Restoring Nonvital Premolars with Composite Resin Onlays: Effect of Different Fiber-reinforced Composite Layers on Marginal Adaptation and Fracture Load

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Purpose: To evaluate the marginal adaptation and fracture load of composite resin onlays reinforced with different substructures.

Materials and Methods: Thirty-two extracted, caries-free premolars were selected for this study and endodontically treated. Group 1 was used as the control group, and the teeth were restored only with as-manufactured composite resin overlays. Group 2 teeth were restored with composite resin overlays with 3 fiber-reinforced composite (FRC) layers placed horizontally on the bottom of the restoration. Group 3 teeth were restored with composite resin overlays with 6 fiber-reinforced composite (FRC) layers placed as in group 2. Group 4 teeth were restored with composite resin overlays and FRC placed with an anatomical design. All specimens underwent SEM evaluation of their marginal adaptation before and after thermocycling and cyclic mechanical loading. All specimens were then subjected to a fracture test, recording the value for the initial (IF) and final (FF) failure. Differences in the means were compared using matched-pairs t-tests and one-way ANOVA. The level of significance was set at $\alpha = 0.05$.

Results: No statistically significant difference between the four groups in terms of marginal adaptation was observed at the tooth/luting composite and luting composite/overlay interfaces before and after loading. The fracture loads of IF and FF, from most to least resistant were: group 4 (1431.8 \pm 294.3 N / 1710.1 \pm 326.6 N), group 3 (1428.1 \pm 251.4 N / 1467.9 \pm 242.4 N), group 2 (852.6 \pm 413.5 N / 1058.1 \pm 251.5 N) and group 1 (899.8 \pm 352.7 N / 923.5 \pm 318.8 N). Significant differences ($p = 0.026$) were observed comparing group 1 to groups 2 and 3, and group 1 to 4. Three irreparable fractures were found in group 3, four in group 2, and five in groups 1 and 4.

Conclusions: The presence or absence of reinforcement and the different configuration of the reinforcement fibers affect fracture strength but only partially the failure modality. The presence or absence of reinforcement does not alter marginal adaptation.

Keywords: FRC, endodontically treated teeth, glass fibers, fracture, marginal adaptation, onlays.


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The restoration of endodontically treated teeth has been widely discussed in the prosthodontic and endodontic literature.\textsuperscript{30} The higher incidence of fractures in endodontically treated teeth appears to be due more to the loss of structural integrity associated with access preparation, which results in an increased cuspal deflection during function, rather than to structural changes in dentin.\textsuperscript{11}

Fracture prevention in posterior teeth is traditionally accomplished with complete tooth preparation, often in combination with the reconstruction of the abutment with a metal or fiber post and a full crown. Sorensen and Martinoff\textsuperscript{35} even suggested that nonvital posterior teeth should be treated with a cuspal coverage restoration. In particular, maxillary premolars are characterized by an unfavorable anatomic shape and a crown volume...
and crown:root ratio that make them more prone to fractures. Preserving tooth structure makes it possible to avoid using posts and allows restoration of the tooth with an onlay. Krejci et al showed no in vitro differences in the retention, marginal adaptation, or fracture resistance of endodontically treated and untreated teeth that were restored with an onlay. A recent clinical study found that after 3 years of service, there was no difference in the survival rates of endodontically treated premolars with intact cusps that were restored with fiber posts and a direct composite resin restoration vs those restored with full-coverage metal-ceramic crowns. In contrast, a different study confirmed the need to place a final restoration as quickly as possible to protect the cusps. Manhart et al reported that annual failure rates of posterior composite resin inlays and onlays range between 0% and 10%, and the main reasons for failure are secondary caries, fracture, wear, and marginal deficiencies, suggesting that indirect posterior restorations are a good, longer-lasting alternative for the restoration of large defects. Tamse et al found that longitudinal root fractures are more frequent in teeth with a narrow mesiodistal dimension, such as maxillary premolars.

Costa et al related cusp fractures of endodontically treated maxillary premolars to the width of tooth preparation. These authors found that in premolars, MOD preparation decreased fracture resistance, while an onlay preparation with cusp coverage increased fracture resistance.

