# A Conceptual Model of Dual-Mode Tomography Technique for Dental Diagnostics

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**ABSTRACT**

Monitoring changes in tooth structures and early diagnosis of carious lesions require quantitative imaging techniques. A chalky white spot on the tooth's surface indicates enamel demineralization, early stage of the carious lesion. Many advanced imaging modalities for identifying tooth tissues image have been created, including magnetic resonance imaging (MRI), X-ray Computed Tomography, Positron Emission Tomography (PET), ultrasound, Single Photon Emission Computed Tomography (SPECT), and the most recent, Optical Coherence Tomography (OCT). In obtaining image information, some modalities use high doses of radiation and energy that might harm patient's health. Most early commercial OCTs had limitations, such as bulky size and low image resolution. To address the issues, this study proposes a dual mode tomography technique by combining OCT and ultrasound system using COMSOL Multiphysics software. Both methods offered non-invasive, non-ionizing, economical, and painless imaging techniques. The application of ultrasound system will help to overcome the OCT's limitation to detect the penetration depth of caries lesion. Several simulations were performed to analyze the light and ultrasonic propagated waves which penetrate through the incisor teeth. In response to this goal, images of incisor teeth were created in silico with a high spatial resolution. As a result, the combination of OCT and ultrasound may offer the best approach for displaying and examining changes in the oral cavity.

**Keywords:** Tooth, Optical tomography, Ultrasound, Carious lesions, Modelling

## 1. Introduction

OCT and ultrasound techniques are the most popular dental imaging technologies that are able to capture a cross-section image of teeth to identify changes in the tooth structure. Both methods provide a non-invasive and non-ionizing tool [1] [2]. Unfortunately, OCT has limitations in its system [3] [4] and image detection [5] [6] [7]. These limitations provide a challenge in clinical settings for detecting submillimeter images because teeth have complicated scattering properties [8]. Even though the OCT system has limitations in terms of its system, image collection rate, and visual field of view (FoV), it is still possible to capture three-dimensional (3-D) structures of the entire tooth in the oral cavity by employing an appropriate technique to create composite 3-D volume images covering a wider FoV utilizing partially overlapped OCT volume photos to expand the limited FoV.

Therefore, this research will introduce a conceptual modelling of portable dental diagnostics based on wave (ultrasound) and light propagation analysis (OCT) via dual-mode tomography approach. These proposed techniques will help overcome the issue of low resolution image reconstruction produced by OCT technique.

### 1.1 Literature Review

In the early OCT development, there were a lot of challenges and limitations of OCT techniques. The biggest challenges of the OCT technique are the limitation of field-of-views (FoV) in proving optical imaging technologies for small particles and shallow penetration depths clinically [6] [7] [9]. The drawbacks of OCT are; poor penetration depth [5] compared to radiographic imaging and limited imaging depth [5] [10] [11] due to multiple scattering, as well as restricting axial or lateral resolution when not using specialized imaging settings [12].Other obstacles in its early transformation are limitations in visual access, insufficient sensitivity of diagnostic equipment, and the impossibility of routine screenings for the identification of oral hard and soft tissues. OCT can detect carious lesions up to the dentin level but cannot clearly display the pulp chamber to establish the lesion's closeness to the pulp. As a result, radiographic testing is still required for people with pulpal symptoms [13]. On the other hand, OCT can show the position of the pulp beneath the cavity floor during deep preparation to avoid pulpal exposure [8].

However, OCT's image acquisition and FOV limitation can be overcome by combining OCT with ultrasound technique. The previous study proved that combining both techniques can reduce multiple scattering as measured by the point spread function (PSF) by at least 20% [14]. Other approach to overcome the problems is by combining OCT with another optical imaging modalities. Nonlinear and multiphoton microscopy, fluorescence, Raman spectroscopy (RS), and photoacoustic imaging have been combined with OCT to maximize the benefits of each modality [15].

