using optical coherence tomography to detect lesions in oral soft and hard tissues, marking the first mention of OCT examination of hard tissue. Two years later, the same research center compared two OCT prototypes using 850 nm and 1310nm light. Their research indicated that longer wavelengths of light are more effective at capturing the anatomical characteristics of the mouth cavity, as assessed by scan quality [15]. At the same time, other publications demonstrated intraoral scanning of both hard and soft tissues using an OCT prototype, showing that infrared light enables imaging of gum margins, periodontal pockets, and both epithelial and connective tissue attachments [16, 17].

Building on earlier pioneering studies such as the work by F. Feldchtein and V. Gelikonov from 1998 [14], which demonstrated the feasibility of in vivo optical coherence tomography (OCT) imaging of oral hard and soft tissues, the latter review by V. M. Gelikonov and N. D. Gladkova, in 2004, provided a comprehensive overview of the development of OCT in Russia over a decade [18]. This article outlined the transition of OCT from an experimental imaging technique to a clinically applicable diagnostic tool, emphasizing advancements in system design, imaging capabilities, and its expanding role in medical and dental practice.

In 2017, Walther et al. [reference?] comprehensively demonstrated the application of polarization-sensitive optical coherence tomography (PS-OCT) for in vivo imaging of human oral hard and soft tissues, highlighting its capability to provide high-resolution, noninvasive assessment of structural and compositional features relevant to dental diagnostics. Since oral soft tissue changes are typically visible in dentistry, PS-OCT was applied to the oral mucosa in this investigation. The PS-OCT provides tissue-specific contrast for collagen fiber bundles in the lamina propria reticular layer and for tissue regions with embedded collagen fibers, such as the dorsum of the tongue. PS-OCT may be more effective at detecting altered oral tissue borders due to increased contrast relative to nearby intact tissue. Using phase-sensitive detection of backscattering signals in two orthogonal polarisation channels to determine distinct tissue characteristics is a cutting-edge technique in PS-OCT applications, enabling detailed physical interpretation of biological tissues such as oral hard and soft tissues. The pilot work demonstrates PS-OCT's potential for in vivo imaging of oral tissues, specifically the anterior oral cavity, using a single circular polarisation input state and appropriate data processing [19].

2.1 OCT Instrumentation

The operation of an OCT imaging instrument is based on constructive interference between light back-scattered by the sample under investigation and a reference beam of light. Optical Coherence Tomography has the potential to generate real-time cross-sectional images of the sample, i.e., two-dimensional images in either the XZ or YZ plane (X, Y: transverse (lateral) coordinates; Z: longitudinal (axial) coordinate). The beauty of the technology is given by the fact that, in contrast to other optical techniques, such as confocal microscopy, its axial resolution is not limited by the numerical aperture of the microscope objective that conveys light on the sample or by its optical aberrations; the axial resolution of a confocal microscope is inferior to that provided by OCT. In OCT, the axial resolution is determined exclusively by the spectral range of the optical source.

In this section, a brief explanation of the operation of the OCT imaging instruments used to produce the images shown in this chapter is provided.

2.1.1 Time Domain Optical Coherence Tomography Instruments

A sketch of a typical TD-OCT experimental setup is presented in Figure 1. The instrument includes two optical sources. OS_1 is a broadband optical source (typically a superluminescent diode (SLD). Light from the SLD is conveyed towards the sample via a beam-splitter (BS_1) and a dichroic mirror (D), a scanning head (GXY) incorporating two orthogonal galvo-mirrors, a microscope objective MO, and towards a reference arm. Light back-reflected by the sample, conveyed into one of the single-mode fiber inputs of a directional coupler (DC, 50/50) using a microscope objective L_S, and from the reference arm, conveyed into the other input of DC via the microscope objective L_R, interferes in DC, then is detected using a balanced photo-detector (BPD). Finally, the electric signal is processed using the processing unit PU_1, and an OCT image is generated.

For constructive interference to happen, the difference between the optical paths of the two arms of the interferometer (optical path difference - OPD) must be less than the coherence length of the optical source, which, for a Gaussian shape of the source spectrum, is mathematically expressed as $l_c = 0.44\lambda_0^2 / \Delta\lambda$. Therefore, l_c, which only depends on the spectral bandwidth ($\Delta\lambda$) and the central wavelength (λ_o) of the spectrum, is a measure of the axial resolution in OCT. If an SLD providing a spectral bandwidth of 65 nm around a central wavelength of 1300 nm should, in theory, be able to deliver an axial resolution of 11.44 μm in air. When imagining a real sample, constructive interference happens for each scattering site within the sample that satisfies the condition OPD < l_c. Therefore, by adjusting the OPD values (via actuation of the translation stage TS), a TD-OCT device outputs an axial reflectivity profile, termed an A-scan. The beauty of this approach is that there is no limitation with regard to the axial size of the A-scans, whereas there is no need to use a fast digitizer. In addition, there is practically no need for complex mathematical procedures to generate images. A-scans can be generated in real-time (points are generated along the A-scan in synchronism with the change in the position of the TS).

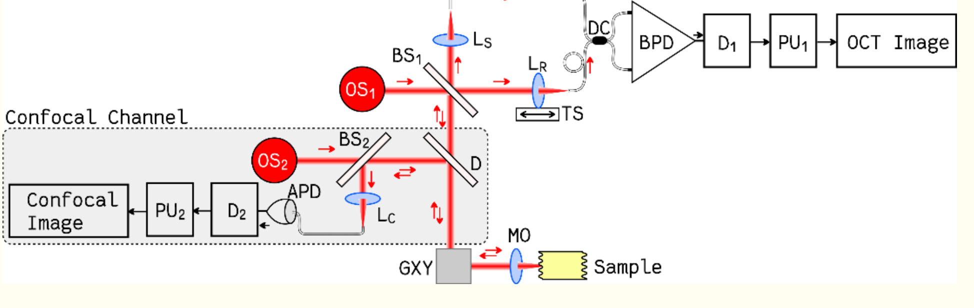

Figure 1. Schematic diagram of a TD-OCT instrument. The device uses a super-luminescent diode (OS_1), a pair of orthogonal galvo-scanners (SXY), a 50/50 beam-splitter, beam-splitters (BS_{12}), a directional coupler (DC), a balance photo-detector (BPD), and an avalanche photo-diode in the confocal channel (APD); $PU_{1,2}$ are data processors, L_S, L_R, and L_C are microscope objectives, whereas light is focused on the sample using the microscope objective MO.

By collecting a sequence of A-scans as the optical beam laterally scans the sample, a cross-sectional (B-scan) image is produced. This type of cross-sectional image, generated by first acquiring A-scans and then assembling the 2D images, is often referred to as A-scan-based B-scan, and the technology as axial or longitudinal TD-OCT. Unfortunately, because axial TD-OCT relies on the mechanical movement of system components, the speed at which the TS is moved is limited. A better way to produce images in TD-OCT is to generate, for a given TS position, a lateral reflectivity profile by transversely scanning the beam over the sample. These profiles (T-scans) can be used to generate cross-sections by varying the OPD (T-scan-based B-scans). If, for a given axial position, T-scans for various y-positions are assembled, a C-scan or *en-face* image is produced. The advantage of this procedure is that an *en-face* image at a constant depth can be produced directly and much faster, since there is no need to build the entire 3D volume. This technique has the advantage that the image quality is not affected by repeated movements of the translation stage. Thus, high-quality en-face TD-OCT images can be produced in real time at as fast as 0.5 Hz. This is the technology implemented in the instruments we used in our investigation. The *en-face* TD-OCT procedure also has the advantage of being easily implemented together with other imaging techniques. The second optical source (OS_2), emitting outside the spectral range of OS_1, is used to generate a confocal microscopy image. This is conveyed towards the sample using a beam-splitter BS_2, the dichroic mirror D, GXY, and MO. Light backscattered by the sample is then directed towards a photo-detector (an avalanche photo-detector (APD) in our case), and the signal is processed by the processing unit PU_2, generating a confocal image simultaneously with the *en-face* TD-OCT image. By tapping into the optical power of OS_1 (i.e., by using a beam-splitter instead of the dichroic D), a confocal channel operating at the same wavelength as the OCT channel can be created (in which case, in the diagram shown in Fig. 1, OS_2 must be eliminated).

2.1.2 Spectral Domain Optical Coherence Tomography Instruments

Currently, there are two modalities for transducing the spectral information at the interferometer output from the optical domain into the electrical domain: camera-based (CB) and swept-source (SS)-OCT, in which a tunable (swept) laser generates the signal, which is detected by a photodetector. An SS-OCT instrument has the advantage of operating at a higher speed and providing a greater axial range than its camera-based counterparts. When producing B-scans, SS-OCT is clearly superior to conventional TD-OCT in terms of both sensitivity and acquisition speed. However, *en-face* imaging is more difficult to produce, but it remains highly interesting, as it often offers enhanced visualization and additional information on sample microstructures. Any TD-OCT instrument can be converted into an SS-OCT one simply by replacing the broadband source with a swept-source laser and by using faster detectors and digitizers. To produce an A-scan, a Fast Fourier Transform (FFT) of the digitized signal is required. This signal is, however, chirped due to the laser's sweeping non-linearities and unbalanced dispersion. A schematic diagram of a typical SS-OCT instrument is depicted in Figure 2. The axial size of the images is restricted now to that given by the instantaneous coherence length of the source. Typically, MEMS-based SSs can provide axial ranges from 3 to 1 cm, depending on their coherence length, although sources with coherence lengths exceeding 200 mm now exist[i].

Before FFT, each collected spectrum is resampled and then multiplied by a function to cancel the effect of the unbalanced dispersion. The calibration process (calculating a new wavenumber distribution) is performed at each spectral acquisition before imaging. All these operations limit the capability of FFT-based instruments to operate in real time because they are executed sequentially. A method that does not rely on FFT was developed by the Applied Optics Group in Kent, Master/Slave (MS). No correction of the sweeping chirp and no correction for dispersion in the interferometer are needed. A supplementary advantage of the MS approach is that it delivers *en face images in real time without requiring the entire 3D volume to* be acquired [20, 21]. This allows defining axial regions of interest where B-scans can be generated without producing redundant data, thereby enabling shorter axial-range B-scan images to be produced in real-time.

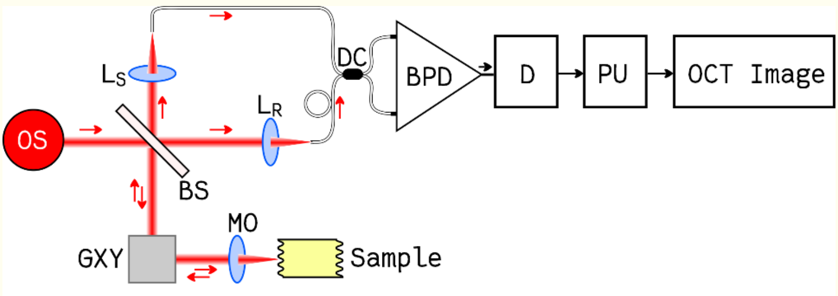

Figure 2. Typical schematic diagram of an SS-OCT instrument. The device uses a swept laser (SS), a pair of orthogonal galvo-scanners (GXY), and a directional coupler (DC). L_S and L_R are microscope objectives, whereas data processing is achieved in the processor unit (PU). BPD is a fast, balanced photo-detector, whereas MO is a microscope objective used to focus light on the sample.

The axial size of the images is restricted now to that given by the instantaneous coherence length of the source. Typically, MEMS-based SSs can provide axial ranges of up to 1 cm, depending on the sampling rate.

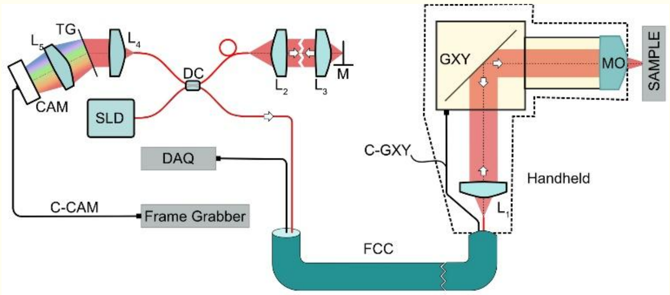

Figure 3. Typical schematic diagram of a CB-OCT instrument. L_1-L_5: achromatic lenses; MO: microscope objective; FCC: flexible cable conduit; C-LL, C-GXY: electric cables connecting the camera to the USB ports or frame grabber and the galvos to the multi-function I/O DAQ, respectively. TG: transmission diffraction grating; GXY: a pair of orthogonal galvo-scanners; DC: directional coupler; SLD: superluminescent diode; CAM: linear camera.

