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Cuspal Flexure and Extent of Cure of a Bulk-fill Flowable Base Composite

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Clinical Relevance

Bulk-fill composites are an attractive alternative to reduce restoration placement time if sufficient cure can be ensured without an increase in shrinkage stress. This study provides evidence that supports bulk filling techniques and may help clinicians use this composite type without jeopardizing cure.

SUMMARY

Objectives: To investigate a bulk-fill flowable base composite (Surefil SDR Flow) in terms of cuspal flexure and cure when used in incremental or bulk techniques.

Methods: Mesio-occluso-distal cavities (4 mm deep, 4 mm wide) were prepared in 24 extracted molars. The slot-shaped cavities were etched, bonded, and restored in 1) two 2-mm increments Esthet-X HD (control), 2) two 2-mm increments Surefil SDR Flow, or 3) 4-mm bulk Surefil SDR Flow (N=8). The teeth were digitized after preparation (baseline) and restoration and were precisely aligned to calculate cuspal flexure. Restored teeth were placed in fuchsin dye for 16 hours to determine occlusal bond integrity from dye penetration. Extent of cure was assessed by hardness at 0.5-mm increments through the restoration depth. Results were analyzed with analysis of variance and Student-Newman-Keuls post hoc tests (α=0.05).

Results: Surefil SDR Flow, either incrementally or bulk filled, demonstrated significantly less cuspal flexure than Esthet-X HD. Dye penetration was less than 3% of cavity wall height and was not statistically different among groups. The hardness of Surefil SDR Flow did not change throughout the depth for both incrementally and bulk filled restora-

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tions; the hardness of Esthet-X HD was statistically significantly lower at the bottom of each increment than at the top.

Conclusions: Filling in bulk or increments made no significant difference in marginal bond quality or cuspal flexure for the bulk-fill composite. However, the bulk-fill composite caused less cuspal flexure than the incrementally placed conventional composite. The bulk-fill composite cured all the way through (4 mm), whereas the conventional composite had lower cure at the bottom of each increment.

INTRODUCTION

Visible light-activated (light-cured) composites are the material of choice for direct restorations because they offer prolonged manipulation time and on-command curing.[1] However, this desirable property has some drawbacks because the depth of light penetration is limited. To ensure adequate polymerization, light-activated composites must therefore be placed and cured in increments that are no more than 1.5 to 2 mm thick.[1-3] The need for curing composite restorations in multiple increments can make restorative procedures time consuming. Over the course of one year, an estimated 20 to 40 hours of chair time is used for light-curing.[3] Recently, a new generation of composites has been introduced that can be cured to depths of 4 mm or more[4-6] without compromising margin quality.[7-10] Cavities can now be filled and light-activated in one increment (bulk), simplifying the restorative procedure and saving time for the patient and clinician.

However, although the time-saving potential of this new class of composites is attractive, there was another major reason why filling in bulk has been discouraged. In dentistry, there has been a strong belief that incremental techniques should be used to reduce polymerization shrinkage stress.[1,11] Although this concept has been challenged by studies showing that incremental placement causes incremental tooth deformation that may lead to higher instead of lower stress,[12-14] incremental placement is still widely believed to alleviate shrinkage stresses. Although the relevance of incremental placement for stress reduction may remain a contentious topic,[15] it is important to keep in mind that many other factors are involved in the eventual level of shrinkage stresses that are likely more critical.[16] To take all relevant factors into account, cure and stress development should preferably be evaluated within the context of their application: as a restoration in a tooth.[17]

The objective of the current study was to evaluate if bulk placement of a bulk-fill flowable base composite is acceptable by examining three factors that are critical for initial clinical success: extent of cure, cuspal flexure, and bond integrity. The extent of cure is critical because adequate polymerization is a prerequisite for achieving optimal mechanical properties and biocompatibility, cuspal flexure is critical because it reflects the level of internal shrinkage stresses, and bond integrity is critical because of its role in structural reinforcement and sealing performance of a restoration.

