Published in final edited form as:

J Esthet Restor Dent. 2018 January ; 30(1): 30–38. doi:10.1111/jerd.12339.

Effect of composite type and placement technique on cuspal strain

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Abstract

Objective—To compare the cuspal strain in Class II restorations made with bulk-fill and conventional composite resins.

Materials and methods—Fifty extracted maxillary premolars were mounted into phenolic rings and divided into five groups ($n = 10$). Specimens received standardized MOD preparations. A two-step self-etch adhesive was applied and the preparations were restored using a custom matrix as follows: Filtek Supreme Ultra in eight 2-mm increments (FSUI); Filtek Supreme Ultra in bulk (FSUB); SonicFill in bulk (SF); SureFil SDR flow in bulk, covered with a 2-mm occlusal layer of Filtek Supreme Ultra (SDR/FSU); Tetric EvoCeram Bulk Fill in bulk (TEBF). Strain gages bonded to the buccal and lingual cusps recorded cuspal strain during restorations. End strain

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The authors do not have any financial interest in any of the companies whose products are included in this paper.

values were determined and data were subjected to Kruskal-Wallis testing, followed by one-way ANOVA and Tukey's *post hoc* test.

Results—Combined strain values and standard deviations (in $\mu\epsilon$) were: FSUI: 723 ± 102.8 , FSUB: 929.2 ± 571.9 , SF: 519.1 ± 80.2 , SDR-FSU: 497.4 ± 67.6 and TEBF: 604.5 ± 127.1 . A significant difference was found between group FSUI and groups SF, SDR-FSU, and TEBF. Group FSUB showed significantly higher mean strain and greater standard deviation than all other groups due to cuspal fractures, and was thus excluded from the statistical analysis.

Conclusions—The tested bulk-fill composite resins exerted less strain onto tooth structure than the incrementally placed conventional composite resin, although the magnitude of generated strain was product-dependent. Bulk-filling with conventional composite resins is contraindicated.

Clinical significance—Bulk-fill composite resins exerted less strain onto adjacent tooth structure than a traditional composite, even when that composite is placed incrementally. Bulk-filling with traditional composite resins is unpredictable and contraindicated.

1 | INTRODUCTION

When restoring a posterior tooth with direct composite resin, polymerization shrinkage stress can be damaging to the tooth, the adhesive interface, and the restorative material itself and can thus lead to a host of clinical problems such as cusp deflection,^{1–4} fracture of enamel margins,^{5–8} debonding,^{8–11} micro-cracking of the composite resin,¹² microleakage,^{13–16} postoperative sensitivity^{15–17} and pulpal irritation.¹⁸ Although no clinical evidence currently exists linking shrinkage stress with clinical failure,^{19–21} it would be desirable for clinicians to minimize polymerization shrinkage stress which might predispose restorations to such problems.

The incremental placement technique has been recommended to reduce polymerization shrinkage stress. While horizontal, vertical and oblique increments have been proposed, all have the same goal of increasing the unbonded area in each increment of composite resin which maximizes the potential for stress relaxation via external flow.^{22,23} Reduced polymerization shrinkage stress via incremental placement and light-curing has been demonstrated in several *in vitro* studies.^{24–26} Other benefits of the technique include optimal physical properties due to adequate photopolymerization of each increment and optimal bond strengths due to controlled shrinkage stress.^{4,27} Improved cavity floor adaptation with the incremental technique vs. bulk-filling with conventional composite resins has also been found *in vivo*.¹⁵

Despite this, the beneficial effects of incremental placement on polymerization shrinkage stress have been questioned. Some authors have argued that incremental placement results in more shrinkage stress affecting adjacent tooth structure, and recommended bulk-filling with conventional composite resins.²⁸ While some researchers have verified a reduction in shrinkage stress *in vitro* while bulk-filling with conventional composite resins, further investigation revealed that the reduction in stress was due to poor polymerization resultant from limited light penetration into the composite resin.^{4,29} Furthermore, the incremental placement technique is technique-sensitive and time-consuming. The market demand seems to favor restorative dental materials that are faster and easier to use. In an effort to meet this

demand, several manufacturers have introduced bulk-fill composite resins to the market. Manufacturers claim an increased depth of cure (4–5 mm deep) and lower polymerization shrinkage stress with bulk-fill composite resins compared to conventional composite resins. This can eliminate the need for a sophisticated layering technique and reduce the chair time needed for each restoration.

