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ResearchPaper: Comparison of Stress Distribution in MOD Premolars Restored with Two Low Shrinkage Resin Composites Using Finite Element Analysis

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ABSTRACT

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Introduction: The incremental filling technique in traditional resin composites results in reduced polymerization shrinkage. However, many products have recently been introduced as low-shrinkage resin composites that make the bulk-filling of cavities possible.

Materials and Methods: Three identical dental models from a premolar tooth were made using a CADCAM digital scanner in the solid work software environment. MOD cavities were designed and filled by Tetric EvoCeram® Bulk Fill, GC KALORE™, and 3M ESPE Filtek P60 (control group) resin composites. Incremental and bulk-fill techniques were used for Tetric EvoCeram® Bulk Fill while GC KALORE™, and 3M ESPE Filtek P60 resin composites were used with incremental technique in Ansys 16 simulation software environment. Stress distribution and cuspal deflection rate were analyzed in Ansys 16 software by Kruskal–Wallis and Mann-Whitney U tests.

Results: The mean stress intensity for Tetric EvoCeram® Bulk Fill in the bulk-fill technique was more than the incremental technique. Cuspal deflection rate and stress distribution among the resin composites, GC KALORE™, Tetric EvoCeram® Bulk Fill, and 3M ESPE Filtek P60 were in ascending order, respectively. Stress distribution was more uniform in the incremental technique.

Conclusion: The GC KALORE™ resin composite had the least stress distribution and cuspal deflection rate.

Keywords:
Composite resins
Finite Element analysis
Filtek p60 composite resin

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1. Introduction

Adhesive resin composites have been widely used for teeth reconstruction by showing great esthetic outcomes, ease of handling and noticeable biocompatibility (1, 2).

Despite all the above mentioned advantages, polymerization shrinkage still remains as a significant problem (3). Methacrylate-based dental composite materials exhibit a wide range of 1.5 to 5 percentage of polymerization shrinkage as a result of curing (4, 5).

Many clinical failures such as restoration debonding, postoperative sensitivity, micro crack, micro-leakage, and secondary caries are some examples of the consequences of polymerization shrinkage (3, 6).

The amount of cuspal deflection could be affected by several factors including: cavity shape and size, elastic modulus of composites, resin composite type, light-curing protocols, and composite placement techniques (4, 7-9).

Composite producers have made many improvements in resin composite's physical properties, as optimized filler particle size, enhanced resin adhesion (1), and increased inorganic filler content (5, 10).

According to manufactures' claim, low shrinkage and bulk-fill resin composites show a decreased volumetric contraction and shrinkage stress (11) through modifications in translucency and their chemical structure, such as the inclusion of pre-polymer filler particles, increased reactive photo initiators, and using stress-relieving monomers (12).

The manufacturer claims that GC KALORE™ resin composite has the lowest shrinkage stress (1.72%). The organic matrix of GC KALORE™ nanohybrid resin composite consists of a newly developed dimethacrylate monomer by DuPont, the DX-511, based on urethane dimethacrylate chemistry. The molecular chemistry of this monomer has an elongated rigid core which decreases polymerization shrinkage, and consists of flexible arms that enhance its reactivity potential. Moreover the monomer's higher molecular weight reduces polymerization shrinkage (13).

The manufacturer of Tetric EvoCeram® Bulk Fill reported that additional photo-initiator (Ivocerin) as a polymerization booster has made a 4 mm of curing depth possible (14). This nanohybrid composite including high nano-filler and added prepolymerized resin fillers functionalized with silane, demonstrated lower shrinkage (15).

To the best of our knowledge, there is no existing study to make a comparison between the properties of these two types of low-shrinkage composites. This is clinically significant because the use of bulk-fill resin composites has been noticeably increasing. To comparatively assess the properties of mentioned material, we used Finite element analysis (FEA).

The hypothesis that was tested was that the stress distribution and cuspal deflection in MOD cavities of maxillary premolars are not be affected by Tetric EvoCeram® Bulk Fill resin composite and GC KALORE™ resin composite.

