Al-Rafidain J Med Sci. 2023;5:143-149.
DOI: https://doi.org/10.54133/ajms.v5i.179

AJMS

Online ISSN (2789-3219)

Research Article

A Comparative in vitro Investigation on the Impact of Fiber Insertion on Cuspal Deflection of Maxillary Premolars Restored with Various Types of Bulk Fill Direct Composite Restorations

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Received: 4 July; Revised: 7 August 2023; Accepted: 12 August 2023

Abstract

Background: Polymerization shrinkage remains a significant disadvantage that makes the use of direct composite restorations difficult. ***Objective***: To evaluate how well a fiber insert and multiple bulk-fill direct restorations worked on the cuspal deflection of MOD cavities in premolar teeth using a Dino-Lite digital microscope and computer software. ***Methods***: In sixty fresh maxillaries first premolars, large MOD cavities were created. Teeth were randomly divided into six groups of ten based on restorative materials. SonicFill®, Beautifil Bulk®, and Filtek® Bulk Fill posterior restoratives were used in groups A1, B1, and C1, whereas groups A2, B2, and C2 used the same bulk composite with E-glass fiber (UFM, Dentapreg). Under a digital microscope, the intercuspal distance between two reference points on the cusp tips was measured before preparation, after preparation, 15 minutes after finishing restorations, and one month following incubation. ***Results***: There was a significant difference between the groups after 15 minutes of restoration, but no significant differences following cavity preparation or one month of incubation. CD values were considerably higher after 15 minutes of restoration in groups restored with bulk fill only. Beautifil Bulk Fill restorative resulted in greater cuspal deflection than the other groups. The CD values in each group were significantly higher 15 minutes after restoration compared to cavity preparation and a month of incubation. ***Conclusion***: Using inserts, cuspal deflection in MOD cavities can be significantly minimized, and stress release usually occurs after water incubation.

***Keywords*: ** Bulk fill composite restorations, Cuspal deflection, Direct posterior restoration, Fiber reinforcement composite, Glass fiber.

دراسة مقارنة في المختبر حول تأثير إدخال الألياف على انحراف اعتاب الضواحك الفكية المستعادة بأنواع مختلفة من الترميمات المركبة المباشرة للتعبئة السائبة

الخلاصة

الخلفية: لا يزال انكماش البلمرة عيبا كبيرا يجعل استخدام الترميمات المركبة المباشرة أمرا صعبا. **الهدف**: تقييم مدى نجاح إدخال الألياف والترميمات المباشرة المتعددة للتعبئة السائبة على انحراف اعتاب تجاويف MOD في أسنان الضواحك باستخدام مجهر رقمي Dino-Lite وبرامج كمبيوتر. **الطرق**: في ستين من الضواحك الأولى من الفك العلوي الطازج، تم إنشاء تجاويف MOD كبيرة. تم تقسيم الأسنان عشوائيا إلى ست مجموعات من عشرة على أساس المواد التصالحية. تم استخدام الترميمات الخلفية ®SonicFill و Beautifil Bulk® Fill و Filtek® Bulk Fill في المجموعات A1 و B1 و C1، بينما استخدمت المجموعات A2 و B2 و C2 نفس المركب السائب مع الألياف الزجاجية الإلكترونية UFMو Dentapreg و تحت المجهر الرقمي، تم قياس المسافة بين نقطتين مرجعيتين على أطراف الأعتاب قبل التحضير، وبعد التحضير، وبعد 15 دقيقة بعد الانتهاء من الترميمات، وشهر واحد بعد الحضانة. **النتائج**: كان هناك فرق كبير بين المجموعات بعد 15 دقيقة من الترميم، ولكن لم تكن هناك فروق ذات دلالة إحصائية بعد تحضير التجويف أو شهر واحد من الحضانة. كانت قيم القرص المضغوط أعلى بكثير بعد 15 دقيقة من الاستعادة في المجموعات التي تمت استعادتها بالتعبئة المجمعة فقط. أدى التصالحية Beautifil Bulk Fill إلى انحراف أكبر عن المجموعات الأخرى. كانت قيم CD في كل مجموعة أعلى بكثير بعد 15 دقيقة من الترميم مقارنة بإعداد التجويف وشهر من الحضانة. **الأستنتاج**: باستخدام الإدخالات ، يمكن تقليل انحراف الأعتاب في تجاويف MOD بشكل كبير، وعادة ما يحدث إطلاق الإجهاد بعد الحضانة في الماء.

