CUSPAL DEFLECTION IN PREMOLAR TEETH RESTORED WITH BULK-FILL RESIN-BASED COMPOSITE MATERIALS

by

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DEDICATION

All the praises to my God whose grace sustains.

This thesis is dedicated to all the people who support me in my life:

To the greatest parents ever, Muftah and Hamida, for their prayers, support, and unconditional love;

To my lovely sisters and brothers, Wafa, Huda, Ibrahim, and Mohamed, for their love and encouragement during my studies;

To my friends, who were like angels around me, especially Nasreen.

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INTRODUCTION

Increasing interest in esthetic restorations and rising public concern regarding the safety of dental amalgam have produced an increase in the demand for composite resin for posterior restorations.[1] Although the esthetic and mechanical properties of the composite resin have been improved over the years, the polymerization shrinkage stress remains one of the concerns that contribute to the clinical drawbacks of the resin-based composite (RBC) materials.[2,3]

Methacrylate-based composite materials produce about 2-percent to 5-percent volumetric shrinkage during polymerization.[3] Polymerization shrinkage can be associated with at least two clinical problems. The first is marginal microleakage, which results from the residual stress from polymerization shrinkage exceeding the bond strength of the resin to the tooth, [1] which may cause gap formation and the composite-tooth interface fails. This may cause post-operative sensitivity and secondary caries.[2,3,4] Secondly, if the 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 width and leading to cuspal deflection. Cuspal deflection can cause changes in occlusion, enamel cracks and tooth fracture.[1,3,4]

Several techniques have been published in the dental literature for evaluating cuspal deflection in mesio-occlusal-distal (MOD) cavities with resin composite restorations, including photography, microscopy with cuspal indices alignment, strain gauges, linear variable differential transformers, interferometry, profilometry, and digital-image correlation. These techniques have recorded up to 50 μm of mean cuspal deflections. The variations in the cuspal deflection records are due to non-standardized MOD cavity preparations in non-standardized tooth sizes.[5]

The level 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, placement technique, and the use of a flowable liner.[4]

Numerous techniques have been used clinically in order to minimize the shrinkage stresses produced by resin composite restorations, but with limited success. Examples are the use of flowable resin liners, indirect resin restorations, control of curing light intensity, and incremental placement techniques. This last method is advocated to reduce the configuration factor (the ratio between bonded and unbonded surfaces), thus reducing the polymerization stresses and the cuspal deflection.[3,6] In contrast, Abbas et al. in their study found that the incremental placement technique produces greater cuspal deflection than a single increment technique.[7] Lazarchik et al. mentioned that the increment thickness of 2 mm is considered adequate for appropriate light transmission and subsequent polymerization.[8] Furthermore, the incremental technique is very time-consuming, as time is required for placement and curing of each increment.[5] Another approach to reduce the polymerization shrinkage is application of elastic, flowable RBC as an intermediate layer, which can absorb shrinkage stresses produced by the subsequent layer of RBCs with higher modulus of elasticity, thereby reducing the stress at the tooth-filling interface,[9] consequently decreasing the cuspal deflection.[10] Shabayek et al. reported that silorane-based composite materials exhibited less polymerization shrinkage, resulting in reduced cuspal deflection.[11]

New materials that have been recently marketed are called bulk-fill resin composite materials. The manufacturers claim that these materials produce less polymerization shrinkage when compared with traditional composites,[12] consequently reducing the cuspal deflection. In addition, the claimed advantage of these newly innovated materials is that they can be placed in a single 4-mm increment and still have adequate light polymerization at the depth of the material. This would simplify and speed up the clinical procedure[13] and would reduce the risk of incorporating air bubbles or contamination between the increments. Traditional composite materials have to be placed in just 2-mm increments to achieve proper light transmission and subsequent polymerization.[8]

There is no great difference in the chemical composition of bulk-fill composite materials when compared with the regular nanohybrid and microhybrid resin based composites.[14] Van End et al. mentioned that the increased depth of cure of bulk-fill composite materials is regulated mainly by improving the translucency of the material.[15,16] This translucency was achieved by reducing the amount of fillers as the filler contents and the translucency correlate linearly.[17] Another way to improve the materials' translucency is by the difference in the refractive indices between the resin matrix and the filler particles.[18] In other words, a similar refractive index of the components of the resin composite materials improves the translucency of the materials.[19] In addition, the ability of the bulk-fill materials to be cured up to 4 mm in thickness is also achieved by the incorporation of a potent initiator system.[16] These materials are classified according to their rheological properties either as a flowable base material to be covered with 2 mm of posterior hybrid composite, or as a final restorative composite that does not require an overlying occlusal layer.[12]

Insufficient literature is available regarding the cuspal deflection of these bulk-fill materials. Therefore, the objective of this study was to compare cuspal deflection in these newly developed bulk-fill composite materials and the conventional composite materials that are currently used by dental clinicians.

HYPOTHESES

Null Hypotheses

The mean cuspal deflection seen with bulk-fill composites will not be statistically different than the mean observed with a traditional composite.

Alternative Hypotheses

The mean cuspal deflection seen with bulk-fill composites will be statistically less than the mean observed with a traditional composite.

REVIEW OF LITERATURE

Resin-based composite materials were first introduced on the market in the 1960s.[20] These materials, which reproduce the function and appearance of the natural teeth, are considered one of the successful biomaterials that are utilized in the dental field.[21] The demand for these esthetic restorations, which has increased dramatically since the last decade,[22] coupled with the widespread clinical acceptance of using the composite materials by dental practitioners are considered main driving factors for continuous improvements on the restorative resin composites. Stein et al. reported that composite is used in 95 percent of anterior teeth and 50 percent of posterior teeth.[23] While some studies showed an acceptable result for the longevity of direct posterior composite restorations of about 10 years and 17 years,[24,25] others reported a lower survivor rate when compared to amalgam restoration.[26] This popularity of using composite materials as posterior restorations is rising despite concerns regarding marginal leakage, recurrent decay,[24] postoperative sensitivity,[27] cytotoxicity,[28] and technique sensitivity.[29] Many of these shortcomings could affect the lifetime of the restoration.