Laboratory studies on low-viscosity bulk-fill materials have shown that they exhibit higher volumetric shrinkage than conventional high-viscosity composite resins, and do not always exhibit lower polymerization shrinkage stress, similar to their “flowable” composite resin counterparts.^{30–33} The high-viscosity bulk-fill materials however, generally exhibit similar or lower volumetric shrinkage and polymerization shrinkage stress than their conventional composite resin counterparts, but to different extents.^{30–32,34} Thus, it appears that the overall ability of bulk-fill composite resins to produce lower polymerization shrinkage stress is product-dependent.

A positive linear correlation has been found between the polymerization shrinkage stress generated by composite resin materials, their linear shrinkage and elastic modulus.^{34,35} Raising the rate of polymerization also increases the shrinkage stress generated due to a more rapidly rising modulus.³⁶ Hence, numerous photopolymerization methods have been recommended to retard the rate of polymerization,^{7,37,38} but controversy exists regarding their efficacy.^{39–41} More recently, resin matrices of some bulk-fill materials have been reformulated to control the rate of polymerization in an attempt to maximize stress relief in the pre-gel phase.^{42,43}

It has been shown that polymerization shrinkage causes cuspal deflection in restored teeth, which indicates the presence of shrinkage stresses.^{1–3} Methods traditionally used to measure cuspal deflection include equipment detecting linear cuspal movement along a straight path,^{26,44,45} microscopes,^{1,2,46} or calipers used to register the intercuspal distance before and after polymerization.^{47,48} However, some of these methods have limitations. Measurements with microscopes or digital calipers are sensitive to accurate reproduction. Furthermore, due to their noncontinuous nature, one could fail to detect rebounding cusps in the occurrence of debonding, which could underestimate the effect of polymerization shrinkage stress. Linear variable differential transformers (LVDTs) have the advantage of continuous, linear recording but are highly sensitive to specimen orientation and distortion during restorative procedures.^{49,50}

Strain gages bonded to buccal and lingual surfaces of cusps are a relatively simple and inexpensive way to record cuspal strain,⁵⁰ which is proportional to the shrinkage stresses imposed on the tooth structure.^{1–3} Strain gages bonded to cusps have the potential to overcome shortcomings of non-continuous methods by offering real-time, multi-linear recordings of cuspal deformation over an area equal to the surface of the gage grid. Furthermore, given precise placement and orientation, they can be less sensitive to specimen orientation and distortion during restorative procedures than LVDTs.⁵⁰

The purpose of the present study was to evaluate the effect of composite resin type and insertion technique on cuspal strain *in vitro*. The null hypothesis was that there is no

significant difference in the cuspal strain exerted on tooth structure between bulk-fill and conventional composite resins.

2 | MATERIALS AND METHODS

2.1 | Specimen preparation

Human premolars recently extracted for orthodontic purposes (IRB #13-1795) were collected and stored in 0.5% thymol at 5°C until ready for use. Specimens were cleaned and carefully examined with 2.7× magnification and illumination, and those containing cracks, caries, wear facets or other defects were eliminated. Fifty specimens were vertically mounted into 1" phenolic rings (Buehler, Lake Bluff, IL, USA) using clear epoxy resin (Buehler). Based on buccolingual measurements, the specimens were grouped into small (8.5–9.24 mm), medium (9.25–9.99 mm), and large (10.0–10.74 mm) groups. The mesiodistal dimension of each specimen was recorded and used as a reference for the subsequent cavity preparation. Specimens were then randomly assigned to five groups of 10 with similar size distribution (blocked randomization).

Strain gages (model EA-06-062AP-120/LE, Micro-Measurements, Raleigh, NC, USA) were trimmed with a scalpel blade and bonded to the buccal and lingual cusps using cyanoacrylate adhesive (M-Bond 200, Micro-Measurements) according to the manufacturer's instructions. The gages were aligned with the long axis of the tooth, with the grid of the gages centered 3.5 mm below the lingual cusp tip. This configuration placed the center gage in line with the pulpal floor of the MOD cavity preparation that would be later performed (Figure 1). The gages and lead wires were then coated with self-curing silicone rubber (M-Coat C, Micro-Measurements), which was allowed to cure in a humid environment for at least 24 h. Impressions were then made of the proximal surfaces with rigid polyvinyl siloxane (PVS) material (Regisil 2×, Dentsply Caulk, Milford, DE, USA), to be used as proximal matrices during the restorative phase. Care was taken to prevent dehydration of the specimens at all times.

