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Cuspal Deflection in Premolar Teeth Restored with Bulk-Fill Resin-Based Composite Materials

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Clinical Relevance

Polymerization shrinkage of conventional resin-based composites can cause cuspal deflection and be associated with enamel cracking, cusp or tooth fracture, and changes in occlusion. High-viscosity bulk-fill resin composites may produce less cuspal deflection than a conventional incrementally placed resin composite.

SUMMARY

The present study investigated the effect of three high-viscosity bulk-fill resin-based composite materials on cuspal deflection in natural teeth. Thirty-two sound maxillary premolar teeth with large slot mesio-occlusal-distal cavities were distributed into four groups (n=8). Three groups were restored with bulk-fill resin composite materials (Tetric EvoCeram Bulk Fill, Ivoclar Vivadent, Schaan, Liechtenstein; x-tra fil, VOCO, Cuxhaven, Germany; and SonicFill, Kerr, Orange, CA, USA) in a single 4-mm increment. The conventional composite group, Filtek Z100 (3M ESPE, St Paul, MN, USA), was used to restore the cavities in 2-mm increments. Cusp deflection was recorded postirradiation using a Nikon measurescope UM-2 (Nikon, Tokyo, Japan) by measuring the changes in the bucco-palatal widths of the teeth at five minutes, 24 hours, and 48 hours after completion of the restorations. Cuspal deflection was significantly higher in the conventional composite than in the Tetric EvoCeram Bulk Fill (p=0.0031), x-tra fil (p=0.0029), and SonicFill Bulk (p=0.0002) groups. There were no significant differences in cuspal deflection among the three bulk-fill materials (all $p<0.05$). In conclusion, all the investigated bulk-fill resin composites exhibited cuspal deflection values that were smaller than those associated with a conventional incrementally placed resin composite.

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INTRODUCTION

The esthetic and mechanical properties of composite resin have improved over the years. Yet polymerization shrinkage stress remains one of the concerns believed to compromise the clinical performance of resin-based composite (RBC) materials.[1,2] During polymerization, monomer molecules convert into a polymer network, resulting in a decrease in the distance between monomer molecules as covalent bond formation occurs. This reduction in overall free volume produces a densely cross-linked polymer and results in volumetric shrinkage.[3,4] If this shrinkage occurs when the resin composite materials are inside a cavity preparation and bonded to cavity surfaces, mechanical stresses develop and transmit to the tooth-restoration interface.[5,6]

Methacrylate-based composite materials experience 2% to 5% volumetric shrinkage during polymerization.[2] Polymerization shrinkage is potentially associated with at least two clinical problems. First, if the stress created by polymerization shrinkage exceeds the bond strength of the resin to the tooth, the resin may detach from the tooth structure, leading to marginal microleakage.[7] This failure at the composite-tooth interface may result in postoperative sensitivity and secondary caries.[1,2,8] Second, if the strength of adhesion between the cavity surface and the restorative material exceeds the shrinkage stresses, no detachment occurs, but the restoration maintains internal stresses that pull the cusps together, reducing the intercuspal distance and leading to cuspal deflection. Cuspal deflection can cause changes in occlusion, enamel cracks, and tooth fracture.[2,7,8]

Several techniques have been published in the dental literature for evaluating cuspal deflection in mesio-occlusal-distal (MOD) cavities with resin composite restorations, including strain gauges,[9-11] microscopy,[12] linear variable differential transformers,[13] and flexible ribbons.[14] These techniques have recorded up to 50 μm of mean cuspal deflection. The variations in the cuspal deflection reported are largely due to sensors being used on various positions on the cusps and nonstandardized MOD cavity preparations in teeth of nonstandardized tooth sizes.[9]

The degree of cuspal deflection is affected by many factors, such as the shape and size of the cavity, the amount of polymerization shrinkage, polymerization kinetics, Young's modulus of the composite resin, and placement technique.[8]

Numerous techniques have been used clinically to minimize the impact of shrinkage stresses produced by resin composite restorations, with limited success. Examples include the use of flowable resin liners, indirect resin restorations, control of curing light intensity, and incremental placement techniques, in which the composite materials are placed in 2-mm-thick increments. This last method is advocated to ensure adequate light transmission and to reduce the configuration factor (the ratio between bonded and unbonded restoration surfaces) during polymerization, thereby reducing polymerization stress transfer to surrounding tooth structure.[2,15,16] Although the incremental placement technique has been recommended by many clinicians, the value of reducing polymerization shrinkage stresses with this technique has been questioned in some studies.[17,18] Furthermore, the incremental technique requires increased time for placement and curing of each increment.[9]

