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Microcomputed Tomography Evaluation of Polymerization Shrinkage of Class I Flowable Resin Composite Restorations

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Clinical Relevance

Since polymerization shrinkage in a 2.5 mm deep class I cavity was, in general, not different in a self-adhesive, a bulk-fill, and a conventional flowable resin composite, endeavors to simplify clinical procedures and to reduce steps and treatment times are promising.

SUMMARY

The present study aimed to characterize the pattern and volume of polymerization shrinkage of flowable resin composites, including one conventional, two bulk fill, and one self-adhesive. Standardized class I preparations (2.5 mm depth × 4 mm length × 4 mm wide) were performed in 24 caries-free human third molars that were randomly divided in four groups, according to the resin composite and adhesive system used: group 1 = Permaflo + Peak Universal Bond (PP); group 2 = Filtek

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Bulk Fill + Scotchbond Universal (FS); group 3 = Surefil SDR + XP Bond (SX); and group 4 = Vertise flow self-adhering (VE) (n=6). Each tooth was scanned three times using a micro-computed tomography (μCT) apparatus. The first scan was done after the cavity preparation, the second after cavity filling with the flowable resin composite before curing, and the third after it was cured. The μCT images were imported into three-dimensional rendering software, and volumetric polymerization shrinkage percentage was calculated for each sample. Data were submitted to one-way analysis of variance and post hoc comparisons. No significant difference was observed among PP, FS, and VE. SX bulk fill resin composite presented the lowest values of volumetric shrinkage. Shrinkage was mostly observed along the occlusal surface and part of the pulpal floor. In conclusion, polymerization shrinkage outcomes in a 2.5-mm deep class I cavity were material dependent, although most materials did not differ. The location of shrinkage was mainly at the occlusal surface.

INTRODUCTION

Polymerization shrinkage is an unavoidable by-product of resin composite restorations, mainly influenced by material formulation/properties, adhesion, flow on the free surface, and polymerization kinetics.[1,2] Shrinkage due to polymerization can result in postoperative sensitivity, marginal gaps and leakage, restoration debonding, tooth fractures, and resin composite fractures.[3]

Incremental resin composite techniques have been suggested to compensate for polymerization shrinkage by reducing the stresses developed within the tooth-restoration system.[4] Although an incremental technique may be important for polymerization stress control and to minimize light attenuation, its disadvantages are the possibility of void entrapment between layers and the extended time required to place restorations.[5]

Developments have been attempted in the field of adhesive systems, and the most recent efforts in resin composite technology have focused on reducing technique sensitivity and chair time while enhancing clinical longevity. Results of such endeavors have led to improvements in bulk fill and self-adhesive resin composites, which are both commercially available as flowable resin composites. In essence, flowable materials are low viscosity resin composites with less filler load or a greater portion of diluent monomers than regular resin composite.[2,6] An increasing number of flowable resin composites have been released in the market, with a proportional number of investigations centered on bulk filling and self-adhering resin composites.[1,7-11]

Bulk fill resin composites are intended for placement in increments up to 4 mm in thickness with reduced volumetric polymerization shrinkage[1] and stress levels.[12] Resin composite bulk application simplifies cavity filling, substantially reducing chair time and requiring fewer clinical steps.[10] According to the manufacturers, matrix and initiator chemistry, as well as filler technology, have been optimized in order to obtain specific properties required for the aforementioned applications.

Another new approach is the self-adhesive resin composite. Data concerning this resin composite are limited,[7,9,13] and the lack of volumetric shrinkage reports warrants investigation. According to manufacturers, self-adhesive resin composite simplifies the restorative procedure by incorporating an all-in-one bonding system into a flowable resin composite, eliminating the need for an additional adhesive application step, saving time and potentially minimizing handling errors.