2.2 | Cavity preparation

Standardized MOD cavity preparations were made in all specimens using a parallel-sided, round-ended diamond rotary instrument (model #835KR.31.008, Brasseler USA, Savannah, GA, USA), mounted in an air turbine, using copious water spray. The occlusal isthmus was 40% of the maximum buccolingual width (BLW). The pulpal floor was 3.5 mm below the lingual cusp tip. The axial wall was 2 mm high and the axial wall depth was 25% of the maximum mesiodistal width of the specimen. All internal line angles were rounded, and all proximal cavosurface angles were oriented so as to achieve a 90° cavosurface angle. All dimensions were confirmed with a digital caliper with 0.01 mm accuracy during cavity preparation.

2.3 | Specimen restoration

After cavity preparation, the specimens were mounted on a polyvinyl siloxane base for stabilization and the strain gages were connected to a data acquisition unit (Model D4 Data Acquisition Conditioner, Micro-Measurements). A dummy specimen, which was prepared

but unrestored was always connected to the data acquisition unit during the restorative procedures to compensate for temperature and humidity fluctuation. Prior to restoration, the PVS proximal matrices were placed against the proximal surfaces. Care was taken to ensure a tight but passive fit which did not interfere with the output of the strain gages. The data collection was initiated immediately before the restorative sequence. The operator was masked of the live feed of strain output during the restorative sequence.

A two-step self-etch adhesive (OptiBond XTR, Kerr Corporation, Orange, CA, USA) was applied and photopolymerized and the specimens were restored according with the following protocols ($n = 10$):

1. Filtek Supreme Ultra (3M ESPE, St. Paul, MN, USA) in 2-mm increments (positive control, FSUI): the proximal boxes were first restored with two cuboidal increments each, followed by the occlusal portion with four oblique increments, two up against the buccal and lingual cusps without touching the adjacent wall. This made for a total of eight increments per specimen. Each increment was photopolymerized separately for 20 s (see below for detailed photopolymerization technique for all groups).
2. Filtek Supreme Ultra (3M ESPE) in bulk (negative control, FSUB): the entire cavity preparation was restored with one increment.
3. SonicFill (Kerr Corporation) in bulk (SF): the proximal boxes were first restored with one increment each and the remaining cavity with one bulk-increment to avoid violating the manufacturer's recommended maximum depth of cure.
4. SureFil SDR flow (Dentsply Caulk) in bulk, covered with a 2-mm occlusal layer of Filtek Supreme Ultra (SDR/FSU): the low-viscosity bulk-fill composite resin was placed and polymerized in bulk, leaving 2 mm of space for the veneering composite resin. The veneering resin was then placed and polymerized in two separate increments.
5. Tetric EvoCeram Bulk Fill (Ivoclar Vivadent AG, Schaan, Liechtenstein) in bulk (TEBF): the proximal boxes were first restored with one increment each and the remaining cavity with one bulk-increment to avoid violating the manufacturer's recommended maximum depth of cure.

All materials were used according to the manufacturers' instructions. Table 1 lists all restorative materials used in this study.

The proximal matrices served as a guide for the volume of composite resin that was inserted since they recorded of the specimen's preoperative shape, as well as provided a reference for the marginal ridges and thus the height of the occlusal table. The occlusal increments were placed in continuation of the existing cuspal inclines and primary occlusal anatomy was recreated. All increments were photopolymerized for 20 s with a high intensity polywave LED curing light (Bluephase G2, Ivoclar Vivadent) on "high" setting, with the tip as close to the specimen as possible without touching it. After the final occlusal layer was photopolymerized the investigators waited for 4 min to allow the polymerization reaction to continue. Data collection was stopped at this point. End values (in microstrain, $\mu\epsilon$) from

buccal and lingual strain gages were recorded and mean strain values per group were calculated. Buccal and lingual mean strain values were also combined for all the groups.

The energy output of the curing light was measured prior to every restorative sequence with a radiometer (Bluephase Meter, Ivoclar Vivadent). The average output throughout the study was 1262 mW/cm².

2.4 | Statistical analysis

All groups were subjected to Kruskal-Wallis ANOVA. Due to the excessively high mean and standard deviation, group FSUB was excluded from further analysis. The remaining groups were subjected to one-way ANOVA and Tukey's *post hoc* test for multiple comparisons. The level of significance was set to .05.

