Effect of polyethylene fiber reinforcement on marginal adaptation of composite resin in Class II preparations

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The aim of this study was to evaluate the effect of polyethylene fibers incorporated in a composite resin matrix on the gingival marginal adaptation of Class II slot restorations. Sixty Class II slot cavity preparations were divided into 2 groups. A fiber-reinforced resin (FRR) group received restorations of composite resin mixed with strips of polyethylene fiber, and an unreinforced resin (UR) group was restored with only composite resin. The groups were subdivided on the basis of the adhesive system (etch-and-rinse or self-etch) that was used. Shrinkage stress was evaluated by placing a strain gauge at the buccal surface of the teeth. A scanning electron microscope was used to evaluate marginal adaptation in terms of a continuous margin (CM) at the gingival margin. Statistical analysis included a 2-way analysis of variance with the Holm-Sidak correction for multiple comparisons at a significance level of 0.05. The mean strain value was significantly smaller in the FRR group (185 [SD 37] µm/m) than in the UR group (295 [SD 21] µm/m). The FRR group presented with a mean CM value of 80.2% (SD 4.6%), which was significantly higher than that of the UR group, which had an overall CM value of 64.4% (SD 4.2%). There was no statistically significant difference between the adhesive subgroups with regard to strain or percentage of CM. The results showed that the incorporation of polyethylene fibers in a composite resin matrix can help to improve gingival marginal adaptation in Class II cavities.

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Modifications in dental composite resins have now allowed for their use in stress-bearing areas of the mouth.[1,2] The increased demand for more esthetic restorative materials has made their use popular among clinicians as well as patients. The incorporation of contemporary filler systems and monomer designs have also improved the physical properties of composite restorations.[1,2]

However, volumetric contraction during the polymerization of monomers continues to limit their clinical longevity.[2-5] As a composite resin cures, there is a volumetric dimensional change from 1% to 5%.[3-5] When a composite resin is allowed to cure outside the dental cavity, the material is able to shrink freely. However, when a composite resin is bonded to a hard dentinal substrate, the volumetric shrinkage leads to the development of stresses at the restoration-tooth interface.[5-7] If these stresses exceed the adhesive strength of the bonding system, marginal gaps will be formed at the interface, leading to marginal leakage and eventual bond failure.[6,7] If the polymerization stresses are less than the adhesive strength, the stresses will be transmitted to the tooth structure, causing cuspal deflection and postoperative sensitivity.[6,7]

The amount of polymerization shrinkage depends mainly on the amount of shrinkable monomers, which are eventually converted into polymers.[6,7] The magnitude of shrinkage stress depends on many factors, including material formulation, type and amount of filler particles, curing technique, and the geometry of the cavity preparation.[6,7] Various strategies have been proposed to reduce polymerization shrinkage stresses, notably the use of modified monomers/fillers, delayed curing/incremental restorations, soft-start curing, and/or inserts.[6-11] Other strategies employ the use of either a stress-dissipating layer of flowable composite at the margin or a glass ionomer cement/bioactive hydraulic calcium silicate cement in an “open sandwich” technique.[12-14] All these strategies have shown promising results; however, the problem of shrinkage stress has still not been fully resolved.

The use of inserts has been advocated as a method to reduce the amount of shrinkable monomers and thus to reduce volumetric changes.[11,15] Ceramic inserts, precured composite resins, and glass fibers have been tested, all with limited success. A 2007 study by El-Mowafy et al evaluated the effect of placing a layer of fiber near the gingival margin in Class II slot cavities restored with composite resin.[15] The authors found that fiber inserts generally reduced the microleakage at the gingival margin in the dentin. However, the fiber insert was placed only at the gingival margin and not dispersed into the cavity.[15] A recent study has proposed the use of polyethylene fibers in lining a fiber post to improve its adaptation to the root canal

Table 1. Composition and mode of application of the adhesive systems and polyethylene fiber used in this study.

Product	Composition	Mode of application
Adper Single Bond	*Etchant:* 35% phosphoric acid gel *Adhesive:* dimethacrylate, HEMA, polyalkenoid acid copolymer, 5-nm silane-treated colloidal silica, ethanol, water, photoinitiator	Apply etchant, wait 15 s, and rinse for 10 s. Blot excess water. Apply 2 coats of adhesive for 15 s. Gently air thin for 5 s. Light cure for 10 s.
One Coat Self-Etching Bond	*Primer:* water, HEMA, acrylamidosulfonic acid, glycerol monomethacrylate and dimethacrylate, methacrylized polyalkenoate *Bonding:* HEMA, glycerol mono- and dimethacrylate, UDMA, methacrylized polyalkenoate, camphorquinone	Apply primer with gentle agitation for 20 s. Gently air thin for 2 s. Apply bonding agent with gentle agitation for 20 s. Gently air thin for 2 s. Light cure for 10 s.
Ribbond fiber	Preimpregnated, silanized, plasma-treated, leno-woven, ultrahigh–modulus polyethylene fibers	Cut 10-mm strips from 3-mm-wide ribbon. Soak fibers in bonding agent. Mesh fibers with composite resin to achieve homogenous mix.

