Identification of Occlusal Sealants Using Optical Coherence Tomography

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Abstract

- **Objective:** Optical coherence tomography (OCT) is a new imaging technique that uses light to image dental structures interferometrically. OCT creates cross-sectional images that have potential diagnostic value for dental applications. When used in epidemiological studies, OCT offers a safe, non-invasive technique to discriminate occlusal sealants and composite restorations. This paper summarizes a study in which dentists were asked to interpret and discriminate between OCT images.
- **Methodology:** Twenty-one dentists were asked to interpret OCT images of nine extracted premolars that were either not restored, contained an occlusal sealant or were restored with a composite restoration.
- **Results:** Although the dentists were previously unfamiliar with OCT images, they adapted well and felt confident in their diagnoses using this new technology. The sensitivity of OCT to discriminate composite and sealants was > 0.92, while the specificity of discrimination was > 0.94. The capacity of OCT to discriminate sealants from non-restored occlusal surfaces was slightly less (sensitivity 0.88; specificity 0.86), but still within a clinically acceptable level. Inter- and intra-rater reliability, as measured by the kappa statistic, also revealed excellent performance by dentists using this new imaging technology. Intra-rater reliability was very good, ranging from 0.82 to 1.0. Inter-rater reliability was also high, predominately in the "Good" to "Very Good" agreement range.
- **Conclusion:** This preliminary study indicates OCT imaging may be an important new technology for discriminating occlusal sealants and composite restorations.

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Introduction

Optical coherence tomography (OCT) is a new, non-invasive imaging technique that was initially developed to image transparent tissues in the eye.[1] Recently, OCT has been used in a wide variety of biomedical applications including dentistry.[2-5] OCT measures the reflections of light from tissues based on the principle of Michelson interferometry, as illustrated in Figure 1. Light from a low coherence source is divided and reflected from a reference mirror and the tissue. When the pathlength of light from the reference mirror is the same as the tissue, an interference fringe is detected. Since the reference mirror is moved by known increments, the position of the reflected light within the sample can be determined. The magnitude of the reflected signal is determined by the optical scattering properties of tissues. By moving the sample arm along the tooth surface using a handheld motorized scanner, a two-dimensional tomographic image is created. OCT images represent a compilation of light reflections from tissue along the axis that the light is scanned. The limitation of OCT for dental imaging is that the maximum depth that can be visualized is restricted to about 3–4 mm. The advantage of OCT is that high-resolution images of both teeth and the periodontal tissues can be acquired simultaneously without exposing the patient to ionizing radiation. OCT is particularly well-suited for imaging the margins of composite restorations.[2-4]

During field epidemiologic studies, it is often impossible to distinguish occlusal surfaces that have resin covering the fissures as either being sealed, having a preventive resin restoration

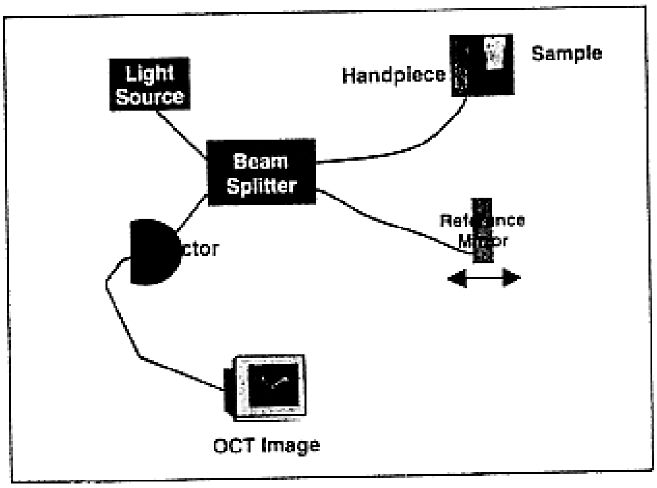

Figure 1. *Schematic diagram of an OCT image system.*

or a posterior composite on that surface. The purpose of this study was to determine the capacity of OCT to discriminate non-restored occlusal surfaces from composite restorations and sealants.