METHODS AND MATERIALS

Specimen Preparation and Scanning

For this study (exempt approved by the institutional review board), 24 extracted human molars kept in 10% formalin acetate were selected in eight sets of three teeth that matched in shape and size. The sample size was based on previously published studies with similar methods; a sample size of eight has 95% confidence to detect a standard deviation difference of 0.7 between groups. The teeth were secured by their roots in stainless steel rings, pumiced to remove residual biofilms, and etched with 37% phosphoric acid solution to achieve a matte surface suitable for optical scanning. During the experiment, all teeth were kept hydrated in water, except during scanning.

Large mesio-occluso-distal slot-shaped cavities were prepared with a 245 carbide bur in a high-speed handpiece under copious amounts of water. During preparation, cavity width was checked with a digital caliper and cavity depth with a periodontal probe. After sectioning, later in the process, the cavity and cuspal dimensions were measured with image analysis software under a stereomicroscope (see the "Dye Penetration" section). The buccolingual width was 4.23 ± 0.13 mm and depth was 3.80 ± 0.32 mm (mean±standard deviation). Widths and depths were not statistically significant different among the three groups (analysis of variance [ANOVA], p=0.9373 and p=0.5798, respectively). The resulting cuspal widths were also not significantly different among buccal and lingual sides (ANOVA, p=0.5452) or between groups (ANOVA, p=0.6413). About 10 to 15 minutes after preparation, the prepared teeth, along with reference spheres embedded in the steel rings, were digitized with an optical scanner (Comet xS 3D Optical Digitizing System, Steinbichler Vision Systems, Neubeuern, Germany). Each point on the scanned surfaces was measured with 5-μm accuracy; the measured points