Flowable resin composites have been regarded as materials that provide polymerization stress relief and improved adaptation.[14,15] Although studies show that this type of resin composite acts as a stress breaker,[2,15] some investigations indicate that volumetric polymerization shrinkage is higher than in conventional resin composites.[15,16] Flowable bulk fill resin composites have also been regarded as presenting less volumetric shrinkage than conventional flowable ones.[1,12]

Different methods have been described to evaluate volumetric shrinkage and/or gap formation, most of them based on destructive methods.[14,17-19] Micro-computed tomography (μCT) has demonstrated its efficacy in the assessment and visualization of resin composites regarding their polymerization shrinkage vectors,[20] volumetric shrinkage,[1] and leakage after curing,[21] among others. The use of μCT allows for nondestructive two-dimensional (2D) and three-dimensional (3D) imaging, and the possibility of analyzing the material behavior inside a given geometric configuration, such as a tooth cavity.[1,22]

This study sought to characterize the volumetric polymerization shrinkage of one conventional flowable resin composite, two bulk fill flowable resin composites, and one self-adhesive flowable resin

Table 1: *Composition and Composites Filler Loading, Manufacturers, and Batch Numbers of the Materials Studied*

Material/ Manufacturer	Batch No.	Composition
PermaFlo Flowable / Ultradent Products, South Jordan, UT, USA	N114	Bisphenol-A-glycidyl methacrylate, triethylene glycol dimethacrylate, sodium monofluorophosphate; zirconium filler. Filler loading: 68 wt%
Filtek Bulk fill Flowable / 3M ESPE, St Paul, MN, USA	1506500564	Silane-treated ceramics, diurethane dimethacrylate (UDMA), substituted dimethacrylate, bisphenol A polyethylene glycol dietherdimethacrylate (BISEMA-6), ytterbium fluoride (YbF3), bisphenol A diglycidyl ether dimethacrylate (BISGMA), benzotriazol, triethylene glycol dimethacrylate (TEGDMA), ethyl 4-dimethyl aminobenzoate. Filler loading: 64.5 wt%
Surefil SDR Flow / Dentsply Caulk, Milford, DE, USA	110527	Barium-alumino-fluoro-borosilicate glass, strontium alumino-fluoro-silicate glass, modified urethane dimethacrylate resin, ethoxylated bisphenol A dimethacrylate (EBPADMA), triethylene glycol dimethacrylate (TEGDMA), camphorquinone (CQ), photo-accelerator, butylated hydroxyl toluene; ultraviolet stabilizer; titanium dioxide; iron oxide pigments, fluorescing agent. Filler loading: 68 wt%
Vertise Flow Self-adhering flowable / Kerr Corp, Orange, CA, USA	5353402	Glycerol phosphate dimethacrylate, prepolymerized filler, 1-μ barium glass filler, nano-sized colloidal silica, nano-sized ytterbium fluoride Filler loading: 70 wt%
Peak Universal Bond / Ultradent Products	H024	2-hydroxyethyl methacrylate, methacrylic acid dehydrated alcohol, chlorhexidine diacetate
Scotchbond Universal Adhesive / 3M ESPE	488169	10-methacryloyloxydecyl dihydrogen phosphate, dimethacrylate monomers, 2-hydroxyethyl methacrylate, polyalkenoic acid copolymer, silane, photoinitiators, filler, ethanol, water
XP Bond Universal Total-Etch Adhesive / Dentsply Caulk	1104001218	Carboxylic acid modified dimethacrylate, phosphoric acid modified acrylate resin, urethane dimethacrylate, triethylene glycol dimethacrylate, 2-hydroxy ethyl methacrylate, butylated benzenediol, ethyl-4-dimethyl aminobenzoate, camphorquinone, functionalized amorphous silica, t-butanol

composite in standardized class I restorations using a μCT tomography technique.

METHODS AND MATERIALS

Twenty-four sound, freshly extracted human third molars were obtained according to protocols approved by the NYU Medical School Institutional Review Board. Teeth were cleaned and kept in distilled water at 5°C until their use. A standardized class I preparation with a cavity design of 2.5 mm depth × 4 mm length × 4 mm width was performed in each tooth with a diamond bur (AD20 Occlusal Reduction Bur, Code 845-022, Strauss, Westport, CT, USA) that presents a standardized active head size and a vertical stop to deliver consistent cavity preparation depth. The bur was replaced after every five cavity preparations. Final cavity preparation was then checked for dimensional accuracy with a digital caliper. All teeth were maintained in distilled water at room temperature (25°C) before and after preparation procedures.