Magne proposed the use of adhesively luted overlays as a more conservative alternative to full crowns, as they reproduce the mechanical properties of the intact tooth from a biomimetic perspective.

The development of fiber-reinforced technology has increased the use of composite resin materials for large restorations. The presence of fibers influences the fracture process by interrupting the progression of crack growth and increasing the fracture toughness of the fiber-reinforced composite (FRC). The use of FRC may prevent undesirable subgingival fractures and have a beneficial effect on the failure mode of composite resin restorations, as well as their reparability in the case of fracture. In spite of the fact that the incorporation of glass in FRC could increase the load-bearing capacity of composite resin restorations, some authors have emphasized that suboptimal vacuum/pressure adaptation of the fibers may compromise the performance of these restorations. Fennis et al concluded that although glass FRC does not increase fracture load of premolars with cusp-replacing restorations, it can affect the failure mode.

Glass fiber techniques offer another attractive alternative for the treatment of structurally compromised, endodontically treated teeth. However, few studies have been conducted to evaluate the fracture resistance of nonvital teeth that have been treated with overlays reinforced with different configurations of woven glass fibers. Therefore, the purpose of this study was to evaluate marginal adaptation, fracture strength, and failure modality of endodontically treated premolars that were restored with composite resin overlays with and without different configurations of glass fiber reinforcement. The null hypothesis is that the presence or absence of reinforcement and the different configurations of reinforcement fibers do not influence marginal adaptation, fracture strength, or failure modality.

**MATERIALS AND METHODS**

For this study, 32 extracted, caries-free maxillary premolars of nearly identical size with completed root growth were selected. The teeth were extracted due to periodontal disease (patients’ ages ranged from 40 to 73 years) and were stored at 4°C in a solution of 0.02% thymol for a maximum of 3 months from the time of extraction. Their use was in compliance with the Commission of Ethics for Research on Humans, University Hospital of Geneva. The teeth were randomly assigned to 4 equal groups. All teeth were endodontically treated, and the root canal preparations were performed with NiTi rotary instruments (Protaper, Dentsply Maillefer; Baligaues, Switzerland) with a low speed handpiece (Tecnika, Dentsply Maillefer) under intermittent rinsing with 5% NaOCl (Niclor 5, Ogna; Muggiò, Italy). An epoxy sealer (AH Plus, Dentsply DeTrey; York, PA, USA) and vertical condensation with warm gutta-percha was used for canal filling (System B, Sybron Dental; Orange, CA, USA). All specimens were fixed with a light-polymerizing composite resin (Filtek Z250, 3M ESPE; Seefeld, Germany) on aluminum bases, then embedded in an autopolymerizing resin (Technovit 4071, Heraeus-Kulzer; Hanau, Germany) to an apical depth of two thirds of the root length to create a strong load-resistant support for each tooth. Provisional restorations of the pulp chamber were made with Cavit (3M ESPE) before cavity preparation.

Twenty-four hours after endodontic treatment, the clinical crowns of all specimens were removed to a level of...
2.5 mm above the cementoenamel junction (CEJ) at the buccal cusps and 3.5 mm at the palatal cusps (Fig 1). The crown was prepared with a 90-degree rounded shoulder 1.0 mm above the CEJ for half the tooth perimeter, and 1.0 mm below the CEJ in the other half using coarse diamond-coated burs (Geneva Prep Set, Intensiv; Grancia, Switzerland) under copious water-spray cooling. All dentinal surfaces of the pulp chamber and the cavity walls were sealed using a three-step etch-and-rinse adhesive system (Optibond FL, Kerr; Orange, CA, USA) according to the manufacturer’s recommendations. Light polymerizing was carried out with a halogen device (Polylight Steril; Polylight Inc., Zoetermeer, Netherlands) for 20 s (output: 800 mW/cm²). The pulp chambers of all groups were filled with a composite resin layer (Miris Dentin S3, Coltène Whaledent; Geneva, Switzerland). Internal and external cavity margins were finished under a stereomicroscope, using a diamond bur (25 μm grain size, No. 3113 NR, Intensiv) and water cooling. Impressions were made in a polyether material (Permadyne, 3M ESPE) using a simultaneous mixing technique according to the manufacturer’s instructions. Provisional restorations were constructed with Fermit N (Ivoclar Vivadent). Vectris (Composhape, Intensiv) and polished with a composite finishing and polishing kit (Astrobrush, Ivoclar Vivadent). The provisional restorations were then finished with 15-μm diamond burs (Composhape, Intensiv) and polished with a composite finishing and polishing kit (Astrobrush, Ivoclar Vivadent). Marginal Evaluation