### 1.2 Significance of work

Most of the previous research focuses on the comparison between X-ray radiation. They proposed the used of OCT to eliminate the effect of radiation to the patient by replacing the X-ray technique. Other papers stated that the combination of ultrasound wave and OCT signal is able to improve OCT imaging by applying ultrasound signal simultaneously with the OCT beam and treating them as parts of the integrated computational imaging for OCT [14]. This proposed research differs from the existing research, where it applies the combination image's result from the dual mode tomography approach. Combination of OCT and ultrasound methods able to overcome the limitation of early transformation of OCT in image penetration depth and field of view (FoV). This research will have a significant impact on dentistry fields. The expected output from this research is a conceptual modelling of a dual-mode tomography approach for dental diagnostics based on ultrasound and light propagation analysis which is beneficial to the dental industries. This research is expected to provide comfort, free radiation, and painless dental care from the above fundamental study.

This research focuses on the health of mouth and teeth which have the same aim as general health in ensuring healthy lives and promoting well-being for people of all ages. If oral health is poor and ignored, it might cause various oral diseases. Thus, this research help communities in promoting prevention and preventing progression of disease for better oral health.

## 2. Methodology

A two-dimensional (2-D) maxillary anterior teeth configuration which has been developed in COMSOL Multiphysics software was used to stimulate waves and light propagation through the teeth. The simulation used a pressure acoustics module, solid mechanics, electrostatics, and electric circuit module for wave propagation, and electromagnetic wave modules were used for light propagation. The 2D images of maxillary teeth were converted to a sensitivity map that involved assembling information. Data were analyzed between normal and defective teeth using the normality test as the output.

### 2.1 Material selection

The investigated object in this study was the enamel structure with the following mechanical properties in wave and light propagation (Table 1). The material of the enamel structure is $Ca_5(PO_4)_3(OH)$ Calcium hydroxyapatite [16].

**Table 1.** Mechanical properties in wave and light propagation

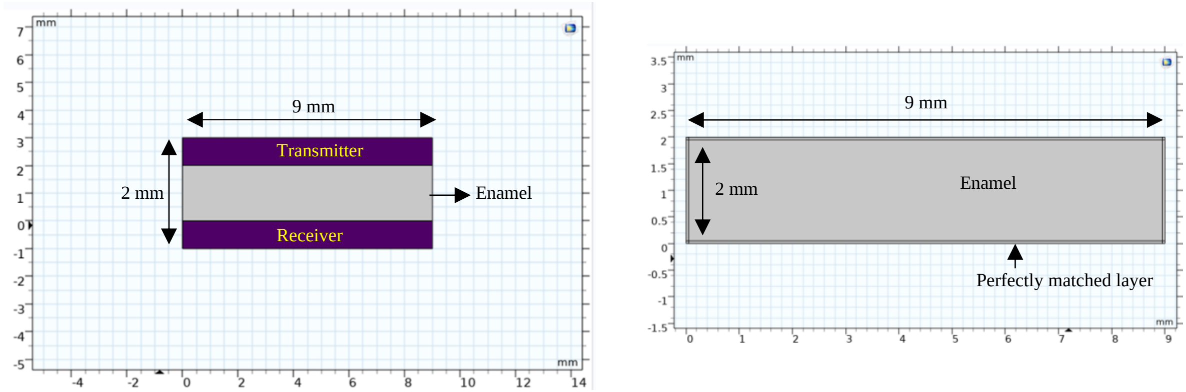
| Property | Value |
|---|---|
| Density (ρ) | rho(T[1/K]) [kg/m^3] |
| Speed of sound | 4500 m/s |
| Refractive index, real part | 1.6 |

A pair of transducers made up of lead zirconate titanate (PZT-5H) were used for the sensing element. For the artificial carious lesion, acid buffer [17] was used with a refractive index of 4.3.

### 2.1 Model geometry and setup

The simulation included one homogenous and one non-homogenous teeth model. Homogenous incisor tooth has a defect-free structure, whereas non-homogenous incisor tooth has a defect structure such as caries lesion. The homogenous incisor tooth was used as a reference model.