Materials and Methods

Restorations

Nine extracted human premolars were used in this study. The teeth were selected because they appeared clinically and radiographically free of caries. Teeth were mounted in acrylic and the surfaces cleaned of debris with a water spray. Sealants were placed on the occlusal surfaces of three of the teeth according to manufacturer's (Heliomolar®, Ivoclar Vivadent, Amherst, NY, USA) instructions using a 20-second etching period, and 40-second curing period. No bonding agent was used. Conservative occlusal cavities were made in three other teeth using a 330 bur with pulpal floors of 2 mm depth. The preparations were filled with Z-100 and finished with rubber points. Three teeth were not restored, as controls.

OCT Images

A hand-held prototype OCT instrument was used in this study. The system consisted of a light source that had a central wavelength of 1310 nm, a spectral bandwidth of 47 nm, and output power of 15 mW. The numerical aperture of this prototype OCT system was 0.46, and the signal-to-noise ratio was 110 dB. The total scan time for each image was approximately 45 seconds, with a scanning resolution of 50 µm and a total scan distance of 15 mm. The teeth were imaged in a buccal-to-lingual orientation to a depth of 4 mm with an axial resolution of 15 µm. The resulting OCT images are illustrated in Figure 2.

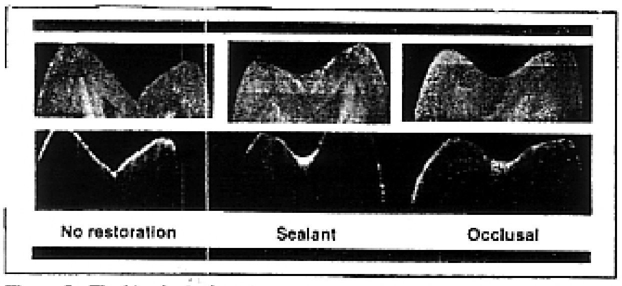

Figure 2. *The histological sections (top row) of three premolars, not restored, containing a sealant and restored with a class I composite restoration are seen together with the OCT image of the corresponding teeth.*

Observer Identification

Twenty-one dentists who were unfamiliar with OCT imaging participated in this study. A brief explanation of the imaging technology was presented together with the training set image illustrated in Figure 2. This training image, consisting of a non-restored tooth, a tooth that contained a sealant and a tooth restored with composite, were shown with the corresponding histological section. After this brief training period, the dentists reviewed all the OCT images on a computer monitor, on an individual basis. Each dentist was asked to determine if the tooth was non-restored, contained a sealant or composite restoration. The dentists did not share information on their determinations with one another, and were also asked to rate the confidence of his/her evaluation on a scale from 1 (low confidence) to 5 (high confidence). The images were presented in two blocks of nine randomized tooth images. The following week, the dentists again evaluated the images and these repeated observations were used to calculate inter- and intra-observer reliability. The dentists were not allowed to review, recall or change their decisions on the images once an assessment was made.

Statistical Evaluation

Inter- and intra-rater agreement was determined using the weighted Kappa statistic.[6] The Kappa statistic is a measure of reproducibility for categorical data. A Kappa value of 1 shows perfect agreement between the two observers, while 0 represents agreement no better than chance. The Kappa value can be used to interpret the strength of agreement according to the following scale: < 0.20 poor; 0.21–0.40 fair; 0.41–0.60 moderate; 0.61–0.80 good; > 0.80 very good.

Results

The results of OCT image interpretation by the 21 dentists are illustrated in Figure 3. Of the 63 potential identifications of teeth with composite restorations, 59 were correctly identified, while four observations classified the tooth as containing a sealant. Sealants were classified correctly 55 times and incorrectly identified as composites seven times and identified as unrestored once. The greatest number of errors occurred in non-restored teeth. Forty-nine of the 63 observations were correctly classified as unrestored. Two of the non-restored teeth were correctly classified by all 21 dentists. The third non-restored tooth was categorized as sealed by 13 dentists and restored by one.