Study materials, manufacturers, and batch numbers are provided in Table 1. Teeth were cleaned with a pumice slurry and randomly divided in four groups (n=6 each): group 1 = PP (Permaflo + Peak Universal Bond); group 2 = FS (Filtek Bulk Fill + Scotchbond Universal); group 3 = SX, (Surefil SDR + XP Bond); and group 4 = VE (Vertise flow self-adhering without separate bonding agent).

μCT Evaluation

Each tooth was scanned three times using a μCT apparatus (mCT40, Scanco Medical, AG, Basserdorf, Switzerland). The apparatus was calibrated using a phantom standard at 70 Kvp/BH 200 mgHA/cm. The

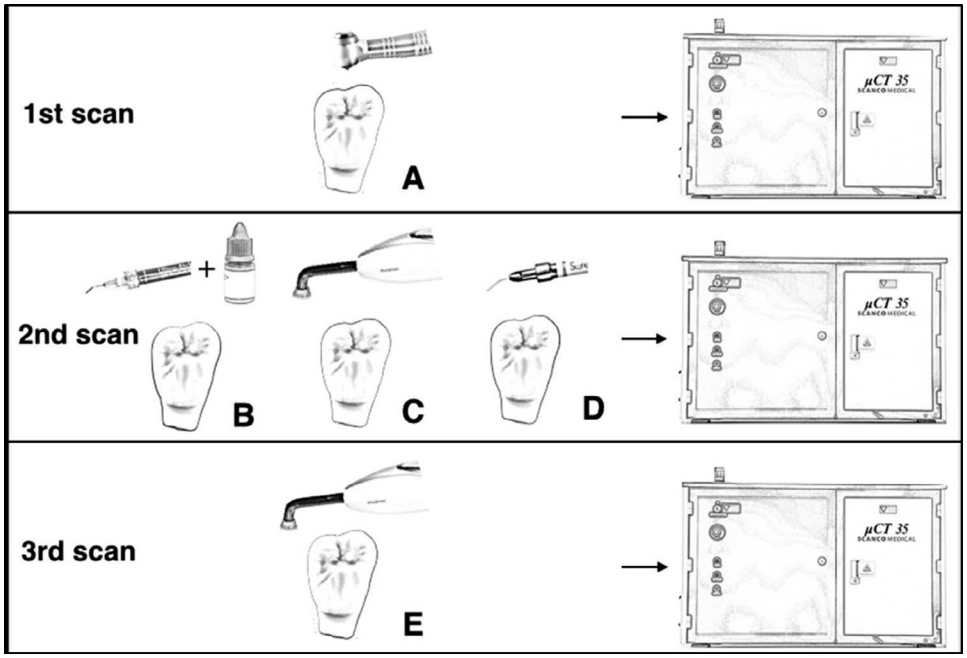

Figure 1. *Representative images describing the scanning and sample preparation workflow. (A): Cavity preparation. (B): Cavity acid-etching and bonding (when indicated by the manufacturer). (C): Light-curing. (D): Cavity filling with the flowable composite. (E): Light curing. The first micro-CT scan was taken after step A, the second after step D, and the third after E.*

operating condition for the μCT device used was 70 kVp–114 microamperes with a resolution giving 16 μm/slice. The average of the total number of slices was approximately 250, and the average scan time was 28 minutes.

Figure 1 shows a schematic of the workflow used for data collection. The first μCT scan was performed after cavity preparation for all teeth. Then, all teeth (except in the VE group) were etched with phosphoric-acid (Ultra-etch 35%, Ultradent Products) for 30 seconds in enamel and 15 seconds in dentin, followed by rinsing for 20 seconds and excess water removal with a thin absorbent paper. Restorative and bonding procedures were performed according to manufacturer's recommendations. Since VE is a self-adhering composite, no bonding agent was used.