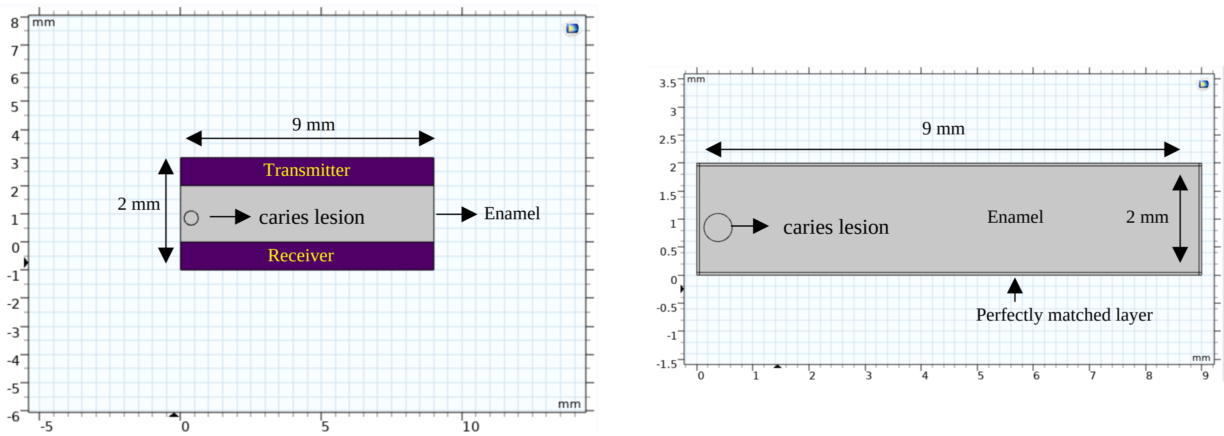
As shown in Figure 1, the simulated incisor tooth model has a cross-section dimension of 9 mm x 2 mm [18] [19]. The transmitting and receiving transducers were oriented in direct transmission at the surface of the enamel structure. For a non-homogenous incisor tooth in Figure 2, the defect was modelled as an acid buffer with its diameter used as the variable. The position and size of the caries lesion (angle of rotation) were taken as the constant variable. The simulation was conducted in a dual mode method; light propagation and wave propagation.




a) Wave propagation orientation

b) Light propagation orientation

Figure. 1. The geometry of homogenous incisor tooth structure




a) Wave propagation orientation

b) Light propagation orientation

Figure. 2. The geometry of non-homogenous incisor tooth structure with acid buffer

## 3. Result and Discussion

The simulation was performed to analyze the propagated waves (wave propagation and light propagation) on incisor teeth. The results were divided into two sections, including the simulation of homogenous and non-homogenous incisor teeth models (with the inclusion of acid buffer). The sensitivity map of both propagated waves were then recorded.

### 3.1 Light Propagation

The simulation for light propagation was applied to the highest wavelength which was 1310nm [10]. The penetration of the laser into the tooth has form difference effects of scattered waves inside the homogeneous and non-homogeneous enamel structure.

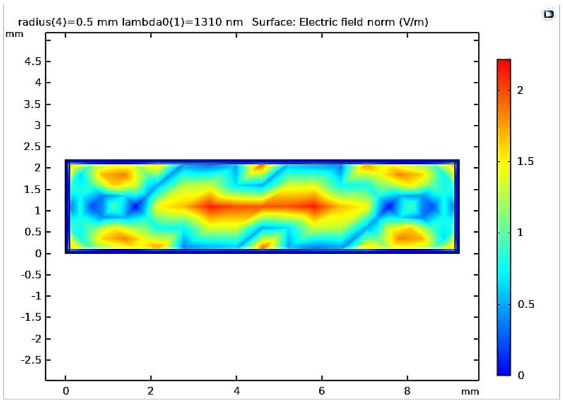



Figure. 3. Light propagation of homogenous incisor tooth structure

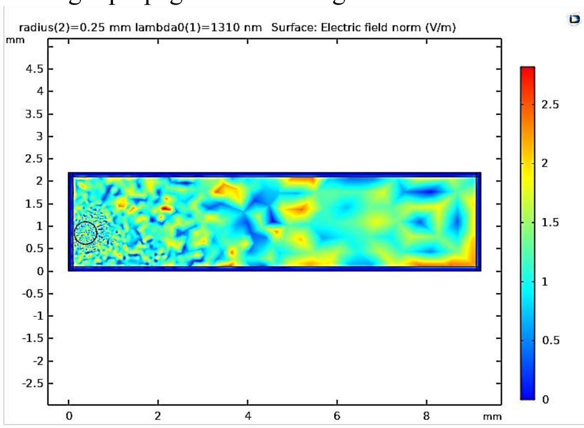



Figure. 4. Light propagation of non-homogenous incisor tooth structure with acid buffer

2D images for Figures 3 and 4 were exported to the sensitivity map. The sensitivity map detailed the information of the scattered wave that propagated inside the incisor teeth. The sensitivity map was then analyzed based on a normality test using Minitab software.