In Figure 3, a schematic diagram of a typical CB-OCT instrument is presented. Light from a superluminescent diode (SLD) is employed. Light from the SLD is directed toward the sample via a 50/50 directional coupler DC. In the sample arm, light passes through an achromatic lens (L_1) and a microscope objective (MO). Two orthogonal galvo-scanners (GXY) scan the optical beam across the sample. Light backscattered by the sample is then recombined with light from the interferometer's reference arm and detected by an in-house-designed spectrometer. The spectrometer includes a transmission diffraction grating, from which the optical beam is diffracted over the pixels of a fast linear camera. Positioning of the galvanometers and triggering of the line cameras is very often achieved via a multifunction I/O device. Data processing in CB-OCT is done in the same way as in SS-OCT, i.e., using techniques such as FFT or MS. All three OCT instruments can be implemented in a handheld configuration, typically including a pair of galvanometer scanners and a microscope objective, as illustrated in Fig. 3.

3. Assessment of dental plaque, calculus, and periodontal tissues

3.1 Dental plaque and calculus evaluation

Dental plaque is defined as a bacterial biofilm that causes dental cavities and periodontal disorders. Non-removal of soft dental plaque can lead to calculus formation, which can cause gingivitis. Common symptoms of gingivitis include swelling, bleeding, and receding gingiva. Gingivitis is a prevalent oral illness globally, with 56% of US people experiencing mild to severe cases [22]. Untreated gingivitis can lead to periodontitis, tooth loss, and other severe oral illnesses [5].

The present diagnosis and assessment of dental plaque and gingivitis depend on visual inspection and the patient's dental and medical history. Dental plaque can be qualitatively evaluated with plaque-disclosing agents, such as solutions or tablets containing iodine, gentian violet, or erythrosine, which impart a vivid coloration to the plaque. Fluorescence imaging can also reveal dental plaque on the surface. However, in contrast to OCT, these techniques do not provide deeper tissue information, limiting the evaluation of therapeutic outcomes and the monitoring of disease progression [5].

In their study, Won et al. implemented a custom-developed CB-OCT system that employed a superluminescent diode (SLD-351-HP2, Superlum, Ireland) centered at 860 nm with a spectral bandwidth of 130 nm. The study of Won et al. examined the practical feasibility and adaptability of a handheld OCT system for assessing dental plaque and gingiva. Trained dental hygienists without OCT experience operated the handheld probe, highlighting its ease of usage. The results show that OCT can detect dental plaque on the enamel surface, at the enamel-gingiva junction, and between neighboring teeth. Additionally, replaceable probe attachments enabled imaging of anterior, posterior, and lingual sides, where plaque accumulation is most prevalent, as illustrated in Figure 4.

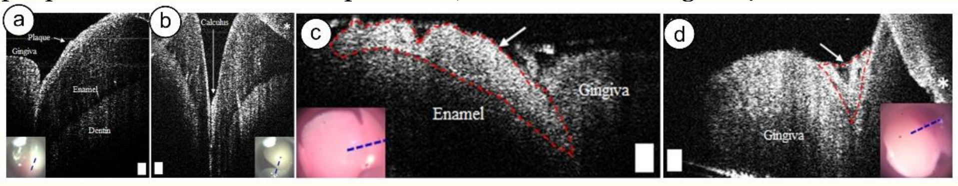

Figure 4. (a) OCT oral cavity imaging of healthy volunteers. Representative images of (a) junction of gingiva and incisor (b) calculus between canine and premolar teeth (c) the presence of dental plaque on the surface of the enamel (d) frontal incisors. Scale bar 200 µm. *Reprinted and adapted from Won J, Huang PC, Spillman DR, Chaney EJ, Adam R, Klukowska M, Barkalifa R, Boppart SA.*

Handheld optical coherence tomography for clinical assessment of dental plaque and gingiva. J Biomed Opt. 2020 Nov;25(11):116011. https://doi: 10.1117/1.JBO.25.11.116011. PMID: 33244918; PMCID: PMC7690845, under Creative Commons (CC BY 4.0)—Gold Open Access https://creativecommons.org/ [5].

Currently, subgingival calculus is most commonly identified through manual periodontal probing, which relies on tactile feedback during the examination. Detecting it manually can be challenging and depends primarily on the clinician's expertise and skill. Recent advancements have introduced several innovative methods for detecting dental calculus, such as fiber-optic endoscopy, spectro-optical technology, and laser-induced autofluorescence. Nevertheless, these new technologies have not yet gained widespread use in clinical settings due to their lack of convenience compared to traditional manual probing.

In a recent interesting OCT study [23], tissue structures were observed in the following order from lightest to darkest: calculus, dentin, enamel, and cementum. Brighter structures in OCT scans indicate increased light reflection and decreased transparency. The internal structure of enamel appears uniform, whereas dentin displays gradation in appearance. Hariri et al. [24] documented the disparity in absorption between enamel and dentin images produced using an OCT instrument operating at ~1,300 nm. The enamel had a monotone look; however, the dentin's appearance varied based on the orientation of the dentinal tubules [23]. In the cited investigation, supragingival calculus was clearly visible in OCT images obtained in the clinic. Subgingival calculus can be observed in vivo as a hazy grey formation on the root surface beneath the gingival tissue, and its presence can be confirmed using two-tone processing and auto-tracing. Subgingival cementum detection was restricted; however, supragingival cementum on the exposed root surface was distinctly observable.

3.2 Periodontal evaluation

In evaluating periodontal disease, measurements of periodontal pocket depth and clinical attachment levels are obtained by probing, while the alveolar bone level is assessed radiographically. Despite being a commonly used clinical evaluation technique, the reliability and repeatability of periodontal probing vary. Radiographic imaging may underestimate osseous deterioration, complicating early detection efforts [25, 26].

Sul-Hee Kim et al. [25] explored whether, with OCT instrumentation, one can visualize the deep sulcus and proposed quantitative methods for determining depth. Using a SS-OCT system with a central wavelength of 1,310±10 nm, 50-kHz sweep rate, and an average output power of 16 mW, the system collected 500 frames per second with 8 μm/pixel axial resolution and 10.03 μm/pixel lateral resolution. The pig mandible model was sectioned to preserve tooth structures and periodontal tissues, enabling measurements of periodontal pocket depth under the gingiva. This study intentionally generated periodontal attachment loss and found that OCT imaging could identify periodontal pockets. This study introduced a quantitative method for estimating periodontal pocket depth using the axial resolution of light traveling through the gingiva. Calculating the gingiva axial resolution is required because the medium through which light flows affects axial resolution. In practical application, the optical probe should be applied to the front, posterior, and each side of the teeth; the axial resolution must be considered to provide valid readings in any position. OCT imaging can directly visualize the buccal and lingual surfaces, which 2-dimensional radiography cannot. Because periodontal attachment loss precedes radiographic alveolar bone loss, OCT images of periodontium microstructure can detect it early.

A similar report by Park et al. [27] demonstrated OCT periodontal images and compared them with micro-computed tomography (micro-CT) images and histologic sections (figure 5).

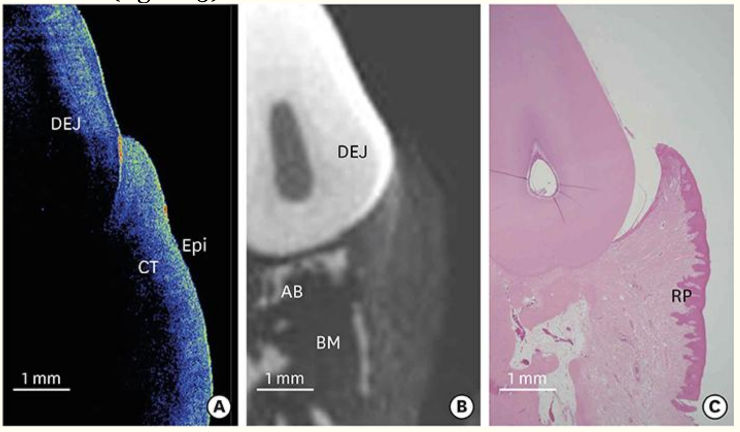

Figure 5. Comparison of (A) OCT, (B) micro-CT, and (C) histology at the buccal furcation region of the second premolar of a canine specimen. The surface topography is more accurately revealed by OCT than by micro-CT. (A) The epithelial thickness appears as a brighter green coloration at the superficial surface of the gingiva, in comparison to the darker blue area corresponding to the loose connective tissue directly underneath. (B) Visualization of gingival soft tissue in a micro-CT image, but with less visual acuity than in the OCT image. Alveolar bone, including the bone marrow space, can be observed. (C) Histologic section showing the rete pegs of the epithelium lining the gingiva with adjacent loose connective tissue. Alveolar bone can be seen below the furcation with its marrow space. *Reprinted from Park JY, Chung JH, Lee JS, Kim HJ, Choi SH, Jung UW. Comparisons of the diagnostic accuracies of optical coherence tomography, micro-computed tomography, and histology in periodontal disease: an ex vivo study. J Periodontal Implant Sci. 2017 Feb;47(1):30-40. https://doi.org/10.5051/jpis.2017.47.1.30, under the CC BY-NC 4.0. (http://creativecommons.org/licenses/by-nc/4.0/)* [27].

Park et al. highlighted several important considerations regarding the use of OCT in periodontics. In their study, OCT scans were 0.41 mm shallower than histologic sections, the gold standard for biologic depth measures [27]. The buccal furcation area of the mandibular premolars was chosen for measurements because it is prone to periodontitis. Due to the horizontal furcal concavity, the gingival attachment requires more imaging depth inside the furcation. The cross-sectional imaging depth of the OCT system used in this work was insufficient to visualize the sulcus architecture within the furcation, likely the main reason for the disparity between OCT and histological depth assessments.

The wavelength of the light source and the numerical aperture of the light-collecting optics influence the OCT imaging depth, thereby affecting imaging quality [28]. Otis et al. demonstrated that operating at longer wavelengths increases the axial imaging range and enhances the image quality (in terms of signal-to-noise ratio) [28]. This is justified because, as the wavelength increases, the scattering coefficient of biological tissues such as enamel and gingiva decreases. The drawback of increasing the central wavelength at which the OCT instrument operates is a potentially lower spatial resolution. Park et al. used OCT to visualize periodontal tissue contour, dental calculus, and connective tissue attachment in great detail [27]. This comprehensive visualization of biological tissues could benefit numerous dental specialties. Before severe alveolar bone loss occurs, this may detect active periodontal disease or causal factors, such as subgingival calculus. The images could be saved permanently for future periodontal examinations to help detect disease recurrence and ineffective periodontal treatment sites during the diagnostic and maintenance phases [27]. The authors of this report also demonstrated the software's ability to evaluate gingival thickness, which can significantly affect periodontal therapy and surgery in aesthetic areas. When planning and performing connective tissue grafting, evaluating epithelial layer thickness confirms undermining around the graft site. Moreover, palatal vascular visualization may reduce donor site bleeding. Real-time quantitative high-resolution imaging during clinical procedures is OCT's main advantage over other technologies.

OCT can simultaneously provide structural and functional imaging by using approaches such as Optical Coherence Tomography Angiography (OCTA). Quantitative studies of gingival vascular morphology using OCTA are still few in dentistry. OCTA systems provide high-resolution, cross-sectional information about gingival vasculature with a wide field of view, unlike other tools such as Laser Doppler flowmetry, laser speckle contrast imaging, and hyperspectral imaging [29-33].

Implementing OCTA for small-scale studies of gingival vascular morphology can enhance the evaluation of disease activity beyond established clinical indicators, offering a novel way to understand the progression of inflammation. OCTA can detect microvascular changes before the onset of inflammation, enabling earlier diagnosis and improved periodontal disease therapy. Initial qualitative studies employing oral OCTA revealed a link between gingival vascular morphology and health. A substantial variation in gingival microvasculature was found between health and illness. Additionally, the gingiva's microstructure and vasculature changed dramatically between thin and thick biotypes. [29, 34, 35].

A very interesting study found that OCTA imaging and three metrics (vessel area density (VAD), vessel skeleton density (VSD), and vessel diameter index (VDI)) can effectively track microvascular changes during experimentally induced gingivitis and its resolution. The quantitative indices were robust and reliable for longitudinal monitoring, as proven by the repeatability test. The findings suggest that OCTA can provide noninvasive insights into gingival inflammation and discriminate responder types, potentially improving diagnosis and optimizing periodontal therapy [29].

In 2019, a group of researchers from Taiwan [36] proposed an OCT model for periodontal examination. This study suggests a non-invasive method for regular periodontal assessment utilizing OCT to estimate the gumline and alveolar line of the target area. Their device precisely measures scanning findings using optical correction and new deep networks for boundary identification, Snake segmentation, intensity calibration, and quantization to locate potential regions and signal ranges, thereby reducing the need for training data and improving efficiency. The results indicate that this method accurately estimates both lines compared to hand labeling. However, the proposed system had multiple drawbacks, which were identified and proposed for future research: the technology cannot automatically detect the junctional epithelium at the bottom of the periodontal pocket. Also, there is still a lack of precision in rebuilding the alveolar bone; identifying the ideal surface alveolar line based on the gumline can improve precision.