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Article Citation: Habeeb LH, Abdul-Ameer ZM. A Comparative in vitro study of the effect of fiber insertion on cuspal deflection of maxillary premolars restored with different types of bulk fill direct composite restorations. *Al-Rafidain J Med Sci*. 2023;5:143-149. doi: https://doi.org/10.54133/ajms.v5i.179

INTRODUCTION

The utilization of bulk-fill resin composites for posterior restorations has increased as a result of material advancements and improved curing, which reduces the adverse effects of curing stresses [1]. Advanced bulk-fill composites could be cured as one layer with a thickness of 4 to 6 mm, whereas traditional bulk-fill composites need a 2-mm incremental layering technique [2]. A factor thought to affect the clinical efficacy of resin-based composite (RBC) materials is polymerization shrinkage stress [3]. The distance between monomer molecules decreases as a result of the development of covalent bonds as monomer molecules transform into a polymer network during polymerization. Mechanical stresses grow and are transmitted to the tooth-restoration interface [4]. At least two clinical issues might be related to polymerization shrinkage. First, the restoration may separate from the tooth structure and cause microleakage if the stress caused by polymerization shrinkage exceeds the bonding strength of the resins to the tooth structure [5]. The failure at the composite-tooth contact may cause secondary caries and postoperative sensitivity [6]. Second, the restoration retains internal stresses that pull the cusps closer, shortening the intercuspal distance and causing deflection of the cusps. If the strength of adhesion between the cavity walls and the restorations overcomes the shrinkage stresses, then no detachment occurs. Cuspal deflection can result in tooth fractures, enamel cracks, and occlusion alterations [5,7]. In order to produce durable dental materials without sacrificing their aesthetic qualities, enormous advancements in dental material manufacturing have been made. One method that achieves this goal is the use of reinforcing glass fibers as fillers in dental materials, typically resin polymers. Glass fiber-reinforced composites offer several benefits over traditional dental materials, although some restrictions have been noted in the literature. Glass fibers are very thin strands of glass with a silica composition that have been extruded into fibers. Glass fiber-reinforced composites are created by enclosing these fibers in a resin matrix. Fine, thin glass fibers are chemically bound by silane coupling agents to a polymerized monomer matrix to create glass fiber-reinforced composites [8]. Particularly with the introduction of resin composite glass fibers, insert technology has received more attention. Due to their elasticity modulus, which is similar to dentin, they have the ability to absorb and distribute stress (9). They have a significant amount of glass fiber embedded within a matrix of completely or partially polymerized polymers. They claim to bond to a directly loaded resinous matrix by either chemical interdiffusion or micromechanical interlocking [10]. There are a limited number of studies investigating the effects of glass fiber-reinforced composite with bulk fill composite on cuspal deflection in high C-factor cavities that are large MOD cavities. Therefore, the study aimed to make a comparison between vs. absence of E-glass fiber and different types of bulk fill direct restoration and assess the influence of these restoration techniques on cuspal deflection in MOD cavities. The null hypothesis of the current study was that fiber reinforcement and type of bulk fill direct restoration in the MOD cavity would have no impact on cuspal deflection.

METHODS

Sample selection

The College of Dentistry, University of Baghdad, Iraq, Research Ethics Committee approved this research project in January 2022. (No.515522). 60 fresh, sound human maxillary first premolars were gathered from multiple private dental clinics for this study. Trans-illumination revealed that the only teeth included were healthy ones with normal occlusal form, proportionate size, and no cracks or cavities [2]. The distilled water used for disinfected teeth is used as a storage solution. By using a digital caliper, each tooth's maximal buccolingual, mesiodistal, and occlusogingival dimensions were measured in order to reduce potential confounding variables. To ensure uniformity of size of the teeth throughout all of the groups, the deviation of any individual tooth within a group from the measured mean of these dimensions shouldn't exceed 10%.

