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Fatigue Strength of Fragmented Incisal Edges Restored with a Fiber Reinforced Restorative Material

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Abstract

Aim: The aim of this study was to determine the compressive fatigue limits (CFLs) of fractured incisor teeth restored using either a conventional adhesive-composite technique or using fiber-reinforced composites (FRCs).

Methods and Materials: Fifteen extracted sound upper incisor teeth were prepared by cutting away the incisal one-third part of their crowns horizontally. The teeth were restored using three techniques. Group A (control group) was restored by reattaching the original incisal edge to the tooth. Group B was restored using particulate filler composite (PFC). Group C was restored with PFC and FRC by adding a thin layer of FRC to the palatal surface of the teeth. The bonding system used was a conventional etch system with primer and adhesive. All restored teeth were stored in water at room temperature for 24 h before they were loaded under a cyclic load with a maximum controlled regimen using a universal testing machine. The test employed a staircase approach with a maximum of 10^3 cycles or until failure occurred. Data were analyzed using analysis of variance (ANOVA) ($p=0.05$). Failure modes were visually examined.

Results: Group A (reattaching fractured incisal edge) revealed the lowest CFL values, whereas the creation of a new incisal edge with PFC revealed a 152% higher CFL value compared to Group A. Group C (teeth restored with FRC) revealed a 352% higher CFL than the control group. ANOVA revealed the restoration technique significantly affected the compressive fatigue limit ($p<0.001$). The failure mode in Group A and B was debonding of the restoration from the adhesive interface. While in Group C, the sample teeth fractured below their cemento-enamel junctions.

Conclusion: These results suggested an incisally fractured tooth restored with the combination of PFC and FRC-structure provided the highest CFL.

Keywords: Fiber-reinforced composite, FRC, compressive fatigue limit, CFL, incisal edge fracture, particulate filler composite resin, PFC resin

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Introduction

Recent investigations into the incidence of dental trauma, especially in pediatric and adolescent populations, have suggested a fracture of the crown of an anterior tooth is common and affects up to one-third of the patients in this age group.[1,2] In addition, some studies have reported estimates of about one out of every four persons under the age of 18 will sustain a traumatic dental injury in the form of an anterior incisal fracture.[3,4]

Previous studies have described techniques to restore a fractured incisal edge to the original shape and color. One of these techniques is reattachment of the enamel-dentin fragment with a dentine-bonding agent.[5-7] While the esthetic outcome can be favorable, they tend to re-fracture or debond most often as a result of a new trauma.[8,9]

The improvement in the esthetic and physical properties of particulate filler composite (PFC) resins have established them as the material of choice for restoration of fracture incisal edges when used in conjunction with the acid-etch technique and dental bonding systems.[10,11] However, controversial results have been reported in different studies when PFC was used for restoring anterior teeth fractures. Some studies have shown a low long-term survival rate of PFC restored incisal fragments, especially in high stress-bearing areas.[12,13] Some other studies have reported acceptable results after long-term clinical use.[14,15] Attempts have been made to improve the load-bearing capacity of restorations by using different dentin bonding agents and adhesive resins.[9,16] However, these techniques resulted in fracture resistance in only 50-60% of the cases when compared to intact incisors.[16]

Force applied to teeth and dental restorations is generally low and repeated rather than occurring in a single impact to a tooth. It is estimated the intraoral stress received by dental restorations during mastication is repeated more than 3×105 times per year.[17] From this viewpoint, it might be more appropriate to estimate the load-bearing capacity of dental filling material by a dynamic type of mechanical test rather than by a static loading test. Fatigue limit depends not only on the nature of the material but also on the nature of the applied stress. The testing environment and the frequency of cyclic loading are also factors to consider. PFC, like other restorative materials, is subjected to static and cyclic loading in the oral cavity.

Fiber-reinforced composites (FRC) have been tested as dental materials, and their use in dental applications is growing and includes their use in complete dentures, removable partial dentures, and fixed partial dentures.[18-20] Studies have shown FRCs to have superior physical properties over PFCs.[21,22] Many parameters are known to influence the properties of FRC.[21,23-26] These include fiber volume fraction, fiber adhesion to the resin matrix, and fiber orientation. Although a lot is known about the properties of FRC itself, less information is available on the properties of a combination of FRC and PFC materials.

