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Shrinkage vectors of a flowable composite in artificial cavity models with different boundary conditions: Ceramic and Teflon

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ABSTRACT

Polymerization shrinkage of dental resin composites leads to stress build-up at the tooth-restoration interface that predisposes the restoration to debonding. In contrast to the heterogeneity of enamel and dentin, this study investigated the effect of boundary conditions in artificial cavity models such as ceramic and Teflon. Ceramic serves as a homogenous substrate that provides optimal bonding conditions, which we presented in the form of etched and silanized ceramic in addition to an etched, silanized and bonded ceramic cavity. In contrast, the Teflon cavity presented a non-adhesive boundary condition that provided an exaggerated condition of poor bonding as in the case of contamination during the application procedure or a poor bonding substrate such as sclerotic or deep dentin.

The greatest 3D shrinkage vectors and movement in the axial direction were observed in the ceramic cavity with the bonding agent followed by the silanized ceramic cavity, and smallest shrinkage vectors and axial movements were observed in the Teflon cavity. The shrinkage vectors in the ceramic cavities exhibited downward movement toward the cavity bottom with great downward shrinkage of the free surface. The shrinkage vectors in the Teflon cavity pointed towards the center of the restoration with lateral movement greater at one side denoting the site of first detachment from the cavity walls. These results proved that the boundary conditions, in terms of bonding substrates, significantly influenced the shrinkage direction.

1. Introduction

A defect in the tooth enamel, such as caries, that tracks its way into the dentin necessitates the insertion of a restoration that will have an interface with both tissues (Roberson, 2006b). Today, resin-based composites are the most widely used direct dental restorations in many places around the world (Chesterman et al., 2017; Lynch et al., 2013; Rho et al., 2013). Bonding resin based composite restorations (RBCs) to prepared cavity walls restricts the polymerizing molecules to freely shrink and produce interfacial gaps that jeopardize the reliability and clinical effectiveness of the restoration (Bausch et al., 1982; Davidson, 1986). Thus, understanding the polymerization behavior of RBCs furnishes a sound basis for their manufacture, quality control and the assignment of optimum techniques of material manipulation. Bonding to enamel is stronger and less technique sensitive than bonding to dentin due to the compositional and micromorphological differences between the two substrates (Roberson, 2006a; Van Meerbeek et al., 2003). Bonding to these structurally different substrates does not produce a homogenous interfacial attachment along the entire tooth-restoration interface, which affects the pattern of polymerization shrinkage (Chiang, 2009; Chiang et al., 2010).

Chiang et al. were the first to visualize the polymerization shrinkage vectors three-dimensionally and to show how the shrinkage direction was affected by the presence of enamel and dentin as different bonding substrates. In prepared cavities in teeth, with margins of equal enamel thickness, the composite detached from the cavity floor and shrank toward the light source. In contrast, in cavities with margins of unequal enamel thickness, the composite shrank toward the thicker enamel margin while it detached from the opposite side of the cavity (Chiang, 2009; Chiang et al., 2010).

Finite element analysis (FEA) of the effect of boundary conditions on the polymerization shrinkage direction revealed different shrinkage patterns according to changes in the bonding condition. It was concluded that shrinkage is affected by the bonding of the restoration and the presence of free surfaces (Versluis et al., 1998).

Previous studies have substituted human teeth with an artificial

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material to avoid the inhomogeneity of the substrate and the variations in the sizes and properties among teeth. A glass model cavity was used to assess the shrinkage stress in dental composites (Li et al., 2011, 2014; Sampaio et al., 2017a), while in other studies, a block made of resin composite with a standardized cavity served as the bonding substrate for the evaluation of resin composite polymerization by micro-tomography (micro-CT) imaging (Cho et al., 2011; Takemura et al., 2014; Van Ende et al., 2015). The inner surface of glass ceramic restorations, such as inlays, onlays, veneers and crowns, are indicated for etching with 5–10% hydrofluoric acid and subsequent silanization to obtain an optimal bond between the restoration and the tooth structure (Bühler-Zemp et al., 2011). Silane, though not an adhesive, improves adhesion by promoting a chemical bond between the inorganic ceramic material and the organic resin matrix of the composite.

A ceramic mold can provide for an optimal bond with a dental resin composite. Therefore, selecting an alternative substrate to serve as a model cavity system could be a good option when trying to understand the effect of boundary conditions on the shrinkage direction. Cavity boundaries are related to the cavity outlines on one hand and the bonding substrates with the associated bonding conditions on the other hand (Kaisarly, 2014).

The unbonded condition of composite inside a prepared cavity can be presented in different ways: when human teeth are used, the composite is directly applied without prior surface treatment of the cavity or the application of an adhesive (Algamaiah et al., 2017; Chiang, 2009; Chiang et al., 2010; Hirata et al., 2015; Takahashi et al., 2010). If the cavity is prepared in an artificial model, such as a composite or glass, then either no bonding agent is applied or a separating agent is applied (Cho et al., 2011; Takemura et al., 2014).