Sample preparation

An impression of the occlusal surface was taken using a flowable composite (Filtek Supreme, 3M ESPE Dental Products, USA) prior to cavity preparation (stamp method). This method uses composite restoration to return teeth to their original occlusal form, with a minimum of finishing and polishing required. Two reference points were made by preparing two indentations on the tip of the buccal and palatal cusps with carbide round bur, and two heads of pins were bonded to the indentations by using the SBU adhesive system (3M ESPE, USA) to use as reference points for measurement as shown in Figure 1. Then, a standardized class II MOD cavity preparation was performed on each tooth, requiring a 3 mm width at the pulpal floor and gingival seats of the boxes, a 3 mm depth at the occlusal isthmus calculated from the cavo-surface margin of the palatal wall to the pulpal floor, and a gingival seat of the box with a 1 mm axial wall depth and height [11]. When preparing a cavity, a flat-ended diamond fissure bur (Microdent, China) mounted on an adapted dental surveyor established parallelism between the bur's long axis and the tooth. A caliper and periodontal probe were used to measure the cavity's depth and size in order to assure uniformity.

Sample Grouping

The teeth have been divided randomly into six groups in accordance with the restorative material (n = 10). Group A1: Teeth were restored using SonicFill®3 composite; Group A2: SonicFill®3 composite and fiber inserts; Group B1: Teeth were restored with Beautifil Bulk Fill composite; Group B2: Beautifil Bulk Fill and fiber inserts. Group C1: Teeth were restored with Filtek Bulk™ Fill posterior restorative composite, and Group C2: Filtek Bulk™ Fill posterior restorative and fiber inserts.

Figure 1: The tooth with two reference points

Restorative procedure

The prepared cavities in each tooth were etched for 20 seconds with 37% phosphoric acid (Super Etch, SDI, Australia), followed by 5 seconds of water washing and air-drying. Then apply Single Bond Universal with a microbrush (3M ESPE, Germany) to the tooth structure, rubbed the cavity with adhesive for 20 seconds, thinned by a gentle air stream for 5 seconds to ensure complete evaporation of the solvent, and followed the manufacturer's recommendations. The tooth was then cured with an Eighteenth curing pen (Eighteenth, China) placed as close to the cavity as possible and set to a 1,000 mw/cm2 intensity for 20 seconds. In all samples, SuperMat® Universal Matrix Tensioning System (0.038mm thickness and 6.3mm height) (Kerr, USA) was used. Group A1: SonicFill® composite (shade A2) (Kerr Corporation, USA) was used to restore the teeth. As instructed by the manufacturer, the SonicFill® handpiece was turned using a foot pedal to initiate the sonic vibration that altered the SonicFill® composite's viscosity from high to low; the cavity was then bulk-filled in one step. Ash Nos. 6 and 49 were used to compact and adjust the composite materials to ensure no gaps between the material and the tooth, and then to reconstruct the original occlusal anatomy for each tooth, the composite restoration was covered with Teflon. After that, the prefabricated stamp was applied to Teflon and cured for 20 seconds. The restoration was furthermore cured for 20 seconds from the lingual and buccal sides when the SuperMat® matrix band was removed. Group B1: Beautifil Bulk Fill Composite (Universal Shade) (Shofu, Japan) was used to restore this group. It was applied to the cavity in a single layer up to 4 mm, according to the manufacturer's instructions. Adaptation, final anatomy, and curing were done as Group A1. Group C1: A pre-dosed capsule of Filtek® Bulk Fill Posterior Restorative (Shade A2) (3M ESPE, USA) was applied in the gun and directly placed into the cavity from the capsule's tip by dispensing at the deepest region of the cavity, and then slowly withdrawing the tip until the cavity was completely full in one increment, following the guidelines provided by the manufacturer. Adaptation, final anatomy, and curing were done as Group A1. Groups A2, B2, and C2: The teeth of these groups were etched and bonded as for other groups. A Dentapreg fiber ultra-fine mesh (Dentapreg, ADM, Czech Republic), which is uniformly sized, 0.1 thickness, 60 mm length, and 4–10 mm width, pre-impregnated E-glass fiber insert, was used. The fiber was measured with dental floss and cut to fit the buccolingual dimensions of the samples and 1 mm from the cavo-surface margins. The length of Dentapreg® UFM was measured using dental floss, then removed from the blister and cut with scissors to the required length. The protective strip is not to be touched with bare hands. The bonding area was thinly coated with a flowable composite material (Kuraray Noritake Dental, Japan). The protective paper and the plastic foil were left uncured, removed from the strip, then inserted into the uncured composite, adapted to the required position, and cured for 40 seconds. The remaining cavities of A2, B2, and C2 were restored with SonicFill®3 composites, Beautifil Bulk Fill® composite, and Filtek® Bulk Fill Posterior Restorative, respectively, according to the manufacturer's instructions and as in groups A1, B1, and C1. It is necessary to cover the whole surface of the fibers with the composite, followed by light curing in accordance with the guidelines provided by the composite manufacturer, then finish the restoration and polish it. The Enhance finishing system (Dentsply, Germany) was used.