Table 1. Materials used in the study.

Brand	Manufacturer	Lot no.	Composition
Z250	3M ESPE, St. Paul, MN, USA	20040420	Bis-GMA, UDMA Bis-EMA
Scotchbond (multi-purpose) 1. Primer 2. Adhesive	3M ESPE, St. Paul, MN, USA	1. 4AN 2. 4NU	1. HEMA, Bis-GMA, water 2. HEMA, Bis-GMA
everStick	StickTech Ltd, Turku, Finland	2050426-ES-125	PMMA, Bis-GMA
Stick Resin	StickTech Ltd, Turku, Finland	540 1042	BisGMA-TEGDMA

PMMA = poly methyl methacrylate, M_W 220.000
Bis-GMA = bisphenol A-glycidyl dimethacrylate.
TEGDMA = triethylenglycoldimethacrylate.
UDMA = urethane dimethacrylate
Bis-EMA = bisphenol A polyethylene glycol diether
HEMA = hydroxyethyl methacrylate

It has been hypothesized PFC resin reinforced with FRC-structure could improve the compressive fatigue limit (CFL) of composite restoration for a fractured anterior tooth. Thus, the aim of this study was to determine the CFL of a fractured incisal edge restored with PFC reinforced with FRC-structure and to compare this method with other more conventional techniques.

Materials and Methods

Fifteen sound and caries-free extracted human upper incisor teeth were obtained and stored in 1% chlorine-amine. The teeth were mounted into an acrylic block (diameter 2.5 cm) at the cemento-enamel junction using auto-polymerized acrylic resin (Palapress, Heraus Kulzer, Wehrheim, Germany). The crown length for each tooth was measured with digital calipers. One-third of the incisal portion of each tooth was removed from the coronal edge of each tooth. This was done by cutting the teeth horizontally using a thin stainless steel bur in a laboratory handpiece micromotor (Ultimate 500K, NSK, Japan) under a water coolant (Figure 1 A, D). Teeth showing any visible pulp exposures or cracks were excluded from the study.

Each tooth was restored according to the groups to which they were assigned as follows:

Group A. This group of teeth had the incisal edge reattached. The contact surfaces of both the incisal segment and the remaining tooth structure were etched for 20 s using a 37% phosphoric acid etch-gel (3M Scotchbond, St. Paul, MN, USA). Subsequently, the gel was rinsed thoroughly and the tooth structure gently air-dried. Dentin primer and adhesive were applied according to the manufacturer's instructions. Polymerization was accomplished using a light-curing unit (Optilux-501, Kerr Corp., Orange, CA, USA) 30 s from both the labial and lingual aspects of the teeth. The wavelength of the light was between 380 and 520 nm with a maximum intensity of 470 nm, and the light intensity was 800 mW/cm^2. The teeth were stored in distilled water at room temperature after the procedure for 24 h before testing.

Group B. This group had the incisal portion of the teeth reconstructed with PFC. The fracture lines of teeth were finished using a fine diamond bur, identical etching, and adhesive bonding systems and technique were used as in Group A. PFC (Z250, 3M, St. Paul, MN, USA) was applied and polymerized incrementally to recreate the missing incisal portion of the teeth using a hand light-curing unit (Optilux-501) for 30 s from both the labial and lingual aspects of the teeth. The crown length was adjusted to the original length of the tooth. After finishing the procedure, the teeth were stored in distilled water at room temperature for 24 h before testing.

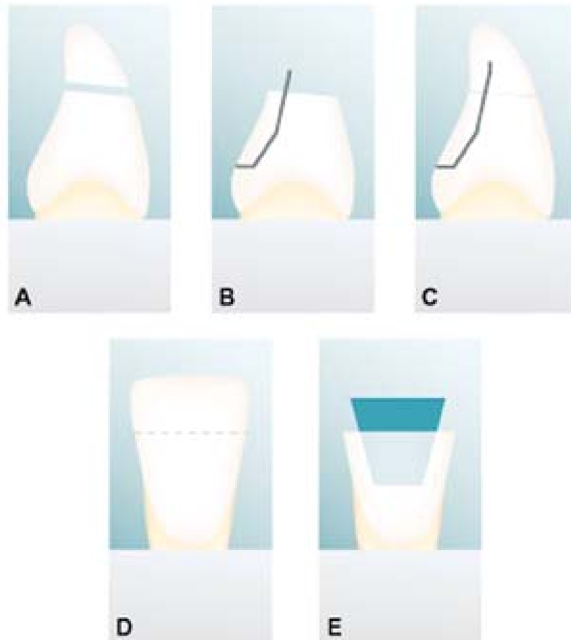


Figure 1. Schematic drawing of the repair procedure.
A and D: Cutting the incisal part of tooth.
B and E: Palatal preparation and FRC application.
C: PFC added to build up the incisal portion of the tooth.

