Resin composite polyethylene fiber reinforcement: Effect on fracture resistance of weakened marginal ridges

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ABSTRACT: Purpose: To investigate the *in vitro* effect of polyethylene woven fiber reinforcement of resin composite on the fracture resistance of weakened marginal ridges in molar teeth. **Methods:** 50 sound extracted human mandibular molars were used. Specimens were divided into five groups (n=10). Group 1: served as a control for comparison; Group 2: Class I cavity preparation with resin composite (Prodigy); Group 3: Class I cavity preparation with polyethylene ribbon fiber (Ribbond) and resin composite. Group 4: Class II cavity preparation with resin composite restoration; Group 5: Class II cavity preparation with polyethylene woven fiber and resin composite. Specimens were stored in 100% humidity at 37°C for 7 days. Compressive loading of the teeth was performed with a universal testing machine at a cross-head speed of 0.5 mm/minute until failure. The data were analyzed with 1-way ANOVA followed by the Ryan-Einot-Gabriel-Welsch Multiple Range Test ($\alpha = 0.05$). **Results:** Reinforcement with polyethylene fiber resulted in significant differences for fracture resistance ($P < 0.001$). Mean fracture resistance (SD) was [1737.4 (84.8) N] for control group. Among the experimental groups, the highest mean fracture resistance (SD) [1543.8 (71.1) N] was associated with Class I cavity preparation with polyethylene fiber and resin composite. The lowest mean fracture resistance (SD) [869.2 (91.7) N] was recorded for Class II cavity preparation with conventional resin composite. (*Am J Dent* 2010;23:133-136).

CLINICAL SIGNIFICANCE: The fiber-reinforced composites tested improved the fracture resistance of Class I cavities.

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Introduction

Dental treatment procedures are increasingly governed by factors such as biocompatibility of restorative materials, patient's demands for esthetics, and a conservative approach to minimize loss of tooth structure.[1]

Following the traditional Black's principles for cavity preparation, all undermined enamel should be removed even for marginal ridges composed of healthy, sound and caries-free undermined enamel.[2] This could be attributed to the brittle nature of the undermined enamel and the inability of the conventional cast inlays and amalgam restorations to strengthen the remaining tooth structure.[3,4] However, the increased use of resin composites in posterior teeth violate these principles.[5,6]

Restoring teeth with minimal sacrifice of sound tooth structure depends mainly on adhesives that provide strong and durable bonding to the remaining sound enamel and dentin. Laboratory reports[7] have proven that modern adhesives do effectively bond to tooth tissue in the short term. However, clinically, marginal deterioration of composite restorations remains problematic in the long term and still forms the major reason to replace adhesive restorations.[8-10] When resin composite is bonded to tooth structure using adhesives, the initial and residual polymerization stresses that are present along the cavity walls may result in gap formation, leakage, recurrent caries and pulp irritation.[11] The detrimental effect of marginal gap formation cannot be offset even with the use of fluoride-releasing adhesives or restorative materials that prevent demineralization along cavity margins.[12] Thus, only hermetic sealing of restorations guarantees clinical success.[13]

The purpose of a restorative material is not only to restore the decayed or defective tooth and provide an effective seal between the restoration and the tooth, but also to strengthen the tooth. Studies[14,15] showed that strength of the teeth was significantly reduced after cavity preparation; others,[16,17] however, report no significant difference between fracture resistance of intact teeth and the teeth that were prepared but unrestored. Morin *et al*[18] showed that the mean relative deformation and stiffness values for acid-etched bonded teeth resemble the mean relative deformation and stiffness values for sound teeth. Simonsen *et al*[19] showed that teeth restored with resin composite were stronger than those restored with amalgam when tested at cusp inclines.

An important clinical controversial condition is the presence of undermined marginal ridge of full thickness of enamel after cavity preparation. The clinician either leaves the undermined marginal ridge and restores the tooth, or removes the thin enamel preparing Class II and restores the tooth. The conservative option depends mainly on the ability of the bonded restoration to strengthen the enamel in the same way that dentin gives strength and supports the enamel.[20-22]

In order for a dental material to reinforce the tooth, it must bond to dentin. As such, an essential attribute of a good dentin adhesive system is the ability of the adhesive to wet and infiltrate the dentin. In restorative dentistry, numerous studies have demonstrated coronal reinforcement of the tooth through bonded restorations.[6] Bonded amalgams and resin composites have all been shown to reinforce remaining tooth structure by bonding to dentin and enamel.[6,23,24] Similarly, bonding endodontic sealers to intra-radicular dentin after root obturation could enhance resistance to fracture of endodontically-treated teeth.[25]

The development of fiber-reinforced composite technology has created a new era in metal-free, adhesive, esthetic dentistry. Resin impregnated fiber-reinforced composite has been shown to possess adequate flexure modulus and flexural strength to function successfully in the mouth.[26] Moreover, the system has demonstrated good results in a wide range of applications including crowns,[27] veneering of metals,[28] fixed partial dentures,[29] splints,[30] and implant prostheses.[31] Clinical studies[32,33] on fiber-reinforced restorations have shown a relatively high success rate over a relatively short evaluation period. However, their use to reinforce structurally compromised marginal ridges has not been shown. This study tested the hypothesis by which a fiber-reinforced resin composite would enhance the performance of resin composites in the marginal ridge area. The null hypothesis was that glass fiber-reinforced composite would have no influence on the fracture resistance of weakened marginal ridges in molar teeth.