The ongoing enhancement of composite materials is mainly directed toward improving the components of these materials. Composite materials consist of three main phases: resin, filler, and indistinctive phases. The resin component consists of monomer, which during polymerization converts from monomer to densely packed polymer. The filler phase is responsible for physical properties, radiopacity, and reducing the polymerization shrinkage. The third phase acts like a coupling agent between resin and filler components. The incorporation of modified or new monomer, initiation systems, and filler technologies has considerably improved the physical properties of the composite materials.[21]

POLYMERIZATION SHRINKAGE

Polymerization shrinkage is an inherent property of resin-based composite materials and considered one of the major concerns when placing direct resin-based posterior composite restorations, a factor which could affect the clinical success of dental composite.[12,20] Many studies have been conducted in order to assess and reduce polymerization shrinkage.[30-33]

During polymerization, monomer molecules convert into a polymer network resulting in a decrease in the distance between monomer molecules due to the short covalent bond formation between those molecules. Therefore, reducing the overall free volume within the monomer molecule subsequently results in producing a densely cross-linked polymer and creates volumetric shrinkage.[20,34] In other words, as resin composite materials are light cured, they transform from a viscous phase to a solid phase and subsequent shrinkage develops. If this shrinkage occurs while the resin composite materials are inside the cavity preparation and bonded to cavity surfaces, mechanical stresses develop and transmit to the tooth- restoration interface.[35,36] If polymerization shrinkage stress forces are greater than the bond strength, debonding might occur.[37] Debonding could cause opening in the margins, marginal staining, fluid leakage, postoperative pain, and recurrent decay, all of which can lead to restoration failure. However, if these forces are smaller than the bond strength, no debonding occurs, but the restoration maintains internal stresses that pull the cusps together, reducing the intercuspal distance width and leading to cuspal deflection. Cuspal deformation could cause enamel microcracks, and cusp or tooth fracture.[32,34,38]

The type of resin monomer,[39] gel point,[40] filler technology,[41] elastic modulus of resin composite, techniques of curing,[42] rate of conversion, and C-factor [43] all can affect polymerization shrinkage stresses.[44]

As the polymerization contraction is currently unavoidable[45] several approaches have been investigated thoroughly in order to produce low-shrinkage restorative materials. Most of the changes have focused on the monomer chemistry and filler technology.[44] One of the approaches is modifications on the present successful methacrylate-based system by changing the chemistry of Bowen monomer (Bis-GMA: 2,2-Bis[4-(2-hydroxy-3-methacryloxyproproxy) phenyl] propane) to produce monomer with lower viscosity.[36,46] This alteration could be achieved by incorporating partially aromatic urethane dimethacrylates,[47] hydroxyl free Bis-GMA, aliphatic urethane dimethacrylates, or highly branched methacrylates.[36] These changes have been claimed to reduce the polymerization shrinkage. In addition, ring-opening system polymerization based on siloranes,[48,49] and organically modified ceramics like ormocers[49] were introduced on the market for the same purpose. Also, one method attempted to reduce polymerization shrinkage is to reduce the reactive site per unit volume by increasing filler load. The increased filler content in composites is reported to be a direct cause for the significantly lower polymerization shrinkage. The higher filler load reduces the amount of resin in the composite materials, thus decreasing the polymerization shrinkage.[50]

Another strategy for reducing polymerization shrinkage stresses at the tooth-restoration interface involves the incremental placement of the resin into the cavity preparation. It has been shown that the incremental placement technique reduces the cavity configuration factor (C-factor), which is the ratio between bonded and unbonded surfaces. As the C-factor increases, there is less chance for stress relaxation to occur through the free surfaces; accordingly, more tension develops at the tooth- restoration interface.[43] Incremental placement technique is recommended to reduce the C-factor and subsequent shrinkage, and using this method, the restoration is placed in small increments and allows the material shrinkage to relax through the free surfaces. Although the incremental placement technique has been recommended by many clinicians, the value of reducing polymerization shrinkage by using this technique has been questioned in some studies.[51,52]

Soft-start curing technique[42] and the application of an intermediate layer[53] were introduced to reduce the polymerization contraction stresses. In the soft-start technique, irradiation initiates at low light intensity; therefore, the polymerization reaction progresses more slowly. There will be a delay in the gel point and more time for flow, which reduces polymerization shrinkage at the cavity margin. According to Feilzer et al., the application of an intermediate layer of low elastic modulus materials, for example flowable composite or glass ionomer liner, acts like a cushion to absorb the stresses that are generated from polymerization contraction.[54] However, some studies reported that application of the intermediate layer did not reveal any significant difference.[55,56]

BULK-FILL COMPOSITE MATERIALS

Ongoing research and development of composite materials resulted in improvements in chemical composition and filler reinforcement, which has led to new categories of resin materials.[57] The latest development among composite materials is the advent of bulk-fill composite materials, recently introduced on the market. There is increasing interest in the use of bulk-fill materials among clinicians due to the more simplified technique. However, the lack of information regarding the performance of these novel materials promotes more *in-vitro* studies.[58] It has been claimed that the main advantage of these materials is lower polymerization shrinkage when compared with flowable or conventional resin based composites.[12,36,59] The reduced polymerization shrinkage was achieved by optimizing the resin matrix and the initiator chemistry, as well as the filler technology.[60]

These materials can be placed up to 4-mm thickness in bulk,[57,61-64] thus simplifying clinical procedures and saving the patient's and the dentist's time. In addition, use of bulk-fill composite materials could reduce both the incorporation of voids in the restoration and the contamination that can occur between resin layers. This is different from conventional composites with the current gold standard, the incremental placement technique, in which the material has to be placed in increments of 2-mm thickness or less. This thickness allows for proper light transmission and subsequent adequate polymerization, and for gaining the optimum physical properties of the composite materials. Therefore, the main reason for developing bulk-fill composite materials is to overcome the problems associated with conventional composites by reducing the polymerization shrinkage stresses and minimizing the stressful incremental cavity-filling technique with its associated complications.

Bulk-fill materials are classified according to their viscosity into low- and high-viscosity bulk-fill RBCs. The low-viscosity bulk-fill materials, which have lower filler content (SureFil SDR flow, DENTSPLY Caulk, Milford, DE ; Venus Bulk Fill, Heraeus kulzer, Hanau, Germany; x-tra base, VOCO, Cuxhaven, Germany; Filtek Bulk Fill, 3M ESPE) have lower mechanical properties.[65] Leprince et al. mentioned a direct linear relation between filler loading and mechanical properties.[58] Therefore, the low viscosity bulk fills need to be covered with a 2-mm conventional RBC layer. But, their rheological property allows for better adaptation of the material to the cavity walls. The high viscosity bulk-fill materials (x-tra fil, VOCO, Cuxhaven, Germany; SonicFill, Kerr, Orange, CA; USA; Tetric EvoCeram Bulk Fill, Ivoclar Vivadent Inc., Amherst, NY) can be placed as a direct restoration without capping. The main concern about placing thick layers of composite is whether the resin composite materials could be cured in the deeper layers to gain acceptable biocompatible, mechanical, and physical properties.[44] The idea of “bulk-filling” is not considered a new concept, as it has been investigated many times in the literature.[66-68] One drawback of using conventional composite materials in bulk is that the material cannot be cured adequately in a depth greater than 2 mm.[8] Additionally, numerous complications are associated with polymerization shrinkage and increased gap formation.[2,31]