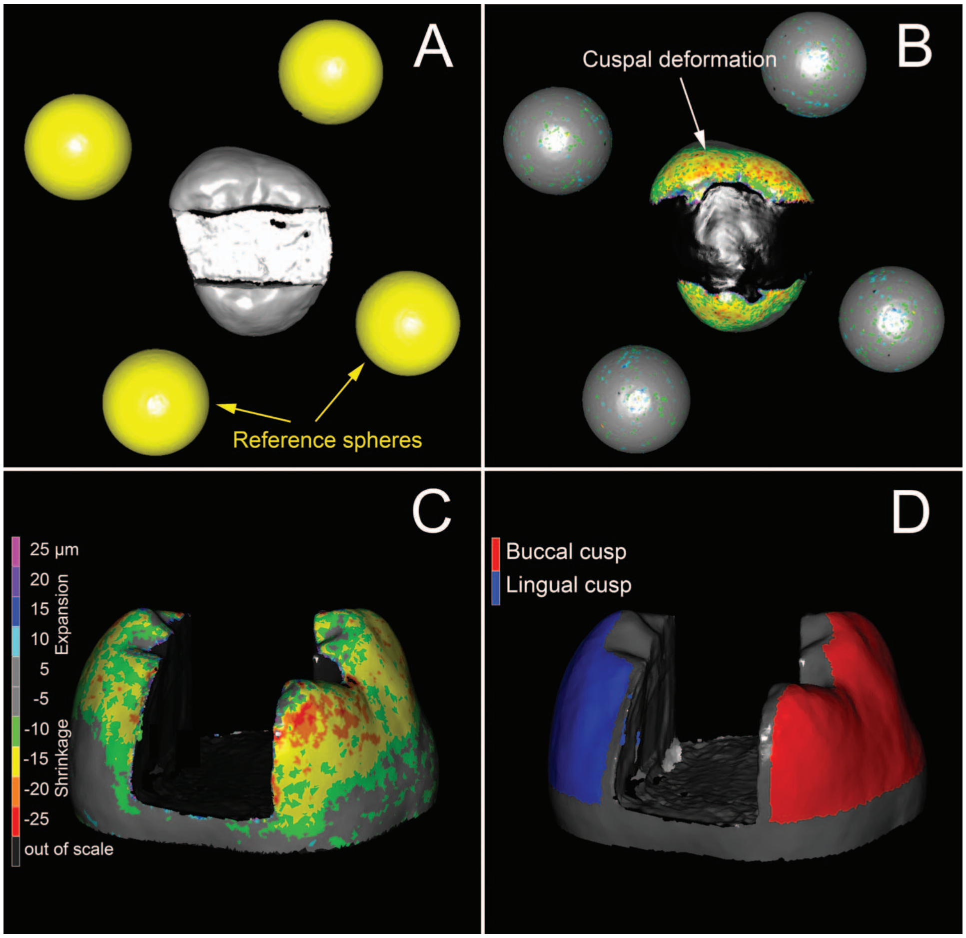

Figure 1. *The preparation scan (A) and restoration scan (B) were aligned in Cumulus software using four stainless steel spheres as the unchanged reference areas shown in yellow (A). Deformation of the buccal and lingual surfaces, that is, cuspal flexure, is visualized in a linear color scale (B, C). Buccal and lingual cuspal surfaces were selected (D) for the calculation of cuspal flexure.*

were 60 μm apart (resolution). The scans of the prepared teeth were used as the baseline (Figure 1A).

Restorative Procedures

Materials used in the study and their compositions are shown in Table 1. A total etch (etch and rinse) bonding technique was used. The cavities were etched with 34% phosphoric acid gel (Dentsply Caulk, Milford, DE, USA) for 15 seconds, rinsed with water, and blotted dry using Kimwipes (Kimberly-Clark, Roswell, GA, USA). Prime & Bond Elect (Dentsply Caulk) was applied and agitated for 20 seconds and gently air-dried for 5 seconds. The mesial and distal halves of the preparation were light-cured for 10 seconds each (VIP Junior, Bisco, Schaumburg, IL, USA). The light intensity was 600 mW/cm^2, measured with a radiometer (Model 100, Demetron Research Corp, Danbury, CT, USA) periodically during the experiments. The three matched teeth from each set were randomly assigned to be restored as follows: 1) two 2-mm horizontal increments using Esthet X HD (Dentsply Caulk) as a control; 2) two 2-mm horizontal increments using Surefil SDR Flow (Dentsply Caulk); and 3) one 4-mm bulk-filling using Surefil SDR Flow. The mesial and distal halves of each increment or bulk material were light-cured for 20 seconds each from the occlusal direction. The composite surfaces were wiped with an alcohol pad to remove the oxygen inhibition layer. After 20 minutes in water, the restored teeth were digitized with the optical scanner.

Cuspal Flexure Analysis

The baseline and restoration scans were accurately aligned by fitting the stainless steel spheres as unchanged references (Figure 1A) using Cumulus software (Copyright Regents of the University of Minnesota).[18] The amount of cuspal flexure was calculated using a custom-developed CuspFlex software. Flexure was determined for the buccal and lingual surfaces from the area between the cusp ridges and the level of the pulpal floor (Figure 1C,D).

Table 1: *Materials Used in the Study*[a]

Material	Composition	Application
Esthet X HD High Definition Micro Matrix Restorative (A2-O) Lot 1301031	Barium boron fluoro-alumino- silicate glass <30% Barium boron alumino-silicate glass <50% Hydrophobic amorphous fumed silica <5% Silica (amorphous) <5% Urethane modified bisphenol A glycidyl methacrylate dimethacrylate <10% Polymerizable dimethacrylate resins <20% Colorants: inorganic iron oxides and titanium dioxide	Light cure 20 s
SureFil SDR Flow – Posterior Bulk Fill Flowable Base (UNIV) Lot 1208221	Barium boron fluoro-alumino-silicate glass <50% Silicon dioxide (amorphous) <5% Strontium aluminosilicate glass <50% Titanium dioxide <1% Polymerizable dimethacrylate resins <10% Polymerizable urethane dimethacrylate <25% Colorants: synthetic inorganic iron oxides	Light cure 20 s
Caulk 34% Tooth Conditioner Gel Lot 121120	Phosphoric acid 34% Blue colorant: fluorescent organic dye	Etch 15 s, rinse with water 10 s, blot dry
Prime&Bond Elect Universal Dental Adhesive Lot 121120	Mono-, di-, and trimethacrylate resins PENTA (dipentaerythritol penta acrylate monophosphate) Diketone Organic phosphine oxide Stabilizers Cetylamine hydrofluoride Acetone Water	Apply and agitate 20 s using microbrush applicator tip, gently air dry 5 s, light cure 10 s

[a] *All materials are from Dentsply Caulk, Milford, DE, USA.*

The average deflection of each surface (buccal or lingual) was calculated from the notional volume change (integrated difference across the selected areas) divided by the selected surface area. The cuspal flexure was the sum of buccal and lingual cuspal deflections.