Intercuspal distance and cusp deflection measurements

We used a computerized digital microscope (Q-Scope® QS.90200-P, Netherlands) with a 150x magnification and Image J software (ImageJ bundled with Java 1.8.0_172, USA) to measure the distance between the cusps and how much they bend. Two reference points (heads of pins) were bonded as close as possible to the cusp tips of samples within restored groups to measure the intercuspal distance (ICD) accurately. The ICD before cavity preparation was measured and considered the baseline measurement. Then cusp deflection (CD) after cavity preparation, 15 min after restoration, and after one-month incubation (CD 1, 2, and 3, respectively) was calculated by subtracting the ICD measurements during restorative phases (after cavity preparation, 15 min after restoration, and after one-month incubation, respectively) from the baseline ICD measurement.

Statistical analysis

The data were represented using descriptive statistics, including means and standard deviations. Normality and homoscedasticity of CD data were checked using Shapiro-Wilk and Levene's tests, respectively. A one-way ANOVA with the Tukey post-hoc test was used in analyzing the results (comparing CD1, CD2, and CD3 between the groups and within each group). Statistical analysis was performed using SPSS software version 26 (SPSS Inc., Chicago, IL, USA), with significance set at $p<0.05$.

RESULTS

Means and standard deviations of CD values within the groups of the restored teeth are listed in Table 1. The highest values were for CD2 (15 min after restoration within each group), while the lowest values were for CD3 (after one-month incubation). CD values were normally distributed (Shapiro-Wilk test $p>0.05$) and the data were homogenous (Levene's test $p>0.05$).

Table 1: ANOVA of CD1 values between groups (after cavity preparation)

Groups		Mean±SD	*p-value*
A	No- fiber	0.81±0.23	0.339
	with fiber	0.71±0.22	
B	No- fiber	0.83±0.30	0.692
	with fiber	0.78±0.27	
C	No- fiber	0.81±0.30	0.794
	with fiber	0.78±0.28	

The ANOVA test revealed no statistically significant difference between groups ($p>0.05$) as shown in Tables 1 and 3, except for CD2 values ($p<0.05$) as shown in Table 2. One-way ANOVA was used to compare CD values within the same restored group. The results showed a statistically significant difference in CD2 values between B1 and both A1 and C1 ($p<0.05$) respectively, and there was a significant difference in CD2 between B2 and both A2 and C2 ($p<0.05$) respectively, as shown in Table 2.

Table 2: ANOVA of CD2 values between groups (after 15 minutes of composite curing)

Groups		Mean±SD	*p-value*
A	No-fiber	5.52±0.98	0.00
	with fiber	3.26±0.59	
B	No-fiber	7.84±1.04	0.00
	with fiber	4.58±0.54	
C	No-fiber	5.73±0.93	0.00
	with fiber	3.39±0.63	

There was a significant difference in CD between (A1, B1, and C1) and (A2, B2, and C2) ($p<0.05$) respectively. The Tukey post-hoc test revealed statistically significant differences between CD1 vs. CD2 and CD2 vs. CD3 values, while no significant differences were detected between CD1 vs. CD3 values within each tested group, as shown in Table 4.