The chemical composition of bulk-fill materials does not differ from traditional composites. They contain monomers like bisphenol-A and glycidyl methacrylate (Bis-GMA), urethane dimethacrylate (UDMA), and ethoxylated bisphenol-A-dimethacrylate (EBPDMA) in the organic matrix and the filler particles as well. An increased curing depth of 4 mm with adequate polymerization was accomplished by increasing the translucency of materials.[15] Changing the filler technology and matching the refractive indices of filler and resin matrix achieve the improved translucency of bulk-fill materials;

therefore, materials become very conductive to light transmission for proper polymerization.[69] It has been shown that the depth of cure increases as the difference between the refractive indices of resin matrix and filler decreases.[70] Also, incorporation of larger size-fillers increases the amount of transmitted light. As the filler size increases, there will be a decrease in filler surface area, and subsequently, the filler-matrix interface is reduced; as such, the scattering light is reduced and more light is transmitted through the materials, thus achieving an improved cure in depth.[65] Large filler size has been observed in some bulk-fill resins (x-tra fil and x-tra base, VOCO, Cuxhaven, Germany; SureFil SDR flow, DENTSPLY Caulk, Milford, DE, USA; Sonic Fill, Kerr, Orange, CA, USA). In SureFil SDR flow, a patented urethane dimethacrylate with photoactive groups is added to control the polymerization kinetics.[59] In Tetric EvoCeram Bulk Fill (Ivoclar Vivadent Inc., Amherst, NY) the manufacturer claims that an initiator booster called Ivocerin as well as a regular initiator system have been incorporated in the organic matrix to polymerize the materials in depth.[71] Ivocerin has better photo-curing activity than camphorquinone. Apart from that, it can be utilized without the addition of a coinitiator as an amine. For that reason, it is more efficient than the camphorquinone/amine system.[72] No changes in the polymerization initiating system of the other bulk-fill materials have been reported.

The magnitude of polymerization shrinkage is affected by the characteristic of the composite, such as the type of matrix, filler technology, and polymerization kinetics. The increased filler content in high viscosity bulk-fill composites is reported to be a direct cause of the significantly lower polymerization shrinkage. The higher filler load reduces the amount of resin in the composite materials thus decreasing the polymerization shrinkage.[50] In Tetric Evoceram Bulk Fill, the manufacturer states that the incorporation of stress reliever minimizes polymerization.[72] In SureFil SDR flow, the shrinkage property is based on incorporating stress-decreasing resin technology, where a high molecular weight polymerization modulator is added to the resin matrix. This modulator causes a delay of the gel point. Therefore, it allows for greater pregelation phase time (flow phase) and compensates the shrinkage; consequently polymerization shrinkage will be reduced.[59]

Van Ende et al. found that bulk-fill materials provide good bond strength, regardless of the filling technique or cavity configuration, while adhesion fails when conventional composite is used in bulk.[15] It has been shown that bulk-fill materials exhibit creep deformation similar to that demonstrated by conventional composite resins.[69] Creep deformation is considered an important property. It is reported that materials with high creep provide more resistance to mechanical stresses, thus improving the clinical durability of the restorations.[73] Moreover, for flexural strength, it has been reported that bulk-fill materials showed better values than conventional hybrid composites. Based on Llie et al., the modulus of elasticity values indicates that bulk-fill could be classified between conventional and flowable composites.[65] Clinical data are limited; however, van Dijken and Pallesen conducted a three-year clinical study[44] and Manhart et al. performed four years of clinical study [74] with promising results. Nevertheless, results related to these specific bulk-fill materials cannot be generalized to describe all kinds of bulk-fill composites.[75]

CUSPAL DEFLECTION

It has been shown that placing composite materials in class II cavity preparations causes an inward movement of the cusps or cuspal deflection.[76-78] Cusp movement of teeth has been attributed to polymerization contraction stresses.[78] The amount of cuspal deflection is reported in the literature to vary from 15 μm to 50 μm. Most of the cusp deformation occurs within the first 5 minutes. However, complete recovery to the original position has been reported with small cavities, though it has not been shown with large cavities.[78] Flexibility of the tooth increases as the size of the cavity increases. Also, large cavities require a greater bulk of composite material, which means more polymerization shrinkage, thus more cuspal deflection. It is believed that water sorption is considered the main contributing factor of contraction stress relief as the oral fluids diffuse through the composite materials producing gradual expansion.[79,80] Feilzer et al. found that the original shrinkage stress and the hygroscopic expansion are not uniform throughout the restoration.[80]

Cuspal deflection of natural extracted teeth has been investigated thoroughly in the literature.[1,5,78,81,82] Many approaches have been used in order to assess cuspal deformation, including strain gauges,[5,83] photography, microscopes, profilometry, and Direct Current Differential Transformer (DCDT).[84] Difficulties with the methodological approaches have been reported due to many factors that can be addressed in the type of the tooth (molar or premolar), size of the tooth (maximum bucco-palatal width), as well as the restoration placement technique (incremental or bulk).[5] Therefore, the variations in the reported cuspal deflection records were attributed to the non-standardized cavities in non-standardized teeth, because the inward cuspal movements depend on the remaining tooth structure.[5] Measurement of cuspal deflection is considered one of the methods to assess the polymerization shrinkage.[67] As reported by many studies, the cuspal deflection could cause enamel cracks, cusp or tooth facture, and/or alteration in the occlusion.[1,3-5] It is claimed that the innovative bulk-fill materials produce lower polymerization shrinkage when compared with traditional composites. Therefore, the present was conducted in order to assess the effect of newly introduced resin composite materials, which are proposed for bulk-fill placement, on the cuspal deformation of teeth.

MATERIALS AND METHODS

Three high viscosity bulk-fill resin-based composite materials, and one traditional universal composite were included in this study (Table I). Thirty-two maxillary premolar teeth free from caries, defects, or cracks were received in bulk, as well as de-identified (Indiana University/IRB 1501282185) and used in this *in-vitro* study. All the selected teeth were cleaned with a hand scaler, and then fixed into a cube-shaped mold with acrylic base plate material (Bosworth, IL, USA) extending 2 mm cervical to the cementoenamel junction, to simulate the position of the tooth in the alveolar bone and also to prevent the reinforcement of the crown by the base. The measurement of the mean of three maximum bucco-palatal widths (BPW) for each tooth was recorded with a micrometer screw gauge (Moore and Wright, Sheffield, England) accurate to 10 μm. The measurements were used to distribute the specimens into 4 groups (n = 8). The mean of BPW between groups varied by less than 5 percent according to one-way analysis of variance (ANOVA).

