Optical Coherence Tomography (OCT) for the evaluation of internal adaptation of class V resin restorations on Dentin

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ABSTRACT

Internal adaptation of adhesive restorations affects their longevity. In a clinical setting, the dentists use visual and tactile examination to evaluate marginal adaptation, while radiographs provide somewhat reliable information about adaptation or secondary caries present. For class V restorations located on the vestibular (buccal) surfaces, none of the tools available can provide any information about the internal adaptation or the presence of secondary caries. OCT has been proven to be a useful tool for non-destructive assessment of internal adaptation of adhesive restorations. This paper is evaluating the use of a new high-resolution handheld OCT prototype with a pen-shaped intraoral tip and an imaging depth of 8mm to examine the internal adaptation and the presence of demineralization under resin restorations on the vestibular dentin surface.

The Axsun OCT system helped evaluate the internal adaptation of composite restorations, differentiate between healthy and demineralised dentin, adhesive, and restoration layers. OCT provided a unique visualization and characterization of internal structures as well as non-contact assessment of marginal adaptation.

1. INTRODUCTION

Defects of the marginal seal of a restoration affects the longevity of an adhesive restoration. The loss of marginal and internal adaptation leads bacterial microleakage, secondary caries, discolorations and hypersensitivity of the restored vital tooth\textsuperscript{1,2}.
Dentists rely on visual and radiographic examination to evaluate existing restorations. Visual assessment is subjective and provides no information concerning internal adaptation. While radiographic examination can provide some information about the tooth/restoration topography, it can also give false negative or false positive results. A comprehensive review of the literature concluded that “the extent to which variation in dentists’ evaluation of existing restorations is associated with characteristics of the dentist and the practice is completely unknown”. While depending on the classic methods, gaps and secondary caries can be easily missed or detected at advanced stage. Providing a non-invasive reliable tool to evaluate marginal and internal adaptation of restoration can be highly valuable.

In vitro, experiments evaluating internal adaptation usually rely on subjective assessment of the gaps under microscope. For example, Scanning Electron Microscope (SEM) has been used for the evaluation marginal and internal adaptation for many years. This method is destructive, requires special specimen preparation and can be time consuming. Optical coherence tomography (OCT) is a well-established modality in many medical fields. Without the use of radiation or magnetic field, near-infrared light is utilized to generate depth-resolved images from light scattering media almost in real time. It has been used to image caries under sealants and composite restorations.

OCT has also enabled fine quantitative measurements of the adaptive behaviour of dental restorations at micron scale in two-dimensional (2D) and three-dimensional tomograms without the destruction of the samples.

For occlusal and proximal restoration, the imaging with OCT has been limited by the depth of the restoration as the OCT systems previously employed had a limited imaging depth of only 3mm. A high-speed 3D OCT imaging system that maintains a high resolution over a much more extended imaging depth is more suited for clinical imaging.

The aim of this paper is to investigate OCT as tool for class V restoration assessment, using Axsun’s dental OCT prototype. Using OCT we will evaluate the internal adaptation of composite restorations using this system on healthy and carious dentin surfaces. The null hypothesis is that there is no difference between internal adaptation on healthy or carious dentin with or without acid etching.

2. MATERIALS AND METHODS

2.1 Sample preparation:

Thirty-two extracted posterior teeth under perfusion of simulated dentinal fluid (Phosphate Buffer Saline+ horse serum) were used. Class V cavities prepared on healthy (H) or formic acid (FA)-demineralised. For the groups on demineralized dentin, before exposure to 10% formic acid 5 hours, samples were protected outside the cavity with a silicon impression material (President, Light Body, COLTENE Whaledent, Batch Number I38648). After demineralization the silicone was removed, and samples were rinsed with tap water and stored under humidity until the tests were performed. Samples were restored using a universal adhesive (Clearfil Universal Bond:CUB) in etch&rinse or self-etch mode, i.e. with or without phosphoric acid etching (PA) prior to the application of CUB, and a resin composite (Clearfil APX: APX). This resulted in 4 groups: Group 1: Healthy dentin (H), adhesive (CUB), composite resin (APX). Group 2: Healthy dentin (H), acid-etching (PA), adhesive (CUB), composite resin (APX). Group 3: Simulated carious dentin (FA), adhesive (CUB), composite resin (APX).
composite resin (APX). Group 4: Simulated carious dentin (FA), acid-etching (PA), adhesive (CUB), composite resin (APX). Restorations were then subjected to a thermo mechanical fatigue test (200'000 load cycles and 500 thermal cycles from 5°C to 50°C).