After the first scan, cavities were filled in bulk using their assigned resin composites, left uncured, and immediately placed inside the μCT holder. To prevent unwanted curing, the μCT holder was first covered with a dark plastic, avoiding contact with any light source, and then placed inside the μCT apparatus for the second scan and volume quantification. Samples stayed in a dark environment until light curing. Subsequently, resin composites were light cured for 40 seconds with a Polywave light-curing unit (Bluephase 20i, Ivoclar Vivadent, Schaan, Liechtenstein) and inserted back into the holder for the third scan.

The μCT data were imported into a workstation and evaluated with Amira software (version 5.5.2, VSG, Burlington, MA). Superimposition of all three scan images was performed by the software, perfectly aligning them.[1] Due to the similar radiodensity of the tooth and the resin composite, this procedure was performed in order to avoid scattering and possible noise formation.[1] Registered μCT data of uncured and cured samples were subtracted from the cavity data, isolating the restoration (cavity filled with uncured resin composite minus cavity preparation, and cavity filled with cured resin composite minus cavity preparation), avoiding any scattering interference in the measurements. This procedure enabled both uncured and cured resin composite volumes to be isolated and quantified, allowing the volumetric polymerization shrinkage to be calculated as a percentage. Afterward, another subtraction was conducted for uncured minus the cured for imaging of the resin composite's shrinkage.

Statistical Analysis

Data were analyzed using a one-way analysis of variance. Post hoc comparisons were carried out using 95% confidence intervals based on the pooled estimate of residual variability.

To determine sample size, we started with previous data suggesting a standard deviation (SD) of 1% shrinkage in each treatment group and posited a clinically important reduction of at least 1.5% in absolute terms, or 30% relative to a mean level of 5% shrinkage. Six samples per group provided 80% power to detect a reduction of 1.5 SD (or 1.5%

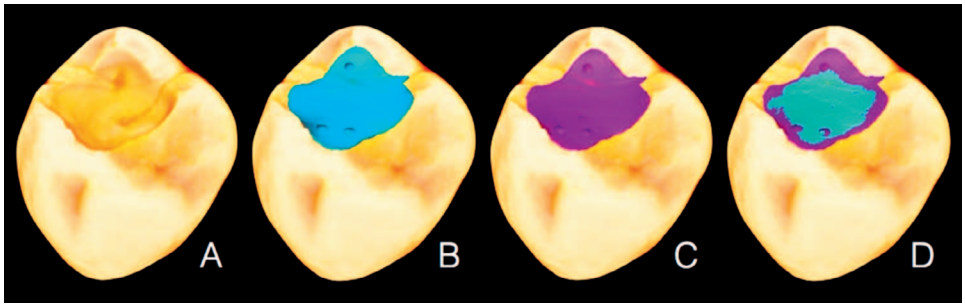

Figure 2. *Diagram of the cavity in different stages. (A): Preparation. (B): Uncured composite. (C): Cured composite. (D): Shrinkage.*

absolute) between any two groups in an independent samples t test at $p<0.05$ (one-tailed, because we want to detect reduced shrinkage) (G*Power, v3).[1]

RESULTS

Figure 2 shows representative images obtained from the μCT scans. The mean (95% confidence level) of the volumetric shrinkage of groups is presented in Table 2. Group 3 (SX), a bulk fill resin composite, showed the lowest shrinkage values and was significantly different from all other groups. Group 1 (PP), a conventional resin composite, Group 2 (FS), a bulk fill resin composite, and Group 4 (VE), a self-adhesive resin composite, showed higher shrinkage values, but there were no statistical differences between those groups ($p<0.05$).

Qualitative 3D reconstructions depicted voids within most of the resin composite fillings (Figure 3). However, these were present in qualitatively higher levels for the FS and VE groups relative to the other resin composites. For PP, voids were seldom observed. The SX samples showed voids in half of the samples and their absence in the other half.