A very recent review in this regard also concludes that OCT can detect gingival microstructures, subclinical inflammation, and soft-tissue regeneration with greater resolution than traditional probes and radiography. It effectively detects subgingival calculus and early crestal bone changes, enabling accurate evaluation of disease activity and treatment response. OCT is ideal for personalized periodontal therapy due to its dynamic, quantifiable outputs (tissue thickness, pocket geometry, microvascular flow), despite challenges such as limited penetration depth, high equipment costs, and operator learning curves. AI integration can automate segmentation, reduce observer variability, and provide decision-support analytics for patient risk stratification and therapeutic customization [37].

4. Tooth structure evaluation

Daily clinical imaging in dentistry for visualization of hard tissues often involves intraoral, panoramic, and 3D Cone Beam Computed Tomography (CBCT). In addition to the risks associated with exposure to X-ray radiation, there are other drawbacks, mainly limited resolution: approximately 127 µm for panoramic images, 144 µm for intraoral radiographs, and 75 µm for CBCT [12, 38]. In comparison, the image resolution in OCT is significantly better, with typical axial resolution values of 8 µm reported in some publications [12] and state-of-the-art values of 2 µm for both axial and lateral resolutions [39].

4.1 Dental caries

Dental caries, a chronic infectious disease, is a prevalent condition in clinical dentistry that causes localized disintegration and destruction of mineralized tissue. Caries, the leading dental disease, remains common in modern society; early diagnosis and treatment of lesions before cavitation are crucial, enabling non-surgical therapy [40].

Carious lesions are typically detected through visual inspection and radiography. The International Caries Detection and Assessment System (ICDAS) uses visual examination to diagnose and classify carious lesions, guiding treatment decisions. Visual examination of posterior teeth is difficult due to adjacent teeth, and it cannot detect minor carious cavitation, even under laboratory conditions. OCT demonstrated higher sensitivity than radiography and is a safer method for diagnosing proximal caries in posterior teeth [41].

Multiple studies have used OCT to diagnose dental hard tissues due to its features that support such a diagnosis. It is known that medium translucency greatly affects OCT imaging depth. For OCT imaging, the medium that does not transmit light and deeper structures beyond the range of light penetration are irrelevant. Therefore, at OCT wavelengths, sound enamel is nearly transparent, and the dentin-enamel junction appears as a dark border, distinguishing enamel from dentin. Demineralized enamel and dentin appear as bright zones because of the many micro-porosities that increase the OCT signal backscatter. Even when cracks extend beyond the dentin-enamel junction, SS-OCT can determine their depth of penetration [41]. Shimada et al. showed in a 2020 comprehensive study that SS-OCT effectively detects dental caries and tooth cracks with great sensitivity and specificity (Figure 6). Additionally, SS-OCT can detect non-carious cervical lesions and occlusal tooth wear in cross-sectional images, estimating tooth structural loss. To understand how OCT images aid in dental diagnosis, they considered various clinical scenarios, including caries on different dental surfaces and non-carious dental lesions. They evaluated, using SS-OCT, the formation of numerous microporosities in structures with local refractive index variations. It is of great importance to understand the essential difference between dental radiographs and OCT images: in OCT images, demineralized lesions appear white on a grey scale by enhancing the backscattered signal, whilst in radiographic images, they show radiolucency due to mineral loss. Shimada et al. [41] showed that even early enamel demineralization can be detected by OCT, which has a high light penetration depth in enamel. However, dentin attenuates incident light, limiting imaging depth for deeper dentin caries. If the lesion penetrates dentin, carious demineralization increases laterally along the dentin-enamel junction, which is strongly reflected in the OCT signal. In their findings, visual inspection was less sensitive than SS-OCT for diagnosing all caries levels. SS-OCT has higher sensitivity than ocular assessment (0.98 for enamel demineralization and 0.60 for dentin caries). The specificity for visual acuity assessment was 0.69 for caries lesions and 1.00 for dentin caries, while the specificity for SS-OCT was 0.75 and 0.98, respectively. In the same study, increased utility of OCT was demonstrated in areas difficult to access for visual inspection, the proximal ones, for which bitewing radiography is usually used. Their results demonstrated that SS-OCT was superior to bitewing radiography for diagnosing approximal caries up to the level of the superficial dentin. However, a limitation of the technique must be kept in mind: the SS-OCT images in this study did not show the pulp chamber, making it impossible to determine the distance of the caries from the pulp. Regarding non-carious lesions (cracks, cervical lesions, occlusal wear), a significant correlation was observed between SS-OCT measurements and micro-CT evaluations, indicating that OCT imaging is effective for diagnosing dental caries, tooth fractures, and age-related alterations in tooth structure, including non-carious lesions and occlusal wear.

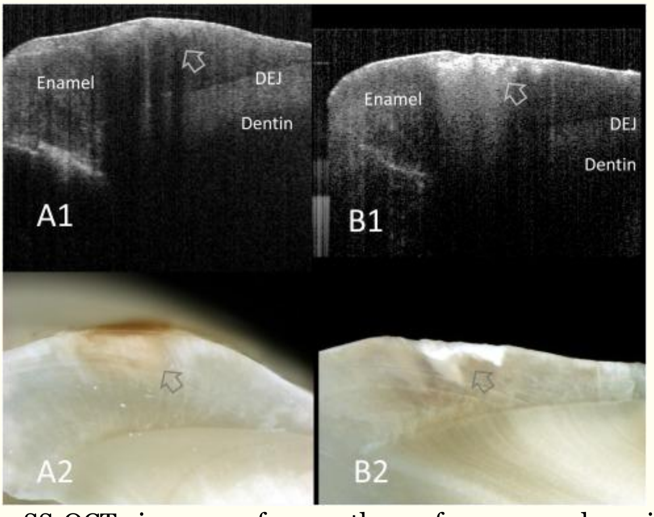

Figure 6. SS-OCT images of smooth surface enamel caries obtained noninvasively (A1, B1) and corresponding histological view after cross-sectioning (A2, B2). In SS-OCT, the presence of enamel demineralization is observed as a bright zone because of the increased scattering (arrows). Counter of slight cavitation is also depicted in SS-OCT. A1, A2: Enamel demineralization without cavitation B1, B2: Enamel caries with cavitation. *Reprinted from Shimada, Y., Burrow, M.F., Araki, K. et al. 3D imaging of proximal caries in posterior teeth using optical coherence tomography. Sci Rep 10, 15754 (2020).* [*https://doi.org/10.1038/s41598-020-72838-2*](https://doi.org/10.1038/s41598-020-72838-2)*, under Creative Commons CC-BY-NC-ND license [41].*

In 2023, Henriksen et al. published an article [42] that aimed to compare OCT, radiography, clinical photography, and polarisation microscopy for evaluation of hypomineralisation disturbances in enamel. Their results showed that OCT enables real-time, non-contact, non-invasive imaging to a depth of 2 to 3 mm within the enamel, capable of detecting structural details as small as ≤12 μm in the tooth. Their pilot investigation indicated that OCT is particularly valuable for examining and assessing regional hypomineralization abnormalities, but it is likely less effective for generalized enamel hypomineralization disorders. In localized hypomineralization disturbances, OCT demonstrated superior accuracy compared to digital radiography and visual assessment. Optical Coherence Tomography (OCT) could yield insights into the degree of localized hypomineralized anomalies in the enamel, equivalent to those obtained using polarisation microscopy of tooth sections. These attributes render OCT an appropriate instrument for identifying subsurface alterations and a viable and beneficial technique in contemporary dental diagnostics.

In a series of studies conducted in Japan, the ability of OCT systems to efficiently and accurately diagnose enamel caries and white spots [43, 44], dentinal caries, root caries [45, 46], and even the enamel remineralization capacity [47] and the influence of phosphoric acid etching on the dentin-enamel junction [48] were investigated. All studies concluded that OCT may be used to assess the progression of enamel and dentinal carious lesions and to identify cavities, which appear as a luminous area beneath composite material up to 2 mm in thickness. SS-OCT demonstrated superior diagnostic precision compared to radiography. Furthermore, SS-OCT was verified for identifying microleakage and white-spot lesions beneath and adjacent to orthodontic brackets. In terms of demineralized dentin, it was more distinctly observable under dry settings compared to wet conditions.

OCT can detect early tooth demineralization and caries progression in vivo without ionizing radiation, revealing morphological and optical changes in both healthy and demineralized teeth, similar to sophisticated technologies such as μCT. Additional information about oral health may aid clinical diagnosis and research. To improve in vivo studies and clinical adoption, challenges in designing a lightweight probe, achieving fast acquisition times, achieving deeper penetration, and developing a clinical acquisition protocol must be addressed while maintaining optimal image quality and resolution [49].

A dynamically sliced 3D OCT image might enhance visual inspection for identifying caries, particularly for dentin lesions with or without cavitation. With excellent inter-examiner reliability, 3D dynamic slicing revealed the lesion's lateral extent compared with 2D OCT imaging. OCT can help clinicians diagnose concealed occlusal caries by estimating lesion depth relative to the DEJ, indicating the need for surgical intervention [50].

4.2 Tooth wear and cracks

In similar investigations, researchers successfully identified structural cracks, craze lines, and split lines in tooth cracks utilizing SS-OCT image data and automatically detected the locations of numerous cracks within the OCT images. Despite being a prevalent condition, cracked tooth syndrome (CTS) can be challenging to diagnose because the cracks may be too small to detect by eye or on radiographs. In vivo diagnostic procedures for this condition include transillumination, an effective method for identifying many types of dental fractures, but it cannot differentiate fractures by depth or classification [51, 52]. Various radiographic techniques are also employed, such as intraoral X-ray imaging, cone-beam computed tomography (CBCT), and micro-computed tomography (micro-CT). Consequently, the detection performance of SS-OCT images may render SS-OCT a valuable diagnostic tool for cracked tooth syndrome [51].

The tooth wear was also studied by Mercut et al. [53]. The study elucidated the distinct clinical subtypes of tooth wear by OCT signal features and, in conjunction with clinical factors, identified the mechanism by which the primary etiological component contributes to lesion formation. The erosive lesion resulting from chemical aggression evolves rapidly, beyond the human body's capacity to respond. The attrition lesion was caused by grinding and clenching movements (bruxism), resulting in fissures in the hard dental tissues. Abfraction results from a complex interplay of multifactorial reasons, including chemical, abrasive, and mechanical factors; however, this investigation affirms the significant impact of excessive forces. Abrasion is a physiological phenomenon that may become pathological only when associated with additional factors, such as friction and erosion. OCT analysis may have clinical utility in identifying relevant components within each clinical subtype and in detecting and monitoring them.

Not only can three-dimensional OCT correctly and reproducibly visualize and assess the extent of tooth wear and identify dentin exposure at the wear surface, but it may also be used to formulate a novel guideline for evaluating tooth wear, as reported by a group of researchers [54].

Some separate Romanian studies [55, 56] examined the morphological and optical coherence tomography characteristics of non-carious cervical lesions (NCCL). The OCT examination revealed NCCLs that were undetectable during macroscopic assessment, demonstrating its efficacy in the early detection of these lesions. A 3D reconstruction of OCT images, performed using ImageJ, revealed fractures on all axial surfaces, particularly within the tooth enamel, progressing towards the enamel–dentin junction and exhibiting numerous ramifications.

4.3 Other applications for dental hard tissues

Optical coherence tomography, as a non-invasive imaging modality, has significant potential to enhance the efficacy and reproducibility of caries diagnosis and treatment. Caries lesions can be identified considerably earlier, and the progression of early dental caries, along with the efficacy of restorative treatment options, can be monitored over time. This exploratory technique may yield supplementary clinically pertinent information, is rapid, and is therefore appropriate and economical for research applications [57].

Visual inspection and OCT provide better diagnostic accuracy and sensitivity than intraoral radiography for identifying moderate lesions from initial ones. The remarkable sensitivity of OCT in detecting subtle demineralization and structural changes suggests it may be useful for identifying lesion stages that conventional radiography cannot. Although OCT had higher sensitivity than radiography, it had slightly worse specificity, which was not statistically significant. The slightly higher false-positive rate suggests that OCT may classify initial lesions as moderate. Clinicians using OCT should prioritize preventive treatments and surveillance over rapid therapy, especially for early-stage disease when interpreting borderline data. This approach follows minimally invasive dental concepts and utilizes OCT's enhanced detection capabilities [7].

In addition to detecting caries, OCT can also detect structural problems in dental restorations, particularly at the tooth-composite contact. OCT imaging can detect interfacial flaws due to its high resolution, which enables it to identify differences in light reflection and scattering patterns at material interfaces. OCT imaging can detect minor defects such as air bubbles, microgaps, and adhesive failures that can compromise the integrity of the repair. Similarly, OCT can detect fissures in enamel and dentin layers without intrusive preparation [7].