Recently marketed bulk-fill resin composite materials have been reported to have lower polymerization shrinkage stresses than do conventional resin-based composites,[6,19,20] consequently reducing cuspal deflection.[21] In addition, these materials can be placed in a single 4-mm increment and still have adequate light polymerization at the depth of the restoration. This simplifies the clinical procedure.[22] An added benefit would be the reduced risk of incorporating air bubbles or contamination between increments.[23]

The primary chemical composition of bulk-fill resin composite materials is similar to that of other methacrylate-based resin composites.[24] Some studies[25,26] mention that the increased depth of cure of bulk-fill composite materials is regulated mainly by increasing the translucency of the material. This translucency is achieved by reducing the concentration of fillers (filler content and translucency correlate linearly)[27] or by minimizing the difference in the refractive indices of the resin matrix and the filler particles.[28,29] In addition, the incorporation of a potent initiator system enhances the polymerization.[26] These materials are classified according to their rheological properties as flowable base materials that require a 2-mm overlay of posterior hybrid composite or as high-viscosity restorative composites that do not require an additional overlying occlusal layer.[19]

There is limited information about the amount of cuspal deflection that occurs from the placement of these bulk-fill materials. Therefore, the objective of this study was to compare cuspal deflection following placement of these newly developed bulk-fill composite materials in a single increment and placement of a conventional incrementally placed composite material. The null hypothesis was that the mean cuspal deflection seen in teeth restored in a single increment with bulk-fill would not be statistically

Table 1: *The Materials Used in this Study*

RBCs	Manufacturer Color, Lot No.	Resin Matrix	Filler	Filler Wt%/Vol%	Volumetric Shrinkage, %	Instruction for Use
Bulk-Fill Resin-based Composites						
Tetric EvoCeram Bulk Fill nanohybrid	Ivoclar Vivadent, (Schaan, Liechtenstein), IVA, T29056	Bis-GMA, UDMA, Bis-EMA	Barium-aluminum-silica glass, prepolymer filler (monomer, glass filler, ytterbium fluoride), spherical mixed oxide	79-81/60-61	1.7	4-mm increment, cure for 10 s. Additional curing from buccal and palatal aspect for proximal resin after removing the matrix
x-tra fil hybrid	VOCO (Cuxhaven, Germany), universal 1445489	Bis-GMA, UDMA, TEGDMA, Bis-EMA	Inorganic fillers	86/70.1	1.7	4-mm increment, cure for 20 s. Additional curing from buccal and palatal aspect for proximal resin after removing the matrix
SonicFill nanohybrid	Kerr (Orange, CA, USA), A2, 5299375	Bis-GMA, TEGDMA, EBPDMA, UDMA	SiO_2, glass, oxide	83.5/67	1.6	4-mm increment, cure for 20 s. Additional curing from buccal and palatal aspect for proximal resin after removing the matrix
Traditional universal composite (increments)						
Filtek Z100	3M, ESPE (St Paul, MN, USA), A2, N595515	Bis-GMA, TEGDMA	Silica/zirconia	84.5/66	2.4	2-mm increment, cure for 20 s. Additional curing from buccal and palatal aspect for proximal resin after removing the matrix

Abbreviations: Bis-EMA, bisphenol A polyethylene glycol diether dimethacrylate; Bis-GMA, bisphenol A and glycidyl methacrylate; EBPDMA, ethoxylated bisphenol A–dimethacrylate; RBC, resin-based composite; TEGDMA, triethyleneglycol dimethacrylate; UDMA, urethane dimethacrylate.

different than the mean observed in teeth restored with a traditional incrementally placed resin composite.