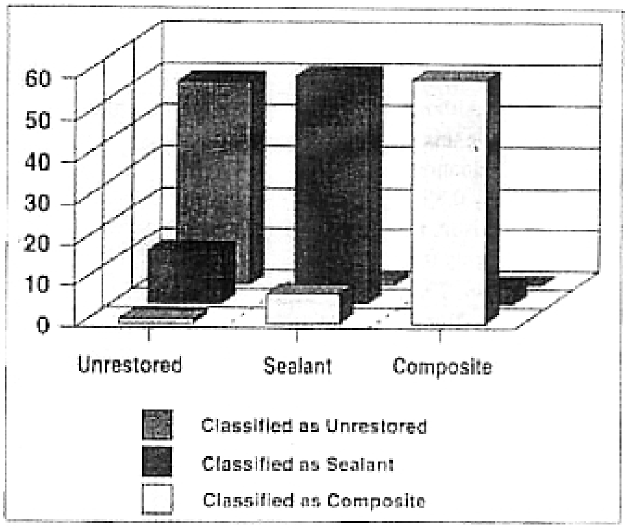

Figure 3. *Twenty-one dentists evaluated OCT images of nine teeth. The results of the identification of teeth as having sealants, composite restorations or no restorations are illustrated in this bar graph.*

The sensitivity and specificity for the observations are given in Table I. Sensitivity refers to the probability that the test results will be positive when the disease is present (true positive rate expressed as a percentage). Specificity refers to the probability that the test result will be negative when the disease is not pre-

Table I
Sensitivity and Specificity of OCT Imaging for the Discrimination of Sealant, Non-Restored and Composite Restorations

	Composite vs. Non-Restored	Sealant vs. Non-Restored	Composite vs. Sealant
Sensitivity	0.94	0.88	0.92
Specificity	0.95	0.86	0.94

sent (true negative rate expressed as a percentage). Overall, the dentists were quite confident with their ability to evaluate these new images (Figure 4). Seventy-one per cent of the dentists

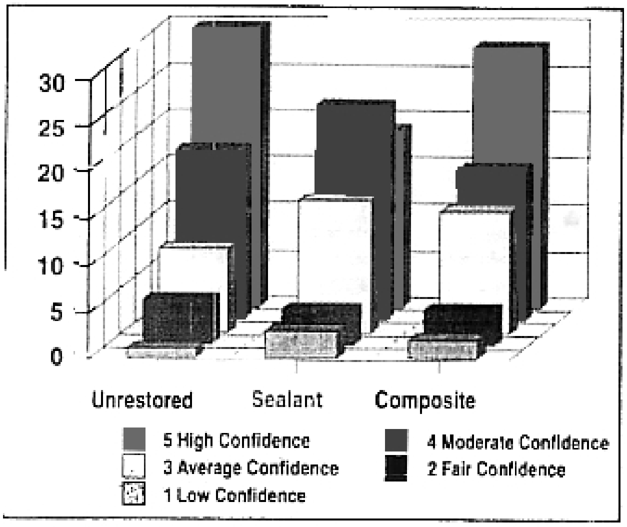

Figure 4. *Twenty-one dentists ranked their confidence of OCT image interpretation of first observations. There was no significant difference in confidence of interpretation among the unrestored, sealant and composite groups.*

rated their confidence for image interpretation as "high" or "moderate," while only 10% rated their confidence as "fair" or "low." While sealants had the lowest number of "high" ratings, there was no significant difference in the number of confidence ratings above or below "average confidence" ratings among the different treatment groups (unrestored, sealant and composite). Confidence ratings for the repeated observations were quite similar, with 64% of the total rating classified as "high" or "moderate," and only 12% of the observations "fair" or "low" (Figure 5).

The kappa statistics for inter- and intra-rater reliably of the dentists' interpretation of OCT images demonstrated that eleven of the dentists had perfect intra-rater agreement in the repeat evaluation of OCT images, while perfect inter-rater agreement occurred 34 times in the 210 inter-rater observations. Fourteen dentists had predominately "very good" inter-rater reliability measurements; four dentists had predominately "good," and three dentists had predominately "moderate" inter-rater reliability measurements.

Discussion

As OCT imaging becomes more widely available, it will be necessary for clinicians to adapt to a new type of image. There are two ways that OCT images are unique. First, OCT images are "cross-sectional." In OCT imaging, sections of the internal

