Title
Clinical Monitoring of Early Occlusal Caries on Primary Teeth with Optical Coherence Tomography

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Clinical Monitoring of Early Occlusal Caries on Primary Teeth with Optical Coherence Tomography

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JungSoo Kim

ABSTRACT

Purpose: The purpose of this study is to observe structural changes and lesion activity of early occlusal pit and fissure caries on primary teeth using CP-OCT. The hypothesis is that CP-OCT will be able to successfully identify the presence of a transparent surface zone of reduced reflectivity that is indicative of remineralization and an arrested lesion.

Methods: Participants (n=30 with 61 primary molars) aged 6 to 10 years old participated in the study. All lesions were clinically examined and given a diagnosis according to the ICDAS codes. All lesions were then scanned with CP-OCT. Images were converted and analyzed with image analysis software.

Results: OCT scans showed that 57 teeth (93%) had pit and fissure lesions and 4 teeth (7%) were without lesions. Several teeth, n=16 (26%), showed a distinct surface zone that indicated arrested lesions. Most of the teeth, n=45 (74%), did not show evidence of surface zone, indicative of active lesions. Several of the teeth, n=11 (18%), had lesions that were visible with OCT but were not visible in the visual examination.

Conclusions: OCT can detect early occlusal caries that cannot be identified on radiographs or through a clinical exam. OCT can provide information on lesion activity by detecting the presence of a transparent surface zone, indicative of lesion arrest, and can precisely show the depth of the lesions. OCT will be a valuable tool in the future that can provide useful information to the clinicians to aid with their diagnosis of early occlusal pit and fissure caries.

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LIST OF ABBREVIATIONS

CP-OCT = Cross-Polarization Optical Coherence Tomography

DEJ = Dentin-Enamel Junction

HIPAA = Health Insurance Portability and Accountability Act

ICDAS = International Caries Detection and Assessment System

OCT = Optical Coherence Tomography

UCSF = University of California, San Francisco

INTRODUCTION

Optical Coherence Tomography (**OCT**) is an imaging method that can capture high-resolution cross-sectional images of structures in the oral cavity.[1] It has widely been used in the medical field, especially in ophthalmology, as it is very effective in imaging ocular structures with great scanning speed, high sensitivity and resolution.[2] Colston et al., in 1998, published one of the first studies that applied OCT to dentistry and used the system to image hard and soft tissue in the oral cavity.[3] Their study showed that OCT can successfully be used to provide high-resolution images of enamel-cementum and gingiva-tooth interfaces. In subsequent studies, OCT has subsequently been used to image teeth, periodontium and to evaluate margins between teeth and restorative material.[1]

Currently, carious lesions are diagnosed with visual-tactile methods, using the explorer, and radiographs. For pit and fissure caries, the tactile method via probing with an explorer showed low sensitivity and has been found to be unreliable in its diagnosis.[4] There are risks for false positives when using radiographs to diagnose occlusal caries, as 12% of caries-free surfaces were incorrectly diagnosed as carious by experienced dentists in Espelid et al.'s study.[5] Furthermore, there is great variation in the diagnosis of occlusal caries with radiographs between dentists, indicating the unreliable nature of diagnosing caries with our currently existing methods.[5] In this regard, OCT may be a viable future method that will allow us to reliably diagnose caries and provide information on lesions that are not available with our current technologies.