Table 3: ANOVA of CD3 values between groups (after one-month incubation)

Groups		Mean±SD	*p-value*
A	No-fiber	0.64±0.29	0.701
	with fiber	0.69±0.31	
B	No-fiber	0.69±0.27	0.916
	with fiber	0.68±0.26	
C	No-fiber	0.75±0.32	0.383
	with fiber	0.63±0.29	

Table 4: Mean and standard deviation (µm) of Cusp deflection (CD) of different cavity types at different time intervals

Subgroup	CD1	CD2	CD3
A1	0.81±0.23^{a}	5.52±0.98^{a,b}	0.64±0.29^{b}
B1	0.83±0.29^{a}	7.85±1.04^{a,b}	0.69±0.27^{b}
C1	0.81 ±0.29^{a}	5.73±0.93^{a,b}	0.75±0.32^{b}
A2	0.71 ±0.22^{a}	3.26±0.59^{a,b}	0.69±0.3^{b}
B2	0.78 ±0.27^{a}	4.58±0.54^{a,b}	0.68±0.26^{b}
C2	0.78±0.28^{a}	3.39±0.63^{a,b}	0.63±0.29^{b}

CD1: cusp deflection after cavity preparation, CD2: cusp deflection 15 min after restoration, CD3: cusp deflection after one-month incubation, CD2 values were significantly different to CD1 and CD3 values in all group. Identical superscript small letters represent significant differences between the relevant groups.

DISCUSSION

Cuspal displacement may eventually result in microcrack propagation, enamel cracks, crazing, and a decrease in fracture resistance [1]. In recent years, new dental materials containing glass or other types of fibers have become available. Glass fibers have proven they are capable of withstanding tensile stress and preventing crack propagation in composite materials [12]. All steps for specimen preparation were carried out by the same operator to prevent variations in results brought on by various operators' skill levels [13]. Additionally, maxillary premolars are more prone to cusp deflection than other posterior teeth due to their anatomical form, crown size, and crown/root ratio [14]. There is a clear correlation between cuspal deflection and tooth structural loss [15]. For the purpose of weakening the tooth structure and allowing cuspal deflection, substantial MOD cavity preparations were carried out in the current research [1]. The intercuspal measurements were performed by using a digital microscope (a non-destructive method to take images for samples). This provides a detailed, easy, and reliable procedure for facilitating the storage and recall of the deflection data of the cusps. Unlike other ways to measure intercuspal distance, such as with a traditional caliper, this method measures liner deflection without touching the tooth. Because of this, it doesn't stop the cusps from moving freely [16]. Several studies on cusp deflection of teeth restored using bulk-fill composite resins have been published in the scientific literature [1,17].