Before making the impressions for the replicas, the specimens were cleaned with rotating nylon brushes (Hawe Neos; Bioggio, Switzerland) and a dentifrice (Signal Anti Caries, Unilever; London, UK). Polyvinylsiloxane impressions (President Plus Light-body, Coltene) were formed with a mold. After a cycle of vacuum forming and light curing in a specific unit (VS1, Ivoclar Vivadent) for 10 min, the excess FRC was removed with a carbide bur up to the vertical cavity wall. The FRC base was then airborne particle abraded with small grains of 80 μm (Rocatec system, 3M ESPE) at 0.25 MPa pressure for 10 s, then treated with silane (Monobond S, Ivoclar Vivadent). In all groups, the resin composite (Adoro, Ivoclar Vivadent) was built up incrementally, with each increment being pre-cured using a pre-curing light polymerizing unit (Quick, Ivoclar Vivadent). Final polymerization was performed in the Lumamat 100 (Ivoclar Vivadent) unit using both light and heat. An additional tempering step at 104°C was performed to maximize the strength and surface quality of the restorations.

Adhesive Procedure

The provisional restorations were removed, and the inner surfaces of the teeth that had been previously sealed with bonding agent were airborne particle abraded (particle size 30 μm; CoJet system, 3M ESPE) at a pressure of 0.2 MPa for 2 s. The enamel margins were etched for 30 s with 37% phosphoric acid (Total Etch, Ivoclar Vivadent). After rinsing and drying, primer and adhesive (Optibond FL, Kerr) were applied in a thin layer to the enamel and dentin according to the manufacturer’s instructions. The inner surfaces of the FRC were treated with the CoJet system (particle size 30 μm, 0.2 MPa for 10 s), and two layers of silane coupling agent (Monobond S, Ivoclar Vivadent) were applied to all the inner restoration surfaces. A layer of the same adhesive system was applied with a microbrush to the treated composite surfaces. Restorations were luted with a light-curing composite resin (Miris Enamel WR, Coltene; Altstätten, Switzerland); polymerization was performed for 60 s each on the cervical, buccal, palatal, and occlusal surfaces. The margins of the restorations were then finished with 15-μm diamond burs (Composhape, Intensiv) and polished with a composite finishing and polishing kit (Astrobrush, Ivoclar Vivadent). Laboratory Manufacturing Process

Group 1 was used as the control group and was restored only with composite resin overlays (Adoro, Ivoclar Vivadent). Adoro is a microfilled resin composite veneer system containing UDMA monomer. Group 2 was restored with composite resin overlays and 3 FRC layers that were horizontally placed on the bottom of the restoration (Vectris, Ivoclar Vivadent). Vectris consists of several layers of fiber wafers and woven fiber bundles embedded in an organic polymer matrix. Group 3 was restored with a composite resin overlay and 6 FRC layers in the same manner as group 2, whereas group 4 was restored with a composite resin overlay and FRC placed in an anatomical design to support the composite resin beneath the cusps (Fig 2). An impression of the gypsum model with transparent vinyl polysiloxane paste (VPS, Memosil 2, Ivoclar Vivadent) was taken of each gypsum model with transparent vinyl polysiloxane paste (VPS, Memosil 2, Ivoclar Vivadent) and a dentifrice (Signal Anti Caries, Unilever; London, UK). Polyvinylsiloxane impressions (President Plus Light-body, Coltene) were placed in an anatomical design to support the composite resin beneath the cusps (Fig 2). An impression of the gypsum model with transparent Vin