Few tools exist for precise measurements of enamel thickness, despite its importance in clinical assessment. OCT may accurately evaluate enamel thickness in maxillary central and lateral incisors nondestructively. A controlled investigation was conducted utilizing teeth with intact surfaces. Enhancing dependability requires a different approach and additional devices to improve measurement conditions. Additionally, data should be acquired from teeth with damaged surfaces [58]. Therefore, OCT can serve as an effective diagnostic tool for assessing enamel thickness before and after orthodontic treatment [59].

It was also demonstrated that OCT has the potential to be employed for noninvasive, cross-sectional imaging during orthodontic operations, including prophylaxis and enamel etching, to monitor enamel loss. Using OCT, interior structural changes were observed during prophylactic and etching treatments. Additionally, depth-intensity analysis was used to study and report enamel throughout these treatments. Advancements in OCT technology, including portability, resolution, depth-resolved imaging, and tiny, portable probes, can significantly benefit orthodontists and dental practitioners in clinical practice [60].

5. Marginal adaptation and dental materials evaluation

The durability of resin-based composite (RBC) restorations depends on their ability to form a reliable marginal seal, thereby avoiding microleakage at the tooth-material junction [61, 62]. Although adhesive methods and restorative materials have improved, interfacial gaps and microleakage still contribute to RBC failure over time. OCT, despite scaling and image fusion limitations, is valuable for providing 2D and 3D images without X-rays, and its speed and specimen preservation make it superior to micro-CT, offering fast and accurate results for shallow interfaces [63].

Modern dentistry has advanced significantly with CAD/CAM technology, enabling the fabrication of aesthetic restorations. This revolutionary technology aligns with patients' aesthetic expectations and enables greater light transmission, matching natural tooth color and translucency. Marginal adjustments are crucial for the effectiveness of these restorations. Insufficient adaptation can lead to a range of complications, including cement deterioration, microleakage, tissue irritation, decay, and restorative failure. The marginal adaptation of CAD/CAM restorations is influenced by several variables, including margin design, die spacer thickness, cement type, and cementation technique [64, 65]. In the context of prosthetic dentistry, accurate assessment of marginal fit and the detection of defects—such as gaps, voids, or microleakage—are critical for the longevity and clinical success of restorations.

Usually, the clinically acceptable marginal gap ranges from 100 μm to 200 μm [66, 67], with 120 μm generally accepted. Previous research has explored many methods for measuring marginal adaptation, including direct viewing, cross-sectioning, replica, profile projection, digital scanning, and microcomputed tomography [64]. The conventional evaluation methods, including visual inspection, radiography, and sectioning techniques, are often limited by insufficient resolution, invasiveness, or the inability to provide three-dimensional structural information. The marginal adaptation of restorations has also been assessed using various methods, including sectioning the luted restorations and subsequently measuring them with optical microscopy, scanning electron microscopy (SEM), micro-computed tomography (micro-CT), transmission electron microscopy (TEM), or the replica technique [68]. OCT overcomes many of these limitations by utilizing low-coherence interferometry to generate detailed subsurface images without damaging the restoration or surrounding tissues. This capability allows clinicians and researchers to precisely evaluate marginal integrity, identify early-stage defects, and monitor restoration performance over time, making OCT a valuable tool for improving diagnostic accuracy and treatment outcomes in prosthetic dentistry.

Zeng et al. published their research in 2025 on the evaluation of marginal adaptation fit using OCT, highlighting several important conclusions. They used an SS-OCT system with a central wavelength between 1,260 nm and 1,360 nm, and a focus of 1,310 nm, capable of producing NIR light at a sweep rate of 20 kHz. In the aerial medium, the apparatus attained a depth resolution of under 7 µm, with axial and lateral resolutions measuring 11 µm and 17 µm, respectively. They examined the samples at three distinct light incidence angles: 60°, 75°, and 90°, measuring the intensity of backscattered light to yield positional information with a resolution of up to 20 microns. In the examination of marginal adaptation, the measurement sites were positioned at the peripheries of the abutment tooth and the restoration (Fig. 7). Thus, the refractive index exerted a diminished influence on these particular locations. In clinical scenarios, when the anatomical structure is obscured, a clean image is compromised because the resin crown's edge is positioned farther from the light source than at a 90° angle. They showed that the tooth's anatomical configuration and the length of the restorative contour influenced the SS-OCT image. The configuration of the tooth obstructs perpendicular NIR light, resulting in an image being taken at an oblique angle, which substantially influenced the measurements when employing SS-OCT. In a clinical context, ascertaining the tooth axis and probe inclination is essential for precise evaluation of marginal adaptation utilizing OCT. With an incidence angle less than 90°, near-infrared light must travel a longer path to penetrate the edge of the resin crown. The enhanced distance renders acquisition more difficult. They concluded that the SS-OCT method can serve as a viable alternative to the silicone replica method for assessing marginal adaptation when the observation incidence is set at 90° towards the CAD/CAM resin crown. However, it is important to note that the angle of near-infrared light incidence significantly affects the precision of the marginal adaptation analysis. Furthermore, the marginal discrepancy of the CAD/CAM resin crowns was consistent across the four observed positions [64].

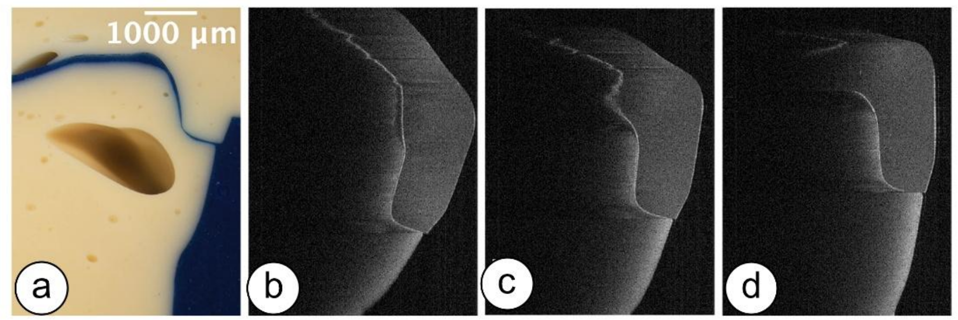

Figure 7. (a) Microscopic images and 2D SS-OCT images of the mesial point. (b) – (d) B-scan SS-OCT images of the mesial point for 600, 750, and 900 of incident angles, respectively. *Reprinted and modified from Zeng C, Tabata T, Takahashi R, Ikeda M, Shinagawa J, Nakagawa H, Tsuchida Y, Takano S, Sumi Y, Shimada Y. Marginal adaptation analysis of CAD/CAM resin crown with non-invasive methods. Clin Oral Investig. 2025 Feb 26;29(3):158. https://doi: 10.1007/s00784-025-06215-6. PMID: 40000502; PMCID: PMC11861017, under Creative Commons Attribution 4.0 International License https://creativecommons.org/licenses/by/4.0/ [64].*

In 2022, another group of researchers published an article [69] on marginal discrepancy and internal cement gap of dental crowns, assessed from images obtained using SS-OCT and spectral-domain CB-OCT. The SS-OCT and CB-OCT demonstrated comparable marginal fit for lithium disilicate crowns (a 10 µm difference between the two systems) and zirconia crowns (a 3 µm difference between the two systems). No significant difference in the internal cement gap was observed between the two OCT systems for lithium disilicate crowns. Nevertheless, for zirconia crowns, the CB-OCT exhibited a substantially larger internal cement gap (92 µm) compared to the SS-OCT (68 µm). Furthermore, the internal fit of zirconia crowns could not be evaluated at 47% and 34% of sites using CB-OCT and SS-OCT, respectively. Given that OCT systems possess varying configurations, it is crucial to evaluate factors such as instrument resolution, depth of field, sensitivity, pixel size, and wavelength to mitigate these disadvantages.

Other research has also shown different outcomes, where the evaluation parameters differed significantly. A study employing 930-nm OCT objectively assessed the marginal and internal adaptations of ceramic inlays. This in vitro investigation revealed that the replica and OCT approaches had distinct marginal and internal adaptation values, with the replica technique demonstrating superior adaptation in both categories. Despite OCT exhibiting inferior results, all adaptation values were within clinically acceptable parameters [70].

On the other hand, many other studies have used OCT to assess the marginal adaptation of either indirect, prosthetic, or direct restorations in different clinical scenarios, with positive results: comparison of the marginal adaptability of composite inlays generated through direct and indirect approaches [68], study of the demineralization inhibitory effect of ion-releasing restorations on neighboring enamel [71].

Sinescu et al. also conducted studies on the capacity of En-face OCT imaging technology to identify material defects and microleaks at prosthetic interfaces [72, 73]. These early in vitro studies demonstrated the use of en-face OCT technology for dental imaging, including different image orientations compared to A-scan-based OCT findings, rectangular image orientation, and the combination of en-face OCT with confocal microscopy for a superior real-time investigation method.

Excellent marginal adaptation also prolongs the lifespan of direct restorations. Todea et al.'s previous studies showed that time-domain en-face OCT is more appropriate for investigating cavity microleakage for three reasons: (i) its versatile orientation, as previously mentioned; (ii) its ability to control focus and dynamic focus; and (iii) its ease of comparison with microscopy images. Authors have achieved results comparable to those already published using A-scan-based OCT, whether in time-domain longitudinal or spectral OCT (Figure 8). They were able to conduct a high-quality, entirely non-invasive, and accurate examination of the cavities filled with composite resin using en-face OCT, which provided adequate tissue scanning across a specific number of layers [74].

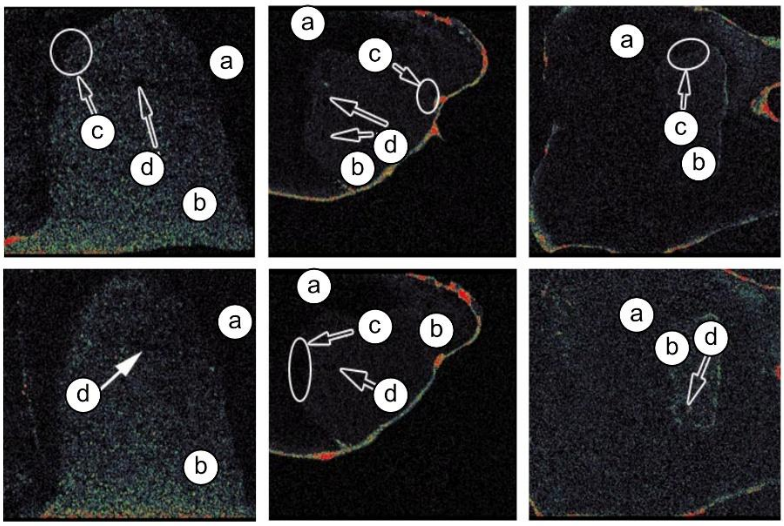

Figure 8. *En-face* OCT images (4 mm x 4 mm lateral size slices) of two samples with Class V cavities prepared conventionally, acid etched and filled with diacrylic composite resin.

Coronal microleakage (c) is detected between the restorative material (b) and the tooth structure (a). Also, voids of different sizes (d) are present inside the restorative material.
Reprinted from Carmen Todea D.D.S., Cosmin Balabuc M.D., Cosmin Sinescu M.D., Meda Negrutiu, Laura Filip M.D., Adrian Bradu, and Adrian Gh. Podoleanu "En-face OCT microleakage investigation after laser-assisted dental hard tissue treatment", Proc. SPIE 7139, 1st Canterbury Workshop on Optical Coherence Tomography and Adaptive Optics, 71390M (30 December 2008); https://doi.org/10.1117/12.814917[74]

6. Oral mucosa evaluation

The sixth most prevalent cancer worldwide is oral [75]. Current visual screening programs struggle to detect early malignancies, with up to 50% of cases not discovered until advanced stages. Optical biopsy in vivo is a popular area of study for early cancer diagnosis, and OCT is a promising method. OCT can provide label-free, radiation-free, real-time cross-sectional images and 3D reconstructions with excellent resolution and sufficient tissue penetration depth. These features aid in early cancer diagnosis and in monitoring tumor treatment. Oral cancer researchers have already used OCT to detect early malignancies in both animals and humans [75]. Identifying oral dysplastic and early-stage malignant tumors is challenging with existing methods. Fifty percent of oral malignancies are identified at an advanced stage. The identification of the first stromal alterations predictive of malignant transformation represents a novel approach to the diagnosis of early-stage oral cancer. The application of novel optical instruments for in vivo imaging of the stroma is now being explored, with polarization-sensitive optical coherence tomography (PS-OCT) as a potential candidate. Using PS-OCT, small birefringent alterations in the oral mucosa in vivo can be detected. The en-face birefringence mapping technique exhibits higher sensitivity and precision in identifying small dysplastic and early-stage malignant oral lesions. The anticipated application of this approach for delineating tumor margins is also projected. Additional research is needed to integrate intensity OCT and PS-OCT in humans to confirm their clinical applicability [75].

