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ORIGINAL RESEARCH

The Effect of Composite Fiber Insertion along with Low-shrinking Composite Resin on Cuspal Deflection of Root-filled Maxillary Premolars

Siavash Savadi Oskoee, Parnian Alizadeh Oskoee, Elmira Jafari Navimipour, Amir Ahmad Ajami Gazale Ahmadi Zonuz, Mahmood Bahari, Fatemeh Pournaghiazar

ABSTRACT

Aim: The aim of the present study was to evaluate the effect of three methods of composite fiber placement along with silorane-based composite resin on cuspal deflection and fracture strength of root-filled maxillary premolars.

Materials and methods: Mesio-occluso-distal cavities were prepared in 60 extracted premolars subsequent to endodontic treatment. The remaining thickness of buccal and lingual walls at height of contour was 2.5 ± 0.2 mm and the gingival cavosurface margin was 1.5 mm coronal to cementoenamel junction. Subsequent to measurement of primary intercuspal distances, the teeth were randomly divided into four groups. In group 1, the cavities were only filled with Filtek Silorane composite resin. In the other three groups, preimpregnated glass fibers were placed at gingival, middle and occlusal thirds respectively, and the cavities were restored similar to the group 1. Cuspal deflection was recorded in micrometer using a stereomicroscope. Fracture strength of the samples was measured in Newton subsequent to thermocycling. Data was analyzed using Kruskal-Wallis, Mann-Whitney U, one-way ANOVA and post-hoc Tukey tests at a significance level of $p < 0.05$.

Results: The highest cuspal deflection was recorded in the group 1, and the difference between group 1 and other groups was significant ($p < 0.001$). Fracture resistance in group 4 was significantly higher than that in other groups ($p < 0.001$).

Conclusion: In restoring root-filled premolars with silorane-based composite resins, cuspal deflection decreased with the use of preimpregnated glass fibers.

Clinical significance: Using preimpregnated glass fibers along with silorane-based composite resin may lead to better results in cuspal deflection and fracture resistance of endodontically-treated maxillary premolars.

Keywords: Fiber-reinforced composite resin, Cuspal deflection, Fracture strength, Glass fiber, Silorane-based composite resin, Laboratory research.

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INTRODUCTION

Restoration of endodontically-treated teeth is a critical final stage in a successful root canal treatment.[1] Maxillary premolars have an undeniable role in esthetics and, on the other hand, they are subjected to a combination of compressive and shearing forces in terms of function. Therefore, there is a need for high-strength tooth-colored restorations in such teeth.[2] Based on the results of previous studies, endodontically-treated teeth can be restored with crowns, cast onlays, amalgam onlays or composite resins.[3, 4] Recent developments in adhesive technology, offering new composites, have led to direct conservative restorations with high esthetic results.[3] The majority of light-cured composite resins used in dental procedures are based on dimethacrylate. Free radical-mediated polymerization of such composite resins subsequent to light activation results in closer packing of molecules and volumetric shrinkage of the material.[5] Polymerization reactions of composite resins can be divided in pre- and postgel phases. After completion of the gelation phase, formation of a relatively rigid polymer network presents plastic deformation and, as a result, continuation of polymerization shrinkage produces internal stresses within the material, at tooth/restoration interface and inside the tooth structure.[6] Polymerization shrinkage can result in gap formation or enamel cracks, leading to recurrent caries and ingress of bacteria.[7,8] In addition, when the bond strength between the adhesive and tooth structure is sufficient, the shrinkage stress is transferred to tooth structure and appears as cuspal deflection. Cuspal deflection is the result of interactions between the polymerization shrinkage stress of composite resin and the compliance of cavity walls and is a common biomechanical phenomenon observed in teeth restored with composite resin restorative materials.[8] There are two important categories of biomechanical factors that influence cuspal deflection. The first category is composed of geometric and material factors, such as cavity width, cavity depth, the thickness of remaining tooth, material polymerization shrinkage and flowability of the composite resin. The second category is comprised of clinical factors, such as use of liner, filling technique (bulk *vs* incremental technique), restoration methods (direct *vs* indirect) and method of light curing.[8]