The repeated measurement of bucco-palatal width was standardized using an innovative approach. In summary, small cylinders of flowable composite (Filtek Supreme Ultra, 3M ESPE) were constructed, coated with nail polish (Sally Hansen, NY) to minimize water sorption and attached on both buccal and palatal cusps. Then a rhinestone (Figure 1 and Figure 2) was glued to the upper flat surface of the cylinder and used as a reference point. Rhinestone has many facets, and these facets meet to form line and point angles. Therefore, two point angles (one on the buccal cusp and one on the palatal cusp) were used as a fixed reference points to measure the linear intercuspal distance over time.

The mean of three readings of the bucco-palatal width was recorded for each maxillary premolar tooth.

Large slot MOD cavity preparations were performed on the teeth, in order to weaken tooth structure and favor cuspal deflection. A single operator accomplished the procedures. The mounted teeth and high-speed contra angle air-turbine hand piece were positioned on a dental surveyor (J.M. Ney, Hartford, USA, Figure 3 and Figure 4) 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, 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 bucco-palatal width of the tooth. Sharpie permanent marker (Sanford Manufacturing Co., IL, USA) was used to draw the position of cavity preparation on the tooth structure to ensure that the prepared cavity was in the center of the tooth. The cavity depth was 4 mm from the cavity occlusal cavosurface margin to the pulpal floor. The buccal and lingual walls were prepared without occlusal convergence (parallel). The slot MOD cavities (Figure 5) were prepared without proximal boxes in order to reduce the preparation variation. All the cavosurface margins were prepared without beveling, and all internal line angles were rounded.[3]

A Tofflemire matrix band was shaped and placed around the teeth and held firmly at the proximal aspects of the teeth. A total-etch technique with 37.5-percent phosphoric acid (Kerr Gel Etchant; Kerr, West Collins, Orange, CA, USA) was utilized. 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, control company, Texas, USA) for 1 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, West Collins, Orange, CA, USA) 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 the compressed canned air was applied for 3 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 managing accurate resin curing device (MARC Resin Calibrator; BlueLight, Canada). The light was monitored after every 8 samples.

Three bulk-fill composite groups (Tetric EvoCeram Bulk Fill nanohybrid RBC, x-tra fil hybrid RBC, SonicFill nanohybrid RBC) and one conventional composite (Filtek Z100) were prepared. For each bulk-fill group, a single bulk-fill RBC increment was placed and irradiated for 20 seconds with the LED curing wand touching the slopes of the cusps of the tooth to achieve maximum curing depth and to maintain fixed distance (Figure 6). Only SonicFill was sonic activated with an oscillating hand piece as recommended by the manufacturer. The conventional composite group was incrementally restored with Filtek Z100 in three triangular-shaped increments with approximately 2-mm thickness for each increment, and each 2- mm increment was irradiated for 20 seconds with the LED curing wand touching the slopes of the cusps of the tooth (mesial and distal to the bonded reference cylinders).

CUSPAL DEFLECTION MEASUREMENTS

A Nikon measurescope UM-2 (Nikon, Tokyo, Japan)(Figure 8) 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 poly methyl methacrylate (PMMA) (Figures 9 and 10) sheet was used to standardize and maintain the horizontal orientation of each sample during the repeated measurements. Baseline measurements were recorded by measuring the linear distance between the two point angles on the rhinestone on the cusp tips (the reference points) prior to tooth preparation by using the Nikon measurescope. After restoration placement, the measurements of the cuspal deflection were recorded after 5 minutes, 24 hours, and 48 hours. The mean of the three bucco-palatal width measurements was recorded for each maxillary premolar tooth. The cuspal deflection was obtained by recording the difference between the baseline measurements and the time point measurements for each tooth.[1] The teeth were stored in water at room temperature (23° C ±1). All the procedures were performed by the same examiner. The whole procedure was performed for 4 teeth from each group at a time.

STATISTICAL METHODS

The effects of the composite material and time on cuspal deflection were analyzed using the mixed-model ANOVA, which included fixed effect terms for material, time, and their interaction as well as a repeated measures effect to account for correlations among the times, as well as the different variances at each time. Pair-wise comparisons between groups were made using Tukey’s method to adjust for multiple comparisons. An overall 5-percent significance level was used. With a sample size of 8 per group, the study had 80-percent power to detect a difference of 5 μm between any two groups.

RESULTS

Post-restoration cuspal deflection and standard error were measured for four groups of eight teeth at three times and are illustrated in Table II and Figure 11. Cuspal deflection was significantly greater in conventional composite than in Tetric EvoCeram Bulk Fill ($p = 0.0031$), x-tra Fil Bulk ($p = 0.0029$), and SonicFill Bulk ($p = 0.0002$). There was no significant difference in cuspal deflection for Tetric EvoCeram Bulk, x-tra Fil Bulk, and SonicFill Bulk Composites. Cuspal deflection was significantly greater at 5 minutes than at 24 hours ($p < 0.0001$) or 48 hours ($p < 0.0001$), and significantly greater at 24 hours than at 48 hours ($p < 0.0001$).

For Tetric EvoCeram Bulk, cuspal deflection was significantly greater at 5 minutes than at 24 hours ($p = 0.0001$) or 48 hours ($p < 0.0001$), and significantly greater at 24 hours than at 48 hours ($p = 0.0001$). For x-tra Fil Bulk, cuspal deflection was significantly greater at 5 minutes than at 24 hours ($p < 0.0001$) or 48 hours ($p < 0.0001$), and significantly greater at 24 hours than at 48 hours ($p = 0.0005$). For SonicFill Bulk, cuspal deflection was significantly greater at 5 minutes than at 24 hours ($p = 0.0001$) or 48 hours ($p < 0.0001$), and significantly greater at 24 hours than at 48 hours ($p = 0.0007$). For conventional composite, cuspal deflection was significantly greater at 5 minutes than at 24 hours ($p < 0.0001$) or 48 hours ($p < 0.0001$), and significantly greater at 24 hours than at 48 hours ($p = 0.0002$).