Oral squamous cell carcinoma (OSCC) is a keratinocyte-derived malignancy arising from the oral mucosa of the lips and cavities, comprising 90-95% of malignant tumors in this region [76]. Delays in diagnosing OSCC lead to high mortality and morbidity, particularly due to late-stage metastases. Misdiagnosis or mistreatment, especially in early stages, might further tumor progression and metastasis. This leads to shorter overall survival and poor quality of life for "survivors of advanced OSCC" due to extensive neck dissections and mutilating primary tumor removal [77].

Early diagnosis, together with risk factor avoidance, is the most effective way to reduce OSCC mortality and associated treatment effects. The current OSCC diagnostic technique is time-consuming and invasive, requiring multistep procedures, a gold-standard biopsy, and histological examination [77, 78]. Despite their importance, biopsy and histopathology evaluations are time-consuming. The suggested three-step diagnostic strategy employs noninvasive imaging modalities to improve presurgical accuracy in suspected or tumoral oral lesions. They are positioned temporally and conceptually before the traditional bioptic method removal, and they involve the following: in the initial phase (data collection), anamnestic data and conventional clinical examination are supplemented by adjunctive investigations to gather more information on the suspected lesion or cancer within the clinical-anamnestic protocol. The vital stains and autofluorescence can distinguish positive/negative diagnostic suspects. At this stage, OCT can be used to take preliminary measurements of tumor size. Finally, in vivo RCM enables optical biopsy for real-time architectural information of the lesion at microscopic resolution. The surgeon uses data integration before biopsy to determine the need for surgery, plan the approach (incisional or excisional), and accurately define the three-dimensional extent of the incision/enucleation, thereby concluding the diagnostic procedure with conventional histopathological evaluation [77].

OCT devices can be customized for specific applications, such as non-contact scanning with supercontinuum light sources and objective lenses for sub-micron resolution, while fiber-optic endoscopic systems can access luminal organs but have lower resolution (~40 µm lateral) [79-81]. The flexibility of OCT has led to its use in several cancer imaging applications, yet no consensus exists on diagnostic criteria for OCT in oral cancer, despite ongoing research. OCT intensity can be used to estimate the depth-resolved attenuation coefficient, revealing the optical characteristics of the sample. Various methods, including qualitative classification systems, quantitative assessments of epithelial thickness, optical attenuation, and textural features, have also been investigated [82].

Albrecht et al. collected in vivo OCT cross-sections of healthy human oral mucosa to standardize the processing of intensity-based OCT images. In addition to prior OCT research, information on inaccessible posterior regions, such as the oropharynx and palatine tonsils, was obtained [83]. To evaluate images, seven criteria were used, including epithelial surface integrity, profile, and vascular supply grade by major vessels as indicators for detecting worrisome oral lesions. They expanded our knowledge of healthy adult oral soft tissue by developing a collection of example photos that display regional characteristics, thereby broadening the scope of openly available OCT cross sections. Stained image material from a virtual library of human tissue was used for histological correlation to avoid unnecessary biopsies, with good correlation. Image analysis suggests simplifying future in vivo measurements by collecting brief OCT cross-sections from a few spots inside the investigation region. Additionally, automatic epithelial thickness determination is possible using the presented data and future investigations with additional image datasets and analysts. Authors conclude that OCT is a screening tool that can supplement visual evaluation and help determine the biopsy site in clinical practice. The study provides recommendations for selecting measurement points and provides detailed data on OCT image appearance.

An interesting systematic review identified specific OCT diagnostic patterns for the preliminary diagnosis of Desquamative Gingivitis (DG) associated with pemphigus and mucous membrane pemphigoid, despite the lack of standardized OCT diagnostic criteria for DGs [84]. The authors showed that an OCT-based diagnostic framework could enable future clinical assessment and monitoring of complex pathological disorders, as well as the development of standardized software for digital diagnosis.

Quantitative measurement of oral microvasculature using optical coherence tomography angiography is a valuable application for intraoral assessments. OCTA is a promising in vivo approach for oral imaging, as demonstrated in a recent study by Zhang [85]. This work presents a quantitative method for measuring intraoral OCTA scanning outcomes, ensuring reproducible data without subjective visual judgments. The authors used four quantitative metrics—vessel area density, skeleton density, diameter index, and a novel weighted Tortuosity Index—to evaluate OCTA images in oral applications. Collectively, the four parameters presented deviations from healthy tissue, the proposed quantitative assessment of OCTA imaging showing great potential for future research and therapeutic management of oral disorders.

Another group of researchers suggested employing optical coherence tomography to monitor cancer cell invasion in a three-dimensional oral cancer model, using quantitative, longitudinal imaging. Thus, their unique 3D organotypic oral cancer models with OCT enable real-time tumor formation and treatment responses, making them more relevant than 2D cultures. This method could improve personalized medicine by enabling drug screening and biomarker discovery in clinical models. SD-OCT may become a new imaging tool for cancer research and 3D culture-based biomedical studies. Combining OCT with deep learning for quantitative, longitudinal monitoring of cancer cell invasion, OCT nondestructively visualized tissue microarchitecture by capturing cross-sectional images and identifying three regions: primary cancer cell region, invasive cancer cell region, and stromal layer based on scattering intensity and optical density. OCT sequencing enabled 3D picture reconstruction and repetitive monitoring. Using 3D OCT images, planimetric and volumetric analyses revealed internal structural changes and allowed for comparison of invasion behaviors among OSCC cell types, TME settings, and culture durations. The invasiveness parameter from 3D OCT images corresponded well with histomorphometric data, indicating its reliability. These findings suggest OCT imaging is a promising method for noninvasive, quantitative assessment of invasiveness in organotypic cancer models [86].

7. Bone evaluation

Crestal bone level (CBL) measurement is crucial for dental treatments and must be accurate and non-invasive. Standardized periapical radiographs accurately detect interproximal bone abnormalities, but they encounter complications when used in the buccal and lingual areas. Early OCT research showed promising results in examining fragile periodontal substructures, but generally lacked well-controlled measurements and focused on conceptual assessment. A recent study shows that OCT may be used for precise measurements [87]. The authors emphasize that, to conduct intraoral OCT measurements, it is important to consider both scanner head stability and the depth of detection within the periodontal tissue. Overall, their 1310-nm dental SS-OCT system demonstrated high accuracy in measuring CBL in vitro within the research limits. Additionally, en-face OCT imaging enabled precise visualization of complex periodontal profiles, with the potential to monitor bone changes around teeth or implants. This innovative noninvasive technology, along with clinical and radiographic information, can provide doctors with valuable insights to improve periodontal care.

OCT images facilitate the visualization of peri-implant bone levels and the identification of bone defects. The capability of quantitative non-invasive assessments of bone loss was likewise validated [88].

Another study showed that OCT may swiftly and noninvasively visualize the bone surface before and after Er:YAG laser ablation across four distinct moisture levels. The architecture of ablation grooves, along with the roughness and thickness of the heterogeneous layer on the bone surface, may be quantitatively characterized with strong correlation to SEM and histology [89].

Bone characterization is also possible in clinical scenarios, such as cortical bone microdamage after orthodontic miniimplant insertion. One study suggests that OCT is a non-invasive imaging modality capable of detecting and assessing cortical bone microdamage at the mini-implant bone interface. To be categorized as a microcrack, the crack must be visible in 5 or more consecutive lateral and depth OCT scans. In both insertion methods, placing the mini-implant at a 45° angle increases microdamage due to greater cortical bone engagement and insertion torque. The presence, shape, and quantity of bone debris can be assessed using OCT imaging. En face images from 3D volumetric OCT reveal bone debris. This bone debris is present due to the non-drilling nature of miniimplants and does not interfere with the visualization of microcracks on scanned images. Deep penetration of OCT enhances the visualization of micro-damage and microcracks on bone structures. 3D modes enable navigation through debris to discover and analyze these structures. Clinically, deposition of bony debris near miniimplants and screw threads can increase tension in cortical bone, disrupting the implant-bone interface [90]. The microdamage in the cortical bone is clearly observable, and a quantitative study of the microcracks as they propagate through it can be conducted using A-scan analysis of OCT images.

In our group research, we investigated the efficacy of a complex master-slave (CMS)-enhanced swept-source (SS) OCT imaging system for delivering reliable data on bone regeneration. Given the significance and potential ramifications of bone regeneration, ex vivo samples of rat calvarial wounds treated with various bone augmentation protocols, including those assisted by low-level laser therapy (LLLT) or photobiomodulation (PBM) [91], have been investigated. CMS enhanced SS-OCT was used to capture and analyze data from several groups to evaluate the progression of new bone growth. To our knowledge, this was the first use of OCT to evaluate the impact of laser photobiomodulation on bone regeneration. Notwithstanding the method's intrinsic limitations, the results obtained and the statistics derived from OCT were in substantial concordance with prior studies that examined new bone development using alternative methodologies, including histology (Figure 9). Consequently, it was asserted that this research represents an advancement in the study of bone development through en face imaging.

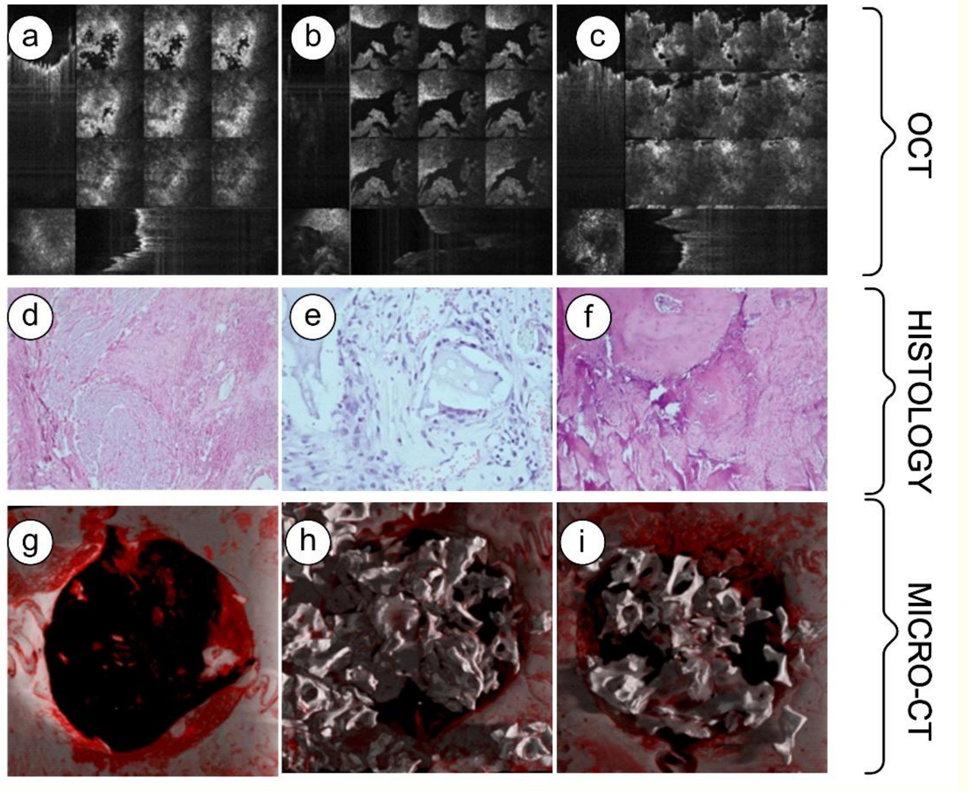

Figure 9. Images were produced on samples harvested after 21 days of healing. (a-c) OCT images obtained at 21 days: NC (negative control group), PC (positive control group), and after low-level laser therapy (LLLT), (d-f) Histology images: NC, PC, and treated with LLLT, respectively. (g-i) Micro-CT frontal view images of repaired sites in representative retrieved samples: NC, PC, and treated with LLLT, respectively. (l-n) Micro-CT 3D sagittal

reconstructions of repaired sites in representative retrieved samples: NC, PC, and treated with LLLT, respectively