3 | RESULTS

The Kruskal-Wallis ANOVA revealed that a significant difference existed among the groups for buccal, lingual and combined data.

Results (mean strain values) for each experimental group are shown in Table 2. Figure 2 shows a representative data output curve for specimens in the study, showing a clear, stepwise increase in cuspal strain for each increment placed and photopolymerized in all of the groups. Figure 3 shows a graphical comparison of the buccal and lingual strain values per group combined.

For buccal cusps, group FSUI had a significantly higher mean strain value than groups SF and SDR-FSU, while groups TEBF, SF, and SDR-FSU were not significantly different.

For lingual cusps, group FSUI had a significantly higher mean strain value than groups SF and SDR-FSU, while groups TEBF, SF, and SDR-FSU were not significantly different.

For combined strain, group FSUI had a significantly higher mean than groups TEBF, SF, and SDR-FSU.

4 | DISCUSSION

Bulk-fill composite placement techniques have gained considerable attention recently, but their effect on cuspal strain has not been fully investigated, particularly when different types of composite materials are compared in a similar study design. In this study three different bulk-fill composite resins were compared against a conventional nano-filled composite resin, in the manner which they are clinically used. Two of the bulk-fill materials (SF and SDR-FSU) generated significantly lower cuspal strain than the control group. Group TEBF had a clear tendency to exhibit lower cuspal strain than the incrementally placed composite resin, reaching a level of significance for combined strain, but not for separate buccal or lingual strain. The null hypothesis of this study can therefore be rejected; restoration with all bulk-fill materials resulted in lower cuspal strain compared to conventional composite resin placed incrementally, although the magnitude of cuspal strain was product dependent.

These results are in agreement with other *in vitro* studies where cuspal flexure was examined. Moorthy et al. found significantly less cuspal flexure when MOD cavities in premolars were restored using two veneered low-viscosity bulk-fill composite resins than when the veneering composite was placed by itself incrementally.⁴⁵ Do et al. found noticeably less cuspal flexure when MOD cavities in premolars were restored with Tetric EvoCeram Bulk Fill than with Filtek Supreme Ultra although the difference did not reach a level of significance, mirroring the results of the present study.⁵¹

To enable a greater depth of cure, bulk-fill materials in general have greater translucency and more potent photoinitiator systems than conventional composite resins.^{43,52,53} There are conflicting findings in the literature on whether some of these materials have the ability to polymerize to the claimed depth, which in part relate to the testing methods used. It was recently found that the standard method to investigate depth of cure, the ISO 4049 method, is unsuitable for bulk-fill composite resins, as it resulted in overestimated curing depths.⁵⁴ Other methods, such as the acetone-shake method⁵⁵ and hardness tests on opposing ends of polymerized composite resin cylinders have been proposed as substitutes. In the latter, a ratio of 80% from bottom/top hardness values has been found to represent a clinically acceptable depth of cure.⁵⁶ Regardless of testing methods, the low-viscosity bulk-fill materials have consistently been shown in *in-vitro* studies to polymerize to the claimed curing depths.^{30–32,55,57–60} However, conflicting results have been obtained regarding the abilities of the high-viscosity materials to do the same, even when substitute methods to the ISO 4049 method are used.^{30–32,55,57,58,60} Thus, controversy still exists regarding the ability of high-viscosity bulk-fill materials to polymerize to the proposed depths. Inadequate polymerization would indeed result in lower cuspal strain values. In the present study, no attempt was made to confirm adequate polymerization at the bottom of the cavity preparation. According to the manufacturer, the allowable increment thicknesses of SonicFill, SureFil SDR flow, and Tetric EvoCeram Bulk Fill are 4, 5, and 4 mm, respectively. To avoid violating the recommended maximum depth of cure for these materials, the proximal boxes (2 mm deep from the pulpal floor) were first restored, followed by the occlusal portion which was 3.5 mm deep from the lingual cusp. According to this, the incremental thicknesses were well below the maximum recommended limit.