At 5 minutes, cuspal deflection was significantly greater in conventional composite than in Tetric EvoCeram Bulk ($p = 0.0003$), x-tra Fil Bulk ($p = 0.0007$), and SonicFill Bulk ($p < 0.0001$). At 24 hours, cuspal deflection was significantly greater in conventional composite than in Tetric EvoCeram Bulk ($p = 0.0305$), x-tra Fil Bulk ($p = 0.0123$), and SonicFill Bulk ($p = 0.0015$). At 48 hours, cuspal deflection was significantly greater in conventional composite than in Tetric EvoCeram Bulk ($p = 0.0328$), x-tra Fil Bulk ($p = 0.0236$), and SonicFill Bulk ($p = 0.0037$).

TABLES AND FIGURES

TABLE I

The materials used in this study*

Bulk Fill Resin-based Composites					
RBCs	Manufacturer Color, LOT	Resin Matrix	Filler	Filler Wt%/Vol%	Instruction for use
Tetric EvoCeram Bulk Fill nanohybrid	Ivoclar Vivadent, (Schann, Liechtenstein) IVA, T29056	Bis-GMA, UDMA Bis-EMA	Ba-Al-Si glass, prepolymer filler (monomer, glass filler, ytterbium fluoride), spherical mixed oxide	79-81 / 60-61	4 mm increment cure for 10 seconds. 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	4 mm increment cure for 20 seconds. 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	SiO2, glass, oxide	83.5/67	4 mm increment cure for 20 seconds. Additional curing from buccal and palatal aspect for proximal resin after removing the matrix
Traditional Universal Composite (Increments)					
Filtek Z100	3M,ESPE A2, N595515	Bis-GMA, TEG-DMA	Silica /zirconia	84.5/66	2 mm increment cure for 20 second. Additional curing from buccal and palatal aspect for proximal resin after removing the matrix

(continued)

TABLE I (continued)
The materials used in this study*

*Abbreveations:Resin based composite (RBC); Bisphenol-A and glycidyl methacrylate (Bis-GMA); Triethyleneglycol dimethacrylate (TEGDMA); Urethane dimethacrylate(UDMA); Ethoxylated bisphenol-A-dimethacrylate(EBPDMA); Bisphenol A polyetheylene glycol diether dimethacrylate(Bis-EMA).

TABLE II

Mean and standard error (µm) for cuspal deflection for the investigated materials*

Material	5 Minutes	24 Hours	48 Hours
Tetric EvoCeram Bulk	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

*Different upper case letters represent significant differences in cuspal deflection between various resin composites within each time point.
Different lower case letters represent significant differences in cuspal deflection within each type of resin composite at various time points.

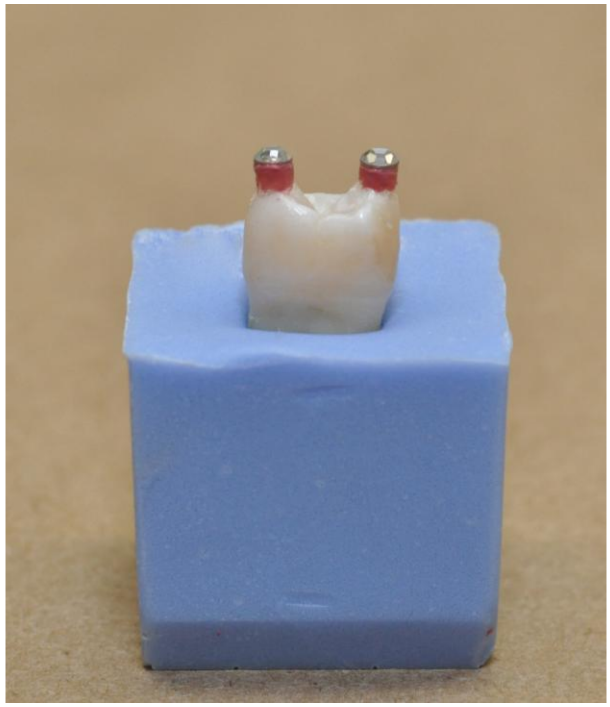

FIGURE 1. Tooth with cylindrical composite and rhinestone.

FIGURE 2. Tooth with cylindrical composite and rhinestone.

FIGURE 3. A mounted tooth and a high-speed contra angle air-turbine handpiece were positioned on an A.M.D. surveyor.

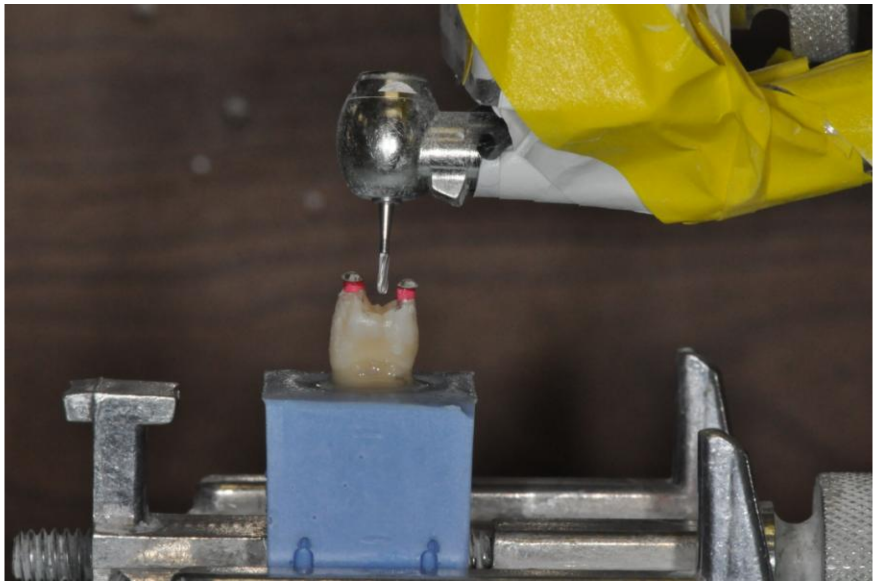

FIGURE 4. The mounted teeth and a high-speed contra angle air-turbine handpiece were positioned on an A.M.D. surveyor.

