

***In vitro* effect of fiber reinforcement on fracture resistance of incisal edge composite restorations**

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Abstract

Objective: Introduction of fiber-reinforced composites (FRC) greatly enhanced the restoration of fractured anterior teeth. The purpose of this study was to assess the effect of fiber reinforcement on fracture resistance of incisal edge composite restorations of variable thicknesses.

Methods: Forty extracted sound human maxillary incisors were divided into four groups of 10. Incisal reduction was done by 3mm in groups 1 and 3 and by 4mm in groups 2 and 4. Incisal edge was restored with hybrid composite in groups 1 and 2 and hybrid composite reinforced by two Ribbond fibers in the palatal surface in groups 3 and 4. All specimens were mounted in acrylic blocks, stored in saline solution and thermocycled. The teeth were then subjected to static load by universal testing machine until fracture. The load was applied at 135° angle relative to the tooth surface to an area 2mm apical to the incisal edge at a crosshead speed of 1mm/min. Data were analyzed using Tukey's test and $p \leq 0.05$ was considered significant.

Results: The mean fracture resistance was 436 (242) N, 492 (195) N, 992 (275) N and 1080 (236) N in groups 1 to 4, respectively and the difference in this regard among the 4 groups was statistically significant ($p=0.000$). The mean fracture resistance in group 3 (fiber-reinforced, 3mm thickness) was higher than that in group 1 (no fiber, 3mm thickness). This value in group 4 (fiber-reinforced, 4 mm thickness) was also higher than in group 2 (no fiber, 4mm thickness). The highest fracture resistance was seen in group 4. Thickness of composite had no significant effect on fracture resistance ($p=0.347$).

Conclusion: Application of two Ribbond fibers can significantly increase the fracture resistance of incisal edge composite restorations.

Key words: Anterior tooth, Crown fracture, Fiber-reinforced composite, Fracture resistance.

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Introduction:

Crown fracture is a commonly encountered traumatic injury affecting approximately 25% of the population below 18 years of age (1). Incidence of such traumatic injuries is higher for maxillary anterior teeth due to their special position in dental arch (2-4).

Selection of a restorative treatment for a broken permanent maxillary incisor is not a simple decision to make and represents a clinical

challenge to the clinician. Patient age, size of fracture, pulp exposure, size of the broken fragment, stage of dentition and type of occlusion must be all taken into account when deciding on the best treatment for each patient (5). Many techniques have been suggested for restoration of tooth crown fractures such as porcelain or metal-ceramic crowns or re-attachment of the broken segment (6). However, the efficacy of these treatment modalities is questionable since they all require reduction of

sound tooth structure known as tooth preparation (7). Introduction of dental adhesive systems enabled more conservative restorative treatments. Direct composite laminate veneers are among the minimally invasive techniques with advantages such as no tooth preparation, low cost and reversibility of treatment (8). Moreover, their intraoral polishing is easy and possible cracks or fractures may be intraorally repaired. However, they have some shortcomings as well, namely low resistance to wear, discoloration and fracture (9). Low mechanical properties of conventional composites necessitate the use of fiber-reinforced composites for specific cases. Clinical evidence shows acceptably high short-term success rate for FRC restorations (10).

The effect of fiber reinforcement on fracture resistance of composites has been the subject of many previous investigations (11, 12). Garoushi, *et al.* in 2007 evaluated the static load-bearing capacity of maxillary incisors restored with complete crowns made of fiber-reinforced composite resin and reported superior load-bearing capacity of fiber-reinforced composite restorations compared to those restored with regular composite (13). The same author in another study investigated the load-bearing capacity of posterior composite crowns made of fiber-reinforced composite and demonstrated their superior load-bearing capacity compared to conventional non-reinforced composite resins (14). However, Pereira, *et al.* in 2003 assessed the effect of polyethylene fiber reinforcement on flexural strength of a hybrid composite and showed that use of polyethylene fiber in conjunction with hybrid composite did not increase the flexural strength of restoration (15). No previous study is available on the effect of fiber reinforcement on fracture resistance of incisal edge composite restorations. Considering the existing gap of information in this respect, this study sought to assess the effect of application of two Ribbond fibers on fracture

resistance of incisal edge composite restorations in 3 and 4 mm thicknesses under in-vitro conditions simulating the clinical setting (cyclic loading).