A recent clinical study showed that OCT was able to accurately image occlusal caries that were not visible on radiographs. Simon et al. performed an *in vivo* study to image questionable occlusal caries using cross-polarization optical coherence tomography (**CP-OCT**).[6] Thirty test subjects who had questionable occlusal lesions, that were not visible on radiographs, were recruited to participate in the study. Using a CP-OCT system, the study team were able to image the lesions, observe surface demineralization and determine whether the lesion penetrated into dentin or not. This study showed that CP-OCT methods have great potential for use in diagnosing early occlusal caries, and should be able to provide more accurate assessments than current radiographs.[6]

OCT is also able to image recurrent caries underneath existing restorations. It is challenging to diagnose early recurrent caries underneath existing restorations. Clinicians use radiographs to check for radiolucencies underneath restorations for signs of recurrent caries. They may also check for any staining or cavitation around restoration margins. However, when recurrent caries is diagnosed using these methods, the lesions may have progressed significantly requiring more removal of tooth structure to replace these restorations. OCT can be used to detect slight demineralization underneath existing restorations. An *ex vivo* study was performed using forty extracted teeth.[7] Teeth were divided into healthy and carious teeth, and were randomly assigned to get sealants. OCT was able to accurately image recurrent caries and demineralization underneath sealants. Furthermore, dentists were trained to use the OCT system via a ninety-minute standardized training. After their training, dentists were able to more accurately diagnose caries using OCT, compared to their diagnosis using visual and radiographic methods.[7] This study showed that OCT may be a useful tool that the dentists, with training, can use to diagnose early demineralization and recurrent caries.

Current caries diagnosis methods do not provide a quantitative measurement that dentists can use to accurately assess caries severity and changes in lesion structure over time. Dentists currently can only approximate how far lesions have progressed from the dentin-enamel junction

(**DEJ**) and its proximity to the pulp. In contrast, OCT can quantitatively measure mineral changes of a carious lesion longitudinally.[8] An OCT system can measure A-scans (depth vs. reflectivity curve), B-scans (longitudinal images) and C-scans (transverse images at constant depth). It can also measure changes in reflectivity with depth and increased attenuation of light with increasing demineralization.[8] With OCT's quantitative properties, dentists will be able to make a more standardized assessment of carious lesions and will be able to quantitatively monitor changes in lesion structure over time.

With the ability of OCT to quantitatively measure mineral loss, a study was performed to explore whether OCT can monitor demineralization of enamel clinically. Nee et al. performed a randomized controlled clinical study to monitor demineralization of enamel peripheral to orthodontic brackets over 12-month period using CP-OCT.[9] Twenty subjects were recruited to participate in this study with a split mouth design. The results showed that there was an increase in lesion depth and integrated reflectivity over time, demonstrating that there was an increase in demineralization around the brackets over time. This study showed that CP-OCT was able to successfully measure demineralization of enamel and can provide quantitative measurements to monitor lesion changes over a period of 12 months.

Compared to monitoring demineralization, a study was conducted to see whether OCT can be used to monitor structural changes to smooth surface lesions over time when it is remineralized with fluoride varnish. An *in vivo* study was performed by Chan et al. to clinically monitor smooth surface enamel lesions using OCT.[10] Seventeen test subjects with smooth surface lesions were recruited. Lesions were monitored with OCT for 30 weeks total, with fluoride varnish applications every 6 weeks to help with remineralization. With OCT imaging, the lesions were quantified via lesion depth, integrated reflectivity, and surface zone thickness.

Unfortunately, the changes in lesion structure were minimal and non-significant in this study as 62 out of 64 lesions were already arrested prior to the start of the study. Transparent surface zones, that indicate arrested lesions, were already apparent prior to application of fluoride varnish. Therefore, little structural changes could be observed through this study. However, this study showed OCT's ability to image transparent surface zones on lesions, indicating its potential use in diagnosing caries activity and determining whether lesion is active or arrested.

OCT has potential in improving and facilitating caries diagnosis in the future. It provides more information on caries lesions that our currently existing methodologies cannot provide. OCT can provide a more accurate image to detect early demineralization. It can provide quantitative measurement of lesions that can be used to monitor changes in lesions over time. Furthermore, OCT can assess lesion activity by detecting and monitoring the depth of the transparent surface zone. There is no technology that is currently able to provide such diagnosis.[11]

This study aims to assess structural changes and lesion activity of early occlusal pit and fissure caries on primary teeth using CP-OCT following remineralization. Primary teeth were chosen for this study to ensure that a higher percentage of the lesions would be active rather than arrested. The hypothesis is that CP-OCT will be able to successfully monitor these changes by detecting transparent surface zone with increase in its thickness over time, and monitoring decrease in light reflectivity over time with remineralization.