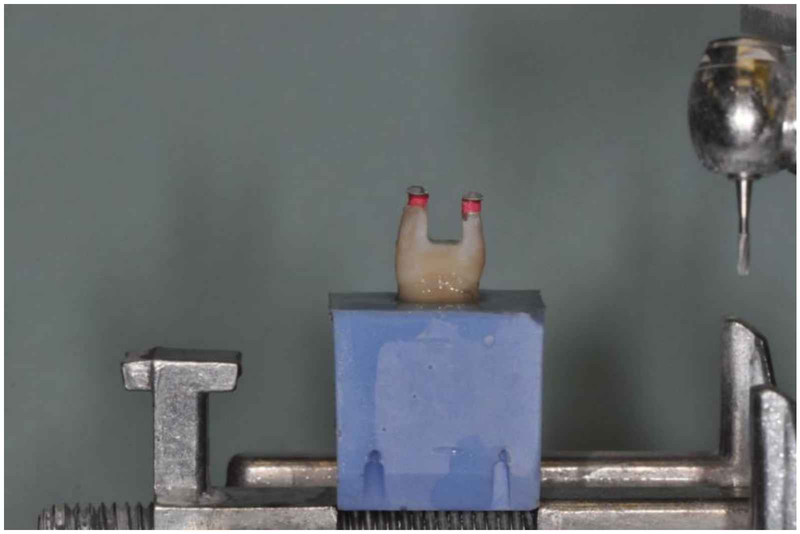

FIGURE 5. MOD slot preparation on maxillary premolar tooth.

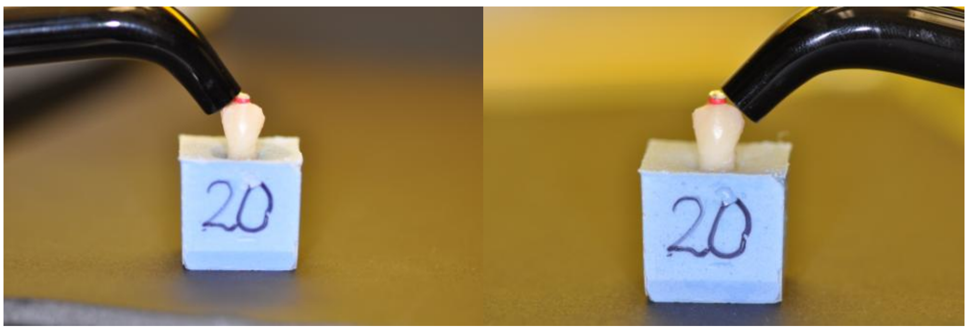

FIGURE 6. LED curing wand touching the slopes of the cusps of the tooth.

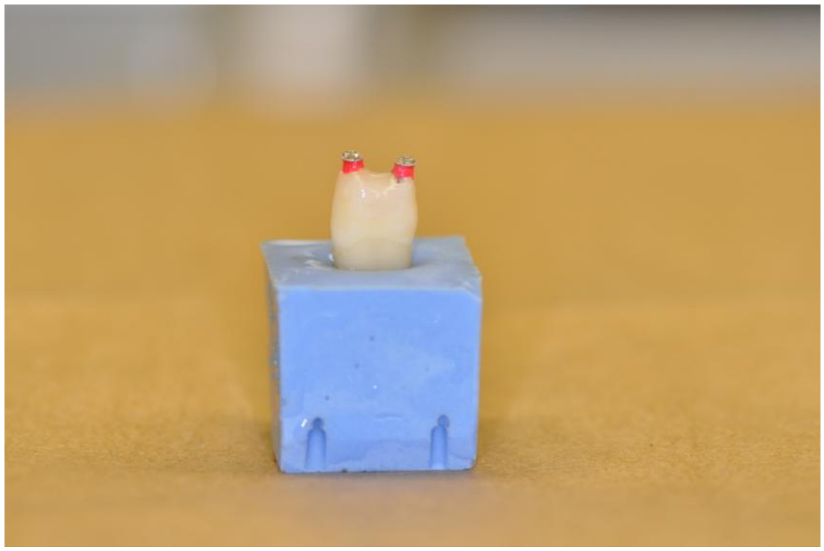

FIGURE 7. Tooth-filled with restoration.

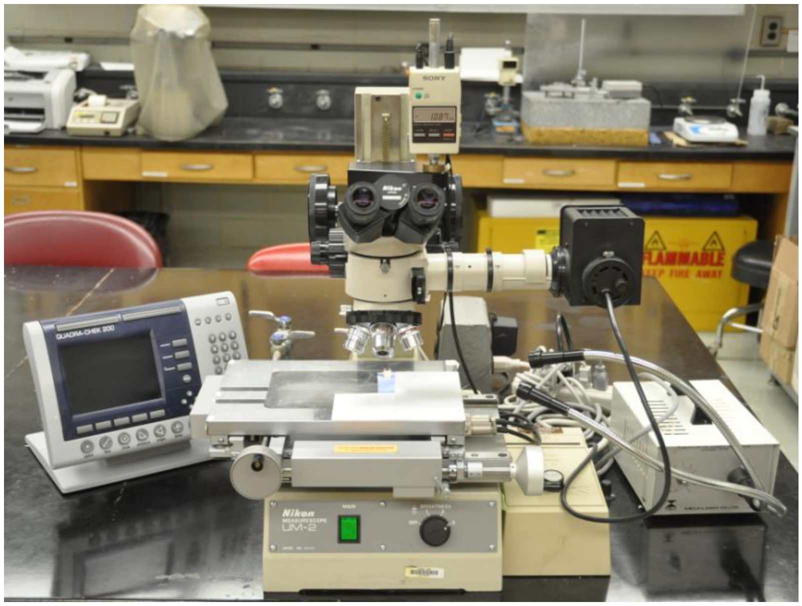

FIGURE 8. Nikon measurescope used to measure the intercuspal width.

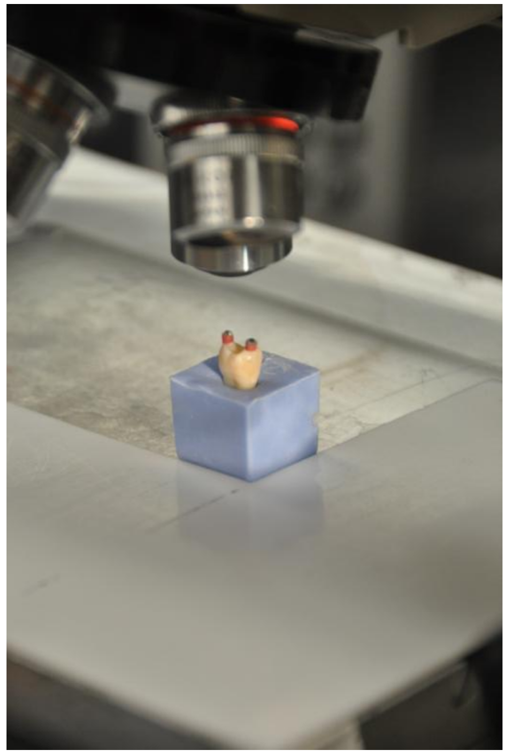

FIGURE 9. The sample under the measurescope.