Extracted intact maxillary premolars were chosen as specimens due to their relative symmetry and similar cusp height.^{61,62} The cavity preparation in this study was of fixed depth with other dimensions being based on the dimensions of the individual specimen. This cavity preparation design weakened the specimens in a relatively similar manner, allowing for comparison between specimens despite inevitable variations in anatomy. It also created cantilever beams out of the buccal and lingual cusps, allowing them to deform around the pulpal floor over which the strain gages were centered. The occlusal isthmus was centralized from the central fossae, terminating at an equal distance from the buccal and lingual cusp tips. A slightly more pronounced buccal bulge commonly seen on maxillary premolars will however have left the buccal cusp slightly more robust with a stronger base support, allowing a greater resistance to shrinkage forces. This would explain lower strain values commonly seen on the buccal side in this study. The decision to prepare the occlusal isthmus to 40% of the maximum BLW was made after performing a pilot study where the isthmus width was 50% of the maximum BLW. In that study the investigators experienced numerous

cuspal fractures due to polymerization shrinkage stress with groups FSUI and FSUB. Interestingly, all bulk-fill specimens prepared with the wider isthmus survived.

The groups SDR/FSU and SF generated the lowest strain values of all groups. SureFil SDR flow has a reported filler load of 68% by weight/45% by volume, and has a patented, photoactive, high-molecular weight (849 g/mol) modified UDMA, which slows the polymerization kinetics, allowing for increased stress-relief via internal flow in the pregel phase.⁴² This material exhibits relatively high volumetric shrinkage but the values of polymerization shrinkage stress have consistently been measured very low due to a slow elastic modulus development during polymerization, and a relatively low final elastic modulus.^{30,42,63,64} According to the manufacturer, this material should be veneered with 2 mm of conventional composite resins to improve strength, wear resistance and esthetics of restorations. If the actual strain values from the buccal and lingual strain gages, prior to polymerizing the veneering increments in this group are investigated, very low strain values averaging at 47.8 $\mu\epsilon$ between both cusps can be seen (Figure 4). A comparison with the mean values for the group reveals that about 80% of the strain generated in this group was generated by the veneering composite material. However, it must be recognized that the cavity geometry is likely to mask a part of the strain generated by the SDR material since the bottom 2 mm of the cusps were supported by the axial wall. It is hard to extrapolate these results to the clinical scenario where cavity preparation geometry inevitably varies greatly.

SonicFill is a highly filled (83.5% bw, 69% bv) composite resin. It contains rheological modifiers that allow for increased particle motion and a severe drop in viscosity upon sonication with a designated hand-piece, leading to increased pre-gel stress-relief via internal flow.⁴³ The high filler content leads to relatively low volumetric shrinkage and a higher elastic modulus than most other bulk-fill composite resins.^{30,63,64} Despite this relatively high modulus, SonicFill, much like Surefil SDR flow, has been found to generate very low polymerization shrinkage stress values compared with other bulk-fill and conventional composite resin materials.^{30,63} In fact, Tiba et al. found SonicFill and SureFil SDR flow to generate the lowest mean polymerization shrinkage stress values out of several tested bulk-fill composite resins,³⁰ supporting the results of the present study where these groups generated the lowest amounts of cuspal strain.

The group TEBF generated higher levels of cuspal strain than the other bulk-fill groups. Unlike SonicFill and SureFil SDR flow, where the pregel phase of the polymerization is altered, Tetric EvoCeram Bulk Fill contains prepolymerized and silanized resin filler particles which lower the elastic modulus of the material.⁵³ The reported filler load is 61/17% by weight (inorganic/organic) and 60% by volume (inorganic), leading to volumetric shrinkage values very similar to those of SonicFill and Filtek Supreme Ultra.^{30,63} Its elastic modulus values are however significantly lower, while still being significantly higher than those of SureFil SDR flow.^{30,63,64} Comparisons of polymerization shrinkage stress values between Tetric EvoCeram Bulk Fill and the other materials in this study have yielded inconsistent results. Tiba et al. found the values of polymerization shrinkage stress of Tetric EvoCeram Bulk Fill to be slightly higher than that of Filtek Supreme Ultra, while SonicFill and SureFil SDR flow had significantly lower values.³⁰ Jang et al. measured slightly lower values for Tetric EvoCeram Bulk Fill than for Filtek Supreme Ultra, but

significantly higher values for SureFil SDR flow.³¹ Lastly, Kim et al. measured very similar values for Tetric EvoCeram Bulk Fill and SonicFill, while the values for SureFil SDR flow were significantly lower.⁶³ Thus, when the results of the present study are compared with other *in vitro* studies where values of polymerization shrinkage stress are measured, only partial agreement exists. However, it seems clear that materials that have a tendency to generate lower values of shrinkage stress also have a tendency to generate lower levels of cuspal strain.