2. Materials and Methods

In this experimental study, geometric models were used to evaluate the stress distribution due to the polymerization of GC KALORE™ and Tetric EvoCeram® Bulk Fill resin composites. Modeling and simulation were conducted according to the following:

Creating geometry and a mesh network, defining the physics of models, solving problems and analyzing results.

A CADCAM three-dimensional laser scan with LAVA 3M ESPE was prepared from an extracted premolar tooth for orthodontic purposes without caries, cracks, and enamel or dentin defects from a human's maxillary two-rooted premolars, which were completely healthy. The initial file was formatted by STL (standard triangle language). This format includes a large number of triangles that represented the outer surface of the tooth.

This STL model was then transformed into a volumetric geometry using parallel periapical radiographs from buccal and mesial aspects considering the natural tooth's structure by SOLIDWORKS software (Figure 1). Sharp points were all smoothed to prevent false stress responses during elements analysis.

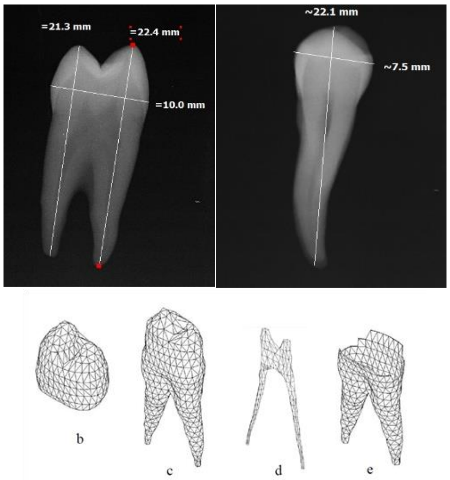


Figure 1. a. Parallel periapical radiographs from buccal and mesial aspects of a maxillary two-rooted premolar.
b, c, d, and e. volumetric geometry of the enamel, dentin, and pulp

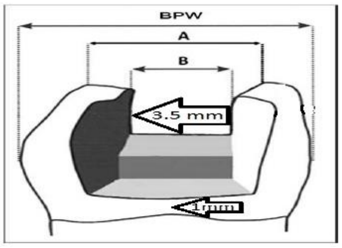
The models were meshed with the number of 23,000 nodes and 12,000 elements (16).

With the help of available information including Poisson's ratio, compressive strength, Young's Modulus, and other physical properties (16, 17) defining the relationships of tooth components was done with maximum adaptation and similarity to the main structure of natural tooth by ANSYS 16.1 software.

Three identical models of maxillary premolars with MOD cavity shape were used to compare the stress distribution and the cuspal deflection of restored teeth in the resin composites.

Two cavities were repaired by GC KALORE™ and Tetric EvoCeram® Bulk Fill composites and one as a control sample was restored by 3M ESPE Filtek P60 resin composite.

The prepared MOD cavity widths were two-thirds of the buccolingual width in the mesial and distal boxes and one-half of the width of the buccolingual in the occlusal. The buccolingual width is 3.5 mm and the axial depth in proximal boxes is located 1 mm closer to the occlusal than the CEJ (Figure 2) (7).



A=2/3BPW, B=1/2BPW

Figure 2. Dimensions of the prepared MOD cavity

Restoration simulation with the nanohybrid composite Kalore (GC, Tokyo, Japan):

According to the manufacturer's suggestion, by using a self-etch G bond with a selective etching technique under the condition of 30 seconds of enamel etching, there will be a bond strength of 33 MPa to the dentin and 27 MPa to the enamel (Table 1). The bond thickness of 30 micrometers was considered and was defined in Ansys software. Then, resin composite was applied in four incremental layers starting from the bottom of the simulated cavity and progressing to the occlusal surface with the maximum thickness of 2 mm for each increment in a reversibly oblique pattern to reach the factory volume shrinkage, i.e., 1.84%, with a curing time of 20 seconds.

Material properties regarding the young's modulus and Poisson's ratio of the tooth structures and resin composites are represented (Table 2).