Depending on the method of measurement, cavity size and the amount of composite polymerization shrinkage, the range of cuspal deflection has been reported to be 4 to 45 µm in various studies.[9-11] Recently, silorane-based low-shrinking composite resins have been introduced in an attempt to decrease polymerization shrinkage and stress at tooth-restoration interface.[12] Silorane-based composite resin is obtained from the reaction of oxirane and siloxane molecules. The mechanism to compensate shrinkage in this type of composite resin involves the opening of oxirane ring.[13] In this context, Palin et al reported that cuspal deflection decreases in mesio-occluso-distal (MOD) cavities restored with silorane-based composite resins.[5]

Regarding the importance of intracoronal strengthening in endodontically-treated posterior teeth, it appears that the use of low-shrinking composite resins along with resin fibers may be useful in restoration of these teeth. Belli et al showed that the use of composite fibers increases fracture resistance of endodontically-treated teeth.[3] Also Oskoee et al reported that fracture resistance of teeth significantly increases by changing the position of fibers from the cavity base to the occlusal surface.[14] The present study made an attempt to evaluate the effect of the use of low-shrinking composite resins along with composite fibers on cuspal deflection and fracture resistance of endodontically-treated maxillary premolars. The null hypothesis was that composite fiber insertion along with low-shrinking composite resin does not affect cuspal deflection or fracture resistance in restoration of endodontically-treated maxillary premolars.

MATERIALS AND METHODS

Sixty intact human single-rooted maxillary premolars, extracted for orthodontic reasons, were selected. The teeth were gathered following informed consent, approved by the Deputy Dean of Research at Tabriz Dental School. They were almost the same size and did not have any caries, preexisting fractures or cracks when surveyed under transillumination and were stored in 0.5% chloramine trihydrate solution (Merck, Munich, Germany) at 4ºC until used for the purpose of the study. After cleaning tooth surfaces with hand instruments, standard access cavities were prepared in all the teeth using coarse taper flat-end burs (Mani, Naka-akutsu, Japan) in a high-speed handpiece. After determining the working length, the canals were filed up to #30 K-files (Dentsply Maillefer, Simfra, Switzerland) using the step-back technique. Canal flaring was carried out using #2 and #3 Gates Glidden Drills (Mani). The canals were irrigated with 5.25% NaOCl after each instrumentation. After irrigation with normal saline, the canals were dried with paper points (Ariadent, Tehran, Iran), and filled with gutta-percha (Ariadent) and AH26 sealer (Dentsply, Konstanz, Germany) using lateral condensation technique. Subsequent to obturation, all the teeth were further examined regarding cracks and fractures using transillumination. The teeth were embedded in self-cured acrylic resin up to CEJ and MOD cavities were prepared in a manner in which the thicknesses of the buccal and lingual walls at height of contour were 2.5 ± 0.2 mm and the gingival floor was 1.5 mm coronal to the CEJ.[14] Thereafter, a round cavity was prepared to the bur diameter on buccal and lingual cusp tips using a 1/4 round carbide bur. The cavities were stained with a mixture of rouge and chloroform and evaluated under a stereomicroscope (SMZ-1000, Nikon, Tokyo, Japan) at 20× magnification. The points produced were visible as circles under the microscope. Three spots were determined on the periphery of each circle and the software program of the microscope (Nikon DS camera control unit, DS-L2, model DS-Fil-L2, Tokyo, Japan) determined the center of each circle based on marked three spots. Then the distance between the two centers was recorded. Five consecutive measurements were carried out for determining the center of the circles and the distance between them in each tooth and the mean of the five measurements were considered as the initial intercuspal distance (Fig. 1A). Then the teeth were randomly divided into four groups of 15 teeth each.