MATERIALS AND METHODS

This project has been approved by the University of California, San Francisco's (**UCSF**) Institutional Review Board (#18-25927).

Study Participants

Participants (n=30) have been recruited from the UCSF Pediatric Dentistry resident and student clinics by the study investigators based on the following inclusion and exclusion criteria.

<u>Inclusion Criteria</u>:

- Provide signed and dated informed consent forms.
- Willing to comply with all study procedures and be available for the duration of the study.
- Male or female, aged 6 to 10.
- Living in San Francisco or in areas with community fluoridation (to eliminate water fluoridation as a potential confounding variable).
- High caries risk.
- Must have at least two primary teeth with suspected pit and fissure caries.
- Must be willing to waive the Health Insurance Portability and Accountability Act (**HIPAA**) acknowledgement that data will only be used for research.

<u>Exclusion Criteria</u>:

- Medical condition that precludes participation.
- In-office fluoride treatment within the past 3 months.
- Obvious cavitation of lesions.
- Sealants covering pits and fissures.
- Anything that would place the individual at increased risk or preclude the individual's full compliance with or completion of the study.

Parent of all participants signed the consent and HIPAA acknowledgement forms. 7 to 10-year-old patients provided assent to participate in the study. Participants were rewarded $200 gift card after their last participation of the study.

Lesion Identification

Lesions were identified by the study investigator (pediatric dental resident) and was given a diagnosis according to the International Caries Detection and Assessment System (**ICDAS**).[12] ICDAS code 0 described sound enamel with no visible caries. ICDAS code 1 was given to teeth with initial changes in pit and fissures of enamel and lesions were visible when air-dried. ICDAS code 2 was given to teeth with greater changes in enamel, that extended beyond pit and fissures, and lesions were visible without drying with air.

CP-OCT System and Image Analysis

Swept-source CP-OCT system from Santec was used along with 3D-printed dehydration attachment made with dental resin to acquire clinical images. Lesions were dried with air with dental air/water syringe. OCT scanner was then used to scan a 6x6 mm^2 area encompassing the lesion. Two OCT scans were taken for each lesion.

Images were converted into 256*256*1024 pixel-format with MATLAB[13] software and then converted (pixel to distance) as: X: 23.438 µm, Y: 23.438 µm, Z: 5.84 µm.

OCT images were then further analyzed with Dragonfly 2021.1[14] software. Manual image registrations, including rotation, translation, and scaling transformation, were performed. Linear interpolation and registration methods were used based on mutual information.

Image intensity profiles were corrected with contrast normalization, in which the maximum intensity was normalized to 65565 and lowest intensity to 0 (Figure 1). Image segmentation was performed to filter the intensity signal on the lesion by applying 85% upper Otsu thresholding (Figure 2). The segmentation was further enhanced by a Gaussian smoothing with kernel size of 3. Speckles around the lesion were removed with this segmentation (Figure 3).

Lesion depth was classified as E1 (lesions were less than half way through the enamel) (Figure 4), E2 (lesions were more than halfway through enamel), and D1 (lesions penetrated into the dentin) (Figure 5). Presence of surface zone was evaluated on a binary scale (Yes/No) (Figure 6).

RESULTS

A total of 61 primary molars from 30 subjects were examined for pit and fissure lesions and then imaged with OCT scans.

According to clinical exam, 50 out of 61 teeth had visible lesions, with 44 teeth (72%) with ICDAS code of 1, and 6 teeth (10%) ICDAS code of 2 (Table 1). 11 out of 61 teeth (18%) showed no lesions according to visual examination.