METHODS AND MATERIALS

Three high-viscosity bulk-fill resin-based composite materials and one traditional universal composite were included in this study (Table 1). Thirty-two extracted maxillary premolar teeth free from caries, defects, or cracks and received in compliance with local human subjects criteria were used in this *in vitro* study. The selected teeth were cleaned with a hand scaler and then fixed into a cube-shaped mold with acrylic base plate material (Bosworth, Skokie, IL, USA) extending 2 mm cervical to the cemento-enamel junction to simulate the position of the tooth in the alveolar bone and to prevent the reinforcement of the crown by the base. The maximum bucco-palatal width (BPW) for each tooth was recorded with a micrometer screw gauge (Moore and Wright, Sheffield, UK) that was accurate to 10 μm. A mean of three measurements per tooth was used to distribute the specimens into four groups (n=8) so that the BPW mean between groups varied by less than 5%. Any tooth that was 5% larger or smaller than the overall mean was excluded from the study. This minimized variation in the buccal-lingual dimension of the cavity preparation.

The repeated measurements of BPW were standardized using an innovative approach that enhanced the ability to determine the amount of deflection at the cusp tip. In summary, small cylinders of flowable composite (Filtek Supreme Ultra, 3M ESPE, St Paul, MN, USA) were constructed, coated with nail polish (Sally Hansen, NY, NY, USA) to minimize water sorption, and attached on both buccal and palatal cusp tips. Then a rhinestone was glued to the upper flat surface of each cylinder to be used as a reference point (Figure 1). Rhinestones have many facets that meet to form sharp line and point angles. Two rhinestone point angles (one on the buccal cusp and one on the palatal cusp) were used as fixed reference points for measurement of the linear intercuspal distance. The mean of three

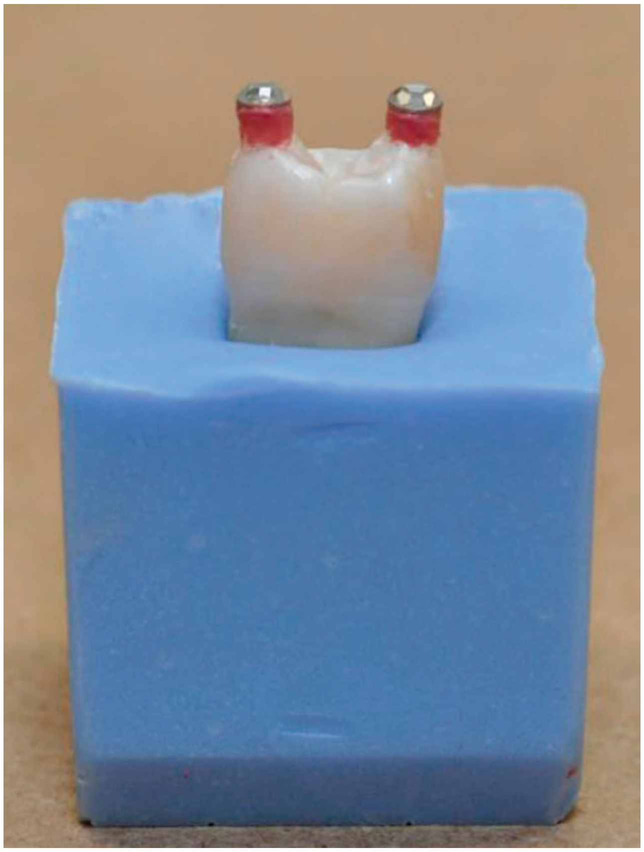

Figure 1. *Tooth with cylindrical composite and rhinestone.*

readings of the intercuspal width was recorded for each maxillary premolar tooth, as described below.

Large slot MOD cavities were prepared on the teeth in order to weaken tooth structure and favor cuspal deflection. The mounted teeth and a high-speed contra-angle air-turbine handpiece were positioned in a dental surveyor (J.M. Ney, Hartford, CT, USA) to ensure proper angulation during tooth preparation. All the teeth were prepared with a straight fissure carbide bur with a rounded end (#1158, SS White, Lakewood, NJ, USA) using a high-speed handpiece with air/water spray. The bur was changed after every five cavity preparations. The width of prepared cavities was two-thirds of the BPW of the tooth. An extrafine Sharpie permanent marker (Sanford Manufacturing Co, Oak Brook, IL, USA) was used on the tooth structure to guide the cavity preparation in the center of the tooth. The cavity depth was 4 mm from the occlusal cavosurface margin to the pulpal floor, and all margins were in enamel. The buccal and lingual walls were prepared to be parallel. The cavities were prepared so that the pulpal floor and mesial and distal gingival walls were at the same level (there was no step going from the pulpal floor to the gingival wall) in order to reduce preparation variation. Any tooth with pulp exposure was excluded from the study. All cavosurface margins were prepared without beveling.[2]