In the group 1, subsequent to measuring the initial intercuspal distance, silorane self-etch primer and silorane bond adhesive (3M ESPE Dental Products, St Paul, MN, USA) were applied to cavity surfaces according to manufacturer's instructions, and light-cured at a light intensity of 400 mW/cm^2 (Astralis 7, Ivoclar, Vivadent, Liechtenstein). Then the cavities were restored with composite resin (Filtek Silorane, 3M ESPE) using the incremental technique. Each horizontal layer was 1.5 to 2 mm thick and was cured for 40 seconds before placing the next layer using the pulse program of the light-curing unit. After completing of the restoration procedures and removal of the matrix bands, the restorations were again light cured from mesial and distal directions for 40 seconds,[14] and the timer was started. Approximately 180 seconds after the completion of the restorative procedures,[11] intercuspal distance was measured again under the stereomicroscope (Fig. 1B). The difference between the two measurements before and after restoration was considered as cuspal deflection.

In group 2, after application of the primer and adhesive as in group 1, composite resin (Filtek Silorane, 3M ESPE) was placed on the cavity floor and the gingival third of the buccal and lingual walls at a thickness of 1 mm. Prior to the curing procedure, resin-impregnated glass fiber (Interlig, Angelus, Londrina PR, Brazil), an interwined tape with thickness of 0.3 mm and width of 2 mm, was placed from the gingival third of the buccal wall to the gingival third of the lingual wall on the cavity floor and inside the composite resin (Fig. 2A). Light-curing was carried out for 40 seconds with the pulse program. Then the rest of the cavity was restored with composite resin similar to that in group 1.

In group 3, after application of the self-etch primer and the bonding material, the cavity was filled up to the middle third with composite resin using the incremental technique. Before curing the final layer, the fiber was placed so that it covered the middle third of the buccal and lingual walls (Fig. 2B). After curing this layer for 40 seconds, the rest of the cavity was restored with composite resin similar to that in group 1.

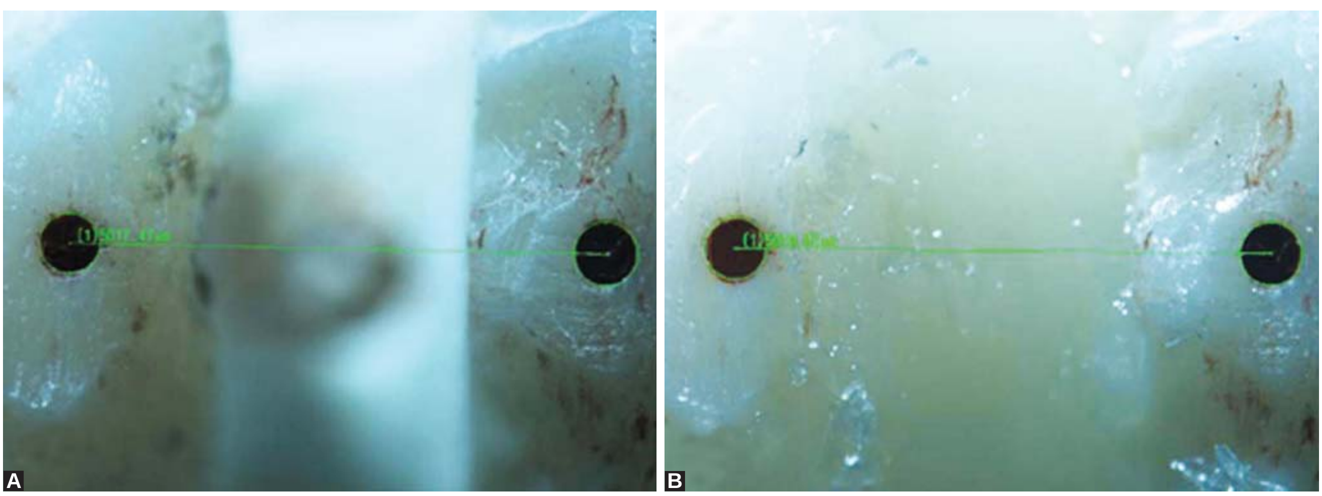
In group 4, a ditch cut was prepared adjacent to the circles; the ditch ran from the buccal to the lingual aspect was 2 mm wide and 1 mm deep. The ends of the ditch were placed on the occlusal thirds of buccal and lingual surfaces. Subsequently, the cavity was filled with composite resin up to the occlusal third as group 1. Before light-curing the final layer, the fiber was placed in the cavity (Fig. 2C). Then the whole structure was light-cured for 40 seconds. Finally, the surface of this combination was covered with Filtek Silorane composite resin and light cured for 40 seconds.