Dye Penetration

Dye penetration of the occlusal interface was assessed to verify the bond integrity. After the restored teeth had been scanned, restoration margins were finished with composite finishing burs (LogicSet, Axis Dental Corp, Coppell, TX, USA). Root apices were obstructed with utility wax, and the roots were painted with nail polish. The teeth were then placed in 0.5% basic fuchsin dye solution overnight (16 hours), embedded, and sectioned buccolingually into two halves. One half was used for the bond integrity assessment and the other half for the depth of cure evaluation. For the bond evaluation, the samples were sectioned buccolingually into 1-mm slices, yielding 4-6 slices per sample. Each slice was imaged using a stereomicroscope with a charge coupled device camera (SZX16 & UC30, Olympus, Tokyo, Japan). The distances of dye leakage at the occlusal margins along the buccal and lingual interfaces were measured by two independent evaluators using image analysis software (Stream Basic, Olympus Soft Imaging Solution GmbH, Münster, Germany) (Figure 2). If the distances measured by the two evaluators differed more than 10%, a consensus value was reached. The dye penetration distances were averaged for each tooth. In addition, the wall height of each cavity interface was measured from the occlusal margin to the pulpal floor.

Depth of Cure Measurement

The other tooth half was used to assess the depth of cure by measuring hardness on the cross-sectional surface.[19,20] Thus, the hardness was measured one day after the restoration had been cured. The tooth halves were embedded in acrylic resin, and the cross-sectioned surfaces were serially polished with 400- and 600-grit silicon carbide paper followed by 1 μm and 0.05 μm alumina pastes. Vickers hardness (QV-1000 Micro Hardness Tester, Qualitest USA LC, Fort Lauderdale, FL, USA) was measured from indentations made across the restoration at 0.5 mm increments from the occlusal surface to the bottom of the restoration (pulpal floor) (Figure 3A). The indentation load was 200 g at 15 seconds dwell time.

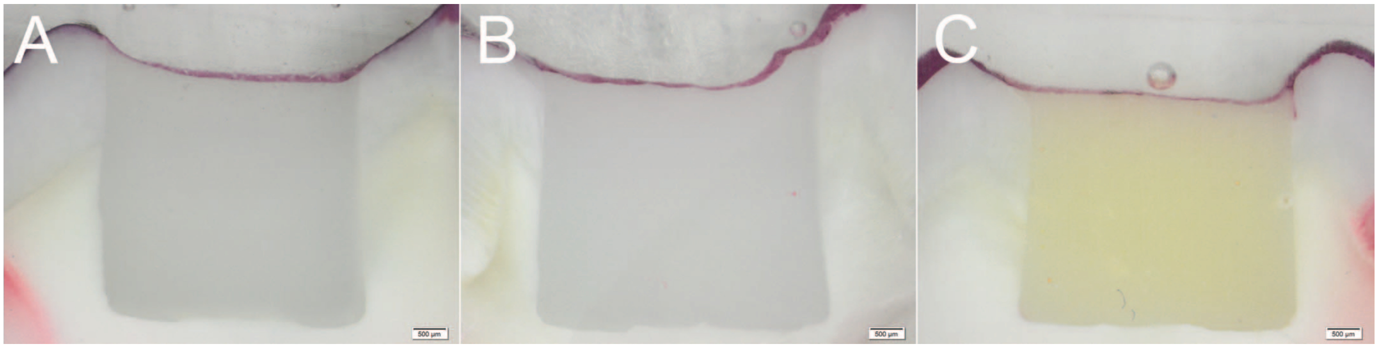

Figure 2. *Buccolingual sections of restored teeth illustrating no or small dye penetration at the occlusal enamel interface: (A) Surefil SDR Flow placed in bulk. (B) Surefil SDR Flow placed in two increments. (C) Esthet X HD placed in two increments.*

Statistical Analysis

The differences in cuspal flexure and dye penetration among groups as well as differences in hardness values among various depths within each group were statistically analyzed with ANOVA followed by Student-Newman-Keuls post-hoc tests (significance level 0.05).

