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3D-microleakage assessment of adhesive interfaces: Exploratory findings by μCT

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ABSTRACT

Objectives. To explore the feasibility of a 3D-microleakage protocol for the evaluation of various configurations of adhesive–tooth interfaces.

Methods. Three different kinds of specimens were prepared: (1) a Class-I composite restoration placed without any bonding to maximize gap formation at the interface; (2) a glass-fiber post cemented with a self-adhesive composite cement into a prepared root canal; and (3) inlay MOD composite restorations placed with either a 1-step self-adhesive or a 2-step etch-and-rinse composite cement. After silver-nitrate ($AgNO_3$) infiltration, the specimens were scanned using a Skyscan 1172 X-ray microtomograph (μCT; Skyscan Bruker) at 100 kV, 100 μA and 7.8–9.5 μm resolution. Projection images were reconstructed, after which maximum-intensity projections (MIPs) and 3D-volumetric renderings were produced. For the inlays, an additional conventional stereomicroscopic (SM) microleakage evaluation was accomplished after specimen sectioning.

Results. MIPs and 3D-renderings from specimens (1) and (2) revealed strongly varying microleakage patterns along the marginal gap/interface. For the specimens of setup (3), the high radiopacity of the 2-step composite cement hindered evaluation of the MIPs. MIP-microleakage patterns along the enamel margin of the restoration cemented with the 1-step composite cement corresponded well to the stereomicroscopic images.

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Significance. The reported μCT-protocol revealed good sensitivity to detect $AgNO_3$ infiltration at the adhesive–tooth interface when considerable microleakage was present. When microleakage was less apparent and spread in a more diffuse pattern, evaluation with μCT was less sensitive compared to stereomicroscopic evaluation.

1. Introduction

Microleakage is defined as the clinically undetectable penetration of fluid, bacteria, molecules and ions between the cavity wall and the restoration. It is known to cause post-restorative sensitivity, marginal defects and staining, and may eventually even lead to secondary caries and pulp irritation [1]. Acting independently or synergistically, these factors will compromise the longevity of composite restorations *in vivo* [2].

Marginal leakage is attributed to different factors, including imperfect bonding at the adhesive-dentin/enamel interface resulting from composite-polymerization shrinkage, mismatch in the coefficients of thermal expansion between composite and tooth, or fatigue resulting from cyclic loading, to which the tooth-restoration complex is exposed during oral function [3].

The traditional method to detect microleakage is to evaluate the penetration of a specific tracer microscopically after sectioning of the sample [4]. Organic dyes (*e.g.* basic fuchsin, methylene blue, rhodamine B) and silver nitrate ($AgNO_3$) are the most commonly used agents for this purpose. $AgNO_3$ is also electron dense and radiopaque, which allows its use with correlated microscopy techniques, such as scanning [5] or transmission electron microscopy [6]. More recently, $AgNO_3$ has been applied in conjunction with X-ray micro-computed tomography, commonly known as micro-CT or μCT [8–10].

Criticism about microleakage tests encompasses mainly the lack of correlation with clinical data [11]. This can be attributed to several reasons. First, proper standardization of the methodology between studies is lacking, together with the use of different kinds of tracers, concentrations and immersion times. Secondly, variability regarding the quantification of the tracer infiltration, ranging from a semi-quantitative approach based on different scoring systems to more quantitative techniques, and based on different numbers of inspected sites, hinders proper comparison between studies and increases the inter-study variability [12,13]. However, the main disadvantage of a conventional microleakage test is that a tri-dimensional (3D) microleakage phenomenon is assessed two-dimensionally (2D), often even based on a single longitudinal or transverse section [14]. Moreover, it results in irreversible loss of information because the specimen is partially destructed by sectioning [15,16]. Only a limited number of locations can be evaluated, which may lead to an underestimation or overestimation of the total leakage and to ignoring detailed information about the distribution pattern.

[1] Equal first-author contribution.

Several techniques have been proposed to overcome shortcomings associated with a single two-dimensional surface observation in microleakage studies, such as spectrophotometric dye-recovery methods [17], serial grinding and imaging methods [18] and the 'whole wall technique', which involves removal of the restoration and analysis of the entire gingival floor for possible leakage [19]. All these techniques still share unfortunately the same limitation, as they are of destructive nature.

Micro-CT, on the other hand, is a non-destructive technique, originated from further development of conventional computer tomography. It can reach a potential resolution in the submicron range, depending on the computer hardware capabilities and X-ray source characteristics [20]. In dental materials research, desktop μCT has been used for various approaches, including the evaluation of polymerization shrinkage of dental composites [21], quantification of interfacial void fraction in composite restorations [22], and presence of marginal/internal gaps in ceramic restorations [23].

The aim of this study was to explore the feasibility of 3D visualization/quantification of silver-nitrate penetration (microleakage evaluation) in various configurations of adhesive–tooth interfaces using a desktop μCT apparatus.

2. Materials and methods

Three different types of specimens were prepared on six extracted teeth that were stored in 0.5% aqueous chloramine solution at 4 °C for less than 6 months:

Specimen setup 1: A 4 mm × 4 mm × 2 mm Class-I cavity ($n = 1$) was prepared on a sound premolar using a micro-specimen former (University of Iowa, Iowa City, USA), equipped with a high-speed regular-grit (100 μm) diamond bur (842, Komet, Lemgo, Germany). The cavity was filled with the microhybrid composite Gradia Direct (shade A2; GC, Tokyo, Japan) without any adhesive pre-treatment at the interface to intentionally create a marginal gap. To maximize exposure of the gap to the infiltration medium, the occlusal margins of the restoration were additionally prepared with the bur to remove possible areas of overfilling after curing the restorative material.

Specimen setup 2: A composite glass-fiber post (Parapost FiberLux, Coltène-Whaledent, Altstätten, Switzerland) ($n = 1$) was cemented into the root canal of an extracted lower premolar using a self-adhesive cement (Rely-X UniCem, 3M ESPE, Seefeld, Germany). The root canal was prepared as described in detail elsewhere [24]. Briefly, the tooth was cut at the most apical point of the cement–enamel junction using a low-speed diamond saw (Isomet 1000, Buehler, Lake Bluff, IL, USA). Endodontic treatment was performed following a