According to OCT scans, 57 teeth (93%) had pit and fissure lesions and 4 teeth (7%) did not have any lesions (Table 2). Furthermore, 16 (26%) of teeth showed a distinct surface zone that indicated arrested lesions. 45 teeth (74%) did not show evidence of surface zone, which is indicative of active lesions (Table 2).

From OCT images, lesions were classified according to its depth (Table 2). There were n=40 teeth (66%) with lesions classified as E1, indicating the lesions were less than halfway through enamel. There were n=11 teeth (18%) with lesions that were more than halfway through enamel (E2 classification) and n=6 teeth (10%) with lesions that OCT scans showed penetration into dentin (D1 classification).

Comparing findings from clinical exam and OCT scans, n=46 out of 61 teeth were "true positives" in that it showed lesions both clinically and through OCT images (Table 3). Eleven (n=11) out of 61 teeth showed lesions on OCT image, but failed to be identified in visual exam (false negatives). There were n=4 teeth that did not show lesions per OCT image, but were suspected to have caries from visual exam (false positives).

DISCUSSION

OCT was successful in detecting early pit and fissure caries in primary teeth. All lesions were able to be visualized and light reflectance could be observed in pit and fissures where lesions were present. This is consistent with Simon et al.'s study that was able to use OCT to image questionable occlusal caries *in vivo*.[6] These early pit and fissure caries are usually not visible on radiographs and depend on clinicians' visual and tactile methods for its diagnosis. Being able to detect and visualize these initial lesions, OCT will be a valuable tool in helping clinicians detect these lesions early and help in preventing the lesions from progressing into larger lesions.

Distinct surface zones, indicative of arrested lesions, were visible through OCT on our test subjects. This finding is significant in that OCT was able to recognize activity of lesions, such as whether lesions are active or arrested, that no other current diagnostic tools can identify. This is consistent to findings by Chan et al.[10] Their study also found distinct transparent surface zones in 62 out of 63 lesions using CP-OCT *in vivo*. They were also able to measure the thickness of the surface zone and correlate it to the level of lesion activity. An increase in the surface zone thickness indicated lesions being more arrested, as the surface zone represented mineral deposition in remineralized lesions.[10] Primary teeth were chosen for this study to ensure that a higher percentage of the lesions would be active rather than arrested, that proved to be the case, and only 16 out of the 61 teeth in this study had an initial surface zone visible on the lesion surface for the first visit. OCT can be a useful tool in the future that can provide more precise information on the activity of lesions. Being able to confirm whether lesions are active or arrested, through observation of surface zones, will be valuable information to the clinicians when deciding on the treatment plan and interventions for caries control in patients.

Lesions in this study were classified into ICDAS codes to compare visual diagnosis to OCT scans. When lesions are more apparent, it could be identified through both visual exam and OCT image. However, there were significant number of teeth that were viewed as sound, but showed lesions on OCT images. This is consistent with previous study that also compared lesions based on OCT images and ICDAS codes. A study examined 133 smooth surfaces *in vitro* using ICDAS and OCT.[15] This study showed that 42% of lesions showed caries on OCT when these lesions were diagnosed as sound per ICDAS. These results show how it is unreliable to diagnose early caries just through visual exam as it can provide a false negative result. OCT can be a useful technology that can confirm the presence of early carious lesions, when the lesions cannot be identified clinically. It was surprising that only four of the teeth had surfaces that were considered carious via visual exam but were sound according to OCT (false positives). We had anticipated a much higher number due to misdiagnosis due to presence of stain. Stains are invisible at 1300 nm which is advantageous for avoiding false positives.