![Fig 2 Schematic of the different groups with the specific fiber reinforcement arrangement. Group 1: no fiber reinforcement (FR); group 2: 3 horizontal layers of FR; group 3: 6 horizontal layers of FR; group 4: anatomical arrangement of FR.](image-url)
taken before and after thermomechanical tests to compare the quality of marginal adaptation. Gold-sputtered (SCD 030, Provac; Balzers, Liechtenstein) epoxy resin replicas (Epofix, Struers; Copenhagen, Denmark) of all specimens were evaluated for marginal adaptation at the standard 200X magnification using SEM (XL20, Philips; Eindhoven, The Netherlands) and a custom-made module in image processing software (Scion Image, Scion; Frederick, MD, USA). This qualitative evaluation included continuous margins (no gap and no interruption of continuity), noncontinuous margins (a gap due to adhesive or cohesive failure, fracture of the restorative material, or fracture of the enamel related to the restoration margins), overhangs, and underfilled margins at two interfaces, ie, the tooth/luting composite interface and the luting composite/overlay interface. The specimens were mechanically loaded on the inner side of the palatal cusp by a sliding movement towards the central fossa. This was accomplished by using palatal cusps of the maxillary first premolars as antagonists with a computer-controlled masticator set to 1,200,000 cycles of 49 N each at a frequency of 1.7 Hz. A total of 3000 thermocycles (from 5°C to 55°C) were performed simultaneously. The chamber was automatically emptied after 2 min, with 10 s of air pressure to avoid mixing the cold and the warm water.19,21 By having the specimen hold-

![Graph](image1)

**Fig 3** Percentages of continuous margins at the tooth/luting composite interface before (a) and after (b) loading. No significant differences (NS: \( p > 0.05 \)) were detected between the groups.

![Graph](image2)

**Fig 4** Percentages of continuous margins at the luting composite/overlay interface before (a) and after (b) loading. No significant differences (NS) were detected before loading. All significant differences observed between the groups after loading (b) are marked with different letters.
ers mounted on a rubber rest, a sliding movement was produced on the restorations during loading. The stress these conditions place on the specimens is believed to simulate approximately 5 years of normal oral function.\textsuperscript{18,20}

After thermocycling and mechanical loading, all groups were subjected to a fracture test designed to measure the fracture strength and patterns. The test was performed at a temperature of 25°C using a universal testing machine (Instron Model 4301, Instron; Norwood, MA, USA). A spherical stainless steel punch with a thin copper layer and a diameter of 4.0 mm was used at 90 degrees in the middle of the specimen’s occlusal surface. A central fossa was prepared in the premolars in order to insert the spherical punch. The crosshead speed was 1.0 mm/min, and the load was applied until the specimen fractured. The load-deflection curves were recorded with PC computer software (Instron 8.2, Instron). The start of specimen damage can be classified as initial failure (IF).\textsuperscript{10} The IF was recorded when at least two of the following conditions were met: (1) there was a sharp decline in the load/displacement curve, called a knee or corner, (2) visible signs of fracture were observed, or (3) audible emissions, caused by the generation of elastic waves by crack formation and/or progression, were heard. The final failure (FF) of the specimen was defined when one of the following occurred: (1) the specimen attained an “instable” condition, with a zero (or negative) slope of applied stress vs strain, (2) the maximal load or displacement before the load decreased by 50%, or (3) an apparent catastrophic rupture was observed. The failure mode or damage accumulation (restoration chipping, restoration fracture, restoration and coronal fracture, restoration and irreparable fracture [if below the CEJ]) was noted and determined after testing. Differences in the means were compared with the use of matched pairs of t-tests and one-way ANOVA. The level of significance was set at $\alpha = 0.05$.

**RESULTS**

Percentages of continuous margins before and after loading at both the tooth/composite and composite/onlay interfaces are shown in Fig 3.