Methods:

The study protocol was approved in the ethics committee of Islamic Azad University, Dental Faculty. This experimental study was conducted on 40 extracted sound human maxillary central incisors that were free from cracks, caries, restorations or congenital defects. The teeth with approximately similar dimensions (mesiodistal width of 6-8 mm and length of 8-10mm) were selected. Sample size was calculated to be 40 according to previous studies (12). Any debris or soft tissue residues were removed and the teeth were cleaned using pumice paste and rubber cup. The teeth were then immersed in 0.5% chloramine T solution for disinfection for 24 hours and then transferred to saline solution.

Specimen preparation:

The teeth were randomly divided into 4 groups of 10 and received the following preparations: Group 1 (control group 1): Incisal edges of the teeth in this group were reduced by 3 mm using a metal disc with 0.2mm diameter and high speed hand piece at a direction perpendicular to the long axis of the teeth. The cutting line was parallel to the incisal edge. Teeth with accidental pulp exposure were excluded and replaced with new ones. Incisal reduction was done with one move to prevent excess reduction of tooth structure. Each disc was only used for 3 teeth. Using football-shaped bur (SS White, RSQR Ltd., UK) a continuous bevel with 2mm width was made below the fracture line. The teeth were then mounted in auto-polymerizing acrylic resin (Acropars, Iran) with 1cm diameter. The prepared surface was etched by 37% phosphoric acid (Kerr, Orange, USA) for 15 seconds according to the manufacturer's instructions, rinsed with water for 30 seconds and air dried

for 10 seconds using air spray. Using a microbrush, OptiBond Solo (Kerr, Orange, USA) bonding agent was then applied to the surface and light cured for 20 seconds using Coltolux 215 light curing unit (Coltolux, Coltene/Whaledent Inc., Switzerland) with a light intensity of 500 mW/cm^2 . Hybrid composite (Herculite, Kerr, Orange, USA) was then incrementally applied to the incisal edge. Each increment was light cured for 40 seconds from the palatal, 40 seconds from the labial and 40 seconds from the incisal directions. The final tooth morphology was reconstructed as such.

Group 2 (control group 2): The teeth in this group were prepared the same as in group 1. The only exception was that incisal reduction was done by 4 mm.

Group 3 (case): The teeth were prepared as in group 1; but after the conduction of 2mm bevel, 2 grooves were prepared at 1mm distance from the proximal surfaces using depth-cut bur (GOTA, Switzerland) and high-speed hand piece. The grooves were below the fracture line and had 2mm length, 1 mm width and 0.5mm depth corresponding to the dimensions of the fibers to be used. The teeth were then mounted in autopolymerizing acrylic resin (Acropars, Iran) with 1cm diameter. The prepared surface was etched by 37% phosphoric acid (Kerr, Orange, USA) for 15 seconds according to the manufacturer's instructions, rinsed with water for 30 seconds and air dried for 10 seconds using air spray. Using a microbrush, OptiBond Solo (Kerr, Orange, USA) bonding agent was then applied to the surface and light cured for 20 seconds using Coltolux 215 light curing unit (Coltolux, Coltene/Whaledent Inc., Switzerland) with a light intensity of 500 mW/cm^2 . The grooves were filled with flowable composite (Premise, Kerr, USA) and resin-soaked polyethylene fibers (Construct, Kerr, Orange, USA) were placed over the composite in such way that 2mm of the fibers were positioned on the prepared grooves in the palatal surface while

the remaining 2mm was above the fractured edge. Excess composite was removed and the fibers and flowable composite were light cured for 40 seconds.

Hybrid composite (Herculite, Kerr, Orange, USA) was applied to the palatal surface and incisal edge around the fibers and was formed 1mm higher than the fiber height. After final shaping, the composite was cured for 40 seconds from the palatal, 40 seconds from the labial and 40 seconds from the incisal edge (Figure 1).