Group C. This group had the incisal portion of the teeth reconstructed with a combination of PFC and FRC. A cavity preparation of 0.5 mm depth was prepared on the palatal surface of each tooth with a diamond bur using a water coolant (Figure 1 B, E).

Etching and bonding were carried out as described for the other two groups. Light-curing everStick fibers of silanated E-glass (StickTeck Ltd, Turku, Finland) and dimethacrylate polymethyl methacrylate resin matrix were placed into the palatal cavity and extended above the fracture margin. After polymerization of the FRC, the PFC was applied to build up the coronal part of the tooth structure (Figure 1 C). A thin layer of PFC was used to cover the FRC on the tooth. The restored teeth were stored in distilled water 24 h before testing.

The Fracture Load Test

The acrylic block containing the restored tooth was tightly fixed to the inclined metal base to provide a 45° angle between the palatal surface of the tooth and the loading tip (spherical Ø 2.0 mm) (Figure 2a.). Compressive fatigue load under a cyclic load with maximum of 10^3 cycles, or until failure occurred with speed of 1.0 mm/min was applied to the restored teeth with a material testing machine (Model LRX, Lloyd Instruments Ltd, Fareham, UK). Compressive fatigue limits at 10^3 stress cycles were determined by testing according to the staircase or up and down method.[27,28] The frequency of cycles was ≈ 0.3Hz. The failure mode for each specimen was visually analyzed and categorized to two typical failure

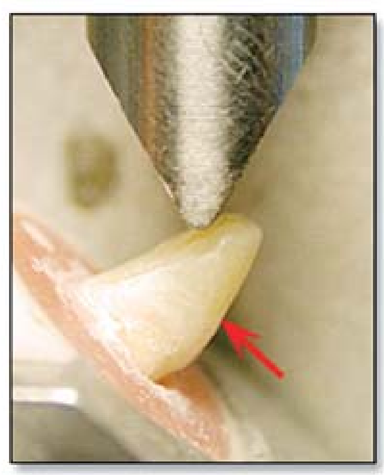


Figure 2a. Position of loading tip on the restored tooth. Arrow shows line between tooth and restored fragment.

Figure 2b. Adhesional failure between the restoration and tooth structure.

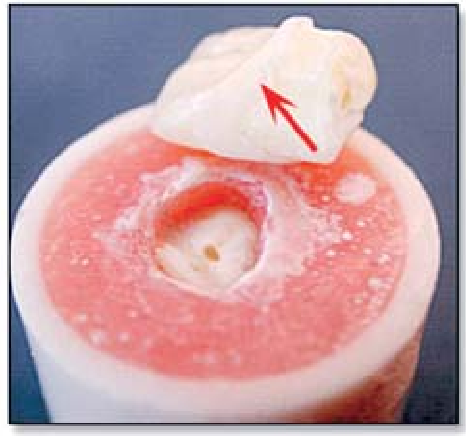


Figure 2c. Cohesional failure below the cemento-enamel junction (CEJ). Arrow shows line of (CEJ).