At the tooth/luting composite interface, no significant differences between the groups could be observed either before ($p = 0.418$) or after loading ($p = 0.240$), indicating that the fiber reinforcement had no significant influence on the marginal adaptation at this interface (Fig 3). At the luting composite/overlay interface, no significant differences between the groups were observed before loading ($p = 0.586$). However, after loading, significant differences ($p = 0.026$) were observed between group 1 vs groups 2 and 3, and group 1 vs group 4. Interestingly, the lowest marginal adaptation scores (Fig 4) were observed in the group with no reinforcement (group 1, 90.1% ± 16.5%) and in the group with anatomic cusp reinforcement (group 4, 81.6% ± 12.8%). The results of fracture load are detailed in Fig 5. For both initial and final failure parameters, groups 3 (1428.1 ± 251.4 N and 1467.9 ± 242.4 N) and 4 (1431.8 ± 294.3 N and 1710.1 ± 326.6 N) resulted in significantly higher fracture loads than groups 1 (899.8 ± 352.7 N and 923.5 ± 318.8 N) and 2 (852.6 ± 413.5 N and 1058.1 ± 251.5 N).

In group 4, with FRC anatomic cusp reinforcement, and in group 3, with the horizontal 6-layer FRC (Fig 6), significantly higher loads were required to cause specimen fracture. In respect to failure types, groups 1 and 4 had the highest number of catastrophic failures (irreparable, with fracture below the CEJ) compared to the rest of the groups (Table 1). Fisher’s Exact Test was performed to evaluate the effect of the presence/absence of reinforcement on catastrophic failures (irreparable fracture). The test ($p = 0.691$) found no statistically significant correlation between the catastrophic failure and the presence or absence of reinforcement.
DISCUSSION

In this study, the marginal adaptation after mechanical fatigue cycles and thermocycling was evaluated. In addition, the fracture resistance of nonvital premolars restored with composite resin overlays with or without woven fiber reinforcement was assessed. Both of these factors are essential for achieving a durable restoration that can effectively protect the remaining tooth structure. When considering the marginal adaptation results obtained here, it is worth noting that the application of the fatigue and thermal cycles led to a loss of integrity for both interfaces evaluated in all four study groups. This loss of integrity was most evident at the tooth/cement interface, but considerably less at the cement/overlay interface. De Munck et al. showed that the aging induced by thermocycling leads to both contraction and expansion stresses at the tooth/restoration interface due to the different thermal coefficients of the restoration and the tooth structure. Moreover, thermocycling accelerates the chemical degradation of the adhesive interface. In particular, the lowest marginal quality of the tooth/cement interface was recorded for group 4 specimens, while the highest results were recorded for group 2 specimens. It must also be emphasized that, after the thermal and fatigue cycles, the marginal continuity of the tooth/cement interface was reduced by half in all groups, and by one-third of the initial value in group 2. In contrast, the marginal adaptation of the cement/overlay interface remained constant even after cyclic tests. Several authors have confirmed that marginal continuity is a key factor required for achieving a durable restoration. A recent study demonstrated that the use of inlays reinforced with unidirectional fibers did not decrease the marginal adaptation compared to the use of nonreinforced inlays. Another study evaluated the marginal adaptation of molars after thermocycling and fatigue of composite resin overlays reinforced with glass fiber, ceramic, or composite. Those authors found no statistically significant differences at the tooth/composite and composite resin/restoration interfaces, but differences were found after thermal fatigue cycling in the group restored with ceramic-reinforced overlays. In the present study, lower values of marginal adaptation were obtained for the groups restored with reinforced restorations. This phenomenon could be due to the increased difficulty of managing a higher number of fiber layers in the smaller volume of a premolar, with the risk of fiber exposure and decoupling from the polymer matrix.

When looking at the fracture resistance results reported by Dere et al., it is important to remember that their results were obtained on molars rather than premolars. In this work, the highest values of fracture resistance were recorded in the group with the woven glass fibers arranged in an anatomical design (1710.12 ± 326.64 N), while the lowest values of fracture resistance were recorded in the group of teeth restored with non-reinforced overlays (923.50 ± 318.80 N). Intermediate values were obtained from the experimental groups with overlays strengthened by three (1058.13 ± 251.51 N) and six (1467.88 ± 242.36 N) layers of woven glass fibers. These data show an improvement in the fracture strength depending on the number of fibers layers. However, the use of woven fiber reinforcement reduces the fracture resistance moreso than does the use of unidirectional fibers. The use of woven fibers causes the restoration to exhibit orthotropic behavior. Hence, the strength of specimens was reduced by 25% to 50%, because not all fibers are arranged perpendicularly (as opposed to the case with unidirectional fibers) to the direction of load application, as described by the equation of Krenchel. However, the results obtained in this work are different from those of Akman et al. The latter found that the addition of fiber reinforcement of composite restorations does not improve the fracture strength on molars.