Visual exams alone cannot provide a reliable assessment on the depth of carious lesions. In this study, OCT was able to reproduce lesions in 3-D image where it was possible to visualize and quantify the exact depth of lesions. OCT was used to visualize how far lesions progressed into the enamel and whether it progressed into dentin or not. Although majority of teeth in this study were classified as ICDAS code 1, OCT showed that some of the lesions were actually into dentin. This finding is consistent to the previous study that compared ICDAS codes of lesions to the depth of caries as observed in OCT images.[15] Consistent to our findings, this previous study by Park et al. showed that there were great variations between ICDAS and OCT. The study found that greater than 40% of lesions identified as ICDAS code 2 were actually cavitated and had dentin involvement when observed with OCT. These findings, consistent to our study, further suggest the unreliable nature of visual exams in assessing the depth of caries. OCT technology can provide useful information regarding the depth of lesions that is crucial to the clinicians.

The limitation of this study is that lesion diagnosis in this study could not be compared to a gold standard. It would be the most ideal if this study's findings could be validated by comparing the ICDAS codes and OCT images to the actual lesion (e.g., histological sample). This was an *in vivo* study, therefore, the findings from our study could not be compared to a histological sample. Another limitation was that this study could not provide a longitudinal result, as in whether OCT could monitor changes in lesion structure over time. This project is still in progress by the study team, and results on longitudinal findings will be furthered studied in the future.

The findings from this study were significant in that it showed OCT as a promising technology that clinicians can use to obtain more information on pit and fissure caries. OCT can detect early occlusal caries that are not able to be identified on radiographs and through visual-tactile exams. Furthermore, OCT can assess the activity of these lesions and indicate whether these lesions are active or arrested by detecting the transparent surface zone. Also, OCT can more precisely display the depth of the lesions – how far the lesions progressed through enamel and into dentin. None of the diagnostic tools currently used in clinical setting can provide this information. OCT will be a valuable addition to the clinicians and will be able to provide useful information that can assist in accurate diagnosis, which subsequently will help with their treatment planning and patient care.

CONCLUSIONS

OCT can detect early occlusal caries that cannot be identified on radiographs or through clinical exam. OCT can provide information on lesion activity. OCT can detect the presence of a transparent lesion surface zone, that is indicative of arrested lesions. Moreover, OCT can precisely show the depth of the lesions through enamel and dentin layers. These are all information that can benefit the clinicians in making a more accurate diagnosis of early occlusal caries.

FIGURES

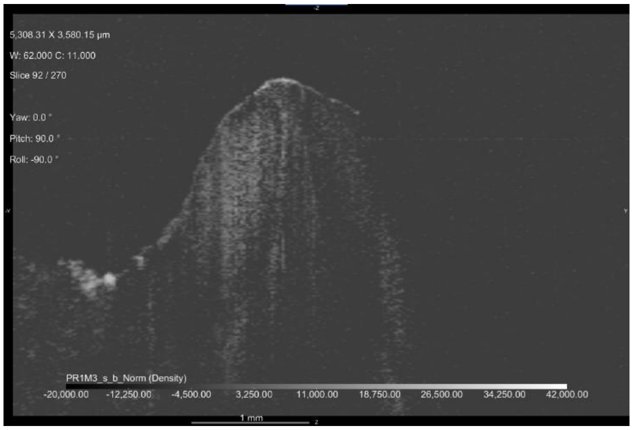

Figure 1. OCT image intensity profile corrected with contrast normalization

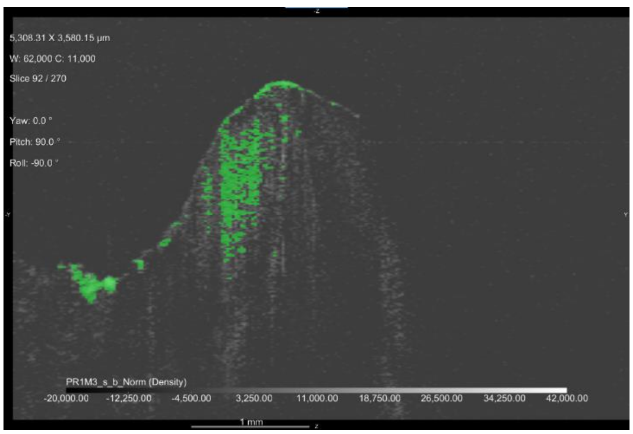

Figure 2. OCT image thresholding segmentation with upper Otsu = 85% to filter the intensity signal on the lesion