In the latter three groups, the primary and secondary intercuspal distances and cuspal deflection were measured in a manner similar to those in group 1. Finally, 500 cycles thermocycling procedure was carried out at 5 ± 2 to 55 ± 2ºC with a dwell time of 30 seconds and a transfer time of 10 seconds. Then the teeth were incubated at 37ºC at a relative humidity of 100% for 24 hours. In the final stage, the teeth were subjected to a compressive force in a universal testing machine (Hounsfield Test Equipment, H5K-S Model, Surrey, England) at a crosshead speed of 0.5 mm/min. The force application tip was 5 mm in diameter contacted buccal and lingual cusps, and the force was applied parallel to the long axis of the teeth. The force necessary to fracture the teeth was measured in Newton.

Cuspal deflection data was analyzed using Kruskal-Wallis and Mann-Whitney U tests; whereas fracture resistance data was analyzed by one-way ANOVA and a post-hoc Tukey test. Statistical significance was defined at $\alpha = 0.05$. Linear regression model was used to evaluate the relationship between cuspal deflection and fracture resistance.

RESULTS

Cuspal deflection values in the study groups have been shown in Table 1. The results of nonparametric Kruskal-Wallis test revealed statistically significant differences in the means of cuspal deflection values among the study groups ($p < 0.001$).Two-by-two comparison of the groups by Mann-Whitney U test demonstrated statistically significant differences between no-fiber group and each of the other groups ($p < 0.001$); however, there were no significant differences between groups 2 and 3 ($p = 0.26$), 2 and 4 ($p = 0.56$) and 3 and 4 ($p = 0.23$).



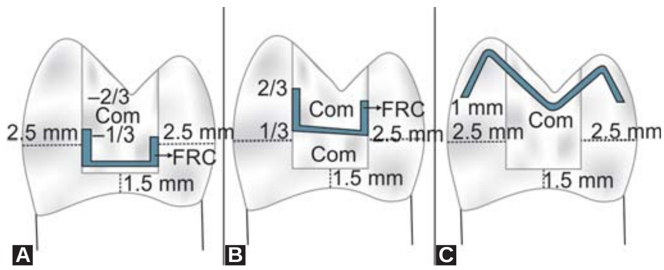
Figs 1A and B: (A) Initial intercuspal distance, (B) secondary intercuspal distance

The means of fracture resistance values in the study groups have been shown in Table 2. One-way ANOVA revealed statistically significant differences in the means of fracture resistance values among the study groups ($p < 0.001$). Two-by-two comparison of the groups by a post hoc Tukey test showed statistically significant differences in the means of fracture resistance values between the group 4 and each of the other groups ($p < 0.001$); however, there were no significant differences between groups 1 and 2 ($p = 0.93$), 1 and 3 ($p = 0.60$) and 2 and 3 ($p = 0.91$). The results of linear regression showed that cuspal deflection cannot be considered as a predicting factor for fracture resistance ($R = 0.55$; Fig. 3).

DISCUSSION

Polymerization shrinkage is a major concern regarding the clinical efficacy of composite resins.[6] One of the compensating techniques is the use of nonshrinking composite resins.[15] In this context, low-shrinking composite resins with silorane-based monomers have been introduced. Several studies have shown a decrease in polymerization shrinkage in silorane-based composite resins compared to conventional methacrylate-based ones.[5,16-18] Ring-opening polymerization in silorane-based composite resins decreases composite resin shrinkage below 1 volume percent.[18] However, polymerization shrinkage in Bis-GMA-containing composite resins has been reported in the range of 2.9 to 7.1%.[19] Various studies have reported that silorane-based composite resins have mechanical parameters comparable to those of methacrylate-based composite resins.[16,18,20] Despite favorable mechanical properties, direct composite resins are still considered low-strength materials which are predominantly used in small- and medium-sized cavities.[21] One of the techniques to strengthen composite resins is the use of fibers and fiber-reinforced composite resin technology. Various studies have confirmed the reinforcing effect of fibers on some dental materials, including composite resins.[22-27] In addition to factors, such as the type of the resin, fiber length, fiber position, number of fibers, adhesion of fibers to polymer matrix, and properties of fiber and polymer matrix, the reinforcing effect of the fiber is influenced by fiber placement technique and its distance from force exertion point.[14,28,29]