RESULTS

Cuspal flexure and dye penetration distance are shown in Table 2. Surefil SDR Flow, either incrementally or bulk filled, caused significantly less cuspal flexure than Esthet X HD (ANOVA, p=0.0211, followed by Student-Newman-Keuls post-hoc test, $p<0.05$). Dye penetration distances at the occlusal enamel interface were less than 3% of the wall height and did not show statistically significant differences among groups (ANOVA, p=0.0948). Images of the buccolingual sections of restored teeth, one from each group, are shown in Figure 2; these show no or little dye penetration.

Vickers hardness numbers at various depths in the restorations of each group are shown in Figure 3B. Esthet X HD had higher hardness than Surefil SDR Flow. Incrementally cured Esthet X HD had the highest hardness values at the surface of each increment before gradually decreasing with increasing depth. The hardness value of Esthet X HD was significantly lower at the bottom of each increment

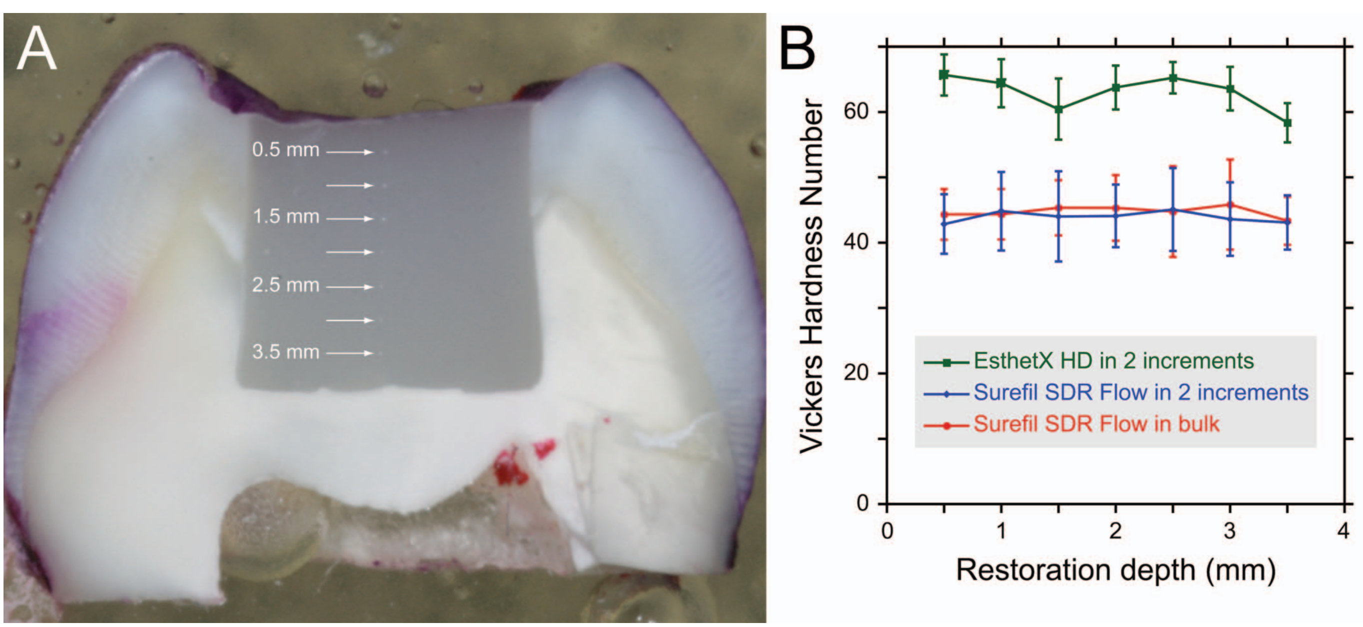

Figure 3. *(A) Cross-section of a restored tooth showing position of Vickers indentations. (B) Plots of Vickers hardness numbers at various depths in the restorations (extent of cure).*