The high mean and standard deviation of group FSUB warrant discussion. The high mean lingual value contains some excessive values that were caused by cuspal fracture in a few of the specimens. A fracture was characterized by a sudden and dramatic change in strain output, several times higher than any output received as a result of shrinkage stress (Figure 5). Invariably, those fractures occurred in a semilunar fashion in line with the pulpal floor and could clearly be seen upon visual inspection. Other reasons contributing to the wide distribution of strain values in group FSUB might be debonding of the adhesive interface and poor polymerization of the composite resin in deeper parts, both of which would explain very low strain values in a number of specimens. Indeed, several other studies lend credence to these explanations. Better cavity floor adaptation has been found for incremental placement than bulk-filling with conventional composite resins *in vivo*, indicating debonding when bulk-filling is applied.¹⁵ Low cuspal deflection values while bulk filling with conventional composite resins have been obtained in another *in vitro* experiment, in which the investigators found the reason to be poor polymerization of the composite resin due to limited light penetration.²⁹ Other investigators have also confirmed poor polymerization of conventional composite resins placed and cured bulk in large MOD cavity preparations.⁴ Furthermore, poor dentin bond strengths in deeper areas of cavity preparations when bulk-filling with conventional composite resins have been reported.²⁷ In summary, poor polymerization and debonding coupled with fractures may have contributed to the wide range of strain values in group FSUB. Future research designed to evaluate this potential is warranted.

Weighing increments has been proposed as a way to standardize the volume of inserted composite resin for each increment.²⁴ While this method can be used in laboratory studies dealing with standardized equipment, it was not considered a practical method for this study due to inevitable variations in specimen and cavity preparation geometry. Small differences in increment size may have contributed to the higher standard deviation in the FSUI group than in groups SF and SDR/FSU. Without performing tests to confirm adequate polymerization one can only speculate on the higher standard deviation in group TEBF than that of the other bulk-fill groups. The material did however have a notably thicker, more viscous consistency than other composite resins evaluated in this study. Because the proximal PVS matrixes, although made of a relatively rigid material, were not very rigidly attached, a placement of high-consistency material into the cavity preparation may, on occasion, have displaced them. Any displacement could result in slight overfilling of some cavities, although this was not noted upon inspection of the specimens. The other materials were of considerably lower consistency, so matrix distortion and overfilling would not have been as likely in other groups. Increasing the flow of higher-viscosity materials via warming techniques might help to eliminate this potential but would likely introduce other variables.

Another contributor to the higher standard deviation in groups FSUI and TEBF might be a higher incidence of debonding. Kim et al. found a strong correlation between measured polymerization shrinkage stress values and debonding incidence with both bulk-fill and conventional composite resins.⁶³ Higher shrinkage stress values have been measured for Filtek Supreme Ultra and Tetric EvoCeram Bulk Fill than for the other materials tested,^{30,63} so a higher incidence of debonding might be expected, contributing to a wider range of strain values than in the other groups. While Filtek Supreme Ultra was used also in group SDR/FSU as a veneering material, it was largely bonded to enamel, lowering the risk of debonding.

Interpretation of the data here presented should be made with caution since *In vitro* studies are generally not good predictors of clinical performance. Only a handful of bulk-fill composite resins were evaluated in this study and these results cannot be extrapolated for other materials in the same category. Ultimately, clinical performance is determined by several dentist, material, patient and tooth-related factors and only long-term clinical trials can reveal how materials will perform over time.

5 | CONCLUSIONS

Within the limitations of this *in vitro* study, the following conclusions may be made:

- Bulk-fill composite resins resulted in lower cuspal strain compared to conventional composite resin placed incrementally.
- The magnitude of cuspal strain in the bulk-fill groups was product dependent.

Acknowledgments

This study was funded by a research project grant from the Dora Lee and John C. Brauer Dental Research Fund, presented by the Dental Foundation of North Carolina and the Office of the Associate Dean for Research at the School of Dentistry, University of North Carolina at Chapel Hill. The authors would like to thank Dr. Ceib Phillips for her help with the statistical analysis. The authors would also like to thank Brasseler USA, Ivoclar Vivadent, 3M-ESPE, Kerr Corporation and Dentsply for providing the materials for this study.