Restoration simulation with Tetric EvoCeram® Bulk Fill composite:

According to the manufacturer's suggestion, with the application of 37% acid etch to enamel (30 seconds) and dentin (15 seconds), and consequently Tetric Nbond bonding, we will reach to 31 MPa enamel bond strength and 32.5 MPa dentin bond strength which was defined in Ansys software. The cavity was filled with bulk-fill to reach the factory volume shrinkage, i.e., 1.94% with a curing time of 20 seconds.

Restoration simulation with 3M Filtek P60 (3M ESPE, St. Paul, MN, USA) composite:

This model is simulated to control the previous two examples. The bonding mechanism to dentin and enamel in this sample is quite similar to the cavity model restored with Tetric EvoCeram® Bulk Fill composite, but the method of applying the composite to the cavity was similar to incremental modeling with GC KALORE™ resin composite.

The chemical ingredients of all included resin composites in this study are presented in Table 3.

Table 1. Shear bond strength related to simulated bonding (13, 18)

	Tetric N-Bond	G Bond
Shear bond strength on dentin (MPa)	32.5	33
Shear bond strength on enamel (MPa)	31	27

Table 2. The young's modulus and Poisson's ratio of materials (16, 19, 20, 21, 22)

Materials	Young's modulus (MPa)	Poisson's ratio
Enamel	84100	0.20
Dentin	18600	0.31
Pulp	2	0.45
Kalore	2600	0.3
Tetric EvoCeram, Ivoclar Vivadent	17000	0.28
3M Filtek P60	19700	0.32

Table 3. Chemical composition of GC KALORE, Tetric EvoCeram Bulk Fill, and 3M Filtek P60

Material	manufacturer	Chemical composition
Kalore	GC Corp., Tokyo, Japan	UDMA, DX-511 co-monomers, dimethacrylate; pre-polymerized filler (20–30 wt%); fluoroaluminosilicate glass; strontium/barium glass; silicon dioxide nanofiller; camphorquinone, pigment Filler load 82 wt%; 69 vol%
Tetric EvoCeram® Bulk Fill	Ivoclar-Vivadent, Schaan, Liechtenstein	BisGMA, UDMA, Ethoxylated, Bis-EMA, barium glass, YbF3, mixed oxide, and prepolymers (34.0 wt%), catalysts, stabilizers, and pigments Filler load 75.5 wt%; 54 vol%
3M Filtek P60	3M ESPE, St. Paul, MN, USA	UDMA, Bis-EMA, Bis-GMA, TEGDMA, Zirconia-Silica Nanoparticles, Aluminum oxide nanoparticles Filler load 83 wt%; 61 vol%

Abbreviations: UDMA=Urethane dimethacrylate, Bis-EMA=Ethoxylated bisphenol-A glycidyl methacrylate, Bis-GMA=Bisphenol A glycol dimethacrylate, TEGDMA=Triethylene glycol dimethacrylate, YbF3= ytterbium trifluoride

In this study tensile stress and elastic modulus were calculated using the following formulas.

% Elongation=(Increase in length / Original length) × 100

Elastic modulus = Stress / Strain

3. Results

To quantitatively compare the amount of stress and cuspal deflection according to two restorative methods and three types of composite materials, a score of the statistic structural color spectrum (1-10) was given. Furthermore, the mean weight for stress intensity and the amount of cuspal deflection was taken based on the images using the statistic structural color spectrum. In this study, each tooth surface was considered as a sample. The mean weight of stress intensity and deflection were compared based on non-parametric Mann-Whitney U and Kruskal–Wallis tests.

The results of stress and cuspal deflection distribution in different simulated models were shown on graphs (Figure 3 & 4).

According to the Kruskal–Wallis test, stress intensity in GC KALORE™ had lower mean and median (0.1611), and in 3M ESPE Filtek P60 had higher mean and median (0.3855), which even though is not statistically significant (P = 0.244), could clinically be important.