For all groups, shrinkage was mostly seen along the occlusal surface and part of the pulpal floor of the class I restorations. For the PP group, samples showed shrinkage only on the occlusal surface, and there was no gap formation on pulpal and lateral walls. For the FS group, most samples presented shrinkage on the occlusal surface and pulpal floor. For the SX group, half of the samples presented shrinkage only on the occlusal surface, and half mainly on the occlusal surface and less so on the pulpal floor. For the VE group, most samples presented only occlusal shrinkage. Gaps and shrinkage were, in general, less frequently observed on the mesiodistal and buccolingual walls of restorations.

DISCUSSION

The present study showed that volumetric polymerization shrinkage varied among the different types of flowable resin composite restorative materials. No conventional resin composites (ie, methacrylate based) were included in this study as controls because previous research from our group showed increased shrinkage for some conventional composites relative to bulk fill resin composites.[1] With the aim of understanding polymerization shrinkage values and patterns of currently available flowable resin composites, this study showed a smaller percentage of volumetric polymerization shrinkage for one bulk fill (SX), whereas no differences between the other bulk fill (FS), the conventional (PP), and a self-adhesive (VE) flowable were detected.

A recent study[10] reported similar results, when volumetric shrinkage of Surefil SDR was compared to a conventional flowable resin composite. However, in contrast to our results, significantly different polymerization shrinkage between groups SX and FS was not found. Other investigations[16,23] have also shown that Surefil SDR resin composite has lower shrinkage levels compared to other bulk fill and

Table 2: *Volumetric Polymerization Shrinkage (n=6) of Each Flowable Composite*

Groups and Composites	Shrinkage[a] % (SD)
Group 1: Permaflo + Peak Universal (PP)	4.81 (0.42) a
Group 2: Filtek Bulk Fill + Scotchbond Universal (FS)	5.49 (1.84) a
Group 3: Surefil SDR + XP Bond (SX)	3.31 (0.33) b
Group 4: Vertise (VE)	5.79 (1.13) a

[a] *Means followed by different letters differ from each other in the same column (p≤0.05).*

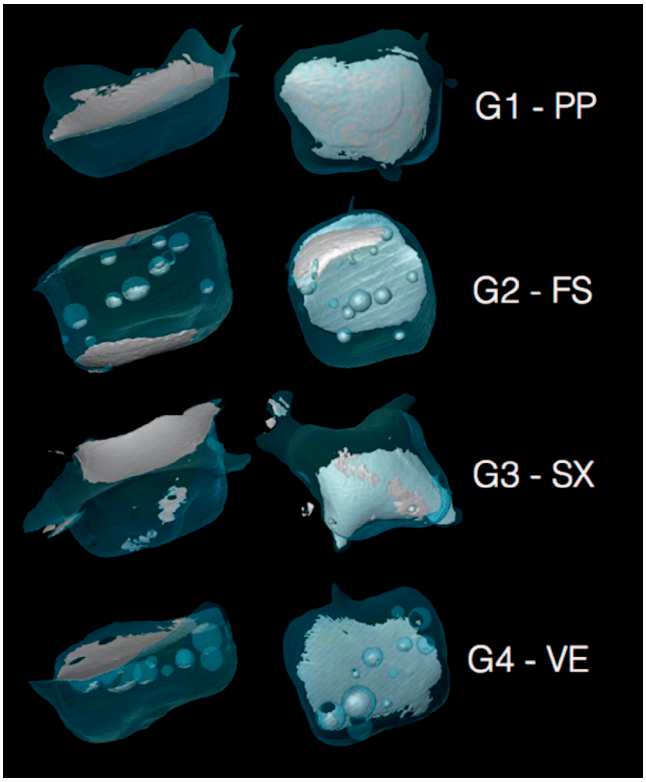

Figure 3. *3D renderings of the groups in distal (left) and pulpal (right) views.*

conventional flowable materials, which is in agreement with our findings.