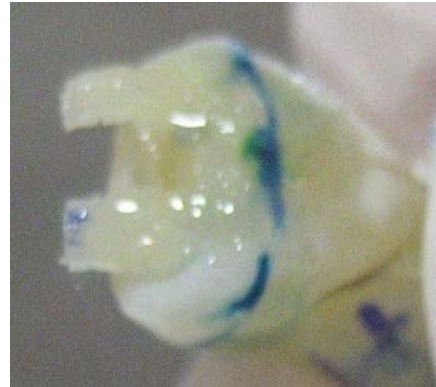


Figure 1- Preparation of teeth

Group 4. The teeth were prepared as in group 2 (4mm incisal reduction) and restored as in group 3 (palatal fibers).

The only difference was that the thickness of hybrid composite at the incisal edge was 2mm higher than the fiber length (total composite thickness of 4mm).

Thermocycling:

During the study period, the teeth were stored in saline solution at room temperature to prevent dehydration. After restoration, the teeth were subjected to 5000 thermal cycles between 5-55°C with a dwell time of 20 seconds and transfer time of 10 seconds to simulate occlusal loads in the clinical setting.

Fracture resistance testing:

After thermocycling, the teeth were transferred to a universal testing machine (Zwick Roell Z20, Germany) to assess their fracture resistance. Static load was applied to the tooth surface at an area 2mm below the incisal edge at 135° angle

relative to the tooth surface using a blade with a mesiodistal width greater than that of the teeth at a crosshead speed of 1mm/min. To prevent blade misplacement, a groove corresponding to the blade was created at the desired location. The load required for fracture in each tooth was recorded in Newton.

Statistical analysis:

Data were statistically analyzed using SPSS version 20 (Microsoft, IL, USA) and Tukey's test.

Two-way ANOVA was applied to assess the effect of fiber reinforcement and thickness of composite on fracture resistance. $P \leq 0.05$ was considered statistically significant.

Results:

Forty maxillary central incisors were prepared and restored as described earlier and were subjected to thermocycling and fracture resistance testing. The fracture strengths of composite restorations in the 4 groups are shown in Table 1.

As seen in Table 1, fiber reinforcement of

composite in both 3 and 4 mm thicknesses increased the fracture resistance of incisal restorations. However, by increasing the composite thickness over the fiber, fracture resistance did not change significantly ($p=0.347$). In group 1 (no fiber, 3mm thickness) fracture resistance was 435 (242) N, which increased to 992 (275) N in group 3 (fiber-reinforced, 3mm thickness); indicating 557 N increase in fracture resistance (1.3 times). This difference was statistically significant ($p<0.0001$). In group 2 (no fiber, 4mm thickness) fracture resistance was 492 (195), which increased to 1079 (236) N in group 4 (fiber-reinforced, 4mm thickness), indicating 588N increase in fracture resistance (1.2 times). This increase was statistically significant as well ($p=0.000$). Two-way ANOVA confirmed the effect of fiber reinforcement on fracture resistance ($p=0.000$) but the effect of thickness on fracture resistance was not statistically significant ($p=0.347$). The interaction effect of fiber and thickness on fracture resistance of incisal edge composites was not significant either ($p=0.838$) (Table 2 and Diagram 1).

Table 1- Fracture resistance in the 4 groups

Fiber/Fracture resistance (N)		Minimum	Maximum	mean	Standard deviation
Thickness					
No fiber (n=10)	3mm (group 1)	21.1	753.4	435.56	242.42165
	4mm (group 2)	221.5	900	491.96	195.51546
Fiber reinforced (n=10)	3mm (group 3)	531.7	1521.3	992.01	274.74038
	4mm (group 4)	600.0	1384.2	1079.518	235.71568

Table 2- Two-way ANOVA

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3326078.810 ^a	3	1108692.937	19.447	.000
Intercept	22485722.266	1	22485722.266	394.419	.000
fiber	3271885.760	1	3271885.760	57.392	.000
thickness	51773.781	1	51773.781	.908	.347
fiber * thickness	2419.269	1	2419.269	.042	.838
Error	2052348.429	36	57009.679		
Total	27864149.505	40			
Corrected Total	5378427.239	39			