### 3.2 Wave Propagation

The simulation for wave propagation was applied using the highest frequency of the transmitter used in dental which was 25MHz [16]. The transmission signal from the transmitter formed different effects of pressure acoustic waves inside the homogeneous and non-homogeneous incisor tooth structure.

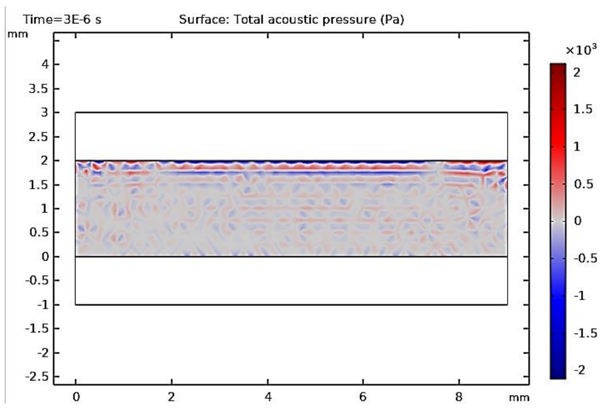



Figure. 5. Wave propagation of homogenous incisor structure

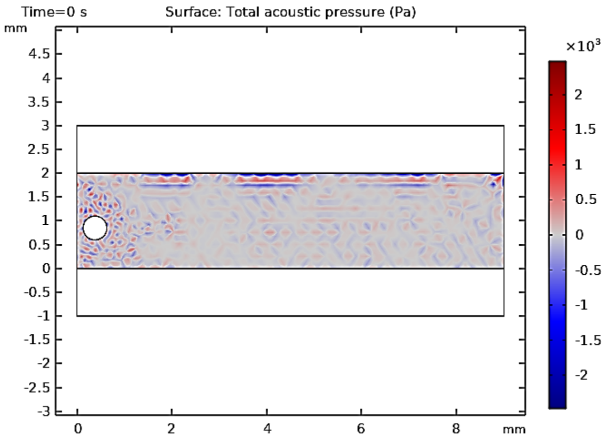



Figure. 6. Wave propagation of non-homogenous incisor structure with acid buffer

2D images of Figures 5 and 6 were exported to the sensitivity map to detail the information of the acoustic pressure wave that propagated inside the incisor teeth. Then, the sensitivity map was analyzed based on a normality test using Minitab software.

### 3.3 Normality Test of Light Propagation

Forty-pixel values were taken from the sensitivity map from Figures 3 and 4 for further analysis using Minitab software. The data consists of information on carious lesions. Each image pixel contains a different value that describes the scattering effect. Therefore, the different effects of scattering can be observed.