Extensive efforts have been put toward the development of low-shrinkage dental restorative materials. Besides changes in filler amount, shape, or surface treatment, changes in monomer structure or chemistry and modification of polymerization dynamics have been regarded as promising approaches.[12] The lower values of volumetric shrinkage observed for the SX group may be explained by the monomer composition of the resin composite, a modified diurethanedimethacrylate (UDMA; 849 g/mol) that has a higher molecular weight than other monomers such as bisphenol a diglycidyl ether dimethacrylate (Bis-GMA; 512 g/mol), bisphenol A polyethylene glycol dietherdimethacrylate (Bis-EMA; 496 g/mol), ethoxylated bisphenol A dimethacrylate (EPBADMA; 452 g/mol), and conventional UDMA (470 g/mol). A higher molecular weight would decrease the number of reactive sites per unit volume, conversely reducing shrinkage.[2,24]

To the best of our knowledge, no bulk fill resin composites have been compared to self-adhesive resin composites when it comes to volumetric shrinkage in a restoration cavity. Although not significantly different from some bulk fill groups, the VE group presented higher numeric volumetric shrinkage compared to three materials studied. Earlier studies have shown that the dentin bond strength of VE is lower when compared to flowable resin composites used along with self-etching or total-etch adhesives.[8,9] The lower bond strength of VE to dentin can also explain the higher mean volumetric polymerization shrinkage values reported here, as this phenomenon may be related to the debonding of the resin composite from the cavity walls of the teeth, allowing higher volumetric shrinkage.[8,9]

Even though FS is a bulk fill material and should theoretically present lower degrees of polymerization shrinkage, our results showed that it did not show significantly different values compared to the conventional flowable resin composite group (PP). This finding may be related to the percentage of fillers contained in the materials, as Permaflo Flowable resin composite contains 68% by weight of fillers and Filtek Bulk fill flowable resin composite contains 64.5%. Previous literature has pointed out that resin composites with a lower percentage of fillers may have a higher shrinkage than those with higher percentages,[2,25] although this finding did not corroborate our study when VE was analyzed. The self-adhesive flowable composite presents 70% of inorganic fillers but still showed the highest polymerization shrinkage percentage among the groups.

Qualitatively, the shrinkage patterns were similar for all groups, which presented higher shrinkage on the occlusal surface relative to other surfaces of the cavity. Although pulpal gaps were frequently seen within the groups, the shrinkage in the free occlusal surface was more prominent, a finding that is in agreement with previous literature that depicts shrinkage occurring in unbonded free surfaces.[1,26] Based on our results, some of the materials, when used for bulk filling of cavities, generate gap formation on the pulpal floor, potentially indicating a technical limitation.

Another clinical concern regarding polymerization shrinkage is the resin composite's degree of conversion. The rate of conversion is a significant factor affecting the generation of contraction stress in dental composites. Previous studies suggested that conversion and its resultant volumetric shrinkage are the most important factors affecting the development of contraction stress in dental composites,[27] and the volumetric shrinkage of composites has been shown to be proportional to its degree of conversion.[28,29] The magnitude of volumetric shrinkage

experienced by a resin composite is determined by its filler volume fraction and the composition and degree of conversion of the resin matrix.[2] Therefore, it is suggested that additional in vitro and clinical studies should be conducted to determine degree of polymerization of such studied materials and to correlate it to their volumetric polymerization shrinkage and polymerization shrinkage stress.

CONCLUSION

The bulk fill resin composite Surefil SDR showed less volumetric polymerization shrinkage compared with the other groups, where no difference was detected among the self-adhesive Vertise flow, the bulk-fill Filtek Flowable, and the conventional Permaflo Flowable resin composites. Results from this study suggest that bulk fill and self-adhesive flowable resin composites present at least comparable volumetric polymerization shrinkage performance relative to a conventional flowable resin composite in a 2.5 mm depth cavity, which is an important finding related to simplification of steps in clinical practice.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of NYU Medical School Institutional Review Board.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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