In the present study, the effect of placing glass fibers in three different locations on the amount of cuspal deflection and fracture resistance of endodontically-treated premolars



Figs 2A to C: Position of fibers: (A) Fiber at gingival third, (B) fiber at middle third, (C) fiber at occlusal third; Com: Composite resin

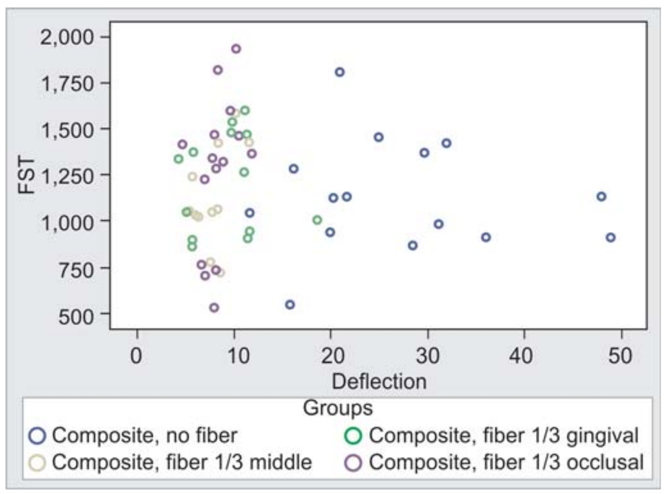


Fig. 3: Scatter plot of cuspal deflection and fracture strength of study groups

Table 1: Results of cuspal deflection measurements (μm) in study groups

Groups	*No.*	*Mean*	*Standard error*	*Minimum*	*Maximum*
Group 1 (without fiber)	15	26.99	2.84	11.60	48.83
Group 2 (gingival fiber)	15	9.13	0.95	4.24	18.59
Group 3 (middle fiber)	15	7.65	0.42	5.35	11.49
Group 4 (occlusal fiber)	15	8.34	0.43	4.64	11.67

Table 2: Results of fracture resistance measurements (N) in study groups

Groups	*No.*	*Mean*	*Standard error*	*Minimum*	*Maximum*
Group 1 (without fiber)	15	1054.66	37.11	870	1373
Group 2 (gingival fiber)	15	1023.80	14.80	897	1376
Group 3 (middle fiber)	15	1136.66	38.09	912	1430
Group 4 (occlusal fiber)	15	1379.40	66.06	1032	1936

restored with low-shrinking silorane-based composite resin was evaluated. Based on the results of the present study, the highest cuspal deflection values were recorded in cavities restored with silorane-based composite resins alone. In other words, the use of composite fibers, irrespective of its location, may decrease cuspal deflection of restored teeth. In the same context, Karbhari and Wang reported that the use of fibers along with composite resins not only increases tooth fracture resistance and decreases concerns about creep and shrinkage but also the fiber-reinforced composite resins can aid in reducing cuspal movement in MOD cavities in posterior teeth.[30]

The ability of glass fibers to withstand tensile stress and to stop crack propagation in composite resins has been demonstrated. During crack propagation, the fibers can act as a crack stopper and the crack can propagate along the fiber or the fiber can break.[31] These fiber breakages and microcracks within the matrix may act as a stress-absorbing mechanism to ease stress resulted of polymerization shrinkage. Another factor contributing to the decrease in cuspal deflection with the application of fibers might be the effect of fibers on the increase in modulus of elasticity of fiber-reinforced composite resins. Zortuk et al demonstrated that the use of polyethylene fibers increased modulus of elasticity of polymethylmethacrylate resin.[32] As modulus of elasticity of composite resin increases, its polymerization shrinkage decreases.[33] In addition, fibers improve flexural properties of fiber-reinforced composite resins.[34] Alander et al demonstrated an increase in ultimate flexural strength of composite resins with the use of composite fibers.[35] Based on the above-mentioned discussion, it can be concluded that the use of fibers along with composite restorations may increase flexural strength and modulus of elasticity of composite resin and also decrease the cavity C-factor effect;[36] leading to lower polymerization shrinkage and cuspal deflection.