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FIGURE 1.
Location of the strain gage in relation to the pulpal floor

FIGURE 2.

A representative data output curve for specimens in the study, showing a clear, stepwise increase in cuspal strain for each increment placed and photopolymerized in all of the groups

FIGURE 3.

Means ($\pm$ SD) for combined strain. Groups indicated by the same letter are not significantly different

FIGURE 4.

Data output from a specimen in group SDR/FSU, illustrating low levels of cuspal strain during photopolymerization of the low-viscosity bulk-fill composite resin.

Photopolymerization of the veneering composite resin was initiated around 2300 and 3300 units for the buccal and lingual cusps, respectively, illustrated by a steep rise in cuspal strain on both sides

FIGURE 5.

Data output from a specimen in group FSUB, illustrating a fracture occurring in the lingual cusp occurring after 3000 units. The buccal cusp remained intact

TABLE 1

Restorative materials used in the study

Product	Type	Manufacturer	Lot no.	Matrix composition	Filler type	Filler size (µm)	Filler load (bw%)
OptiBond XTR	2-step Self-etch Adhesive	Kerr Corporation, Orange, CA, USA	4925697 4989266	Primer: acetone, ethyl alcohol, HEMA. Adhesive: ethyl alcohol, alkyl dimethacrylate resins, filler particles	Barium aluminoborosilicate glass, fumed silica (silicon dioxide), sodium hexafluorosilicate	-	15
Filtek Supreme Ultra	Nanofilled composite resin	3M ESPE, St. Paul, MN, USA	N529636	<i>Bis</i> -GMA, UDMA, TEGDMA, <i>Bis</i> -EMA(6),	Ytterbium trifluoride, Nonaggregated silica, nonaggregated zirconia, Zirconia/silica clusters	0.004–0.02 (0.6–20 clusters)	78.5
SonicFill	High viscosity bulk-fill composite resin	Kerr Corporation, Orange, CA, USA	4948133 5021080	TMSPMA, EBPADMA, bisphenol-A- <i>bis</i> -(2-hydroxy-3-methacryloxypropyl) ether, TEGDMA	Glass, oxide, chemicals, silicon dioxide	0.05–4	83.5
SureFil SDR flow	Low-viscosity bulk-fill composite resin	Dentsply Caulk, Milford, DE, USA	131022	Modified UDMA, EBPADMA, TEGDMA	Ba-Al-F-B-Si glass, SR-F-Si glass	1–10 (4.2 average)	68
Tetric EvoCeram Bulk Fill	High viscosity bulk-fill composite resin	Ivoclar Vivadent AG, Schaan, Liechtenstein	S21840	<i>Bis</i> -GMA, <i>Bis</i> -EMA, UDMA	Ba-glass, YbF ₃ , mixed oxide, pre-polymerized filler	0.16–0.7	79–81

HEMA: 2-hydroxyethyl methacrylate, *Bis*-GMA: bisphenol A glycidyl methacrylate, UDMA: urethane dimethacrylate, TEGDMA: triethylene glycol dimethacrylate, *Bis*-EMA: ethoxylated bisphenol A dimethacrylate, TMSPMA: 3-trimethoxysilylpropylmethacrylate, EBPADMA: ethoxylated bisphenol-A-dimethacrylate.

TABLE 2

Mean strain values per group

Group	Shade	Buccal (SD)	Lingual (SD)	Combined (SD)
FSUI Filtek Supreme Ultra, incremental	A2B	351.0 (75.5) ^A	372.0 (55.9) ^A	723.0 (102.8) ^A
TEBF Tetric EvoCeram Bulk Fill	IVA	284.1 (86.5) ^{AB}	320.4 (70.1) ^{AB}	604.5 (127.1) ^B
SF SonicFill	A2	262.8 (42.8) ^B	256.3 (55.0) ^B	519.1 (80.2) ^B
SDR-FSU Surefil SDR flow veneered with Filtek Supreme Ultra	U/A2B	236.2 (44.1) ^B	261.2 (31.5) ^B	497.4 (67.6) ^B
FSUB^a Filtek Supreme Ultra, bulk	A2B	330.2 (122.6)	599.0 (511.4)	929.2 (571.9)

Groups marked with the same letter are not significantly different.

Units are in microstrain ($\mu\epsilon$).^aExcluded from statistical analysis due to the high mean and standard deviation.