A Tofflemire matrix band was shaped and held snugly in place around the tooth being restored by tightening the retainer to the point at which resistance was initially detected. No further tightening of the matrix was done. A total-etch technique with 37.5% phosphoric acid (Kerr Gel Etchant, Kerr, Orange, CA, USA) was used. The phosphoric acid was applied for 15 seconds and then rinsed with water for 15 seconds. After gentle air-drying with canned air (Whoosh-Duster, Thomas Scientific, Swedesboro, NJ, USA) for one second, a moist dentin surface was maintained by blotting excess moisture from the dentin with a cotton pellet. Two coats of adhesive (OptiBond Solo Plus, Kerr) were actively applied for 15 seconds with a saturated brush tip to the enamel and dentin, until the surface appeared glossy. A gentle stream of compressed canned air was applied for three seconds. Then the adhesive was light-cured for 20 seconds with a visible light unit (DEMI LED light curing system, Kerr) having an irradiance of 1460 mW/cm^2, as measured using a MARC Resin Calibrator (BlueLight Analytics, Halifax, NS, Canada). The light irradiance was monitored after every eight specimens.

Three bulk-fill composites (Tetric EvoCeram Bulk Fill, Ivoclar Vivadent, Schaan, Liechtenstein; x-tra fil, VOCO, Cuxhaven, Germany; and SonicFill, Kerr) and one conventional composite (Filtek Z100, 3M ESPE) were used. For each specimen in the bulk-fill groups, a single bulk-fill RBC increment was placed and irradiated for 20 seconds with the LED curing wand touching the inclines of the cusps of the tooth (mesial and distal to the bonded reference cylinders) to achieve maximum curing depth and to maintain fixed distance. SonicFill was placed with sonic energy using an oscillating handpiece, as recommended by the manufacturer. Tetric EvoCeram Bulk Fill and x-tra fil were placed with plastic hand instruments in order to insure proper packing of materials inside the cavity preparation. The conventional composite group was restored incrementally with Filtek Z100 in three triangular-shaped increments with no more than 2-mm thickness for each increment, and each increment was irradiated for 20 seconds with the LED curing wand touching the inclines of the cusps of the tooth, as described above. After that the matrix band and retainer were removed before measurement under the microscope.

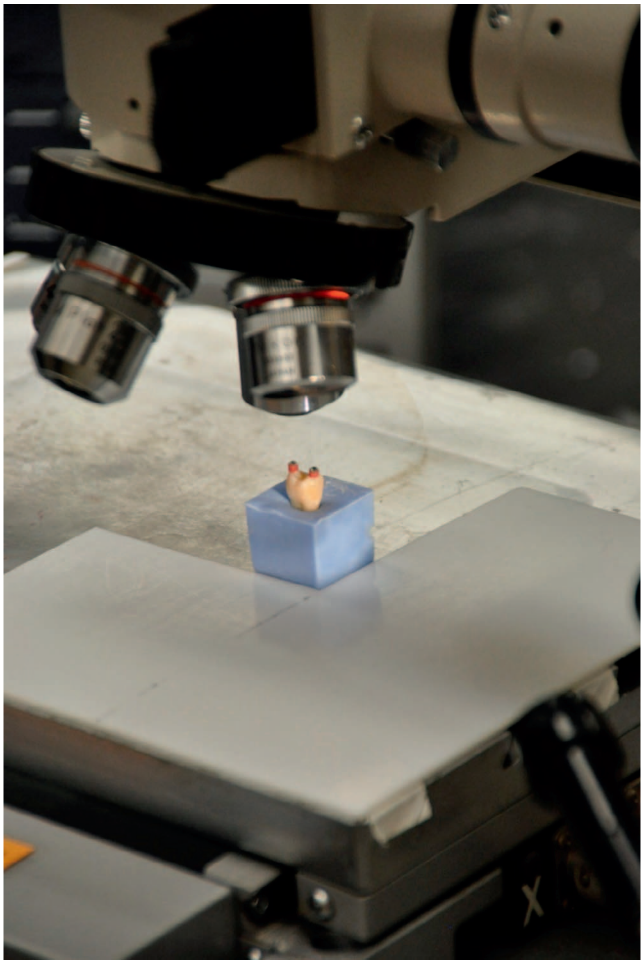

Figure 2. *A custom polymethyl methacrylate (PMMA) sheet and the sample under the microscope.*