2.2. Optical Coherence Tomography (OCT) system:

The internal adaptation was qualitatively assessed using OCT. An Axsun (Billerica, MA) OCT system employing a swept source laser scanned at a 100 kHz sweep rate with a 110 nm bandwidth centered at 1310 +/- 55 nm was used [14]. The axial depth resolution was 6.8-µm and the lateral resolution was 66-µm. A polarization diversity setup was used so that three sets of 512-frame volumes were then acquired for each sample: a) horizontal, H, polarization image; b) vertical, V, polarization image; and c) a vector magnitude, HV, image. Volumes were acquired in less than 5 seconds. Since polarization is not controlled in the interferometer or the probe, H and V are orthogonal to each other but arbitrary in orientation with respect to the sample. A MEMS scanner was integrated into a lightweight dental handpiece with a body measuring 80 by 40 by 40 mm and an extension 90 mm long and 17 mm in diameter with a right-angle mirror. The handpiece is capable of providing a scan volume 8(x) by 8(y) by 8(z) mm. Specifications of the OCT provided by the manufacturer can be found in Table 1.

| AXSUN DENTAL OCT SYSTEM WITH INTEGRATED HANDPIECE |
|-----------------------------------------------|
| **PARAMETER** | **SPECIFICATION** |
| Wavelength | 1310 +/- 55 nm |
| Scan rate | 100 kHz |
| Axial resolution | 6.8 µm (in air) |
| Lateral resolution (spot size) | 66 µm (in air) |
| Lateral scan area | > 8 x 8 mm |
| Imaging depth | > 8 mm |
| Laser class | IEC 60825-1 Class I output (Handpiece) |
| Polarization | Polarization diverse detection |
| Handpiece weight | < 200 grams |
| Handpiece intra-oral segment | 17 mm diameter; 90 mm length |

Table 1: Specification of Axsun OCT system.

3. RESULTS AND DISCUSSION

OCT provided valuable information concerning the internal adaptation of resin restorations. OCT was able to show different kind of defects in the restorations including open margins, air bubbles, gaps and excess of adhesive. Qualitative analysis of OCT images showed that in Group 1, five of eight teeth showed gaps, four of eight teeth showed air bubbles, in Group 2, four of eight teeth showed gaps, while five of eight showed air bubbles. In Group 3: two teeth were lost after fatigue and five of six teeth showed gaps, three of six showed air bubbles, Demineralization under fillings was clearly visible as wide white bands under the restorations. Group 4: Most samples were lost after fatigue, two of two teeth showed
gaps, two of two showed air bubbles, Demineralization under fillings was also visible. Figures 1-3 provide examples of the observed restorations, gaps, air bubbles and the internal and marginal adaption.

Figure 1: Representative OCT images of a restoration from Group 1 showing ideal adhesion with no gaps or marginal leakage.

Figure 2: Representative OCT image from Group 3 showing demineralised dentin, thick adhesive layer and an open margin.

Figure 3: Representative OCT image from Group 4 showing demineralized dentin, air bubbles and an open margin.
The OCT system investigated in this experiment provided high quality images of adhesive restorations. The internal adaptation was easily visually assessed by inspecting the 3D scan. The interface between the dentin and the restoration and the degree of demineralization of dentin surface can be clearly evaluated.

In the first 2 groups where the restoration was placed on healthy dentin, almost no marginal gaps were detected, more than half of the restorations showed other kind of defects like air bubbles and a thick adhesive layer underneath. No specific difference was observed concerning the use of etching prior to the restorations.

In the third and fourth group with demineralized dentin most samples were lost, the remaining samples presented open margins and large gaps. Etching demineralised dentin with phosphoric acid prior to adhesion seems to reduce the quality of the restoration as demineralisation occurs twofold. Different kinds of interface were observed. In samples from Group one, the interface was seamless and the transition between the restoration and the dentin didn’t exhibit high variations in contrast.

In some samples a thick adhesive layer was observed under the restoration (Fig. 4), this is due to excess of adhesive that was not removed properly before polymerization.

The presence of air bubbles may be acceptable when it’s found in the body of the restoration. However, the presence of air bubbles at the restoration- dentin interface may cause post-operative sensitivity and pain. Due to the lack of tools that would provide this information for vestibular restorations, the dentists would usually repeat the whole restoration when in doubt. Using OCT would help confirm the diagnosis and help locate the position of the defect to guide the dentist’s intervention.

A white line underneath the adhesive layer is observed in Fig.4 and Fig.5, previous studies demonstrated that the white line represents the interfacial between dentin and adhesive. Such defect can be caused by the contraction of the restoration after polymerization, or the debonding after the fatigue cycles.

Figure 4: A representative OCT image of a restoration from Group 1 with an intact margin, a thick layer of adhesive and air bubbles.
Images of samples from group 3 and 4 showed a thick layer of demineralised dentin under the restoration (Fig 3, 4). The OCT system may provide a potential tool for monitoring the quality of the restoration over time. Detecting debonding and secondary caries without the need of irradiation can be a valuable tool in everyday clinical practice. Previous studies showed the possibility to show real-time effect of the polymerization contraction and gap formation using OCT 18.

Figure 5: Representative OCT image of a restoration from Group 1 showing a white line (gap) at the restoration-dentin interface.

This paper evaluated a new prototype OCT system which proved to be a valuable, non-destructive, real-time method for assessment of vestibular restorations. The OCT system helped evaluate the internal adaptation of composite restorations, differentiate between healthy and demineralised dentin, adhesive, and restoration layers. OCT provided a unique visualization and characterization of internal structures as well as non-contact assessment of marginal adaptation. The use of such system in the clinical setting may reduce the need for x-rays and unnecessary repetition of restorations. We plan on submitting a full manuscript including a more detailed quantitative analysis for publication in the near future.

4. ACKNOWLEDGMENTS

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