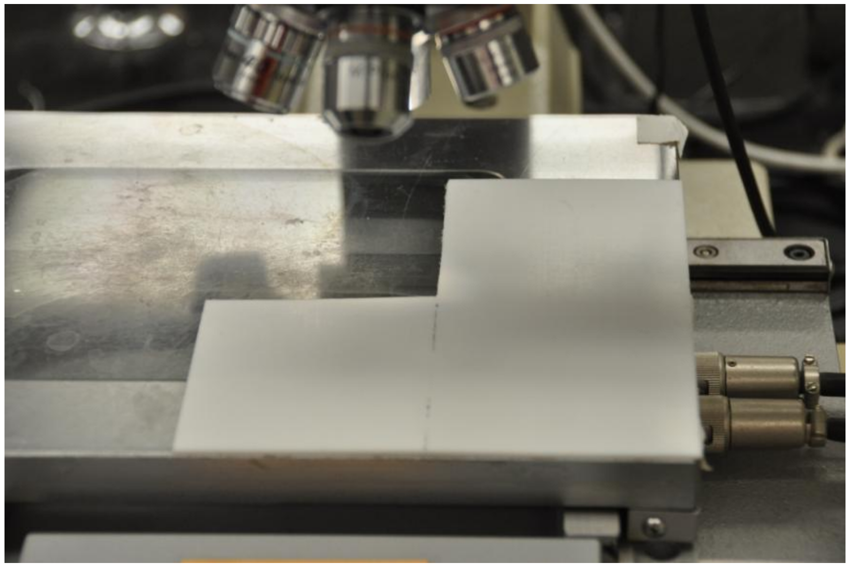

FIGURE 10. A custom poly methyl methacrylate (PMMA) sheet used to standardize and maintain the horizontal orientation.

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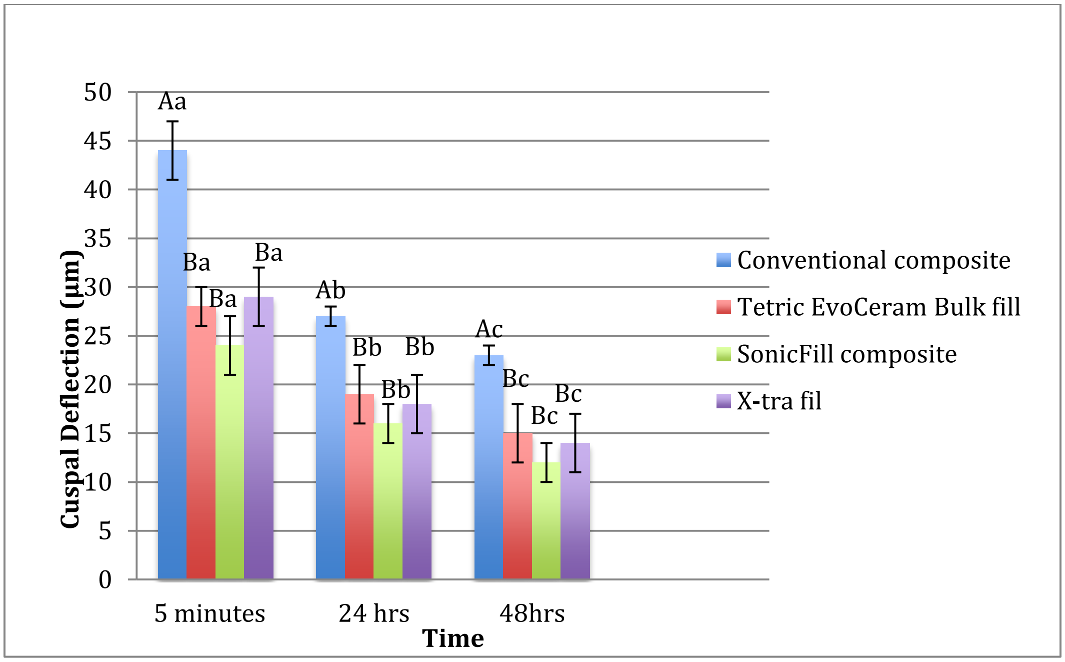

FIGURE 11. Mean (SE) (µm) of cuspal deflection for the investigated materials.*

*Different upper case letters represent significant differences in cuspal deflection between various resin composites within each time point. Different lower case letters represent significant differences in cuspal deflection within each type of resin composite at various time points.

DISCUSSION

This study investigated the effect of three types of high viscosity bulk-fill composites on cuspal deflection of maxillary premolar teeth and compared them with conventional composite. Inward cuspal movement or cuspal deflection means deformation of tooth structure was caused by the effect of polymerization shrinkage stresses.[77,78] Numerous studies have recorded the cuspal deflection to assess polymerization shrinkage stresses of resin composite materials on natural teeth.[81,85,86] Do et al. mentioned that the polymerization shrinkage stress cannot be measured directly.[87] Lee et al. reported that the amount of polymerization shrinkage and cuspal deflection were highly correlated.[45] Several techniques have been used in studies to measure the cuspal deflection, including strain gauges,[5,82,83] linear variable differential transformers (LVDT),[88] flexible ribbons,[77] and microscopy.[55] The amount of cusp deformation has been reported to vary according to many variables, which include the type of resin composite, the type of curing mode, the type of teeth, the size of the cavity preparations, and the methodology of the study.[89] In the current study, the mean of 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,[5,78,83] 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 and mimic the clinical situations. As Lopez et al. 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.[90] Although the value of cuspal deflection might be greater if the baseline measurements were recorded after cavity preparation, Karaman et al. reported that there was no significant difference in the cuspal deflection before or after cavity preparation; for this reason, the baseline measurements were recorded before tooth preparation.[1]

Measurement of cuspal deflection using natural teeth could produce many discrepancies between specimens due to the variations in the tooth size, anatomy and modulus of elasticity between teeth. Therefore, many steps were performed in the present work to minimize the cavity preparation variations: the mean of the bucco-palatal width of the teeth varied by no more than 5-percent difference in the mean of the variance among all the tested teeth; teeth preparations were accomplished without proximal boxes, and a dental surveyor was utilized during cavity preparations to ensure proper alignment of the cavity walls. Moreover, room temperature was selected to allow better comparison with existing studies.[78,87] Future efforts evaluating the impact of 37°C may provide more clinically relevant results.

