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Local deformation fields and marginal integrity of sculptable bulk-fill, low-shrinkage and conventional composites

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A R T I C L E I N F O

Article history:
Received 26 January 2016
Received in revised form
17 June 2016
Accepted 3 September 2016

Keywords:
Bulk-fill
Low-shrinkage
Giomer
Composites
Shrinkage
Microleakage

A B S T R A C T

Objective. To compare strain and displacement of sculptable bulk-fill, low-shrinkage and conventional composites as well as dye penetration along the dentin-restoration interface.
Methods. Modified Class II cavities (N = 5/group) were filled with sculptable bulk-fill (Filtek Bulk Fill Posterior, 3M ESPE; Tetric EvoCeram Bulk Fill, Ivoclar Vivadent; fiber-reinforced EverX Posterior, GC; giomer Beautifil Bulk, Schofu), low-shrinkage (Kalore, GC), nanohybrid (Tetric EvoCeram, Ivoclar Vivadent) or microhybrid (Filtek Z250, 3M ESPE) composites. Strain and displacement were determined using the 3D digital image correlation method based on two cameras with 1 μm displacement sensitivity and 1600 × 1200 pixel resolution (Aramis, GOM). Microleakage along dentin axial and gingival cavity walls was measured under a stereomicroscope using a different set of teeth (N = 8/group). Data were analyzed using analyses of variance with Tukey's post-test, Pearson correlation and paired *t*-test ($\alpha = 0.05$).
Results. Strain of TEC Bulk, Filtek Bulk, Beautifil Bulk and Kalore was in the range of 1–1.5%. EverX and control composites showed 1.5–2% strain. Axial displacements were between 5 μm and 30 μm. The least strain was identified at 2 mm below the occlusal surface in 4-mm but not in 2-mm layered composites. Greater microleakage occurred along the gingival than axial wall ($p < 0.05$). No correlation was found between strain/displacements and microleakage axially ($r^2 = 0.082$, $p = 0.821$; $r^2 = -0.2$, $p = 0.605$, respectively) or gingivally ($r^2 = -0.126$, $p = 0.729$, $r^2 = -0.278$, $p = 0.469$, respectively).
Significance. Strain *i.e.* volumetric shrinkage of sculptable bulk-fill and low-shrinkage composites was comparable to control composites but strain distribution across restoration depth differed. Marginal integrity was more compromised along the gingival than axial dentin wall.

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http://dx.doi.org/10.1016/j.dental.2016.09.011

1. Introduction

Bulk-fill composites are intended for posterior teeth restoration in 4–5 mm thick layers. In general, bulk-fill composites are a heterogeneous group consisting of (1) flowable or low-viscosity materials, mainly indicated for restoring dentin but requiring a top layer of conventional composite, and (2) sculptable, paste-like or high-viscosity materials, which may be used to restore the entire cavity. An exception is a high-viscosity fiber-reinforced bulk-fill composite EverX Posterior (GC) which requires a capping layer due to unfavorable esthetics despite favorable mechanical properties [1]. The so-called 'giomers', marketed as nanohybrid, fluoride release and recharge composites, are also in the sculptable bulk-fill group. Surface pre-reacted glass (S-PRG) fillers in giomers are produced in reaction of fluoride-containing glass with water solutions of polyacids.

A clear advantage of bulk-fill composites is reduced clinical working time, especially for large cavities requiring a number of 2 mm thick layers of conventional composites. Among main concerns with this 'class' of composites are polymerization shrinkage and marginal integrity failure. Polymerization shrinkage of bulk-fill composites was reported to be in the range of 2–3% with the accompanying shrinkage stress between 1.7 and 2.4 MPa, which was sufficient to cause interfacial debonding of bulk-fill restorations [2]. Lower shrinkage was reported for high-viscosity bulk-fill composites when adhesively bonded to enamel and dentin than without adhesives [3].