The results of the present study regarding fracture strength of the specimens showed that the use of glass fibers in the occlusal third of cavities increases their fracture resistance. Considering the results of studies on reinforcing effects of fiber glasses on composite restorations,[37] and the possibility of changes in stress distribution at resin-tooth interface,[3] this conclusion is highly logical. Also, the proximity of fiber location to force exertion point and shortening of the working arm according to the law of levers,[14] and maintaining the buccal and lingual cusps close to each other by occlusal surface fibers[1] might have a role in achieving high fracture strength. However, Sengun et al did not report a significant difference in fracture resistance between the teeth restored without fibers and those restored with polyethylene fibers in the gingival third of the cavity.[38] On the other hand, Belli et al reported an increase in fracture resistance of molars by placing polyethylene fibers even at the gingival third of the cavity.[3] The discrepancy between the results of the present study and those of previous studies might be attributed to differences in the physical and chemical properties of glass fibers used in the present study and the polyethylene fibers and also differences in the type of the studied teeth. In the present study, it was expected that fracture resistance would increase with a decrease in cuspal deflection; however, the results of regression model showed that the amount of cuspal deflection cannot be considered as a predicating factor for tooth fracture resistance. It appears that tooth fracture resistance is influenced by the fiber location and its distance to stress exertion point instead of the amount of cuspal deflection resulted of composite resin polymerization.

Finally, it should be pointed out that in the present *in vitro* study cuspal deflection and tooth fracture resistance were evaluated by application of a static force. Although the results can be useful in predicting clinical function and efficacy, the tooth-restoration complex is sophisticated due to specific geometry and adhesion conditions, therefore, it is suggested that, in future studies, the effect of factors, such as fiber type, fiber location, and the composite resin type on the stress distribution at tooth cusp be evaluated under conditions closer to oral conditions and through finite element analysis.

CONCLUSION

Under the limitations of the present study, it can be concluded that in endodontically-treated maxillary premolars:

1. Use of silorane-based composite resins alone or along with glass fibers may not eliminate cuspal deflection resins.
2. Use of glass fibers along with silorane-based composite resins may decrease cuspal deflection.

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ABOUT THE AUTHORS

Siavash Savadi Oskoee

Professor, Dental and Periodontal Research Center, Dental Faculty Tabriz University of Medical Sciences, Tabriz, Iran

Parnian Alizadeh Oskoee (Corresponding Author)

Associate Professor, Department of Operative Dentistry, Dental and Periodontal Research Center, Dental Faculty, Tabriz University of Medical Sciences, Tabriz, Iran, e-mail: parnianoskuee@yahoo.com

Elmira Jafari Navimipour

Associate Professor, Department of Operative Dentistry, Dental and Periodontal Research Center, Dental Faculty, Tabriz University of Medical Sciences, Tabriz, Iran

Amir Ahmad Ajami

Assistant Professor, Department of Operative Dentistry, Dental Faculty, Tabriz University of Medical Sciences, Tabriz, Iran

Gazale Ahmadi Zonuz

Assistant Professor, Department of Operative Dentistry, Dental Faculty, Babol University of Medical Sciences, Babol, Iran

Mahmood Bahari

Assistant Professor, Department of Operative Dentistry, Dental Faculty, Tabriz University of Medical Sciences, Tabriz, Iran

Fatemeh Pournaghiazar

Assistant Professor, Department of Operative Dentistry, Dental Faculty, Tabriz University of Medical Sciences, Tabriz, Iran