The present study's hypothesis proposed that the mean for cuspal deflection seen with bulk-fill composites would be statistically less than the mean seen with a traditional composite. The study results validated this hypothesis. Cuspal deflection is significantly greater in conventional composite than in Tetric EvoCeram Bulk, x-tra fil Bulk, and SonicFill Bulk. There is no significant difference in cuspal deflection for Tetric EvoCeram Bulk, x-tra fil Bulk, and SonicFill Bulk composites. The reduced polymerization shrinkage stresses and subsequent cuspal deformation of bulk-fill resin composite materials were attributed to optimized resin matrix, initiator chemistry, and filler technology.[60] In the present study, the conventional composite exhibited the greatest cuspal deformation. Both filler technology and monomer content affect the polymerization shrinkage stresses. The present study used a resin matrix of the traditional composite (Filtek Z100) blended with Bis-GMA and lower-molecular-weight TEGDMA as a diluent to facilitate the incorporation of fillers to the resin matrix. TEGDMA-rich matrices create a greater degree of cross-linking and a greater amount of polymerization shrinkage,[91,92] while in bulk-fill composites, the incorporation of UDMA and Bis-EMA with lower TEGDMA content produce less polymerization shrinkage, and consequently, less cuspal deflection. Also, some studies have stated that the incorporation of UDMA and Bis-EMA resulted in reduction in the contraction stresses.[83,93] The increased filler volume content in high-viscosity bulk-fill composites is reported to be a direct cause for significantly less polymerization shrinkage. The higher filler load reduces the amount of resin in the composite materials and thus decreases the polymerization shrinkage.[50] On the other hand, Kim et al. showed that bulk-fill composite and conventional composite exhibited similar polymerization shrinkage stress.[94] This could be attributed to a different methodological approach that was used to assess the polymerization shrinkage stresses.

The rationale for starting measurements at 5 minutes was because the majority of the cuspal movement occurs within 5 minutes after polymerization.[12,78] On the other hand, at 5 minutes there was no statistically significant difference among the bulk-materials. SonicFill composite material exhibited the least cuspal deflection among experimental bulk-fill composites. This is in accordance with the current literature, where SonicFill composite had the least polymerization shrinkage stresses among bulk-fill composites.[36,95] Additionally, the unique advantage of the SonicFill material is its ability to behave like flowable composite during placement, and it provides better adaptation to cavity walls with the properties of hybrid composite when cured. Also, optimizing the filler sizes in SonicFill and x-tra fil composites could be a contributing factor to the lesser polymerization contraction stresses. Likewise, Satterthwaite et al. stated that the smaller filler size showed more polymerization shrinkage stress.[96] In agreement with the present study, Do et al. reported that the cuspal deflection of Tetric EvoCeram Bulk Fill was less when compared with flowable bulk fill and conventional composites. Although they did not find a statistical significance, the author mentioned that the result would be significant if they used a larger group size.[87] This is also in accordance with Zorzin et al., who found that Tetric EvoCeram Bulk Fill has less polymerization shrinkage than conventional composite.[97] The manufacturer claims that the reduced polymerization shrinkage of Tetic Evoceram Bulk Fill is 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.[71]

Cuspal deflection is significantly greater at 5 minutes than at 24 hours or 48 hours and is significantly greater at 24 hours than at 48 hours. Comparisons between the records of cuspal deflection of the investigated groups at 5 minutes, 24 hours, and 48 hours, revealed that all the tested teeth tend to recover to their original position, although complete recovery was not achieved during the 48-hour period. This is in agreement with Suliman et al., as they mentioned that the recovery begins after 10 minutes in hydrated teeth and never returns to the original position in large- or medium-sized cavities.[78] Cusp relaxation or recovery of the cusps could occur due to water sorption, and tooth elasticity; also, gap formation could be a cause as well.

SUMMARY AND CONCLUSIONS

In the present study, the cuspal deflection of bulk-fill materials: SonicFill, Tetric EvoCeram Bulk Fill, and x-tra fill composites produced statistically significant lower cuspal deflection than did the conventional composite (Z100).

There was no statistically significant difference in the cuspal deflection among the bulk-fill composite materials.

Complete recovery of the cusps to the original position was not recorded during the 48 hour-period.

Within the limits of this *in-vitro* study, all the investigated high viscosity bulk-fill resin composites exhibited cuspal deflection lower than conventional resin composite. Two aims of research on resin composite materials are improving their clinical longevity, and simplifying their use. For that purpose, bulk-fill materials are considered promising materials and further clinical studies should be conducted.

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ABSTRACT

CUSPAL DEFLECTION IN PREMOLAR TEETH RESTORED WITH BULK-FILL RESIN-BASED COMPOSITE MATERIALS

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Background: Polymerization shrinkage of conventional resin-based composites (RBCs) can cause cuspal deflection and be associated with enamel cracking, cusp or tooth fracture, and changes in occlusion. Bulk-fill resin-based composite materials are recent additions to the market. These recently developed materials produce less polymerization shrinkage when compared with traditional composite materials. Insufficient data are available in the literature regarding the cuspal deflection associated with bulk-fill resin composite materials.

Objectives: To investigate the effect of bulk-fill resin-based composite materials on cuspal deflection in large slot mesio-occlusal-distal cavities (MOD) in premolar teeth.

Methodology: Thirty-two sound maxillary premolar teeth with large slot MOD cavities were distributed to four groups (n = 8). Three groups were restored with bulk-fill resin composite materials (Tetric EvoCeram, x-tra fil, and Sonic Fill, respectively) in a

single increment. The conventional composite group, Filtek Z100, was used to restore the cavities in 2-mm increments. Cusp deflection was recorded post irradiation using a Nikon measurescope UM-2 (Nikon, Tokyo, Japan), by measuring the changes in the bucco-palatal width of the premolar teeth at 5 minutes, 24 hours, and 48 hours after completion of the restoration. The cuspal deflection was obtained by recording the difference between the baseline measurements and the other measurements for each tooth.

Results: Cuspal deflection was significantly higher in conventional composites than in Tetric EvoCeram Bulk Fill ($p = 0.0031$), x-tra Fil Bulk ($p = 0.0029$), and SonicFill Bulk ($p = 0.0002$). There was no significant difference in cuspal deflection for Tetric EvoCeram Bulk, X-tra Fil Bulk, and SonicFill Bulk composites.

Conclusions: All the investigated bulk-fill resin composites exhibited cuspal deflection values smaller than those for conventional resin composite. Two aims of research on resin composite materials are improving their clinical longevity, and simplifying their use. For that purpose, bulk-fill materials are considered promising materials, and further clinical studies should be conducted.

CURRICULUM VITAE

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