The cusps of every examined composite group deflected inward, which is consistent with the findings of prior research [4,17-19]. This might be due to the preexisting residual stresses in the sound tooth. The cause of these stresses is not clear. However, they could result from extraction and water storage before use or are normal in teeth [20]. In common with the present study findings, González et al. (2006) found that higher cusp deflection was recorded 15 minutes after the restoration of the cavities in each group [15]. This could be due to the fact that during the resin-based restoration, remaining free radicals and double bonds continued to react [21]. Group A1 (restored with SonicFill®3) showed significantly less cuspal deflection compared with Group B1 (restored with Beautifil Bulk Fill) in spite of the high filler loading of Beautifil Bulk Fill. This might be attributed to SonicFill®3 contains rheological modifiers that allow for increasing particle motion and dropping in viscosity upon sonic activation with a designated hand piece. This may result in enhanced internal flow, which could increase pre-gel relief and lower cuspal strain [22]. Additionally, the adequate adaptation of SonicFill®3 restoration to cavity walls without void formation reduces the contraction stress and the possibility of pulling the composite away from the cavity wall during polymerization, lowering the cuspal deflection [23]. In this study, there is no statistically significant difference between teeth filled with SonicFill®3 and teeth filled with Filtek® Bulk Fill because their manufacturers, in order to minimize shrinkage stress, have revolutionized their manufacturing mechanism and their monomer composition, respectively [22]. Group C1 (restored with Filtek® Bulk Fill posterior restorative) displayed significantly less cuspal deflection value than Group B1. This might be attributed to the significantly lower volumetric shrinkage of Filtek Bulk Fill (2.01%) compared with Beautifil Bulk Fill (2.58%), with the same modulus of elasticity of 8.3 and 8.2, respectively [24]. Volumetric shrinkage and the material's elastic modulus determine stress, depending on Hooke's Law. So that the polymerization shrinkage stress of Filtek® Bulk Fill is significantly lower than that of Beautifil Bulk Fill. The reduction in volumetric shrinkage of Filtek® Bulk Fill could be due to excluding TEGDMA monomer (286 g/mol) from its contents. It has a molecular weight of around half that of most commonly utilized dimethacrylates, such as Bis-GMA (512 g/mol) [25]. Additionally, two novel monomers called AUDMA and AFM are used in Filtek Bulk™ Fill composites to reduce polymerization shrinkage stress. AFM provides the additional capacity of fragmentation chain transfer. The advantageous aspect of addition fragmentation chain transfer is that it allows the covalent network to be adapted to stress generation through bond breakage and reformation with no net loss of crosslinking as a result of an allyl disulfide bond [26-29]. Greater cuspal deflection was observed in teeth filled with Beautifil Bulk Fill (groups B1 and B2) than in other groups of bulk fill types used in this study because SonicFill®3 and Filtek® Bulk Fill posterior restoratives contain high molecular weight polymerization modulators, which reduce polymerization shrinkage [24]. According to the findings of this study, cavities received only composites had the highest cuspal deflection values (Groups A1, B1, and C1), as shown in Table 2. In other words, using fibers may decrease a tooth's cuspal deflection. In the same situation, Karbhari and Wang demonstrated that the use of fibers in conjunction with composite resins improves tooth fracture resistance and reduces concerns about shrinkage. Additionally, the FRC can help lessen cuspal deflection in MOD cavities in posterior teeth [30]. Alander et al. showed that the use of composite fibers increased the final flexural strength of composite resins [31]. Based on the explanation above, it can be inferred that adding fibers to composite restorations may raise the flexural strength and elastic modulus of the resin as well as lessen the cavity C-factor influence [32], causing a reduction in polymerization shrinkage and cuspal deflection. Using fibers and FRC resin technology is one way to increase the strength of composite restoration. Several studies have demonstrated that fibers reinforce several dental materials, such as composite resins [33-38]. Glass fibers have proven to be able to resist tensile stress and stop crack progression in resin composites. The fibers may function as a crack stopper during crack propagation, allowing the crack to progress down the fiber or causing the fiber to break [39]. These microcracks and fiber breaks in the matrix might serve as a technique for reducing stress brought on by polymerization shrinkage. The influence of fibers on the improvement in elastic modulus of fiber-reinforced composite resins may be another reason causing the reduction in cuspal deflection with the addition of fibers. The polymerization shrinkage of composite resin reduces as its modulus of elasticity improves [40]. Additionally, fibers enhance the flexural properties of resins used in fiber-reinforced composites [41]. The comparison of the cuspal deflection of teeth restored with several types of bulk fill composites and the effect of fiber inserts by some studies has shown a significant difference [1,4,42], which is consistent with the findings in the current study. On the other hand, other studies disagree with our finding [19,43]. However, this study has a number of limitations. This research was carried out in vitro. In vitro circumstances offer standardized conditions; however, they do not always correspond to in vivo ones. It is necessary to conduct studies that assess cuspal deflection using intraoral scanners or similar devices in an intraoral environment and that investigate both the immediate and long-term consequences by assessing patient complaints and restoration status using intraoral assessment criteria.

Conclusion

By using inserts, the cuspal deflection in MOD cavities may be considerably reduced, and stress relaxation usually happens after incubation in water.

Conflicts of interest

There are no conflicts of interest.

Funding source

There were no particular grants provided for this study by funding organizations in the public, private, or nonprofit sectors.

Data sharing statement

Supplementary data can be shared with the corresponding author upon reasonable request.

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