Low-shrinkage composites generally contain long-chain cross-linking monomers intended to compensate for a reduction of inter-monomer distance within a polymer compared to shorter cross-linking monomers. Commercially available low-shrinkage composites containing urethane-based or silorane cross-linking monomers have shown similar or lower shrinkage than selected conventional dimethacrylate-based composites [4–6]. An experimental low-shrinkage composite based on a urethane-based monomer roughly twice the molecular weight of bisphenol A glycidyl methacrylate (BisGMA) has shown 2–3 times lower shrinkage than BisGMA-based composite [7]. Besides monomer chemistry, filler chemistry and content are also variable in low-shrinkage composites, making it impossible to represent low-shrinkage composites by any one material, similarly as with any other 'class' of composite materials. Selecting one or a few composites from a certain 'class' does not provide conclusive evidence of the behavior of the whole 'class', yet it is a generally accepted approach in testing dental materials.

In previous studies, shrinkage of bulk-fill composites was measured linearly using a strain gage method [1], a modified bonded disc method [2], a custom-made linometer [8] or a Kaman linometer [9]. Rarely is shrinkage measured using three-dimensional (3D) methods such as micro-computed tomography (μCT) [3,10] providing data on internal deformation fields of the shrinking polymer. Though highly informative and precise, as well as non-destructive, μCT measurements are often time-consuming [3]. Another way to measure 3D polymerization shrinkage of dental composites is the digital image correlation method based on two cameras [7,11]. In this non-destructive and high-resolution method, composite specimens are photographed before and after light-curing. Images, acquired far quicker than with μCT, are imported in specialist software to calculate von Mises strain and displacement. In the case of dental composites von Mises strain equals volumetric shrinkage. Unlike linear methods, digital image correlation offers a detailed analysis of local deformation fields and allows zones of greater and lower shrinkage and displacements to be differentiated.

Though a number of studies tested marginal integrity, only a few high-viscosity and one low-viscosity bulk-fills were included in previous studies [12–19]. Better marginal integrity of bulk-fill composites was reported at enamel than dentin [13,18] and following a 'total-etch' than a 'self-etch' adhesive approach [19]. Similar gap formation was reported for bulk-fill composites placed either as bulk or layered [18]. In previous studies, marginal integrity of bulk-fill composites was tested using dye penetration in Class I [18], Class II [17] or Class V restorations [12,14] and replicas of Class II restorations for scanning electron microscopy [16,19].

The aim of the study was to measure (1) von Mises strain *i.e.* volumetric shrinkage and displacement of sculptable bulk-fill, low-shrinkage and conventional composites upon polymerization and (2) axial and gingival microleakage along the restoration-dentin interface. The null hypotheses were that there are no differences in strain, displacements and microleakage among the tested composite.

2. Materials and methods

2.1. *Specimen preparation*

Intact, human third molars extracted for orthodontic reasons were cleaned of debris and stored in 0.02% thymol at +4 °C. Ethical approval to collect such teeth for research purposes was granted by the Ethics Committee of the University of Pristina at Kosovska Mitrovica. Each tooth was embedded in super-hard gypsum up to the enamel–cementum junction. Occlusal one third was sectioned parallel to the occlusal plane using a slow-speed diamond saw (Isomet 4000; Buehler, Lake Bluff, IL, USA) to remove the cusps and expose flat dentin. Class II ('slot') cavity was prepared using a round-end cylindrical bur in a high-speed handpiece. Cavity dimensions, verified with a digital caliper (d = 0.01 mm), were 4 mm occlusal–gingival height, 4 mm vestibular–oral width and 2 mm depth toward the pulp.

Composites used in the study with their respective adhesive systems are presented in Table 1. Each adhesive was used according to manufacturer's instructions. Adhese Universal was applied following a 'total-etch' or a 'self-etch' protocol to bond TEC Bulk and TEC. These groups are indicated as 'TEC Bulk TE' and 'TEC TE' or 'TEC Bulk SE' and 'TEC SE', respectively. Single Bond Universal was applied following a 'total-etch' or a 'self-etch' protocol to bond Filtek Bulk. These groups are named 'Filtek Bulk TE' and 'Filtek Bulk SE', respectively. 'Z250' group was bonded with Single Bond Universal following only the 'total-etch' protocol. FL Bond II was applied following a 'self-etch' protocol to bond 'Beautifil Bulk' group. G-aenial bond was also applied following a 'self-etch' protocol to bond 'Kalore' and 'EverX' groups. Adhesives were