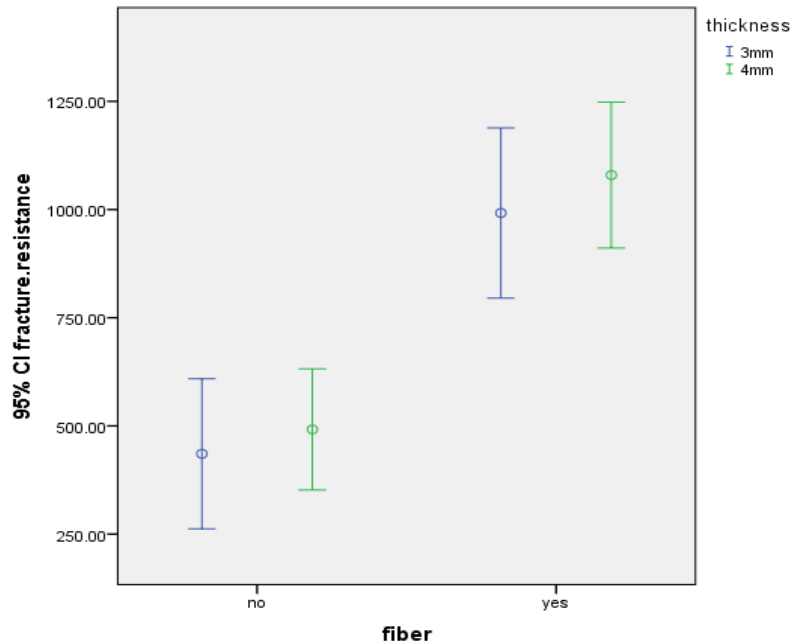


Diagram 1- Fracture resistance of the 4 groups

Discussion:

Traumatized anterior teeth are in need of quick aesthetic and functional repair. Aside from esthetic characteristics, the physical properties of restorative materials should also be taken into account for long-term clinical service of restoration. Reinforcement of composite restorations with fiber aims to enhance the physical properties of composite resins. The purpose of this study was to assess the effect of fiber reinforcement on fracture resistance of incisal edge composite restorations and showed that application of two Ribbond fibers increased fracture resistance of incisal edge composite restorations. However, increasing the thickness of composite from 3 to 4mm had no significant effect on fracture resistance of restorations.

In 2007, Garoushi, *et al.* evaluated the fatigue strength of fractured teeth restored with FRC (16) and reported higher fatigue resistance in FRC restored group compared to the control group (reattached tooth) and regular composite group; which is in accord with our results. In

2009, Fennis, *et al.* assessed the fracture resistance of fractured teeth reattached with FRC (17) and showed higher fracture resistance in cases where coronal fragments were reattached to the remaining tooth with two FRC anchors placed at the mesial and distal (on palatal surface) to restore fractured incisal edge compared to cases where coronal fragment and composite (without FRC anchors) were used; this finding is in line with our results as well. Badakar, *et al.* in 2011 investigated the fracture resistance of microhybrid, nanofilled and fiber-reinforced composites applied to restore the incisal edge of fractured maxillary central incisors (18). They concluded that FRC was suitable for incisal edge restoration of fractured anterior teeth in terms of both aesthetics and longevity. These results confirm our findings. Fennis, *et al.* evaluated the fracture resistance of FRC cusp-replacing restorations in premolar teeth (19) and found no significant difference in fracture resistance of different groups (2 layers of glass fiber+ composite versus 1 layer of glass fiber+ composite versus composite alone).

