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Can pulpal floor debonding be detected from occlusal surface displacement in composite restorations?

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ABSTRACT

Objectives. Polymerization shrinkage of resin composite restorations can cause debonding at the tooth–restoration interface. Theory based on the mechanics of materials predicts that debonding at the pulpal floor would half the shrinkage displacement at the occlusal surface. The aim of this study is to test this theory and to examine the possibility of detecting subsurface resin composite restoration debonding by measuring the superficial shrinkage displacements.

Methods. A commercial dental resin composite with linear shrinkage strain of 0.8% was used to restore 2 groups of 5 model Class-II cavities (8-mm long, 4-mm wide and 4-mm deep) in aluminum blocks (8-mm thick, 10-mm wide and 14-mm tall). Group I had the restorations bonded to all cavity surfaces, while Group II had the restorations not bonded to the cavity floor to simulate debonding. One of the proximal surfaces of each specimen was sprayed with fine carbon powder to allow surface displacement measurement by Digital Image Correlation. Images of the speckled surface were taken before and after cure for displacement calculation. The experiment was simulated using finite element analysis (FEA) for comparison.

Results. Group I showed a maximum occlusal displacement of $34.7 \pm 6.7\ \mu m$ and a center of contraction (COC) near the pulpal floor. Group II had a COC coinciding with the geometric center and showed a maximum occlusal displacement of $17.4 \pm 3.8\ \mu m$. The difference between the two groups was statistically significant (p-value = 0.0007). Similar results were obtained by FEA. The theoretical shrinkage displacement was 44.6 and 22.3 μm for Group I and II, respectively. The lower experimental displacements were probably caused by slumping of the resin composite before cure and deformation of the adhesive layer.

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Significance. The results confirmed that the occlusal shrinkage displacement of a resin composite restoration was reduced significantly by pulpal floor debonding. Recent in vitro studies seem to indicate that this reduction in shrinkage displacement could be detected by using the most accurate intraoral scanners currently available. Thus, subject to clinical validation, the occlusal displacement of a resin composite restoration may be used to assess its interfacial integrity.

1. Introduction

Many of the failures of resin composite restorations are related to failure at the tooth–composite interface, which can lead to marginal staining, postoperative sensitivity, secondary caries, and tooth fracture [1,2]. One of the main reasons for interfacial failure in resin composite restorations is shrinkage stress due to polymerization of the resin composite during cure. The polymerization reaction of a light-cured resin composite starts with the illumination of the resin composite with a curing light that rapidly transforms the monomers into polymers. The stiffness and strength of the resin composite are increased in the process. However, polymerization also results in shrinkage of the resin composite, which can lead to shrinkage stress in a bonded restoration. The generated shrinkage stress in a restoration is highly varied and non-uniform. The magnitude and distribution of the shrinkage stress depends on the geometry of the cavity, material properties, and the restorative procedures [3,4]. When the shrinkage stress exceeds the interfacial bond strength, debonding would occur [5].

Several studies have been performed to understand the shrinkage patterns in resin composite restorations and their relationships with shrinkage strain, cavity configuration and interfacial bonding conditions. The analysis methods include Digital Image Correlation (DIC) [6–8] and micro-computed tomography (μCT) [9–13]. The former method is mostly limited to analyzing displacements on a 2D plane while the latter method can capture displacements in a 3D space.

An analysis using DIC confirmed that isotropic shrinkage occurred toward the center of a resin composite specimen when it was allowed to shrink freely without bonding [14]. DIC was also used to validate a finite element study of the influence of the ratio between bonded to non-bonded surfaces, i.e. the configuration factor (C-factor), on the shrinkage stresses [6]. In that study, shrinkage strain for Class-II restorations with four different cavity sizes and various bonding conditions was investigated. The results showed that shrinkage at the free occlusal surface was related to the cavity width and C-factor [6].

Several μCT analyses have been performed to investigate the magnitude and direction of polymerization shrinkage, and the internal adaptation of the restoration for different boundary conditions [9–13]. Radiopaque markers were mixed in with the resin composite and movements of the markers were quantitatively evaluated from the tomographic images taken before and after cure. The degree of adhesion of the resin composite to the surrounding walls was found to significantly influence the shrinkage patterns [13]. Again, the direction of the shrinkage displacements in a non-bonded Class-I restoration was oriented toward the center of mass. In bonded restorations, the greatest deformation occurred at the free occlusal surfaces [15]. Imperfectly bonded restorations, on the other hand, exhibited two contraction patterns: either toward one side of the cavity or toward the top surface of the restoration [10]. In both cases, the restorative material shrunk toward the bonded surfaces. Another analysis of Class-I restorations of 2.4 mm and 4.0 mm deep showed that the shrinkage displacement were all pointing downwards in the shallower restorations. In the deeper restorations, the downward displacements reversed to an upward direction from a depth of approximately half the restoration's height due to debonding at the pulpal floor [10]. It appeared that the shrinkage stress at the floor of the deeper restorations was higher than that of the shallower restorations, or that the bond strength at the floor of the deeper restorations was lower, thus causing debonding [16].

The above studies demonstrate that the displacement of a resin composite restoration due to polymerization shrinkage is directly related to the bond integrity at the cavity surfaces. This finding implies that debonding may be detectable from the displacements on the free occlusal or proximal surfaces of a restoration without taking X-ray images, which may not be able to differentiate between a gap and the radiolucent adhesive layer. The purpose of this study is therefore to examine the possibility of detecting subsurface debonding of resin composite restoration from measurements of the superficial shrinkage displacements. To this end, the difference in occlusal surface displacements in bonded and debonded model restorations are investigated through mathematical analysis and experimental studies using DIC.

2. Materials and methods

2.1. Theory

According to Generalized Hooke's Law, the total strains in a linearly elastic resin composite restoration with isotropic shrinkage in the three orthogonal directions x, y and z can be expressed as:

$$\varepsilon_x = \frac{1}{E}\left[\sigma_x - \nu\left(\sigma_y + \sigma_z\right)\right] - \varepsilon_s,$$

$$\varepsilon_y = \frac{1}{E}\left[\sigma_y - \nu\left(\sigma_z + \sigma_x\right)\right] - \varepsilon_s,$$

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