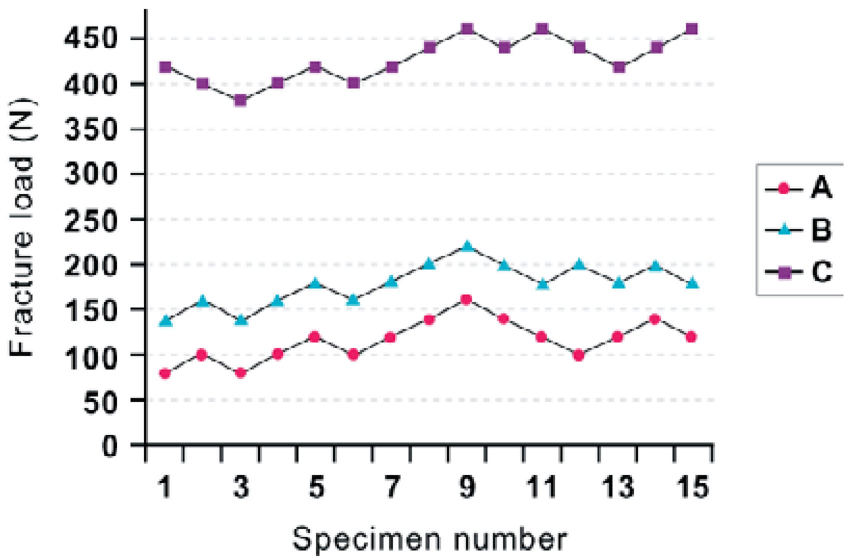


Figure 3. CFL of restored teeth according to the staircase method.

modes: a fracture between the remaining part of the tooth and the adhered part and cohesive breakage of the remaining part of the tooth (Figures 2b and 2c).

In this method, tests were conducted sequentially with the maximum applied stress in each succeeding test being increased or decreased by a fixed amount, according to whether the previous stress resulted in failure or no failure (Figure. 3).

The method provided a measure of the mean CFL and permitted calculation of the standard deviation of that mean. Since the data was concentrated around the mean stress, the number of specimens required was less than with the other methods. A minimum of 15 specimens was considered enough for accurate data analysis.[27] The mean CFL for 10^3 cycles was calculated using equation one and then the standard deviation using equation two as follows:[29,30]

$$CFL = X_0 + d\left(\frac{\sum i n_i}{\sum n_i} \pm 0.5\right) \qquad (1)$$

$$SD = 1.62d\left(\frac{\sum n_i \sum i^2 n_i - \left(\sum i n_i\right)^2}{\left(\sum n_i\right)^2} + 0.029\right) \qquad (2)$$

Where x_0 is the lowest load level considered in the analysis and (d) is the fixed load increment (20N). To calculate the CFL, the analysis of the data is based on the least frequent event (failures versus non-failures). In Eq. (1) the negative sign is used when the analysis is based on failures, otherwise the positive sign is used. The lowest stress level considered is designated as i=0, the next as i=, and so on; ηι is the number of failures or non-failures at the given stress level.

Data of fracture load was statistically analyzed with SPSS, version 10.0 (SPSS Inc, Chicago, IL, USA) using the analysis of variance (ANOVA) followed with a Tukey post hoc test at the significance level of 0.05 to determine differences among the groups.

Results

The mean CFL and standard deviations of restored teeth with different techniques are given in Table 2.

The data showed restored teeth with reattached pieces of tooth (Group A) revealed the lowest CFL values, whereas rebuilding the incisal edge using PFC (Group B) revealed 152% higher values compared to Group A. Teeth restored with PFC and FRC (Group C) revealed 352% higher values than obtained with Group A (control group) (Figure 4).

The ANOVA revealed the restorative technique significantly affected the load-bearing capacity ($p<0.001$). However, there was no statistical difference between Groups A and B ($p>0.05$). A statistical difference was found with Group C ($p<0.001$). Failure modes in Groups A and B were debonding (adhesional failure) (Figure 2b). In Group C the teeth fractured below the cemento-enamel junctions (Figure 2c).

Discussion

This *in vitro* study was designed and conducted to restore fractured incisors using different techniques with the same bonding agent and PFC. Reattachment of a fractured piece may offer a conservative, cost-effective, and esthetic option if the tooth fragment is available after trauma. However, the load-bearing capacity

Table 2. Mean values of CFL with standard deviations (SD) of testing groups.