Abbreviations: HEMA, hydroxyethyl methacrylate; UDMA, urethane dimethacrylate.

space.[16] It was hypothesized that if glass fibers were mixed with restorative resin, the amount of polymerizable resin would be reduced, which could result in better marginal adaptation.

The present study evaluated the effect of the incorporation of polyethylene fibers on the marginal adaptation of composite resin in Class II slot preparations. The cavities were restored with 2 different bonding strategies, and the amounts of polymerization stress were evaluated. After the restorations were subjected to simulated mechanical cyclic loading, the gingival adaptation of the restorations was evaluated in terms of a continuous margin (CM). The null hypothesis was that the incorporation of glass fibers in composite restorations would not affect the polymerization stresses or marginal adaptation.

Materials and methods

The study involved the use of 60 human mandibular third molars. The teeth were neither carious nor restored, and all had similar coronal dimensions. The teeth were subjected to the experiment within 1 week of their extraction. In the meantime, they were stored in distilled water at 4°C.

Cavity preparation

A standardized Class II slot cavity was prepared on the mesial surface of each tooth. The width of the isthmus was approximately 3.25 mm (± 0.25 mm). The approximate width of the gingival floor was 4.00 (± 0.25) mm. The gingival floor was kept at 1.00 mm below the cementoenamel junction to keep the gingival margin of the cavity in dentin. The cavity preparations were carried out using diamond burs in a water-cooled, high-speed turbine (KaVo Dental). All the experiments were carried out at room temperature.

The buccal surface of each tooth was ground to produce a flat surface. A strain gauge (EA-06-062AP-120, Vishay Precision Group) was attached to the surface using a cyanoacrylate adhesive (M-Bond 200, Vishay Precision Group). The attached tooth was allowed to set for 24 hours before the experiment began. The stress data were acquired using a D4 data acquisition conditioner (Vishay Precision Group).

The specimens were divided into 2 experimental groups (n = 30) based on the type of resin composite used to restore the cavity. The specimens in each group were then further divided into 2 subgroups on the basis of the adhesive system used.

Restorative groups

Fiber-reinforced resin

The specimens in the fiber-reinforced resin (FRR) restoration group were divided into 2 subgroups based on which adhesive system was used: The first subgroup (FRR-SB) employed an etch-and-rinse, single-bottle adhesive (Adper Single Bond, 3M ESPE); the second subgroup (FRR-OC) utilized a 2-bottle, 2-step, self-etching bonding system (One Coat Self-Etching Bond, Coltène/Whaledent).

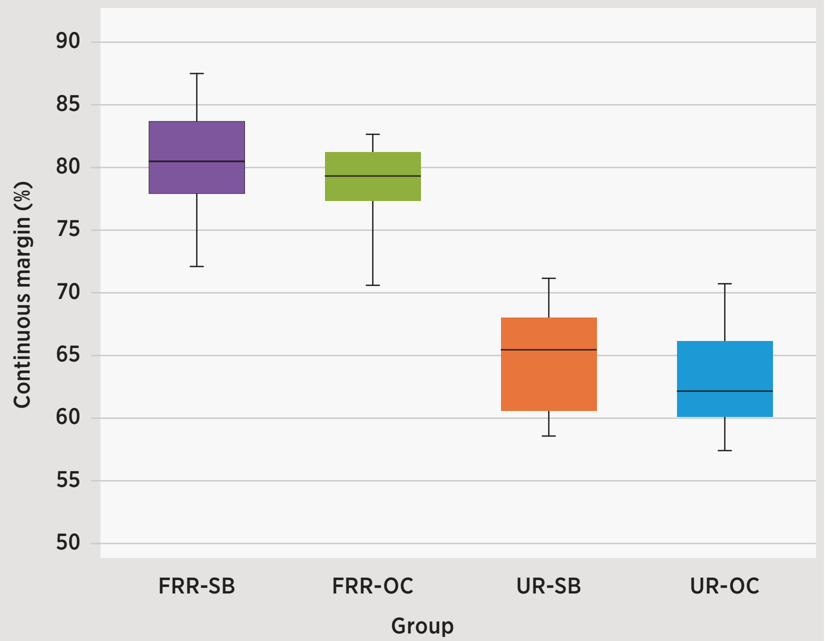
The composite resin was mixed and reinforced with a polyethylene fiber ribbon (Ribbond). A 3-mm-wide × 10-mm-long ribbon strip was transversely cut to obtain thin fiber strips. The strips were saturated with the selected adhesive system, and a 5-mm length of the corresponding composite material—Filtek Z350 (3M ESPE) for Single Bond and Synergy D6 Universal (Coltène/Whaledent) for One Coat Self-Etching Bond—was squeezed out of the tube. The fibers were meshed with the composite resin into a homogenous mix. The composition and mode of application of the bonding systems and the polyethylene fiber ribbon used in this study are described in Table 1.