An excellent non-adhesive substrate is Teflon (polytetrafluoroethylene). In dentistry, Teflon is not being used in dental applications either by the dentist or by the dental lab technician. However, in research, Teflon is commonly used as an adjunctive material or cavity model for gap and volumetric analysis of resin composites (Cheetham et al., 2014; de Melo Monteiro et al., 2011; Miletic et al., 2011; Pereira et al., 2008; Takahashi et al., 2010). The unbonded situation in a non-adhesive Teflon cavity is just one of many possibilities of a non-adhesive situation.

This study aimed to investigate the influence of the boundary condition, in terms of bonding substrate and bonding condition, on the polymerization shrinkage pattern in the following three cavity models with different boundary conditions: a silanized ceramic cavity, i.e., "ceramic"; a silanized ceramic cavity with a layer of dentin bonding agent, i.e., "ceramic + bond", to detect the effect of a layer of bonding agent; and a non-adhesive Teflon cavity model. The hypothesis states that the shrinkage vectors differ according to the boundary condition.

2. Materials and methods

The experimental composite and the dentin-bonding agent used for the restorative procedures and the artificial cavity models are listed in Table 1.

2.1. Specimen preparation

Three groups of artificial cavity models (n = 9) were prepared, i.e., two ceramic groups and a Teflon group. A total of 18 ceramic specimens were cut from ceramic blocks (IPS Empress CAD, Ivoclar Vivadent, Schaan, Liechtenstein), and cylindrical cavities with parallel walls (diameter 6 mm, depth 3 mm, n = 9) were prepared (Chiang, 2009; Chiang et al., 2010; Versluis et al., 1998). The outer surface of the ceramic was trimmed to fit into the micro-CT sample holder, flowable composite was applied and light-cured all around to obtain a reference mark that simulated enamel. This procedure was important for the process of rigid registration (for the overlay of both scans) at a later step, identification of different substrates depended on the corresponding gray value. The specimen was fixed into the sample holder with composite to avoid its movement during scanning.

The specimens were divided into two groups. In the "ceramic" group, the cavity was etched with 5% hydrofluoric acid (VITA CERAMICS ETCH, Vita Zahnfabrik, Bad Saeckingen, Germany) for 1 min, thoroughly rinsed with water for 1 min, air dried, and silane coupling agent (ESPE Sil, 3 M ESPE, Seefeld, Germany) was applied and air dried for 5 min for optimal bonding. In the "ceramic + bond" group, an additional layer of dentin bonding agent (OptiBond FL, Kerr, Scafati, Italy) was applied, air thinned for 5 s and light-cured for 20 s using Elipar FreeLight 2 (3 M ESPE, Seefeld, Germany) prior to the application of the experimental composite (power output 1200 mW/cm^2 according to the manufacturer's instructions; the light intensity was checked once/week with a dental radiometer). OptiBond FL forms a thick film of adhesive and has good mechanical properties; thus, a good bond is expected.

A Teflon cylinder (diameter 11 mm, height 15 mm) was cut from a block of Teflon, and a cylindrical cavity (diameter 6 mm, depth 3 mm, n = 9) was prepared in this block (Chiang, 2009; Chiang et al., 2010; Versluis et al., 1998). Flowable composite was applied to the outer surface of the Teflon cylinder and light-cured all around to obtain a reference mark. The specimen was fixed into the sample holder with composite to avoid its movement during scanning. The experimental composite was applied into the prepared cavity of the Teflon model without the use of any adhesive. Attachment to cavity walls was mediated only by secondary van der Waals forces. After the first scan of uncured material, the composite was light-cured for 40 s perpendicular to the long axis of the tooth.

2.2. Preparation of the experimental traceable resin composite

A flowable resin composite (Tetric EvoFlow, Ivoclar Vivadent, Schaan, Liechtenstein), was mixed with 2 wt% silanized radiolucent glass fillers with an average particle size of 40–70 μm (Sigmund Lindner GmbH, Warmensteinach, Germany) (Chiang et al., 2010). Silanization of the glass fillers was performed to ensure a durable bond between the fillers and the resin matrix (Liu et al., 2001). The flowable composite was used to ensure good marginal adaptation, and the depth of cure at 3 mm was confirmed (Lindberg et al., 2004). Moreover, the flowable composite allowed for the comparison of our results with those of Chiang (2009), Chiang et al. (2010), and it has the perfect radiopacity for the segmentation of the glass beads.

2.3. X-ray micro-computed tomography measurements

A high-resolution micro-computed tomography apparatus (Micro-CT 40, Scanco Medical AG, Brüttisellen, Switzerland) was used to scan the samples. The settings for the micro-CT were an acceleration voltage of 70 kVp and a cathode current of 114 μA. The samples were scanned at high-resolution (8^3 μm^3 voxel size) using an integration time of 600 ms (Chiang, 2009; Chiang et al., 2010). The sample holder was covered with a radiolucent and dark cap to avoid premature polymerization of the uncured resin composite material during the scanning procedure, and the sample was then placed inside the micro-CT machine for the first micro-CT scan.

Then, the composite was light cured for 40 s, and the sample was scanned again using the same parameters as before. During the whole process, the sample remained in the sample holder to avoid gross displacement of the tooth and to facilitate and expedite the subsequent registration of the data sets. After the raw micro-CT, the scans were reconstructed and saved as 16-bit data sets of the attenuation coefficient per voxel. Each data set was approximately 3.9 GB in size. Details of the workflow are presented in Fig. 1.