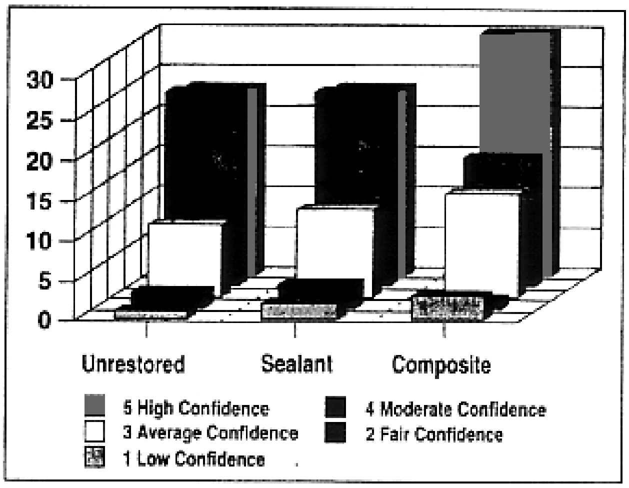

Figure 5. *The confidence ranking for repeat OCT image interpretation did not differ significantly from the initial rankings. Sixty-four percent of the observations were "moderate" or "high" confidence, while only 12% were ranked "fair" or "low."*

structure of teeth to a depth of about 3 mm can be viewed *in vivo*. When a fiberoptic probe is mechanically scanned across teeth, a cross-sectional image is created along the path that the fiber was translated. In Figure 2, the OCT images were created by scanning the fiber over the mid-point of occlusal surface, creating an image that appears as if the tooth were sectioned, revealing the buccal and lingual cusp contours and the thickness of the enamel covering the occlusal surface. The second way OCT images are unlike other dental images is that they contain a high level of "speckle artifact." Speckle artifact is created when the property that is quantified by an imaging system is present at a low level. Most of the light that is incident upon teeth is scattered; only a very small portion of the incident light interacts with the tooth as "specular reflections." It is the specular reflections that give teeth their characteristic luster and contain information about the material properties and structure of teeth. The reflected light that is measured in OCT imaging is present at a low level and thus OCT images contain a high level of speckle artifact. One of the unique advantages of OCT imaging is that it uses light of a wavelength and power that has no known detrimental biological effects.

To be useful as a diagnostic technique, OCT images must reliably reproduce the outline of various materials that are placed in or on the tooth, but dentists must also be able to confidently interpret these images. We undertook this study to determine how well dentists adapted to these unusual images and to ascertain the accuracy of OCT image interpretation. The dentists who participated in this study rapidly accommodated to the images and were quite confident in their assessments of the diagnostic information contained in OCT images.

This preliminary study suggests that OCT may be used to discriminate among sealants, composite restorations and non-restored surfaces. Some of the dentists commented that composites were easier to identify in OCT images because of the straight demarcation of the axial walls. Whether or not this observation holds up in a larger study is unknown. Of more concern is the fact

that debris in the fissure of one non-restored tooth resulted in mistaken identification as a sealant in the OCT image (13 of 63 observations). Visualization of plaque would discriminate this situation clinically, and it is likely that plaque and debris could be more problematic in a clinical setting. The more difficult clinical assessment is whether the material is a restoration or a sealant. This appears to be an easy discrimination in OCT images. It should be kept in mind that the nature of preventive strategies currently employed is an evolving science that is dynamic both concerning tooth preparation and the materials used.

Newer fissureotomy techniques may make it more difficult to distinguish a preparation from a sealant. Some clinicians advocate enlarging fissures with a 1/4 round bur by following the groove pattern. This may complicate OCT interpretation. Some authors have advocated this practice to increase the surface area of the enamel to improve sealant retention by the resultant thicker layer of sealant within the fissures/grooves.[7-10] This method can also be used to increase the practitioner's confidence that caries does not exist beneath the surface. An extension of the preventive resin restoration is where only the area containing the caries is removed, but the entire occlusal surface is not prepared as a conventional occlusal preparation. Rather, the filled composite is placed only in the small areas where the caries is removed and sealant is then placed over the entire surface, including over the composite. Similarly, the use of "flowable composite" material that is placed only within enamel may also lead to more difficult OCT interpretation.

To verify the practical utility of OCT imaging for discrimination of occlusal restorations and sealants, it is recommended that a larger study measures accuracy in a clinical epidemiological setting. This would more rigorously evaluate this technology. Future investigations should focus on this technology with a wide variety of materials and tooth preparation.

What this preliminary study did show was that although OCT is new and the participating dentists were not experienced with the unusual imagery, they adapted to the technology quite well and were confident in their ability to interpret the images. The authors believe that OCT may improve the accuracy of DMFS assessments.

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