Table 2: *Cuspal Flexure and Dye Penetration Distance (Mean±Standard deviation; microns)*[a]

	Esthet X HD Incremental	Surefil SDR Flow Incremental	Surefil SDR Flow Bulk
Cuspal flexure (μm)	22.8 ± 3.9 a	17.2 ± 4.2 b	18.9 ± 2.0 b
Dye penetration (μm)	85 ± 27 a	60 ± 32 a	47 ± 33 a

[a] *Different letters indicate statistical differences between groups (analysis of variance followed by Student-Newman-Keuls post hoc tests, significance level 0.05).*

compared with values closer to the top of increments (ANOVA, $p=0.0020$, followed by Student-Newman-Keuls post-hoc test, $p<0.05$). The hardness values of incremental or bulk-filled Surefil SDR Flow were not significantly different at any depth (Student-Newman-Keuls post-hoc test, $p<0.05$) and did not significantly change throughout the 4-mm depth of the restorations (ANOVA, incremental $p=0.9881$ and bulk-filled $p=0.9786$).

DISCUSSION

Bulk filling has long been viewed with skepticism, but the advent of viable bulk-fill composites that promise to simplify and shorten restoration procedures may be changing this perception. The effect of bulk filling on cure and stress in a composite restoration cannot be easily determined clinically nor can it be extrapolated from the material properties alone. To evaluate the viability of a bulk-fill composite, this study examined three factors in *in vitro* restored teeth: cuspal flexure, extent of cure, and marginal bond.

Three Factors

The three selected factors could be considered most affected by a bulk fill technique. Of the three, the extent of cure is obvious because it determines the feasibility for bulk cure. Cure also affects polymerization shrinkage stresses. Stress is a local condition that is calculated by taking into account the properties of the restored tooth, transient properties of the composite, shapes of the tooth-restoration complex, and the state of bonding. In this study stresses were not determined because that required complex calculations.[21] Instead, cuspal flexure was determined.[22-24] Cuspal flexure is caused by stresses, and thus inherently encompasses all attributes involved in the shrinkage stress, including the transient composite properties.[17,25] Marginal bond, the third factor, was examined because shrinkage stress is generated when composite polymerization contraction is constrained by the bonding to the tooth structure. The state of the restoration bonding must therefore be considered when assessing shrinkage stresses.

Cuspal Flexure

The cuspal flexure for the bulk-fill flowable composite used in this study did not show a significant difference between the incremental or bulk-filling techniques. The cuspal flexure with the bulk-fill flowable base composite restorations was significantly lower than the conventional nonflowable restorative composite that was used as a reference. This suggests that the new bulk-fill flowable base composite generated lower shrinkage stresses in the tooth than those of a conventional, well-accepted restorative composite system.[5,26] It also suggests that for controlling shrinkage stresses within a clinical context (ie, restoration of a tooth), the difference between incremental or bulk-fill techniques is probably marginal.[13,20]

Extent of Cure

Interpretation of cuspal flexure results requires caution. As noted previously, differences in cure also cause differences in flexure. For example, inadequate cure leads to lower elastic modulus and less polymerization contraction, which results in less cuspal flexure and hence lower shrinkage stresses in a restored tooth. The trade-off between less cure for lower shrinkage stress is undesirable, and therefore obtaining lower cuspal flexure due to less cure is not necessarily a favorable outcome. To ensure that the cure was adequate or comparable, the extent of cure was determined throughout the depth of the restorations using hardness measurements.