Dere et al. demonstrated that fiber-reinforced overlays, in addition to producing higher fracture toughness values, are also able to produce more favorable fracture patterns. It should be emphasized that the fracture resistance values recorded in all groups of this study represent limits that are difficult to reach in vivo, because the published data on bite forces indicate that the maximum values occurring in the posterior area vary between 300 and 880 N.

Dyer et al. emphasized that the initial failure is a much more significant and useful parameter than the fracture resistance, because the penetration of oral fluids leads to decay and a reduction in the service life of the restoration. When early failure was identified, the load that produced the failure was much lower than the fracture load. For this reason, it is important to understand whether the initial

Table 1  Type and number of failures in the different groups

<table>
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<tr>
<th>Type of failure</th>
<th>No. of failures by group</th>
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<tr>
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<td>Group 1</td>
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<tr>
<td>Irreparable (below the CEJ)</td>
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<td>Reparable (above the CEJ)</td>
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failure also caused a loss of the seal at the adhesive interface. Coronal microleakage is closely related to endodontic treatment and subclinical failures.33 This important issue was evaluated by Belli et al,2 who found that also the use of flowable composite in combination with glass fibers can reduce occlusal leakage in Class II adhesive cavities with enamel margins.

The lack of a statistically significant correlation between catastrophic failure and the presence or absence of reinforcement is probably due to the small number of specimens in each group. Nevertheless, reinforced specimens had a lower tendency to show unrecoverable fractures. The group with composite overlays reinforced with 6 FRC layers showed fracture patterns that would favor retreatment in at least a 62.5% of cases (Table 1). In this group, the arrangement of fibers was able to keep the fracture line within the overlay, keeping the restoration margins of the tooth intact. The ability of the reinforcing fibers to change the failure patterns has already been reported in previous studies.27 In particular, Fennis et al12 found that FRC positively influenced the failure mode of maxillary premolars subjected to thermocycling and static load tests, and that woven fibers are more effective than unidirectional fibers.

Our study also confirms the results of Brunton et al,3 who demonstrated how failures under conditions of compressive loading may be less catastrophic when a fiber-reinforced composite onlay is used instead of an non-reinforced one. It should be stressed that for this group, as in the other two groups tested in this study, that over a third of the failures were re-treatable. These results also confirm the findings of Magne and Knezevic,27 who demonstrated how failures under conditions of composite resin overlays reinforced with 6 FRC layers showed fracture patterns that would favor retreatment in at least a 62.5% of cases (Table 1). In this group, the arrangement of fibers was able to keep the fracture line within the overlay, keeping the restoration margins of the tooth intact. The ability of the reinforcing fibers to change the failure patterns has already been reported in previous studies.37,38 In particular, Fennis et al,27 found that FRC positively influenced the failure mode of maxillary premolars subjected to thermocycling and static load tests, and that woven fibers are more effective than unidirectional fibers.

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CONCLUSIONS

Within the limitations of this in vitro study, it can be concluded that the use of overlays reinforced with woven fibers did not limit the marginal adaptation compared to non-reinforced overlays. In addition, the presence or absence of reinforcement and the different configurations of the fibers affect fracture strength but only partially the failure modality. Composite resin overlays reinforced with woven glass fibers can improve the ability of the restoration to withstand chewing forces. Higher fracture resistance is not necessarily associated with more favorable types of failure in the prosthetic restoration of endodontically treated teeth. These results should, however, be confirmed by controlled clinical trials in the future.

REFERENCES

The use of fiber-reinforced overlays is a valid alternative to prosthetic crowns in endodontically treated teeth. The use of fiber-reinforced overlays, in addition to allowing a greater preservation of tooth structure, can improve fracture strength.