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Cuspal flexure of composite-restored typodont teeth and correlation with polymerization shrinkage values

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ABSTRACT

Objective. The relationship between post-gel shrinkage, total shrinkage, and cuspal flexure was examined. Cuspal flexure was measured on restored typodont teeth, which offered a standardized tooth shape for comparison of shrinkage stress effects among restorative composites.

Methods. Six restorative composites were compared (Filtek LS, Venus Flowable, Tetric EvoCeram, Filtek Flowable, Esthet-X, and Filtek Supreme). Total shrinkage was determined from changes in projected surface area before and after polymerization ($n = 10$). Post-gel shrinkage was determined with a biaxial strain gauge that measured strain development during polymerization ($n = 10$). Cuspal flexure was determined using typodont maxillary second premolars with standard MOD slot preparation ($n = 10$). Flexure was determined by comparing the three-dimensionally scanned cuspal surfaces before and after restoration. Restoration bonding to the typodont cavity was achieved by sandblasting and adhesive application. Bond integrity was verified by measuring dye penetration. Results were analyzed using ANOVA and Student–Newman–Keuls post hoc test (significance level 0.05). Pearson was used for correlations.

Results. Total and post-gel shrinkage were significant different for all composites (t-test; $P < 0.001$). Depending on the composite, only 9–41% of the total shrinkage was recorded as post-gel shrinkage. Bond integrity of restored typodont teeth was 96–99%. Cuspal flexure correlated strongly with post-gel shrinkage, but there was no correlation with total shrinkage.

Significance. Cuspal flexure of restored typodont teeth showed the effect of shrinkage stress caused by polymerizing composite restorations, ensuring standardization while maintaining the effects of tooth/cavity geometry. Post-gel shrinkage gave a good indication to screen

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composites for the stress they may generate; total shrinkage had no direct correlation with stress.

1. Introduction

Adhesively-bonded resin composites have been used successfully in dentistry because they help preserve tooth structure, restore biomechanical tooth integrity, and provide an esthetic quality [1,2]. However, stress that may develop when resins shrink during the polymerization reaction has been a concern since their introduction [3]. Clinicians and researchers have tried to minimize or overcome shrinkage stress by varying restoration techniques or by modifying chemistry to reduce polymerization contraction or to relieve stress buildup [4,5].

Decreasing shrinkage is an obvious approach for reducing shrinkage stress. However, the relationship between shrinkage and stress is not that simple because not all shrinkage causes stress [6]. Viscous flow early in the polymerization process relieves stress development, and reduces the final residual shrinkage stress level [3]. A crucial distinction has therefore been made between the total volume change of a material and how much of that volume change is involved in the stress development. The notional amount of shrinkage that actually causes stress is often called 'post-gel' shrinkage [7,8]. Although post-gel shrinkage has been shown to have a better correlation with shrinkage forces [9], manufacturers and shrinkage studies nevertheless continue to present clinicians almost exclusively with the total shrinkage values.

While shrinkage properties in general are an essential aspect in shrinkage stress considerations, it is only one of the factors that eventually determine the shrinkage stress. Stress is a condition that also depends on other material properties (such as elastic modulus), boundary conditions (such as bonding), geometry, mechanical properties as well as geometry of surrounding tooth structures, and the light irradiation technique and degree of conversion [6,10]. This fact has fundamental implications for any shrinkage stress consideration. For example, it implies that shrinkage stress is a unique value, not a property of a composite, and must be calculated by taking into account the factors of each local condition. Shrinkage stress determination is therefore complex and requires the use of computational aids that allow factoring in all conditions. This can be done with finite element analysis [11–15].

An alternative approach to computational methods is to experimentally assess the effects of shrinkage stress. However, the previous description of stress as being a state in the material determined by multiple factors, applies equally to laboratory experiments, and implies that an in vitro test must replicate clinical shapes and substrates to yield clinically relevant stresses. For that reason experimental shrinkage stress assessments are often performed in cuspal flexure tests because they feature most of the clinically relevant conditions [5,10,16–19]. Although cuspal flexure is not a direct measure of stress, when carefully interpreted it can offer an indication of stress conditions like those encountered clinically [20].

While extracted teeth have the appropriate anatomy and properties needed to yield clinically relevant shrinkage stress conditions, another implication of the stress definition is that any variation in tooth anatomy results in unique shrinkage stresses. Shrinkage stresses are thus different in each tooth, even when using the same composite material and restoration technique. Although this corresponds with clinical reality, it complicates our efforts to compare stress generation by different composite systems. Cuspal flexure studies make every effort to standardize tooth type and tooth size to minimize variations [5,18,21], but often selection is limited by availability of suitable extracted teeth.

The primary objective of this study was examining the relationship between shrinkage values and cuspal flexure. A secondary objective was to test typodont teeth as a substitute for natural teeth in cuspal flexure experiments. Typodont teeth share the geometric characteristics of natural teeth but without the natural variation. One of the challenges of using typodont teeth in cuspal flexure studies is achieving bonding with dental adhesives that were developed to bond to natural tooth structures [22]. Since shrinkage stress assessment from cuspal flexure is only valid if bonding remains intact, bond integrity has to be verified. In this study, dye penetration was used to verify bond integrity.

2. Materials and methods

2.1. *Restorative composites*

Six restorative composites representing a range of shrinkage values were selected. The selected resin-based composites consisted of 3 types: (1) low-shrinkage composite — Filtek LS (3M ESPE); (2) bulk-fill/flowable composites — Venus Bulk Fill Flowable (Heraeus Kulzer), Tetric EvoCeram Bulk Fill (Ivoclar Vivadent), Filtek Bulk Fill Flowable (3M ESPE); (3) nanohybrid/nanofilled composites — Esthet-X HD (Dentsply), Filtek Supreme Ultra (3M ESPE). Material information is listed in Table 1.

2.2. *Total shrinkage*

Total shrinkage was determined with an optical method [23]. Uncured composite samples (~1.5 mm thick, 6 mm diameter) were placed on a smooth platform made from vinyl polysiloxane impression material (Express Light Body, 3M ESPE). Images were captured before polymerization using a stereomicroscope with charge-coupled device camera (SZX16 & UC30, Olympus, Tokyo, Japan) at 1.25 magnification. Samples were light-cured for 40 s with a quartz-tungsten-halogen light source (VIP Junior, Bisco, Schaumburg, IL, USA) which had 1559 mW/cm^2 mean irradiance at 1.5 mm distance (measured with MARC Patient Simulator, Bluelight Analytics,

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