Materials and Methods

Fifty intact recently extracted human mandibular molar teeth with similar dimensions were debrided to remove remnants of periodontal ligaments. The teeth were stored in distilled water with 0.1% thymol disinfectant[a] at room temperature. To minimize the influence of variations in size and shape on the results, the teeth were classified according to their mesiodistal and buccolingual dimensions and randomly divided into five groups (n=10) according to the restoration used. Each tooth was aligned vertically in an individual polymeric tube and embedded with epoxy resin (Epoxide[b]) within 2 mm of the cemento-enamel junction. A dental surveyor[c] was used to position the long axis of each tooth parallel to the tube. Mounted teeth were stored in 100% humidity. The mounted teeth of the five experimental groups were assigned as: (1) intact teeth without cavity preparation or restoration (control), (2) Class I cavity preparation restored with conventional resin composite (Prodigy[d]), (3) Class I cavity preparation restored with fiber-reinforced composite restoration (Ribbond[e]), (4) Class II cavity preparation restored with conventional composite restoration, and (5) Class II cavity preparation restored with fiber-reinforced composite restoration.

Occlusal Class I and compound Class II cavities were designed and standardized to be cut at the corresponding experimental groups. Each cavity preparation was prepared using a water-cooled #56 straight fissure tungsten carbide bur[f] in a high-speed hand piece. A new bur was used after each preparation. Class I cavity preparation had a bucco-lingual width of 2 mm, pulpal depth of 2.5 mm on the occlusal surface, and one marginal ridge thickness to be tested was 1.0 mm while the other marginal ridge was 2 mm. The Class II cavity preparation had a bucco-lingual width of 2.0 mm and pulpal depth of 2.5 mm on the occlusal surface, and the proximal box had an axial depth of 2.0 mm, a bucco-lingual width of 4.0 mm and an occluso-gingival height of 5.0 mm. The buccal and lingual walls were cut parallel to each other on both the occlusal and proximal portions of the cavity. Similarly, the axial wall of the Class II cavity was kept parallel to the long axis of the tooth. The gingival margins were maintained 1.5 mm above the cemento-enamel junction. Bevels and retentive grooves were not used in the study. Cavity preparation was finished by using binangle chisel and enamel hatchet and cavosurface margins were finished to 90°. The internal line angles were not altered with hand instruments but left as cut by the #56 bur.

Each cavity preparation was cleaned, dried, and etched with 32% phosphoric acid[g] for 15 seconds applied with a plastic needle-nose application tip. This was followed by rinsing with water for 30 seconds and air drying. OptiBond Solo Plus[d] bonding agent was placed according to manufacturer's directions, gently dried, and light polymerized for 20 seconds using a curing unit (Demetron[h]). Light intensity output was monitored with a curing radiometer[h] to be less than 750 mW/cm^2. Verification of the unit light intensity output was checked every five samples.

Cavities of Group 2 and Group 4 were then restored with a resin composite (Prodigy) using a bulk technique and cured for 40 seconds.[14] To standardize the curing distance, the tip of the polymerization unit was applied to the occlusal surface of the teeth. A matrix band was applied to each cavity of Group 3 and Group 5 and a flowable resin composite (PermaFlo[d]) was added to the floor of the cavities but not cured. A 3 mm-wide leno weave ultra high modulus (LWUHM) polyethylene ribbon fiber[e] was cut and saturated with adhesive resin (Optibond Solo Plus). The excess adhesive resin was removed with a hand instrument and then placed into the bed of uncured flowable resin composite at the area of marginal ridge from a buccal to lingual direction. This combination was then cured for 20 seconds from the occlusal surface using the same curing unit and the exposed fiber surface was covered with resin composite (Prodigy), and cured for 40 seconds. Excess material was removed and final polishing was performed with stone points, rubber, and wheel instruments (Polierset[i]), following the manufacturer's recommendations. The restored teeth were then stored in distilled water at room temperature for 7 days before testing.

The marginal ridge of each tooth was adjusted with a fine diamond point at high speed under air-water spray, so that each marginal ridge provides a uniform contact for the load applicator. Resistance to fracture was measured by applying a vertical compression force sufficient to fracture the marginal ridge of each specimen with a universal testing machine (model 4204[j]), with a 1000 N load cell and 0.5 mm/minute cross-head speed. A 5 mm-diameter stainless steel bar with round-shape end was affixed to the upper stage of the Instron. The upper stage was positioned so that the bar was centered over the marginal ridge until the bar end just contacted the marginal ridge. Mean values for each group were calculated, and differences between the groups were tested for statistical significance. One-way ANOVA and the Ryan-Einot-Gabriel-Welsch Multiple Range Test at $\alpha = 0.05$, were used. The Ryan-Einot-Gabriel-Welsch Multiple Range Test was used as it appears to be the most powerful, yet valid, step-down multiple-stage test in the current literature.[34]

Results

The one-way ANOVA for the results of marginal ridge reinforcement revealed a statistically significant difference among the group means ($P < 0.001$) (Table 1). The Ryan-Einot-Gabriel-Welsch Multiple Range Test disclosed a significant difference between groups ($P < 0.001$) (Table 2). The marginal ridges of the sound teeth showed significantly higher resistance to fracture (1737.4 N). Class I cavities with fiber-reinforced resin composite had the highest fracture strength (1543.8 N) of the experimental groups, which was 10.2% higher than Class I cavities with conventional resin

Table 1. One-way ANOVA procedure.