Cuspal Deflection Measurements

A light microscope (Nikon Measurescope UM-2, Nikon, Tokyo, Japan) with 0.001-mm accuracy and a modified microscope stage was used in order to determine the measurements of the cuspal deflection of the teeth. A custom-made polymethyl methacrylate (PMMA) sheet was used to standardize and maintain the horizontal orientation for each specimen during the repeated measurements (Figure 2). Baseline readings were recorded by measuring the linear distance between two point angles on the reference rhinestones prior to tooth preparation. Then the linear measurements were obtained after restoration placement, after five minutes, 24 hours, and 48 hours. The baseline records were subtracted from the all the subsequent measurements to obtain the changes in the positions of the cusps. The mean of three intercuspal width readings was recorded for each tooth at each time point.[7] The teeth were stored in double-distilled deionized water at room temperature (23°C±1°C). All the procedures were performed by the same examiner. Reproducibility of measurements was confirmed by a second evaluator. The entire procedure was performed for four teeth from each group at a time.

Table 2: *Mean (Standard Error, both in μm) for Cuspal Deflection for the Investigated Materials*[a]

Material	5 min	24 h	48 h
Tetric EvoCeram Bulk Fill	28 (2) Ba	19 (3) Bb	15 (3) Bc
x-tra fil	29 (3) Ba	18 (3) Bb	14 (3) Bc
SonicFill	24 (3) Ba	16 (2) Bb	12 (2) Bc
Conventional composite	44 (3) Aa	27 (1) Ab	23 (1) Ac

[a] *Different uppercase letters represent significant differences in cuspal deflection between various resin composites within each time point. Different lowercase letters represent significant differences in cuspal deflection within each type of resin composite at various time points.*

Statistical Methods

The effects of the composite material and time on cuspal deflection were analyzed using mixed-model analysis of variance, which included fixed effect terms for material, time, and their interaction and a repeated-measures effect to account for correlations among the times, as well as the different variances at each time. Pairwise comparisons between groups were made using the Tukey method to adjust for multiple comparisons. An overall 5% significance level was used. With a sample size of eight specimens per group, the study had 80% power to detect a difference of 5 μm between any two groups.

RESULTS

Mean (±standard error) postrestoration cuspal deflection values are illustrated in Table 2 and Figure 3. Overall, cuspal deflection was significantly greater in the conventional composite group than in the Tetric EvoCeram Bulk Fill (p=0.0031), x-tra fil (p=0.0029), and SonicFill (p=0.0002) groups. There were no significant differences in cuspal deflection among Tetric EvoCeram Bulk Fill, x-tra fil, and SonicFill composites. Cuspal deflection was significantly greater at five minutes than at 24 hours ($p<0.0001$) or 48 hours ($p<0.0001$) and significantly greater at 24 hours than at 48 hours ($p<0.001$) for all the tested materials. At all time points, conventional composite had significantly greater cuspal deflection than did the bulk-fill materials (all $p<0.05$).

DISCUSSION

This study investigated the effect of three types of high-viscosity bulk-fill composites on cuspal deflec-