According to the Mann-Whitney U test, stress intensity between two restorative techniques in mesial (P = 0.275), occlusal (P = 0.827), and sagittal aspects (P = 0.275) was not statistically different and based on the total mean of all three composites, they had relatively similar statistical indexes.

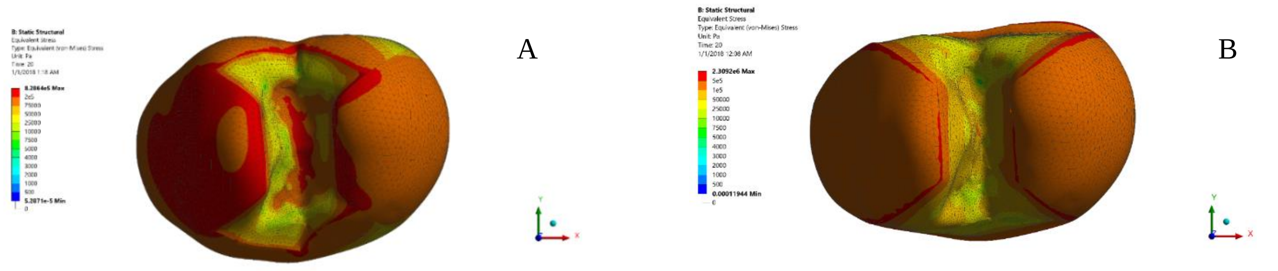


Figure. 3. Stress and cuspal deflection distribution in restored models with Tetric EvoCeram® Bulk Fill composite. A: bulk-filled. B: incremental-filled

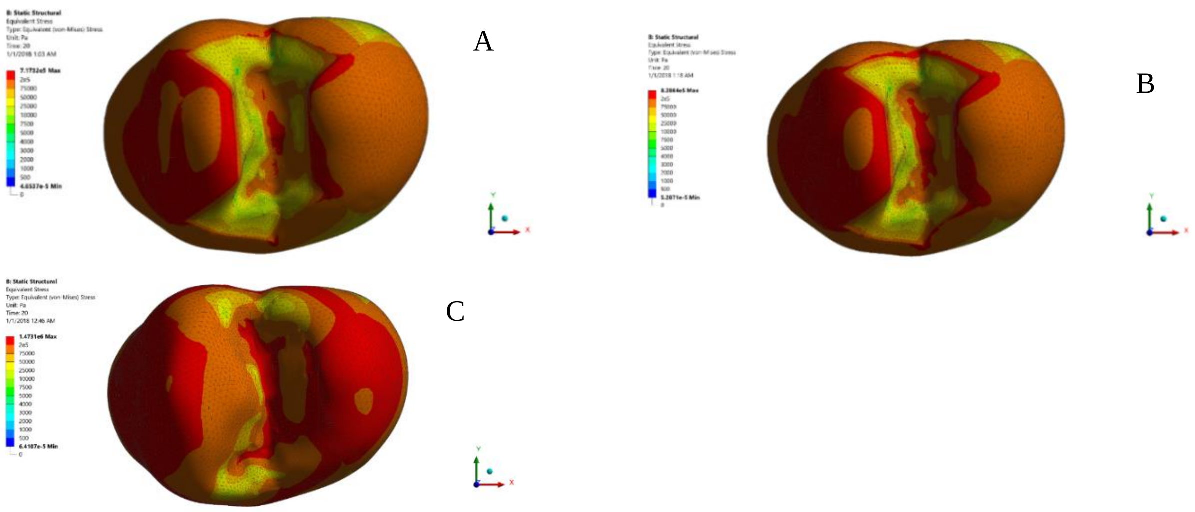


Figure 4. Comparison of stress and cuspal deflection distribution in restored models with incremental filling technique. A: GC KALORE™ resin composite, B: Tetric EvoCeram® Bulk Fill resin composite, C: 3M ESPE Filtek P60 resin composite

Stress intensity comparison among three tooth surfaces according to the resin composite type is shown in table 4.