Source	df	MS	F	P
Between groups	4	1099050.93	165.79	< 0.001
Error	45	6629.29		

composite (1400.1 N). Class II cavities restored with fiber-reinforced resin composite had intermediate fracture strength (1214.5 N), which was 39.7% higher than Class II cavities restored with conventional resin composite (869.2 N).

Discussion

The data supports the null hypothesis of the study, that glass fiber-reinforced composite increases the fracture resistance of weakened marginal ridges in molar teeth. The strengthening effect of polyethylene fibers in weakened marginal ridge is a significant concern. Investigators[23,24,35] have evaluated the effect of polyethylene fibers to prevent the undesirable fractures in cuspal coverage restorations. Fibers have demonstrated their ability to withstand tensile stress and to stop crack propagation in composite material.[36] Moreover, changing the internal stress patterns of the restorative material by the application of the fiber layer may also lead to an increase in the load-bearing capacity of the restoration.[37]

Traditionally, weakened undermined marginal ridges of molar teeth during cavity preparation include extension of the occlusal cavity into the corresponding proximal surface. Class II cavities may initiate caries recurrence at the gingival area, weakening of the tooth structure due to actual cutting of the tooth tissue holding the buccal and lingual cusps together at the marginal ridge area, in addition to periodontal problems.[18]

Adhesive restorative materials have been recommended as cost effective and more esthetic alternative options for protecting weakened tooth structure.[19] In the present study, control sound teeth had the highest fracture resistance at the marginal ridge area as it seems logical that a tooth with no preparation will be stronger than a tooth with either a small or large restoration.

Results of the current study also showed that Class I cavity preparation restored with fiber-reinforced resin composite was stronger than Class II cavities restored with either resin composite or fiber-reinforced resin composite when tested at the marginal ridge area. It was assumed that polyethylene fiber had a stress modifying effect along the restoration and dentin interface. The other possible explanation may be due to the properties of the fiber itself, the degree of chemical bonding between the resin and the fiber and the effect of the leno weave with regard to crack resistance and deflection as well as resistance to shifting within the resin matrix.[30] Previous studies[38,39] showed that Class I preparations restored with resin composite were weaker than Class II preparations restored with either amalgam or resin composite when tested at the marginal ridge area. This contradiction may be due to the difference in the methodology utilized as they used premolars, other brands of resin composite and a very low cross-head speed during testing. Undoubtedly, the rapid advancement in the bonding technology, and dental material science could encourage testing the products in teeth with more compromised tissues. One of such controversial aspects is the management of the undermined, healthy intact marginal ridge during cavity preparation. In the current study, during the preparation of the samples, composite restorations were inserted in bulk and cured from the occlusal surface for 40 seconds although incremental composite curing has been favored in clinical conditions. Using the bulk technique, the effect of restoration placement was eliminated. The results obtained from this study are only introductory and comparative. There were some limitations in the present study. Although fracture resistance was evaluated, marginal gap which could possibly jeopardize restoration longevity was not estimated. Another limitation of this study was that the forces applied were at a constant direction and speed, although forces generated intraorally vary in magnitude, speed of application and direction. Furthermore, only one type of fiber and resin composite was used. Further investigation is required to evaluate the effect of mechanical, thermal and chemical stress on the durability of restoration.

Table 2. Fracture strength of structurally compromised marginal ridges (Mean ± SD; n= 10).

Groups	Fracture strength
Control	1737.4 (84.8)[a]
Class I cavity with resin composite	1400.1 (79.5)[b]
Class I cavity with fiber-reinforced resin composite	1543.8 (71.1)[c]
Class II cavity with resin composite	869.2 (91.7)[d]
Class II cavity with fiber-reinforced resin composite	1214.5 (78.6)[e]

Values with different case letters were significantly different at P< 0.001.

Further laboratory and clinical studies are required to confirm the results of the present study.

a. Sigma Chemical Co., St. Louis, MO, USA.
b. Leco Corp., St. Joseph, MI, USA.
c. Ney Company, Bloomfield, CT, USA.
d. Kerr, Romulus, MI, USA.
e. Ribbond Inc., Seattle, WA, USA.
f. Abrasive Technology Inc., Westerville, OH, USA.
g. Bisco Inc., Schaumburg, IL, USA.
h. Demetron/Kerr, Danbury, CT, USA.
i. Ivoclar Vivadent Inc, Amherst, NY, USA.
j. Instron Corp., Canton, MA, USA.

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