However, FRC changed the mode of failure. In teeth restored with FRC, restoration failed without tooth fracture while in 93% of teeth restored with regular composite (no fiber), cohesive fracture occurred within the tooth structure below the cemento-enamel junction. Their results are in contrast to our findings. Such difference in results of the two studies may be due to the use of different fibers since they used glass fiber while we used polyethylene fiber in the current study. Moreover, use of different teeth, difference in the angle of load application relative to the tooth surface (90° in their study versus 135° in the current study) and different testing machines may also explain the difference in results. Sharafeddin and Bahrani in 2011 evaluated the effect of fiber position on load bearing capacity of the fragmented incisal edge of maxillary central incisors restored with composite (20). They evaluated three types of restorations: with composite without fiber, with composite and fiber in the mid-palatal surface, and with composite and fibers at the two sides of the palatal surface with 1mm distance. The highest fracture resistance was observed in group restored with composite + fiber in the mid-palatal surface while the lowest fracture resistance was noted in group of composite without fiber (20). They demonstrated that application of fiber improved the fracture resistance of teeth due to better distribution of loads and prevention of crack propagation from the restoration to the tooth structure. However, they reported lower fracture resistance in teeth restored with two fibers compared to those restored with only one fiber in combination with composite, which is in contrast to our results. The reason may be due to better distribution of loads in teeth restored with only one fiber due to higher volume of composite around the central fiber, which strengthens the tooth. In other words, composite-fiber bond results in better distribution of stress at the interface and distribution of loads in a wider surface resulting

in decreased stress between composite and fiber and subsequently improved mechanical properties. This design can be efficient for areas under constant loading (20). It appears that by increasing the thickness of composite over the fiber, load is less transferred to the restoration-fiber interface and fracture resistance further increases. However, type of fiber, type of composite, composite-fiber bond, and composite-tooth bond can all affect the outcome and may explain the existing controversy in the results.

Our study had some limitations. The main limitation was evaluation of maxillary central incisors only. Different results may be obtained for other teeth under different occlusal loads. Another limitation was that a static load was employed in the current study while in the clinical setting, teeth are subjected to dynamic loads.

In the current study, fracture resistance was measured by universal testing machine, which is a reliable tool widely used by many studies (15, 21, 22). Also, it has been documented that the crosshead speed of the Zwick machine can affect the fracture resistance of teeth (23). Thus, we used a crosshead speed of 1 mm/min, which has been selected by many previous studies and better simulates the clinical setting (15, 21, 22). The angle of load application relative to the tooth surface has also been variable in different studies (19). Some researchers have evaluated load application from the facial surface and thus selected a 90° angle and applied load from the buccal direction. Others have evaluated anterior function (load applied from the mandibular incisors to maxillary incisors) and selected 135° angle and applied the load from the lingual surface (20). In the current study, we evaluated anterior function and thus selected 135° angle to simulate application of load from the mandibular incisors. Also, to better simulate the clinical setting, considering the normal overbite of 2mm, load was applied at 2mm distance from the

incisal edge (17). Selection of maxillary central incisors in the current study was due to high prevalence of fracture in these teeth. Also, to better simulate the clinical setting and obtain reliable results, specimens were thermocycled for 5000 cycles at 5-55° C (11).

The current study results revealed the efficacy of fiber reinforcement for increasing fracture resistance of composite restorations. The highest fracture resistance value in the group reinforced with fiber and 4mm thickness of composite indicates that application of fiber in restorations with greater thickness of composite would be more efficient; although the effect of thickness on fracture resistance was not significant. Based on the results, fiber reinforcement is suitable for incisal edge repair of anterior teeth with high thickness of composite; but, fiber reinforcement is not necessary for low thickness composite restorations.

The current study had an in-vitro design and suffered limitations of in-vitro studies. Thus,

generalization of results to the clinical setting must be done with caution. Similar studies are required to evaluate different thicknesses of composite restorations in different teeth. Also, it must be noted that risk of pulp exposure exists in vital teeth with >3 mm crown fracture. Thus, the efficacy of fiber post for reinforcement of endodontically treated teeth along with FRC for crown restoration must be evaluated in future studies.

Conclusion:

Application of two Ribbond fibers significantly increased the fracture resistance of incisal edge composite restorations. Increase in thickness of composite by 1mm had no effect on fracture resistance.

Conflict of Interest: “None Declared”

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