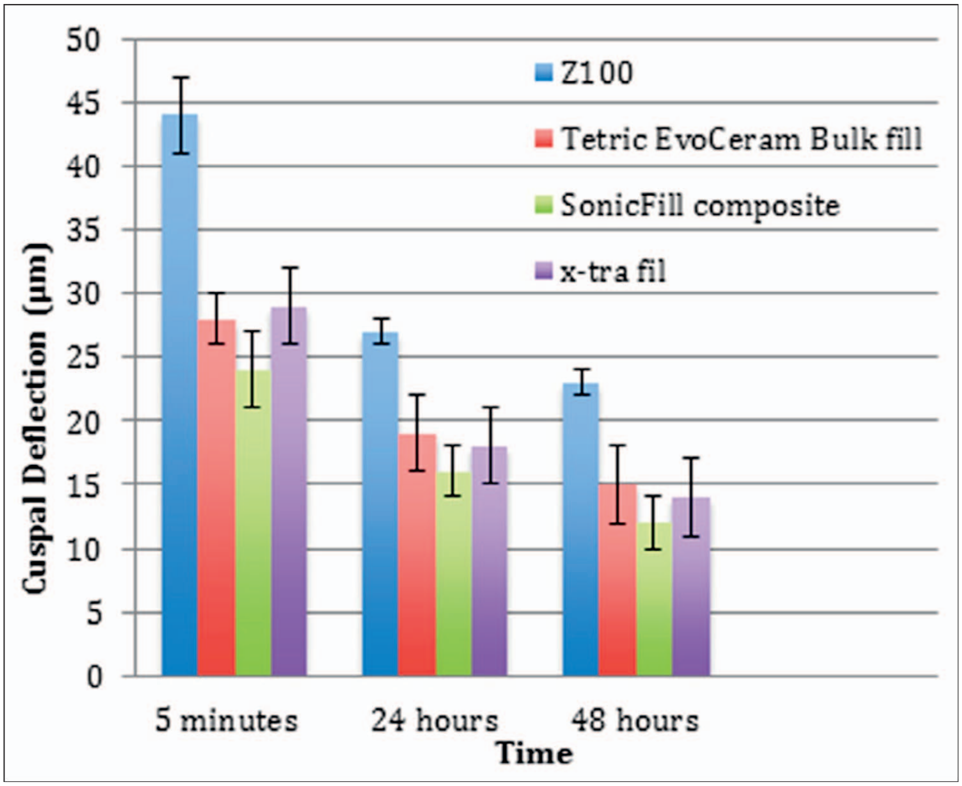

Figure 3. *Mean (standard error) (µm) of cuspal deflection for the investigated materials.*

tion of maxillary premolar teeth compared to an incrementally placed composite. Inward cuspal movement or cuspal deflection represents deformation of tooth structure caused by the effect of polymerization shrinkage stresses.[14,30] In the current study, the mean cuspal deflection varied from 24 µm to 44 µm. Moreover, the inward cuspal movement caused by polymerization shrinkage stresses was observed in each cavity filled with resin composite, as reported by a number of studies,[9,10,30] which means there is an established adhesion at the tooth-restoration interface.

In the present work, a large slot MOD cavity preparation was performed on maxillary premolar teeth in order to weaken tooth structure and favor cuspal deflection. As Gonzalez Lopez and others[31] mentioned, the degree of cuspal deflection is directly related to loss of tooth structure. In addition, as the cavity size increases, more RBC material is required, producing greater shrinkage forces and consequently more cuspal deflection.[31] Although the value of cuspal deflection might theoretically be greater if the baseline measurements were recorded after cavity preparation, it has been reported[7] that there was no significant difference in the cuspal deflection before or after cavity preparation. In addition, reestablishing pre-preparation occlusal relationships should be a goal of restorative treatment. For these reasons, the baseline measurements of the present study were recorded before tooth preparation.[7,32]

Measurement of cuspal deflection using natural teeth can produce many discrepancies among specimens due to the variations in the tooth size, anatomy, and modulus of elasticity. Therefore, to minimize variation among specimens and cavity preparations, our methodology employed the following procedures: 1) specimens were selected, measured, ranked in size, and assigned to treatment groups so that the mean BPWs of all tested groups varied by $\leq$5%; 2) MOD preparations were accomplished so that the pulpal floor and the gingival walls of the mesial and distal boxes were at the same level; and 3) a dental surveyor was utilized during all cavity preparations to facilitate proper alignment of the cavity walls. Moreover, room temperature was selected to allow better comparison with existing studies.[30,33] Future efforts evaluating the impact of 37°C may provide more clinically relevant results.

Our null hypothesis proposed that the mean cuspal deflection caused by bulk-fill resin composites using a single increment would not be statistically different than that of a composite placed in three increments. The study results did not support this hypothesis. Cuspal deflection was significantly greater with the incrementally placed composite than with each of the three bulk-fill composites, which were not different from each other.