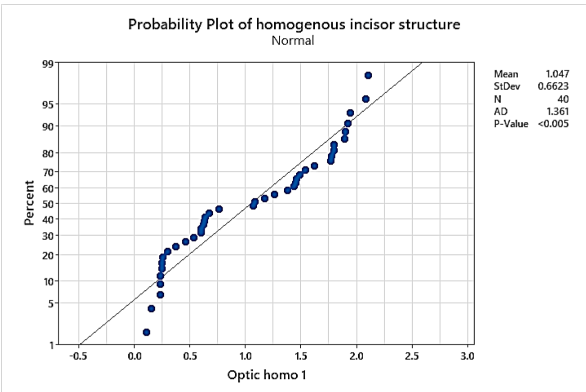



Figure. 7. Normality test of homogenous incisor structure

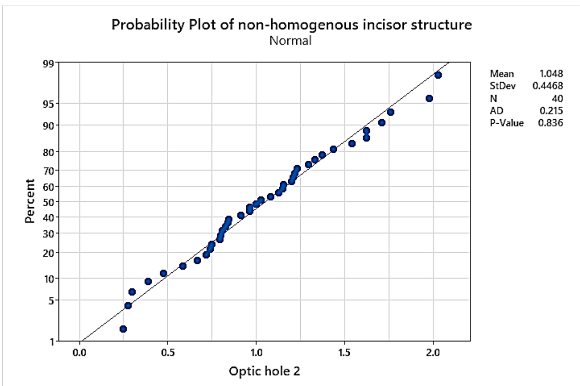



Figure. 8. Normality test of non-homogenous incisor structure with acid buffer

From the above figure, the P-value in Figure 7 is less than 0.05 while the value of P-value in Figure 8 is more than 0.005 which is 0.836. The waves in Figure 7 were scattered and did not converge. Therefore, the P-value is less than

0.05. In contrast with Figure 8, the P-value is higher due to the presence of caries lesion. The wave was convergence due to refraction of the caries lesion. Hence, the repeated value around the caries lesion was produced and the plotted data is near to the linear line. Due to the high P-value, we can infer that the null hypothesis, stating that the data follows a normal distribution, is accepted.

### 3.4 Normality Test of Wave Propagation

Forty data of sensitivity map were taken from Figures 5 and 6, and analyzed using Minitab software. Each pixel of the image contains a different value that describes the scattering effect. Therefore, the different effects of scattered can easily be observed.

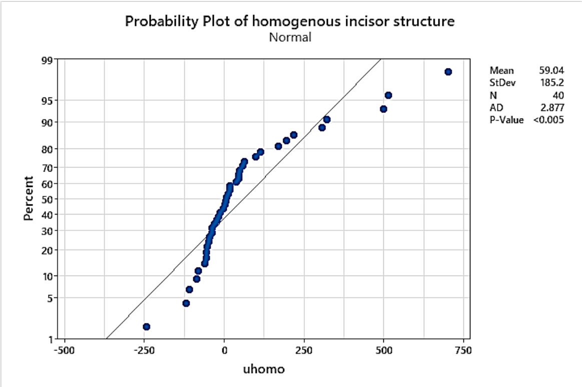



Figure. 9. Normality test of homogenous incisor structure

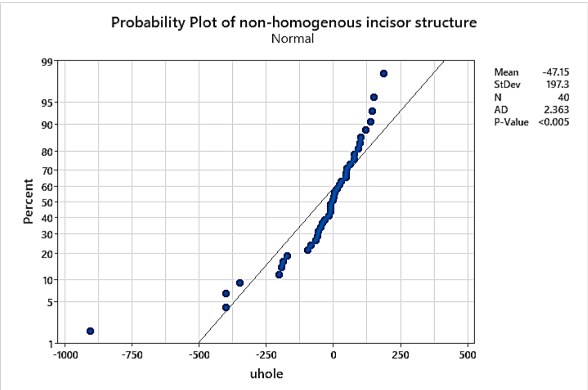



Figure. 10. Normality test of non-homogenous incisor structure with acid buffer

The above figures showed that the ultrasound did not have any effect to P-Value means the wave pattern only changed slightly. Even though this technique cannot define carious lesions by using a sensitivity map, this technique has been proven successfully detect foreign objects in the enamel structure by using time arrival. It is expected that the future research will consider this technique by using time arrival to detect the present of carious lesion [20].

## 4. Conclusion

As a conclusion, this project provides a conceptual modelling of a portable dental diagnostic tool based on a dual-mode tomography method. This project showed the different scattered waves of light propagation and wave propagation from OCT and ultrasound methods. This project also gives many benefits to the field of dentistry in preventing or treating oral health problems by analyzing the propagation of light and waves through the changes in the tooth structures. The limitation of this project is the difficulty in developing a simulation of light propagation, which is OCT, because it requires time and effort to learn new simulation techniques in COMSOL Multiphysics. The OCT limitation in image reconstruction can be solved and proved by combining two techniques: OCT and ultrasound techniques. For future research, ultrasound and OCT techniques will be merged to improve the image reconstruction of incisor teeth. Understanding these limitations of dental imaging technology is essential for enhancing the quality of imaging.

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