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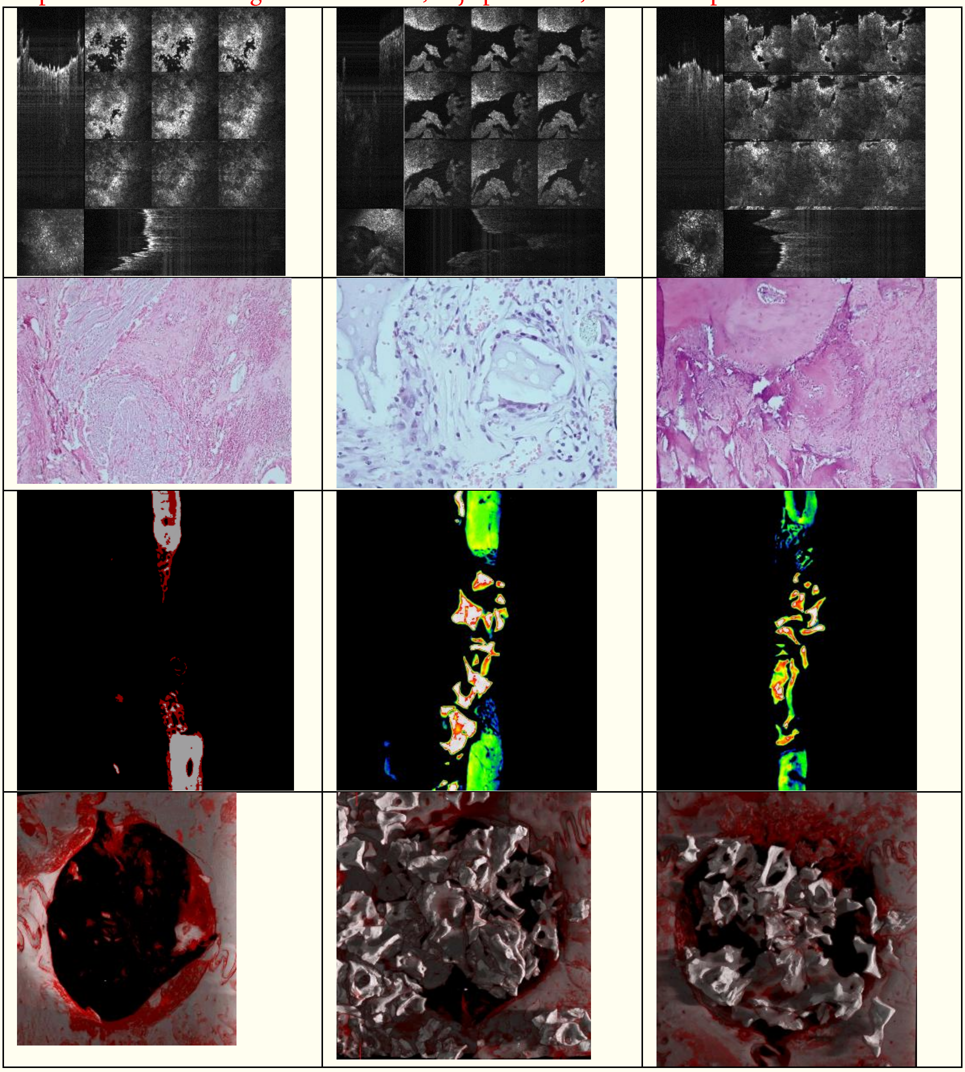

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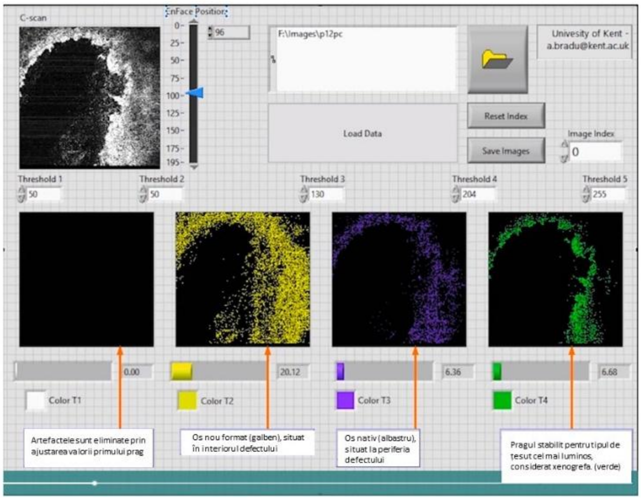

All data acquired with OCT were validated with histology and with micro-CT imaging. The efficacy of the micro-CT methodology is attributed to its three-dimensional nature, which involves acquiring 1000 consecutive two-dimensional sections (each approximately 9 µm thick) to map the entire specimen. Our investigations showed a strong concordance between OCT and micro-CT analyses [92].

Limitations, future research, and conclusions

A limitation of the OCT technique is its applicability only to semi-transparent materials that backscatter light. Teeth containing metal-based restorations or materials are unsuitable for OCT scanning. Additionally, distortion in B-scans may occasionally arise due to the prominence or curvature of the teeth [42, 93].

Another challange in dental diagnosis is the quality of individual teeth. Enamel structure may differ within a single subject. Similarly, dental fillings or prosthetic materials with varying compositions reflect or absorb light to different extents, significantly affecting image quality and interpretability. Materials with a reflectance index similar to that of the background will produce images that are difficult to distinguish from the background. Beyond image quality, the capacity to perform objective measurements on acquired scans is also essential [17].

The use of a thermophotonic-based three-dimensional imaging modality, enhanced truncated-correlation photothermal coherence tomography (eTC-PCT), for early detection of dental caries has been explored. Roointan et al. assessed the detection threshold, sensitivity, and three-dimensional lesion reconstruction capabilities of eTC-PCT for imaging artificially induced caries and surface erosion [94], concluding that eTC-PCT is a promising technology for preventive dentistry. Although these advancements represent significant progress beyond conventional OCT, their integration into routine clinical practice will require further technological refinement. Future OCT systems for dental applications are anticipated to be rapid, handheld, and capable of large-area imaging, with enhanced depth penetration and resolution, automated artifact mitigation, functional imaging features, and user-oriented software tailored to clinical requirements.

Optimizing the effectiveness of dental diagnostic OCT requires careful selection of the wavelengths used for image generation. In the near-infrared spectrum, the central wavelength is critical for determining tissue penetration depth, as it is influenced by scattering and absorption. Wavelengths below 1000 nm provide optimal imaging performance because the light's scattering characteristics align with the sizes of tissue particles. Hydrated tissues emit more energy than denser tissues with lower water content. Therefore, a comprehensive dental OCT system should allow for wavelength adjustment based on the specific tissue type under examination. Distinct wavelengths are necessary for imaging periodontal tissue versus tooth structure [17].

A major advantage of OCT is its use of harmless light, allowing safe and repeated application in children, pregnant women, and other vulnerable populations without the risks associated with ionizing radiation. Its high sensitivity and strong diagnostic performance underscore OCT's capacity to accurately identify a wide range of oral conditions [95]. Recent research consistently demonstrates the remarkable promise of OCT as a noninvasive, high-resolution imaging modality that elevates diagnostic precision and supports early intervention. As advances in OCT technology continue to accelerate, its integration into dental practice holds tremendous potential to revolutionize oral healthcare—enabling safer, faster, and more accurate diagnosis and monitoring for patients of all ages. The future of optical coherence tomography in dentistry diagnostics seems promising, with the potential to significantly enhance patient care and clinical outcomes.

~~Many articles highlighted the promise of OCT as a noninvasive, high-resolution imaging technique that enhances diagnostic accuracy for detecting non-cavitated occlusal caries, despite obstacles like the in vitro study design and the learning curve associated with OCT [7].~~

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Conflict of Interest

The authors declare no conflict of interest.

Appendices and Nomenclature

optical coherence tomography (OCT)
three-dimensional (3D)
Cone Beam Computed Tomography (CBCT),
Fourier domain OCT (FD-OCT)
near-infrared (NIR)
swept-source OCT (SS-OCT)
Cross-polarization OCT (CP-OCT)
polarization-sensitive optical coherence tomography (PS-OCT)
superluminescent diode (SLD)
beam-splitter (BS)

directional coupler (DC)
balance photo-detector (BPD)
avalanche photo-detector (APD)
camera-based (CB)
swept-source (SS)-OCT
Fourier Transform (FFT)
processor unit (PU)
superluminescent diode (SLD)
microscope objective (MO)
micro-computed tomography (micro-CT)
Optical Coherence Tomography Angiography (OCTA).
vessel area density (VAD)
vessel skeleton density (VSD)
vessel diameter index (VDI))
The International Caries Detection and Assessment System (ICDAS)
cracked tooth syndrome (CTS)
non-carious cervical lesions (NCCL)
resin-based composite (RBC)
scanning electron microscopy (SEM)
micro-computed tomography (micro-CT)
transmission electron microscopy (TEM)
polarization-sensitive optical coherence tomography (PS-OCT)
Oral squamous cell carcinoma (OSCC)
Desquamative Gingivitis (DG)
Crestal bone level (CBL)
complex master-slave (CMS)-enhanced swept-source (SS)
low-level laser therapy (LLLT)
photobiomodulation (PBM)
enhanced truncated-correlation photothermal coherence tomography (eTC-PCT)

References

[1] Janjua OS, Jeelani W, Khan MI, Qureshi SM, Shaikh MS, Zafar MS, Khurshid Z. Use of Optical Coherence Tomography in Dentistry. Int J Dent. 2023 Dec 11;2023:4179210. doi: 10.1155/2023/4179210. PMID: 38111754; PMCID: PMC10727803.

[2] L. Y, Zhang Q, Zhu Q. Optical Coherence Tomography in Dentistry [Internet]. Selected Topics in Optical Coherence Tomography. InTech; 2012. https://doi.org/10.5772/33281

[3] J. Fujimoto, W. Drexler, “Introduction to optical coherence tomography,” in Optical Coherence Tomography, Biological and Medical Physics, Biomedical Engineering, pp. 1–45, Springer, Berlin, Heidelberg, 2008.

[4] V. F. Duma, G. Dobre, D. Demian et al., “Handheld scanning probes for optical coherence tomography,” Romanian Reports in Physics, vol. 67, pp. 1346–1358, 2015.

[5] Won J, Huang PC, Spillman DR, Chaney EJ, Adam R, Klukowska M, Barkalifa R, Boppart SA. Handheld optical coherence tomography for clinical assessment of dental plaque and gingiva. J Biomed Opt. 2020 Nov;25(11):116011. doi: 10.1117/1.JBO.25.11.116011. PMID: 33244918; PMCID: PMC7690845.

[6] Graça ND, Palmeira AR, Fernandes LO, Pedrosa MD, Guimarães RP, dos Santos SC, Gomes AS, da Silva CH. In vivo optical coherence tomographic imaging to monitor gingival recovery and the adhesive interface in aesthetic

oral rehabilitation: A case report. Imaging Sci Dent. 2019 Jun;49(2):171-176. https://doi.org/10.5624/isd.2019.49.2.171

[7] Hwang IK, SY, Kim TI. Optical Coherence Tomography for Assessing the Severity of Dental Caries: An In Vitro Validation Study. Dent J (Basel). 2025 Nov 20;13(11):543. doi: 10.3390/dj13110543. PMID: 41294525; PMCID: PMC12651758

[8] S. Ali, S.B.S. Gilani, J. Shabbir, K.S. Almulhim, A. Bugshan, I. Farooq, Optical coherence tomography's current clinical medical and dental applications: a review, F1000Res. 10 (2021) 310, https://doi.org/10.12688/f1000research.52031.1

[9] G. Sharma, S. Sharma, K. Blessing, G. Hartl, M. Waldner, K. Singh, Swept source cross-polarized optical coherence tomography for any input polarized light, J. Opt. 22 (2020) 045301, https://doi.org/10.1088/2040-8986/ab746a

[10] Y. Shimada, A. Sadr, Y. Sumi, J. Tagami, Application of optical coherence tomography (OCT) for diagnosis of caries, cracks, and defects of restorations, Curr. Oral Health Rep. 2 (2015) 73–80, https://doi.org/10.1007/s40496-015-0045-z.

[11] M.-T. Tsai, H.-C. Lee, C.-W. Lu, Y.-M. Wang, C.-K. Lee, C.C. Yang, C.-P. Chiang, Delineation of an oral cancer lesion with swept-source optical coherence tomography, J. Biomed. Opt. 13 (2008) 044012, https://doi.org/10.1117/ 1.2960632.

[12] Erdelyi, R.-A.; Duma, V.-F.; Sinescu, C.; Dobre, G.M.; Bradu, A.; Podoleanu, A. Dental Diagnosis and Treatment Assessments: Between X-rays Radiography and Optical Coherence Tomography. Materials 2020, 13, 4825. https://doi.org/10.3390/ma13214825

[13] B. W. Colston, U. S. Sathyam, L. B. DaSilva, and M. J. Everett, "6, 230–8," Dental OCT Optical Express, p. 3, 1998

[14] F. Feldchtein, V. Gelikonov, R. Iksanov et al., "In vivo OCT imaging of hard and soft tissue of the oral cavity," Optics Express, vol. 14, pp. 239–250, 1998.

[15] L. L. Otis, B. W. Colston Jr., M. J. Everett, and H. Nathel, Dental optical coherence tomography: a comparison of two in vitro systems," Dento Maxillo Facial Radiology, vol. 29, no. 2, pp. 85–89, 2000.

[16] L. L. Otis, M. J. Everett, U. S. Sathyam, and B. W. Colston Jr, "Optical coherence tomography: a new imaging technology for dentistry," Journal of the American Dental Association (1939), vol. 131, no. u, pp. 11–14, 2000.

[17] Machoy M, Seeliger J, Szyszka-Sommerfeld L, Koprowski R, Gedrange T, Woźniak K. The Use of Optical Coherence Tomography in Dental Diagnostics: A State-of-the-Art Review. J Healthc Eng. 2017;2017:7560645. doi: 10.1155/2017/7560645. Epub 2017 Jul 16. PMID: 29065642; PMCID: PMC5534297.