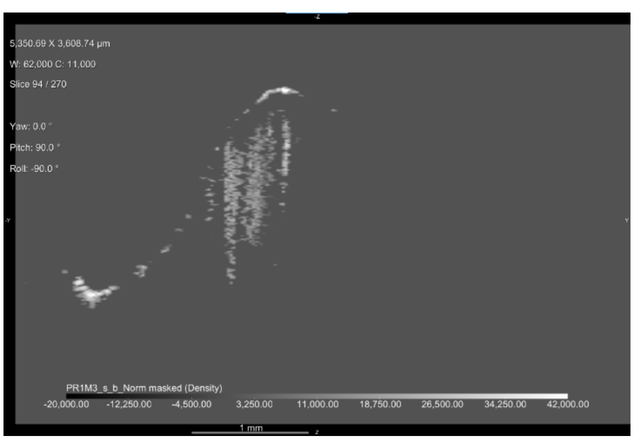

Figure 3. OCT image after removal of speckles around the lesion

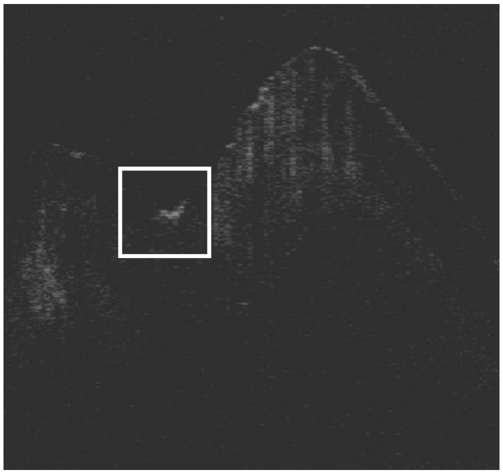

Figure 4. Lesion into less than half way through enamel (E1 classification)

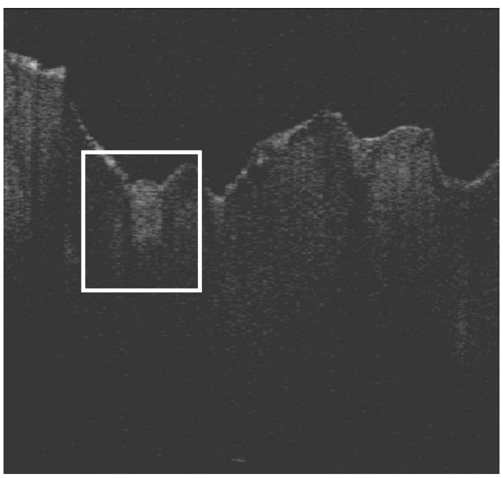

Figure 5. Lesion into dentin layer (D1 classification)

Figure 6. Presence of transparent lesion surface zone

TABLES

Table 1. Description of findings based on clinical visual exams

	0	**1**	**2**
Lesions Classification (ICDAS)	11 (18%)	44 (72%)	6 (10%)

Table 2. Description of findings based on OCT scans

	Yes		**No**	
Lesions Detected on OCT	57 (93%)		4 (7%)	
Surface Zone Detected on OCT	16 (26%)		45 (74%)	
	0	**E1**	**E2**	**D1**
Caries Depth on OCT	4 (7%)	40 (66%)	11 (18%)	6 (10%)

Table 3. Comparing OCT and clinical exam findings

	Lesion Detected in OCT	**Lesion Not Detected in OCT**
ICDAS 1-2	46 (True Positive)	4 (False Positive)
ICDAS 0	11 (False Negative)	0 (True Negative)

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