After application of the bonding agent, the cavities were restored with the prepared fiber-reinforced composite resin in 2-mm increments applied with a clear matrix strip. After curing, the matrix strip was removed, and gingival margins were contoured with a composite resin polishing kit (Shofu Dental).

Unreinforced resin

The specimens in the unreinforced resin (UR) restoration group were also divided into 2 subgroups (UR-SB and UR-OC) based on the same adhesive systems as in the FRR subgroups. After application of the appropriate adhesive system, the cavities were restored with the corresponding—but unreinforced—composite resins used in the FRR-SB and FRR-OC groups.

Chart. Percentages of continuous margin.



Abbreviations: FRR-SB, fiber-reinforced resin restoration with an etch-and-rinse adhesive system; FRR-OC, fiber-reinforced resin restoration with a self-etching adhesive system; UR-SB, unreinforced resin restoration with an etch-and-rinse adhesive system; UR-OC, unreinforced resin restoration with a self-etching adhesive system.

Upper and lower bounds of the boxes indicate 75th and 25th percentiles of the interquartile range, respectively. Lines within the boxes indicate the median. Upper and lower whiskers indicate the minimum and maximum values, respectively.

Strain and marginal evaluations

During restoration of the cavities, strain measurements were recorded. The residual strain at the end of 15 minutes was considered to be the final residual stress. After the stress measurements were completed, the specimens were subjected to cyclic loading. Each specimen was subjected to a total of 150,000 cycles of mechanical loading over a span of 3 months. The specimens were kept at a 100% moisture level during mechanical loading.

After completion of mechanical loading, the gingival margin was analyzed at 25-300× magnifications in a scanning electron microscope (SEM) (EVO LS, Carl Zeiss Microscopy). The marginal adaptation for each subgroup was evaluated in terms of the percentage of CM. The criteria for a CM was a continuous interface between the restoration and tooth that exhibited a gap of less than 1 µm. If the gap was greater than 1 µm, the margin was classified as a gapped margin. The percentage of CM was recorded for each subgroup.

The effect of fiber reinforcement and type of bonding agent on the residual stress values and percentage of CM was analyzed using separate 2-way analysis of variance (ANOVA) tests. The level of confidence was set at 0.05.

Results

The FRR group as a whole had significantly lower mean (SD) strain values than did the UR group: 185 (37) µm/m and 295 (21) µm/m, respectively ($P < 0.05$). Among the subgroups, UR-SB presented with the highest mean strain values (298 [SD 19] µm/m) followed by UR-OC (291 [SD 22] µm/m), FRR-OC (192 [SD 19] µm/m), and FRR-SB (177 [SD 48] µm/m). There was no significant difference between the adhesive subgroups ($P > 0.05$).

The marginal adaptation was evaluated in terms of the percentage of CM (Chart). The FRR group as a whole presented with a higher percentage of CM than did the UR group. Overall the FRR group had a mean CM value of 80.2% (SD 4.6%), which was significantly higher than that of the UR group, which was 64.4% (SD 4.2%). There was a significant difference between the different dentin substitutes, so the null hypothesis was rejected ($P < 0.05$; 2-way ANOVA with Holm-Sidak correction for multiple comparisons) (Table 2). However, there was no significant difference in percentage of CM between the 2 adhesive systems and their corresponding composite resins.

Discussion

The results of the present study indicated that incorporating polyethylene fibers into a composite resin matrix improves the marginal adaptation of these restorations. Light curing of composite resins leads to polymerization of the organic matrix via free radical polymerization.[2-5] As a result, the resin matrix changes from a pre-gel phase to a more viscous state.[2-5,17] At this point, the material is able to relieve the contraction stresses. Further polymerization leads to the formation of a rigid mass,

Table 2. Two-way ANOVA of continuous margins.