The reduced polymerization shrinkage stresses and subsequent cuspal deformation of bulk-fill resin composite materials could be attributed to optimized resin matrix, initiator chemistry, and filler technology.[34] Both filler technology and monomer content affect the polymerization shrinkage stresses. The incrementally placed (control) composite used in our study contains a bisphenol A–glycidyl methacrylate – triethyleneglycol dimethacrylate (TEGDMA) resin-matrix. TEGDMA-rich matrices create a greater degree of cross-linking and a greater amount of polymerization shrinkage.[35,36] The bulk-fill composites, which incorporate urethane dimethacrylate (UDMA) and bisphenol A polyethylene glycol diether dimethacrylate (Bis-EMA), with lower TEGDMA content, produced less polymerization shrinkage and, consequently, less cuspal deflection. This is in accordance with some studies[10,37] that reported reduced contraction stresses among materials containing UDMA and Bis-EMA. Moreover, the positive correlation between filler load and modulus of elasticity of resin composite materials has been confirmed.[20,24,38] A lower filler content of resin composite is generally associated with a lower modulus of elasticity.[39] It has been reported[19] that the lower filler load, and subsequently the lower modulus of elasticity, is considered another contributing factor to the reduced shrinkage stresses of bulk-fill composite materials. This fact might be one of the causative factors in the reduced polymerization shrinkage stresses of Tetric EvoCeram and SonicFill Bulk Fill, which have elastic moduli measuring around 8.5 and 10 GPa,[40] respectively. The elastic modulus of Z100 resin composite is approximately 21 GPa[41] and, consistent with the theory, demonstrated higher cuspal deflection.

On the other hand, Kim and others[42] reported that bulk-fill composite and conventional composite exhibited similar polymerization shrinkage stress. This could be attributed to a different methodological approach that was used to assess the polymerization shrinkage stresses.

Another potential factor that would contribute to reduced polymerization shrinkage stress and reduced cuspal movement is a lower degree of polymerization of the bulk-fill material. Depth of cure for the restorations placed in this study was not measured and is, therefore, a limitation that should be considered when analyzing the results.

The rationale for starting measurements after five minutes was that the majority of the cuspal movement was reported to occur within five minutes after polymerization.[19,30] Although at five minutes there were no statistically significant differences among the bulk-fill materials, SonicFill exhibited the lowest numeric cuspal deflection. Additionally, the unique advantage of the SonicFill material is its ability to behave like flowable composite during placement, providing better adaptation to cavity walls, when compared to traditional resin composite.[43] In addition, optimizing the filler sizes in SonicFill and x-tra fil around 20 μm[39] might be another contributing factor to the lower polymerization contraction stresses when compared to that of the Z100 resin composite, which contains 0.01-3.5-μm average filler size. Likewise, Abe and others[41] suggested that the smaller filler size causes more polymerization shrinkage stress. In agreement with the present study, Do and others[33] reported that the cuspal deflection of Tetric EvoCeram Bulk Fill was less when compared with that of flowable bulk-fill and conventional composites. Although they did not find a statistically significant difference, the authors mentioned that the results may have been significant if they had used a larger sample size.[33] This also agrees with the work of Zorzin and others,[34] who found that Tetric EvoCeram Bulk Fill produced less polymerization shrinkage than conventional composite. The manufacturer claims that the reduced polymerization shrinkage stresses of Tetric EvoCeram Bulk Fill are achieved by the incorporation of a stress reliever, which keeps the chemical cushion between filler particles intact; this cushion helps to improve the elasticity of the materials and reduces polymerization shrinkage.[42]

Cuspal deflection was significantly greater at five minutes than at 24 hours or 48 hours, and it was significantly greater at 24 hours than at 48 hours for all the tested materials. Although most of the polymerization shrinkage and subsequent cuspal deflection occurs within the first five minutes, the aim of measuring the position of the cusps at 24 and 48 hours was to determine if there was a cuspal relaxation and if it would return to its original position. All specimens tended to recover to their original dimensions, although complete recovery was not achieved during the 48-hour period. This is in agreement with the findings of some other studies,[30,31] whose authors mentioned that the recovery begins after 10 minutes in hydrated teeth and never returns to the original position in large-or medium-sized cavities. Cusp relaxation or recovery of the cusps is likely to occur as a result of one or more of the following: water sorption, stress relaxation, tooth elasticity, or tooth-restoration gap formation.[30]

CONCLUSIONS

Within the limits of this *in vitro* study,

- Cuspal deflection was less in teeth restored with bulk-fill resin composites using a single increment compared to teeth filled with a conventional composite placed in three increments;
- Different high-viscosity bulk-fill resin composites produced similar amounts of cuspal deflection; and
- Complete recovery of the cusps to their original positions did not occur during the 48-hour observation period.

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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 Indiana University. The approval code for this study is IRB 1501282185.

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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