Group	CFL (SD) (N)
A	120[a] (30.6)
B	183[a] (29.7)
C	423[b] (40.5)

Superscript letters indicate data sets that are not statistically different (Tukey, $p> 0.05$)

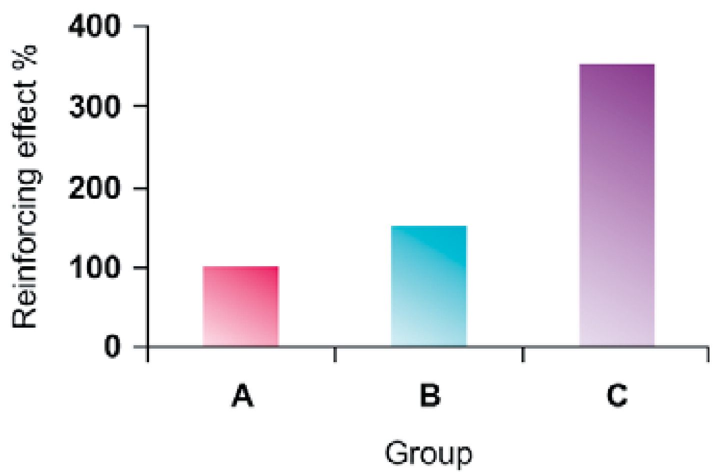


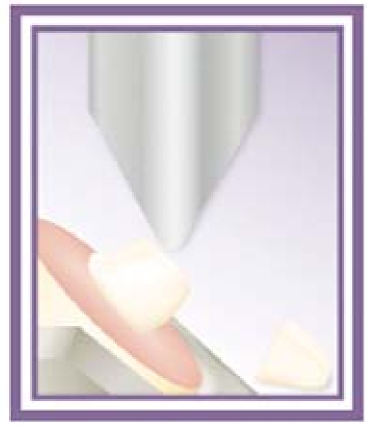
Figure 4. Reinforcing effect of restoring techniques compared to group A. A (Incisal edge reattachment), B (Incisal part made of PFC), and C (Incisal part made of PFC and FRC).

of the reattached tooth fragment was lower compared to teeth restored using a conventional technique using PFC. A review of case reports in which the fracture pattern was determinable by photograph or description showed 80% of traumatized incisors fractured due to debonding of the reattached incisal edge.[31,32] Direct composite restorations are commonly used as small anterior restorations and are not recommended for large restorations in regions with high masticatory forces.[12,13] On the other hand, FRC is a group of materials having high toughness and strength that has been used in many applications in dentistry. Furthermore, the bond strength of chairside-fabricated FRC to tooth substructure is equally as good as PFC.[33]

The data showed substantial improvement in the load-bearing capacity (two to three times) of a restoration when FRC was used compared to conventional restorations. The function of the FRC was based on the theory FRC, in combination with PFC, provides better mechanical properties of the restored incisal portion of the tooth by distributing the forces over a wider surface area. The diminished stress at the interface, and over a larger bonding area have proven beneficial under a repeated loading condition.

Fatigue behavior was determined by subjecting the restored teeth to cyclic stress and determining the number of cycles required to produce failure. The load values and the number of load cycles used in the staircase or up and down method were evaluated prior to actual testing using pilot testing. The “staircase method” automatically concentrated testing near limit and required fewer tests[34], which is equally valid for determining the fatigue limit.[29]

In particular, $\frac{\sum n \sum i^2 n - (\sum in)^2}{(\sum n)^2}$ when is larger than 0.3, the estimation of standard deviation becomes more accurate[29,30]; when the value is less than 0.3, a more elaborate calculation must be employed.[29] All standard deviations of fatigue limits in this study were larger than 0.3. The numbers of cycles used in this study were similar to other studies using the staircase method.[35] Some other studies used cycles such as 5000, 6000, or 10.[5,28,36]



Because of a relationship between fatigue and static loading, the results of this study are in agreement with previous laboratory studies[37] which concluded by using a FRC substructure under the PFC resin, the static load-bearing capacity of material combination was increased.[38,39]

The failure mode in conventional techniques was debonding (adhesional failure) of all restorations at the bonding line. In restorations reinforced with FRC, failure was due to fracture of the teeth below the cemento-enamel junction (cohesional failure). This could be explained by the high strength of FRC, which exceeds the load-bearing capacity of the tooth. This is especially true of teeth with thin roots. Somewhat different failure modes of repairs with conventional techniques were reported by other researchers.[31,40] These differences could partly be explained by differences in the loading technique. In some studies teeth were loaded at a 90-degree angle, whereas in this study the teeth were loaded at an angle of 45° which more closely simulated clinical conditions.

Conclusion

It was concluded by using FRC in repairs of fractured teeth, the compressive fatigue limit of the restored incisal edge was substantially increased. This might have an impact for optimizing properties of directly made composite restorations in anterior teeth.

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