Table 4. Details of stress intensity among three tooth surfaces according to resin composite type

Tooth Surface	Mesial				Occlusal				Sagittal			
resin composite type	3M ESPE Filtek P60	Tetric EvoCeram® Bulk Fill	GC KALORE ™	P-Value	3M ESPE Filtek P60	Tetric EvoCeram ® Bulk Fill	GC KALORE ™	P-Value	3M ESPE Filtek P60	Tetric EvoCeram ® Bulk Fill	GC KALORE ™	P-Value
Mean and median stress (MPa)	.2145	.1848	.1237	0.368	.7029	.3984	.2866	0.102	.2392	.1129	.0729	0.156

The amount of stress (MPa) in Tetric EvoCeram® Bulk Fill resin composite simulated with incremental or bulk-fill restorative techniques is demonstrated in table 5.

Table 5. The amount of stress (MPa) in Tetric EvoCeram® Bulk Fill resin composites with different restorative technique

Filling Technique	Stress (Mpa)
Bulk-fill	23.092
Incremental	8.286

The amount of cuspal deflection was measured by the degree of proximity of the two buccal and palatal cusp tips (overall deformation or movement of both cusps towards each other) (7).

According to the Mann-Whitney U test, incremental technique had lower mean score and median cuspal deflection rate compared with bulk-fill technique which were statistically different (P = 0.002). The cuspal deflection rate between two restorative techniques in mesial surface of the tooth (P = 0.05), sagittal surface (P = 0.05), and during resin composite shrinkage (P = 0.05) was statistically significant.

Descriptive statistical analysis demonstrates that in sagittal and mesial surfaces, and also during composite shrinkage, cuspal deflection rate in bulk-fill technique was more than incremental technique.

According to the Kruskal–Wallis's test, cuspal deflection rate in the incremental technique with GC KALORE™ resin composite had lower mean and median, while in 3M ESPE Filtek P60 the mean and median scores were higher, even though the difference was not statistically significant (P > 0.05). It was also demonstrated that cuspal deflection rate based on resin composite type in mesial surface (P = 0.867), sagittal surface (P = 0.651), and during resin composite shrinkage (P = 0.565) is not statistically different.

The amount of cuspal deflection (μm) in three resin composites simulated with incremental restorative technique and in Tetric EvoCeram® Bulk Fill resin composite simulated with incremental and bulk-fill techniques is demonstrated in Table 6 & 7.

Table 6. Cuspal deflection rate (μm) in resin composites using incremental technique

Material	3M ESPE Filtek P60	Tetric EvoCeram® Bulk Fill	GC KALORE™
Cuspal deflection rate(μm)	13.360	10.163	7.406

Table 7. Cuspal deflection rate (μm) in Tetric EvoCeram® Bulk Fill resin composite with different restorative techniques

Resin Composite Type	Tetric Evoceram® Bulk Fill
Bulk-fill	17.548
incremental	10.163

4. Discussion

Adhesive resins have become one of the most used materials in restorative dentistry, however, the longevity of such restorations can be affected by the adhesive resin's properties and its polymerization shrinkage (23).

There are many improvements in resin composites to reduce their polymerization shrinkage stress, however, it is still an important clinical problem (24, 25).

There are various approaches to analyze stress and strain distribution and polymerization shrinkage in dental research; however, they have some limitations and inexact outcomes in some cases. The FEA has overcome the difficulties of dental research caused by the unequal elastic modulus of enamel and dentin. The FEA is widely used in dental research subjects because of being able to analyze linear/nonlinear and static/dynamic problems, reproducible with low cost, and time-saving (3, 26).

The present study used FEA to evaluate and compare stress distribution quantitatively and qualitatively in all three types of composites by using universal mechanical laws (27).

The null hypothesis that Tetric EvoCeram® Bulk Fill resin composite and GC KALORE™ resin composite can result the similar polymerization shrinkage stress and cuspal deflection was rejected.