[18] Gelikonov, V.M., Gladkova, N.D. A decade of optical coherence tomography in Russia: From experiment to clinical practice. Radiophys Quantum Electron 47, 835–847 (2004). https://doi.org/10.1007/s11141-005-0023-8

[19] Walther J, Golde J, Kirsten L, Tetschke F, Hempel F, Rosenauer T, Hannig C, Koch E. In vivo imaging of human oral hard and soft tissues by polarization-sensitive optical coherence tomography. J Biomed Opt. 2017 Dec;22(12):1-17. doi: 10.1117/1.JBO.22.12.121717. PMID: 29264891.

[20] Bradu A., Rivet S., Podoleanu A., Master/slave interferometry – ideal tool for coherence revival swept source optical coherence tomography, Biomed. Opt. Express 7, 2016, 2453-2468

[21] Bradu A., Israelsen N.M., Maria N., Marques M.J., Rivet S., Feuchter T., Bang O., Podoleanu A., "Recovering distance information in spectral domain interferometry," Scientific Reports 8, 2018, 15445

[22] Eke PI, Dye BA, Wei L, Thornton-Evans GO, Genco RJ; CDC Periodontal Disease Surveillance workgroup: James Beck (University of North Carolina, Chapel Hill, USA), Gordon Douglass (Past President, American Academy of

Periodontology), Roy Page (University of Washin. Prevalence of periodontitis in adults in the United States: 2009 and 2010. J Dent Res. 2012 Oct;91(10):914-20. doi: 10.1177/0022034512457373. Epub 2012 Aug 30. PMID: 22935673.

[23] Tsubokawa M, Aoki A, Kakizaki S, Taniguchi Y, Ejiri K, Mizutani K, Koshy G, Akizuki T, Oda S, Sumi Y, Izumi Y. In vitro and clinical evaluation of optical coherence tomography for the detection of subgingival calculus and root cementum. J Oral Sci. 2018 Sep 23;60(3):418-427. doi: 10.2334/josnusd.17-0289. Epub 2018 May 24. PMID: 29794398.

[24] Hariri I, Sadr A, Shimada Y, Tagami J, Sumi Y (2012) Effects of structural orientation of enamel and dentine on light attenuation and local refractive index: an optical coherence tomography study. J Dent 40, 387-396

[25] Kim SH, Kang SR, Park HJ, Kim JM, Yi WJ, Kim TI. Improved accuracy in periodontal pocket depth measurement using optical coherence tomography. J Periodontal Implant Sci. 2017 Feb;47(1):13-19. https://doi.org/10.5051/jpis.2017.47.1.13

[26] Mota CC, Fernandes LO, Cimões R, Gomes AS. Non-invasive periodontal probing through fourier-domain optical coherence tomography. J Periodontol 2015;86:1087-94

[27] Park JY, Chung JH, Lee JS, Kim HJ, Choi SH, Jung UW. Comparisons of the diagnostic accuracies of optical coherence tomography, micro-computed tomography, and histology in periodontal disease: an ex vivo study. J Periodontal Implant Sci. 2017 Feb;47(1):30-40. https://doi.org/10.5051/jpis.2017.47.1.30

[28] Otis LL, Colston BW Jr, Everett MJ, Nathel H. Dental optical coherence tomography: a comparison of two in vitro systems. Dentomaxillofac Radiol 2000;29:85-9.

[29] Nhan Minh Le, Geng Wang, Zhiying Xie, Cheng Feng Yue, Shatha Bamashmous, Hrebesh Subhash, LaTonya Kilpatrick-Liverman, and Diane M. Daubert, "Quantitative analysis of gingival vascular morphology using optical coherence tomography angiography in induced gingivitis," Biomed. Opt. Express 16, 4300-4311 (2025)

[30] Wang RK, Jacques SL, Ma Z, Hurst S, Hanson SR, Gruber A. Three dimensional optical angiography. Opt Express. 2007 Apr 2;15(7):4083-97. doi: 10.1364/oe.15.004083. PMID: 19532651.

[31] Wang Q, Gong P, Cense B, Sampson DD. Short-time series optical coherence tomography angiography and its application to cutaneous microvasculature. Biomed Opt Express. 2018 Dec 19;10(1):293-307. doi: 10.1364/BOE.10.000293. PMID: 30775101; PMCID: PMC6363186.

[32] K. Liang, Z.Wang, O. O. Ahsen, et al., “Cycloid scanning for wide field optical coherence tomography endomicroscopy and angiography,” Optica 5(1), 36–43 (2018)

[33] Weiye Song, Wenjun Shao, Wei Yi, Rongrong Liu, Manishi Desai, Steven Ness, and Ji Yi, Visible light optical coherence tomography angiography (vis-OCTA) facilitates local microvascular oximetry in the human retina, Biomed. Opt. Express, 2020, 11:4037-4051

[34] N. M. Le, S. Song, H. Zhou, et al., “A noninvasive imaging and measurement using optical coherence tomography angiography for the assessment of gingiva: An in vivo study,” J. Biophotonics 11(12), e201800242 (2018)

[35] G. Wang, N. M. Le, X. Hu, et al., “Semi-automated registration and segmentation for gingival tissue volume measurement on 3D OCT images,” Biomed. Opt. Express 11(8), 4536–4547 (2020).

[36] Lai, Y.-C.; Chiu, C.-H.; Cai, Z.-Q.; Lin, J.-Y.; Yao, C.-Y.; Lyu, D.-Y.; Lee, S.-Y.; Chen, K.-W.; Chen, I.-Y. OCT-Based Periodontal Inspection Framework. Sensors 2019, 19, 5496. https://doi.org/10.3390/s19245496

[37] Rigotti, P.; Polizzi, A.; Verzì, A.E.; Lacarrubba, F.; Micali, G.; Isola, G. Impact of Optical Coherence Tomography (OCT) for Periodontitis Diagnostics: Current Overview and Advances. Dent. J. 2025, 13, 305. https://doi.org/10.3390/dj13070305

[38] Erdelyi, R.A.; Duma, V.-F. Optimization of radiation doses and patients' risk in dental radiography. AIP Proc. 2019, 2071, 040013

[39] Canavesi, C.; Rolland, J.P. Ten years of gabor-domain optical coherence microscopy. Appl. Sci. 2019, 9, 2565

[40] Park YS, Cho BH, Lee SP, Shon WJ. Early caries detection using optical coherence tomography: a review of the literature. Restor Dent Endod. 2011;36(5):367-376

[41] Shimada, Y., Burrow, M.F., Araki, K. et al. 3D imaging of proximal caries in posterior teeth using optical coherence tomography. Sci Rep 10, 15754 (2020). https://doi.org/10.1038/s41598-020-72838-2

[42] Solgaard Henriksen J, Lauridsen E, Gjørup H, Al-Imam H, Lundgren T, Sabel N, Robertson A, Spin-Neto R, Hermann NV. A pilot study comparing optical coherence tomography, radiography, clinical photography, and polarisation microscopy for studies of hypomineralisation disturbances in enamel. Heliyon. 2023 Feb 14;9(2):e13688. doi: 10.1016/j.heliyon.2023.e13688. PMID: 36865454; PMCID: PMC9971029.

[43] SUZUKI, Sumiyo & Kataoka, Yu & Kanehira, Masafumi & KOBAYASHI, Mikihiro & Miyazaki, Takashi & MANABE, Atsufumi. (2019). Detection of enamel subsurface lesions by swept-source optical coherence tomography. Dental Materials Journal. 38. 10.4012/dmj.2017-404.

[44] Velusamy P, Shimada Y, Kanno Z, Ono T, Tagami J. Optical evaluation of enamel white spot lesions around orthodontic brackets using swept-source optical coherence tomography (SS-OCT): An in vitro study. Dent Mater J. 2019 Feb 8;38(1):22-27. doi: 10.4012/dmj.2017-262. Epub 2018 Aug 29. PMID: 30158348.

[45] Zhou Y, Shimada Y, Matin K, Sadr A, Yoshiyama M, Sumi Y, Tagami J. Assessment of root caries under wet and dry conditions using swept-source optical coherence tomography (SS-OCT). Dent Mater J. 2018 Nov 30;37(6):880-888. doi: 10.4012/dmj.2017-273. Epub 2018 Jun 29. PMID: 29962412.

[46] Chihiro MATSUURA, Yasushi SHIMADA, Alireza SADR, Yasunori SUMI, Junji TAGAMI, Three-dimensional diagnosis of dentin caries beneath composite restorations using swept-source optical coherence tomography, Dental Materials Journal, 2018, Volume 37, Issue 4, Pages 642-649, Released on J-STAGE July 29, 2018, Advance online publication April 17, 2018, Online ISSN 1881-1361, Print ISSN 0287-4547, https://doi.org/10.4012/dmj.2017-252

[47] Yavuz BS, Kargul B. Comparative evaluation of the spectral-domain optical coherence tomography and microhardness for remineralization of enamel caries lesions. Dent Mater J. 2021 Sep 30;40(5):1115-1121. doi: 10.4012/dmj.2020-279. Epub 2021 May 11. PMID: 33980748

[48] Sato T, Tabata T, Akabane K, Zhao M, Khaled AHM, Hiraishi N, Sumi Y, Tagami J, Shimada Y. Noninvasive diagnostic method using optical coherence tomography detected a vulnerable dentin enamel junction created by phosphoric acid etching. Dent Mater J. 2023 Aug 2;42(4):552-558. doi: 10.4012/dmj.2022-246. Epub 2023 Jun 3. PMID: 37271540

[49] Mohamad Saberi FN, Sukumaran P, Ung NM, Liew YM. Assessment of demineralized tooth lesions using optical coherence tomography and other state-of-the-art technologies: a review. Biomed Eng Online. 2022 Dec 3;21(1):83. doi: 10.1186/s12938-022-01055-x. PMID: 36463182; PMCID: PMC9719651.

[50] Luong, M.N.; Shimada, Y.; Araki, K.; Yoshiyama, M.; Tagami, J.; Sadr, A. Diagnosis of Occlusal Caries with Dynamic Slicing of 3D Optical Coherence Tomography Images. Sensors 2020, 20, 1659. https://doi.org/10.3390/s20061659

[51] Kim JM, Kang SR, Yi WJ Automatic detection of tooth cracks in optical coherence tomography images. J Periodontal Implant Sci. 2017 Feb;47(1):41-50. https://doi.org/10.5051/jpis.2017.47.1.41

[52] Mathew S, Thangavel B, Mathew CA, Kailasam S, Kumaravadivel K, Das A. Diagnosis of cracked tooth syndrome. J Pharm Bioallied Sci 2012;4:S242-4.

[53] Mercuț V, Popescu SM, Scrieciu M, Amărăscu MO, Vătu M, Diaconu OA, Osiac E, Ghelase ŞM. Optical coherence tomography applications in tooth wear diagnosis. Rom J Morphol Embryol. 2017;58(1):99-106. PMID: 28523304

[54] Kashiwa, M.; Shimada, Y.; Sadr, A.; Yoshiyama, M.; Sumi, Y.; Tagami, J. Diagnosis of Occlusal Tooth Wear Using 3D Imaging of Optical Coherence Tomography Ex Vivo. Sensors 2020, 20, 6016. https://doi.org/10.3390/s20216016

[55] Stănuşi, A.; Ionescu, M.; Cerbulescu, C.; Popescu, S.M.; Osiac, E.; Mercuţ, R.; Scrieciu, M.; Pascu, R.M.; Stănuşi, A.Ş.; Mercuţ, V. Modifications of the Dental Hard Tissues in the Cervical Area of Occlusally Overloaded Teeth Identified Using Optical Coherence Tomography. Medicina 2022, 58, 702. https://doi.org/10.3390/medicina58060702

[56] Stănuşi, A.; Iacov-Crăiţoiu, M.M.; Scrieciu, M.; Mitruţ, I.; Firulescu, B.C.; Boţilă, M.R.; Vlăduţu, D.E.; Stănuşi, A.Ş.; Mercuţ, V.; Osiac, E. Morphological and Optical Coherence Tomography Aspects of Non-Carious Cervical Lesions. J. Pers. Med. 2023, 13, 772. https://doi.org/10.3390/jpm13050772

[57] Schneider, H.; Park, K.-J.; Häfer, M.; Rüger, C.; Schmalz, G.; Krause, F.; Schmidt, J.; Ziebolz, D.; Haak, R. Dental Applications of Optical Coherence Tomography (OCT) in Cariology. Appl. Sci. 2017, 7, 472. https://doi.org/10.3390/app7050472

[58] Miyagi, H.; Oki, K.; Tsukiyama, Y.; Ayukawa, Y.; Koyano, K. Assessment of the Accuracy in Measuring the Enamel Thickness of Maxillary Incisors with Optical Coherence Tomography. Diagnostics 2022, 12, 1634. https://doi.org/10.3390/diagnostics12071634

[59] Seeliger J, Machoy M, Koprowski R, Safranow K, Gedrange T, Woźniak K. Enamel Thickness before and after Orthodontic Treatment Analysed in Optical Coherence Tomography. Biomed Res Int. 2017;2017:8390575. doi: 10.1155/2017/8390575. Epub 2017 Jan 24. Erratum in: Biomed Res Int. 2020 May 14;2020:7291314. doi: 10.1155/2020/7291314. PMID: 28243604; PMCID: PMC5294353.