Source of variation	*df*	SS	MS	*F*	*P*
Incorporation of polyethylene fibers	1	3738.283	3738.283	223.257	< 0.05
Adhesive system and composite resin	1	64.067	64.067	3.826	0.055 (NS)

Abbreviations: ANOVA, analysis of variance; *df*, degrees of freedom; MS, mean square; NS, not significant; SS, sum of squares.

also known as a *post-gel phase*.[17] This phase has a higher modulus of elasticity and is unable to relieve the volumetric contraction stresses.[17]

In clinical conditions, a composite resin solidifies almost immediately after the application of light curing, and a very short period of time is available for stress-relieving, pre-gel shrinkage. As a result, stresses begin to develop at the resin-tooth interface as soon as curing is initiated.[17] To decrease the rate of polymerization and allow more time for pre-gel shrinkage, the initial methods used to control polymerization shrinkage stresses were aimed at modifying photoactivation methods.[18,19] The soft-start method employs the use of an initial low irradiance followed by full-strength irradiance. The pulse-delay method consists of an initial low irradiance followed by alternating periods of no irradiance and full-strength irradiance.[18] However, these methods did not provide the desired results, since most shrinkage occurs during the post-gel phase.[19]

Some authors have advised the use of a liner below composite resin.[12] Various liners have been evaluated, including flowable composites, resin-modified glass ionomer cements, and even hydraulic calcium silicate materials.[12-14] Flowable composites have a low modulus of elasticity and are used in stress-bearing areas.[11,12] The other liners reduce the bulk of composite material, thus reducing the overall shrinkage of the mass.

Another method to reduce the bulk of the composite matrix is the use of inserts.[11,15] One study evaluated the use of composite inserts on gingival microleakage in Class V cavities.[20] The results suggested that inclusion of inserts improved the sealing ability at the gingival margins compared to a bulk insertion technique.[20] However, concerns were raised regarding the high elastic moduli of these megafillers, and the bonding between inserts and composite matrices was questioned.[15] Some studies reported little or no beneficial effect of ceramic inserts on the marginal adaptation of composite restorations.[21-23] In a study using glass fiber inserts (which have a low modulus of elasticity), El-Mowafy et al incorporated the inserts at the gingival seats of Class II slot preparations.[15] The results indicated that the use of fiber inserts reduced gingival microleakage, regardless of the bonding system used. However, the fiber inserts were placed only on a single margin and were not evenly distributed in the restoration.[15]

A new method of incorporating fiber inserts was evaluated in the present study. A polyethylene fiber ribbon was used as an insert. This ribbon has also been referred to as a *leno-weave ultrahigh-modulus polyethylene fiber*.[24] As stated previously, in the present study the fiber ribbon was cut and meshed with the composite resin. To improve the bonding between the fiber-composite matrix, the fibers were soaked with a bonding agent before they were mixed with the composite resin. A homogenous mass was achieved and packed in increments in the cavity.

The gingival margins of the restorations were evaluated under an SEM, and the marginal adaptation was evaluated in terms of percentage of CM. This method has been shown to overcome the shortcomings of traditional microleakage assay methods.[14] The results suggested that incorporating these fibers in the composite resin matrix improved the marginal adaptation of the composite resin to the dentinal substrate. A specimen from the FRR-SB group was sectioned and observed under an SEM at 40× magnification, revealing that the fibers were well distributed throughout the composite matrix.

The ability of polyethylene fibers to improve marginal adaptation in these Class II restorations involved 3 factors. First, the fibers reduced the bulk of the composite matrix, leading to a reduction of shrinkable mass.[15,25] Second, the fibers combined the resin into a single mass that resisted deformation. Third, the fibers may have helped in dissipating the simulated mechanical loading.

The effect of the fibers on the shrinkage stress was also evaluated by placing a strain gauge on the buccal surface of the specimens.[25] Placing fibers in the composite resin matrix reduced the strain values transmitted to the tooth surface. The values obtained were less than those that have been reported in the literature.[5,12,17] This can be explained by the fact that the present study evaluated small Class II slot preparations. The bulk of the tooth was intact, which could have helped prevent the deformation of the tooth. Moreover, the cavity preparation sizes were minimal, reducing the overall size of the restoration, and the total stresses transmitted to the teeth were less than those associated with mesio-occlusodistal cavities.[24]

The present study has other limitations. One goal was to standardize the ratio of composite resin matrix to polyethylene fiber (5-mm-long increment of composite resin mixed with 10 × 3-mm-wide fiber ribbon). However, it was difficult to repeat this ratio with precision every time. In addition, the stress measurements were taken at room temperature and not at a standardized 37°C. It has been well documented that changes in temperature affect strain measurements.[4,5] However, in this case, the differences would have been similar for both groups.

Conclusion

Within the limitations of this in vitro study, results suggest that incorporating polyethylene fibers in a composite resin matrix can help to improve gingival marginal adaptation in Class II cavities.

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Disclaimer

The authors report no conflicts of interest pertaining to any of the products or companies discussed in this article.

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