The hardness measurements of the bulk-fill flowable base composite indicated that a homogeneous cure through the entire 4-mm depth of the composite was achieved with both the incremental and bulk cure. If the cure at the surface is assumed to have been adequate, the cure throughout the 4-mm-deep restorations must have been adequate also, ensuring optimal mechanical properties, biocompatibility, and chemical stability regardless of whether incremental or bulk curing techniques were used. Unlike the bulk-fill composite, the conventional composite showed a decrease in hardness (and thus extent of cure) at the bottom of each 2-mm increment, demonstrating that composites that are not designed for bulk curing should be cured in increments to avoid compromising their mechanical and biophysical properties. It is important to mention that no direct comparisons were made about the degree of cure of the bulk-fill and conventional composites using the hardness data because hardness is a material-specific property that also depends on composition (eg, filler distribution, resin type).[19] The lower hardness values of the bulk-fill composite, consistent with previous studies,[26] were likely due to the lower filler loading of this flowable restorative.[4]

Marginal Bond

The third factor that was examined was the state of the bond at the occlusal margins. Clinically, good bonding between composite and tooth structure is critical for restoring the structural integrity of a restored tooth[27] and for sealing the inside of the tooth structure from bacteria and their nourishments. A restoration bond is challenged by polymerization shrinkage as well as stresses caused by thermal and mechanical loading. Resisting those challenges requires sufficient bond strength. Although strength or longevity of the bond are important for the performance of a restoration, it was not the objective of this study. For the present study design, intact bonding needed to be verified to ensure that the measured cuspal flexure was due to polymerization shrinkage and not modified by bond failure. Debonding would relieve shrinkage stresses and reduce the cuspal flexure, wrongly suggesting lower shrinkage stresses. Clinically, reduction in shrinkage stress due to debonding is also undesirable. Penetration of the fuchsin dye revealed that the bond remained largely intact for all groups, thus indicating comparable quality of the bonds among the three groups. Therefore, comparison of the cuspal flexure among the three groups was justified and could be used to draw conclusions about the effect of bulk filling on the stresses in restored teeth.

Interpretation of Cuspal Flexure

Various studies have confirmed the ability of bulk-fill composites to cure much deeper than conventional composites,[4-6] and *in vitro* cuspal flexure and marginal gap studies have not found compelling evidence for avoiding bulk-fill techniques.[7-10] Cuspal flexure measurements are a convenient technique for comparing the state of stresses in teeth restored with different composites or filling techniques, provided that the tooth properties, shapes, and bonding conditions are comparable.[21] However, the performance of a restoration is not determined by shrinkage stress. Stress cannot be extrapolated to performance without the context of strength. A weak interface will fail at low stress values, and thus a low shrinkage stress state can still have little relevance for clinical performance. Moreover, polymerization shrinkage stress is a temporary condition because it is likely to be compensated by hygroscopic expansion and stress relaxation.[28-30] If a bond survives the initial shrinkage stresses, other properties may turn out to be more important for the life expectancy of a restoration.

Based on these considerations and the results of this study, it can be postulated that the most important aspect of a composite restoration technique is maintaining acceptable cure and intact interfaces. The choice between an incremental or bulk-filling technique should be guided by those requirements, rather than by shrinkage stress considerations. From cross-sectioned samples, we observed that the low-viscosity flowable composite provided better adaptation to the cavity walls, floor, and between composite layers in the incremental fillings than the conventional composite. The lower microhardness of the flowable composite compared with the conventional composite supports the recommendation that under clinical conditions this flowable material should be used as a base/liner or dentin replacement.[31] The potential to attain adequate polymerization in deep layers offered by the new generation of bulk-fill composites is an advantage in critical areas where curing can be compromised, such as in the gingival portion of a proximal restoration where a bulk-fill flowable base composite like Surefil SDR Flow is recommended under a universal or posterior composite.

CONCLUSIONS

1. Cuspal flexure was lower with the bulk-fill flowable base composite than with an incrementally cured conventional composite.
2. Filling in bulk or increments made no significant difference in the cuspal flexure of a bulk-fill flowable base composite.
3. The bulk-fill flowable base composite restoration cured all the way through (4 mm) irrespective of bulk or incremental cure, whereas the cure of the conventional incrementally cured composite decreased toward the bottom of each (2 mm) increment.
4. Clinicians can use the bulk-filling technique with the tested bulk-fill composite without jeopardizing depth of cure or elevating the polymerization shrinkage stresses.

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Human Subjects Statement

This study was conducted in accordance with all the provisions of the local human subjects' oversight committee guidelines and policies. The approval code for this study is #13-02372-XM. This study was conducted at the College of Dentistry, University of Tennessee Health Science Center.

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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