[60] Ravichandran NK, Tumkur Lakshmikantha H, Park HS, Jeon M, Kim J. Analysis of Enamel Loss by Prophylaxis and Etching Treatment in Human Tooth Using Optical Coherence Tomography: An In Vitro Study. J Healthc Eng. 2019 Mar 6;2019:8973825. doi: 10.1155/2019/8973825. PMID: 30956785; PMCID: PMC6431396

[61] Deligeorgi V, Mjör IA, Wilson NH. An overview of reasons for the placement and replacement of restorations. Prim Dent Care. 2001;8(1):5–11.

[62] Schneider LFJ, Cavalcante LM, Silikas N. Shrinkage stresses generated during Resin-Composite applications: A review. J Dent Biomech. 2010;2010:131630.

[63] Baldi A, Rossi T, Comba A, Vergano EA, Montrella R, Pampaloni B, Chiecchio V, Rolando C, Scotti N. The ability of highly-filled flowable composites in preventing marginal gap in class V restorations: an optical coherence tomography study. BMC Oral Health. 2025 Apr 23;25(1):619. doi: 10.1186/s12903-025-05970-y. PMID: 40269874; PMCID: PMC12020335.

[64] Zeng C, Tabata T, Takahashi R, Ikeda M, Shinagawa J, Nakagawa H, Tsuchida Y, Takano S, Sumi Y, Shimada Y. Marginal adaptation analysis of CAD/CAM resin crown with non-invasive methods. Clin Oral Investig. 2025 Feb 26;29(3):158. doi: 10.1007/s00784-025-06215-6. PMID: 40000502; PMCID: PMC11861017.

[65] Dennison JB, Sarrett DC (2012) Prediction and diagnosis of clinical outcomes affecting restoration margins. J Oral Rehabil 39:301–318. h t t p s : / / d o i . o r g / 1 0 . 1 1 1 1 / j . 1 3 6 5 - 2 8 4 2 . 2 0 1 1 . 0 2 2 6 7 . x

[66] McLean JW, von Fraunhofer JA (1971) The estimation of cement film thickness by an in vivo technique. Br Dent J 131:107–111

[67] Boening KW, Wolf BH, Schmidt AE, Kästner K, Walter MH (2000) Clinical fit of Procera AllCeram crowns. J Prosthet Dent 84:419–424

[68] Türk AG, Sabuncu M, Ünal S, Önal B, Ulusoy M. Comparison of the marginal adaptation of direct and indirect composite inlay restorations with optical coherence tomography. J Appl Oral Sci. 2016 Jul-Aug;24(4):383-90. doi: 10.1590/1678-775720160012. PMID: 27556210; PMCID: PMC4990368.

[69] Al-Imam, H., Benetti, A. R., Tomlins, P., & Gotfredsen, K. (2022). Optical coherence tomography systems for evaluation of marginal and internal fit of ceramic reconstructions. Biomaterial Investigations in Dentistry, 9(1), 84–91. https://doi.org/10.1080/26415275.2022.2122468

[70] Ayse Gozde T, Metin S, Mubin U. Evaluation of adaptation of ceramic inlays using optical coherence tomography and replica technique. Braz Oral Res. 2018 Feb 1;32:e005. doi: 10.1590/1807-3107BOR-2018.vol32.0005. PMID: 29412222

[71] Albelasy, E.H.; Chen, R.; Fok, A.; Montasser, M.; Hamama, H.H.; Mahmoud, S.H.; Abdelrehim, T.; Chew, H.P. Inhibition of Caries around Restoration by Ion-Releasing Restorative Materials: An In Vitro Optical Coherence Tomography and Micro-Computed Tomography Evaluation. Materials 2023, 16, 5558. https://doi.org/10.3390/ma16165558

[72] Sinescu C, Negrutiu ML, Todea C, Balabuc C, Filip L, Rominu R, Bradu A, Hughes M, Podoleanu AG. Quality assessment of dental treatments using en-face optical coherence tomography. J Biomed Opt. 2008 Sep-Oct;13(5):054065. doi: 10.1117/1.2992593. PMID: 19021443.

[73] Sinescu, Cosmin & Negrutiu, Meda-Lavinia & Hughes, Michael & Bradu, Adrian & Todea, Carmen & Rominu, Mihai & Laissue, Philippe & Podoleanu, Adrian. (2008). An optical coherence tomography investigation of materials defects in ceramic fixed partial dental prostheses. Progress in Biomedical Optics and Imaging - Proceedings of SPIE. 6991. 10.1117/12.780694.

[74] Carmen Todea D.D.S., Cosmin Balabuc M.D., Cosmin Sinescu M.D., Meda Negrutiu, Laura Filip M.D., Adrian Bradu, and Adrian Gh. Podoleanu "En-face OCT microleakage investigation after laser-assisted dental hard tissue treatment", Proc. SPIE 7139, 1st Canterbury Workshop on Optical Coherence Tomography and Adaptive Optics, 71390M (30 December 2008); https://doi.org/10.1117/12.814917

[75] Chen, P.-H.; Lee, H.-Y.; Chen, Y.-F.; Yeh, Y.-C.; Chang, K.-W.; Hou, M.-C.; Kuo, W.-C. Detection of Oral Dysplastic and Early Cancerous Lesions by Polarization-Sensitive Optical Coherence Tomography. Cancers 2020, 12, 2376. https://doi.org/10.3390/cancers12092376

[76] The Global Cancer Observatory; IARC; WHO. Lip, Oral Cavity Cancer. Available online: https://gco.iarc.fr/today/data/factsheets/cancers/1-Lip-oral-cavity-fact-sheet.pdf

[77] Romano, A.; Di Stasio, D.; Petruzzi, M.; Fiori, F.; Lajolo, C.; Santarelli, A.; Lucchese, A.; Serpico, R.; Contaldo, M. Noninvasive Imaging Methods to Improve the Diagnosis of Oral Carcinoma and Its Precursors: State of the Art and Proposal of a Three-Step Diagnostic Process. Cancers 2021, 13, 2864. https://doi.org/10.3390/cancers13122864

[78] Rahman, T.Y.; Mahanta, L.B.; Das, A.K.; Sarma, J.D. Histopathological imaging database for oral cancer analysis. Data Brief. 2020,29, 105114
[79] Drexler, W.; Chen, Y.; Aguirre, A.D.; Považay, B.; Unterhuber, A.; Fujimoto, J.G. Ultrahigh Resolution Optical Coherence Tomography. In Optical Coherence Tomography; Drexler, W., Fujimoto, J.G., Eds.; Springer International Publishing: Cham, Switzerland, 2015; pp. 277–318, ISBN 978-3-319-06418-5.
[80] Gora, M.J.; Suter, M.J.; Tearney, G.J.; Li, X. Endoscopic Optical Coherence Tomography: Technologies and Clinical Applications. Biomed. Opt. Express 2017, 8, 2405.
[81]Zhou, C.; Fujimoto, J.G.; Tsai, T.-H.; Mashimo, H. Endoscopic OCT. In Optical Coherence Tomography: Technology and Applications,2nd ed.; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2015; pp. 2077–2108, ISBN 978-3-319-06419-2
[82] Malone, J.; Hill, C.; Tanskanen, A.; Liu, K.; Ng, S.; MacAulay, C.; Poh, C.F.; Lane, P.M. Imaging Biomarkers of Oral Dysplasia and Carcinoma Measured with In Vivo Endoscopic Optical Coherence Tomography. Cancers 2024, 16, 2751. https://doi.org/10.3390/cancers16152751
[83] Albrecht, M.; Schnabel, C.; Mueller, J.; Golde, J.; Koch, E.; Walther, J. In Vivo Endoscopic Optical Coherence Tomography of the Healthy Human Oral Mucosa: Qualitative and Quantitative Image Analysis. Diagnostics 2020, 10, 827. https://doi.org/10.3390/diagnostics10100827
[84] Panzarella, V.; Bartolone, A.; Rodolico, V.; Capocasale, G.; Maniscalco, L.; Matranga, D.; Di Fede, O.; Campisi, G. Immune-Mediated Desquamative Gingivitis and Optical Coherence Tomography Diagnostic Patterns: Clinical Implication from a Systematic Review. Diagnostics 2021, 11, 1453. https://doi.org/10.3390/diagnostics11081453
[85] Zhang T, Zhang Y, Liao J, Shepherd S, Huang Z, Macluskey M and Li C (2024) Quantitative assessment of the oral microvasculature using optical coherence tomography angiography. Front. Bioeng. Biotechnol. 12:1464562. doi: 10.3389/fbioe.2024.1464562
[86] Haga, K., Kamimura, Y., Yamazaki, M. et al. Quantitative and longitudinal monitoring of cancer cell invasion in a three-dimensional in vitro model of oral cancer using optical coherence tomography. Sci Rep 15, 45449 (2025). https://doi.org/10.1038/s41598-025-28471-y
[87] Chang WT, Lyu DY, Lai YL, Yen JY, Chen YC, Lee SY. High-precision and non-invasive measurement of crestal bone level by optical coherence tomography. J Dent Sci. 2025 Jan;20(1):147-153. doi: 10.1016/j.jds.2024.09.005. Epub 2024 Sep 27. PMID: 39873088; PMCID: PMC11762946.
[88] Kim S, Kang SR, Park HJ, Kim B, Kim TI, Yi WJ. Quantitative measurement of peri-implant bone defects using optical coherence tomography. J Periodontal Implant Sci. 2018 Apr;48(2):84-91. https://doi.org/10.5051/jpis.2018.48.2.84
[89] Huang W, Gao C, Lan Y, Zeng S, Pathak JL, Zhou M, Ge L, Zhang J. Optical coherence tomography characterizes the roughness and thickness of the heterogeneous layer on cortical bone surface induced by Er:YAG laser ablation at different moisture contents. Quant Imaging Med Surg. 2020 Mar;10(3):713-726. doi: 10.21037/qims.2020.02.15. PMID: 32269931; PMCID: PMC7136740.
[90] Lakshmikantha, H.T., Ravichandran, N.K., Jeon, M. et al. 3-Dimensional characterization of cortical bone microdamage following placement of orthodontic microimplants using Optical Coherence Tomography. Sci Rep 9, 3242 (2019). https://doi.org/10.1038/s41598-019-39670-9
[91]Luca RE, Todea CD, Duma VF, Bradu A, Podoleanu AG. Quantitative assessment of rat bone regeneration using complex master-slave optical

coherence tomography. Quant Imaging Med Surg. 2019 May;9(5):782-798. doi: 10.21037/qims.2019.05.03. PMID: 31281774; PMCID: PMC6571200.

[92] Luca, R.E.; Giuliani, A.; Mănescu, A.; Heredea, R.; Hoinoiu, B.; Constantin, G.D.; Duma, V.-F.; Todea, C.D. Osteogenic Potential of Bovine Bone Graft in Combination with Laser Photobiomodulation: An Ex Vivo Demonstrative Study in Wistar Rats by Cross-Linked Studies Based on Synchrotron Microtomography and Histology. Int. J. Mol. Sci. 2020, 21, 778. https://doi.org/10.3390/ijms21030778

[93] H. Al-Imam, S. Michou, A.R. Benetti, K. Gotfredsen, Evaluation of marginal and internal fit of acrylic bridges using optical coherence tomography, J. Oral Rehabil. 46 (3) (2019) 274–281, https://doi.org/10.1111/joor.12746

[94] Roointan S, Tavakolian P, Sivagurunathan KS, Mandelis A, Abrams SH. Detection and monitoring of early dental caries and erosion using three-dimensional enhanced truncated-correlation photothermal coherence tomography imaging. J Biomed Opt. 2021 Apr;26(4):046004. doi: 10.1117/1.JBO.26.4.046004. PMID: 33928770; PMCID: PMC8084349.

[95] Shimada Y, Yoshiyama M, Tagami J, Sumi Y. Evaluation of dental caries, tooth crack, and age-related changes in tooth structure using optical coherence tomography. Jpn Dent Sci Rev. 2020 Nov;56(1):109-118. doi: 10.1016/j.jdsr.2020.08.001. Epub 2020 Oct 2. PMID: 33033549; PMCID: PMC7533308.

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i D. John, C. Burgner, B. Potsaid, M. E. Robertson, B. Lee, W. Choi, A. E. Cable, et al, "*Wideband electrically-pumped 1050 nm MEMS-tunable VCSEL for ophthalmic imaging*," J. Lightwave Techn. 33, 3461–68 (2015).