The mean and median stress distribution in GC KALORE™ and Tetric EvoCeram® Bulk Fill, is less than 3M ESPE Filtek P60 in incremental restorative technique with the minimum amount in GC KALORE™.

This difference is probably due to the use of pre-polymerized filler, and the addition of higher molecular weight monomers like UDMA in the composition of GC KALORE™ (28).

To increase the longevity of composite restorations, manufacturers have tried to establish low shrinkage materials as well as bulk-fill resin composites by the use of innovative monomer chemistry, filler content, and polymerization kinetics resulting in reduced contraction of the material during polymerization (12, 28, 29).

A mixture of hydrogenated dimer acids with bis-GMA and UDMA which have higher molecular weights in monomers, lower c=c double bonds, and higher degree of conversion than those of dimethacrylate resins, decreases polymerization shrinkage and its related stress. GC KALORE™ as a nanohybrid resin composite by the utilization of urethane dimethacrylate resin DX511 which has even higher molecular weight compared to bis-GMA and UDMA indicates reduced contraction shrinkage (26).

The lower shrinkage stress and cuspal deflection demonstrated in GC KALORE™ and Tetric EvoCeram® Bulk Fill resin composites, could be explained due to their composition and manufacturing technology.

The current generation of bulk-fill resin composites which are chemically similar to conventional micro hybrid and nanohybrid restorative material (14), showed better qualities compared to conventional ones (14, 30); however, it is demonstrated that the stress and cuspal deflection rate in incremental technique is less than bulk-fill technique with the use of the same resin composite for both techniques. This finding is in agreement with previous studies. Park et al. (31) reported that bulk filling technique significantly increased cuspal deflection caused by polymerization shrinkage compared to incremental filling technique. In addition, Kim et al. (32) concluded that bulk filling techniques in all resin composite groups with different elastic moduli enhanced cuspal deflection rate. Zhengdi et al. (33) also evaluated resin composite bond strength in class 1 cavities with different size, filled with incremental or bulk filling techniques and found decreased bond strength in large cavities filled with bulk filling technique; however there was no significant difference between the filling techniques in small cavities.

It is well known that incremental filling technique by reduced C-factor results in lower polymerization shrinkage stress and cuspal deflection. On the other hand, in bulk filled restorations, the resin composite that is restricted between the walls of the cavity due to increased C-factor, leads to higher shrinkage stress (31-34).

An improvement in cuspal deflection rate from bulk-fill technique to incremental technique is seen in Tetric EvoCeram® Bulk Fill resin composite (43%).

There is a direct relation between Young's Modulus and the amount of cuspal deflection rate. In this study the maximum amount of cuspal deflection is related to bulk-filled model with Tetric EvoCeram® Bulk Fill resin composite (17.548 µm) and the minimum is related to the model restored with GC KALORE™ composite with incremental filling technique (7.010 µm).

In bulk-fill technique the major stress concentration is located in tooth/restoration surface, while in incremental technique its distribution is more uniform with the minimum stress in bonding surface and internal line angles.

6. Conclusion

Incremental filling technique with the use of resin composites with improved Young's Modulus (more elasticity), and also less shrinkage (e.g., GC KALORE™) could significantly reduce the amount of stress and cuspal deflection.

Within the limits of the present study, we concluded that among the three composite materials, GC KALORE™, Tetric EvoCeram® Bulk Fill, and 3M ESPE Filtek P60, the average stress intensity and cuspal deflection are respectively ascending using incremental restorative technique.

Ethical Considerations

Compliance with ethical guidelines

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Authors'contributions

Seyedeh Maryam Tavangar: Conceptualization, Methodology, Writing - Review & Editing Yasaman Sadeghi: Resources, Investigation, Visualization Farideh Darabi: Methodology, Visualization Sanaz Mihandoust: Writing - Original Draft, Data curation Ali Seyed- Monir: Funding acquisition, Project administration, Supervision Saman Soltani: Writing - Review & Editing Resources Reza Tayefeh Davalloo: Writing - Review & Editing Investigation

Conflict of Interests

The authors declare no conflict of interest

Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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