Fracture Strength of Endodontically Treated Teeth Restored with Composite Overlays with and without Glass-fiber Reinforcement

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\textbf{Purpose:} To evaluate the fracture strength and the failure mode of endodontically treated teeth restored with composite resin overlays with and without glass-fiber reinforcement.

\textbf{Materials and Methods:} A total of 32 extracted molars were divided into four equal groups. In the NFR-NFRC (no foundation restoration, no fiber-reinforced composite) and NFR-FRC (no foundation restoration, fiber-reinforced composite) groups, only a 5-mm-thick composite resin layer sealed the pulp chamber floors, whereas in the FR-NFRC (foundation restoration, no fiber-reinforced composite) and FR-FRC (foundation restoration, fiber-reinforced composite) groups, a 3.0-mm foundation restoration was used. NFR-NFRC and FR-NFRC groups were restored with composite resin overlays, whereas NFR-FRC and FR-FRC groups were restored with fiber-reinforced composite resin overlays. All specimens were subjected to mechanical loading in a computer-controlled masticator and then the fracture resistance was evaluated. Differences in means were compared using two-way ANOVA and Tukey’s test. The level of significance was set at $\alpha = 0.05$.

\textbf{Results:} All specimens successfully completed the fatigue test. The least fracture-resistant group was NFR-FRC, exceeded by FR-NFRC, NFR-NFRC, and FR-FRC, in that order, with FR-FRC being the most fracture-resistant group. Statistically significant differences were detected between the pairs NFR-NFRC/FR-FRC ($p = 0.001$), NFR-FRC/FR-FRC ($p = 0.001$), and FR-NFRC/FR-FRC ($p = 0.001$). Eight vertical root fractures occurred in group FR-NFRC, six in group NFR-NFRC, four in group NFR-FRC, and none occurred in group FR-FRC.

\textbf{Conclusions:} Within the limitations of this in vitro study, the incorporation of glass fibers and the presence of a foundation restoration were found to increase the fracture resistance and can favorably influence the fracture mode.

\textbf{Keywords:} molars, resin-bonded onlays, root fractures.

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The restoration of pulpless teeth is still a much-debated topic.\textsuperscript{13} In recent years, important developments have taken place in the field of adhesive dentistry, due to the concept of minimal invasivity.\textsuperscript{24,25} Clinical studies have shown that the more tooth tissue can be preserved, the greater the chance the tooth has of fulfilling its function over the long term.\textsuperscript{5,8}

The amount of remaining tooth structure in vital teeth after caries, trauma, or previous restorations should determine how the tooth must be restored.\textsuperscript{12} This is also true for endodontically treated teeth. The resistance of endodontically treated teeth restored with composite resins is affected mainly by the number of residual walls.\textsuperscript{28} In cases with sufficient remaining tooth structure, especially if intact enamel is still present, the use of indirect adhesive restorations without posts may present an interesting alternative to conventional treatment concepts.\textsuperscript{30} This approach is the most conservative for both the crown and the root. Nevertheless, in cases of strong loading or fatigue stress, a restoration can fracture and, due to strong adhesion between the restoration and tooth, a crack can occur along the bonding interface and propagate towards the root, leading to irreparable failure.\textsuperscript{37}
A careful approach, considering the variability among individual cases and a solid knowledge of the biomechanical peculiarities of endodontically treated teeth, is always necessary. After root canal treatment, teeth are more susceptible to fracture. The principal reason for this structural weakening is the removal of the tooth structure during the endodontic procedures. The strength of the tooth depends on the amount of remaining hard dental tissues. Thus, attention should be paid to protect structurally compromised teeth from fracture. Root canal treatment should not be considered complete until the permanent coronal restoration has been placed. The functional and morphological integrity of the tooth is usually restored by intracoronal restoration or fixed dental prostheses.

Currently, the best approach for restoring endodontically treated teeth seems to be to (1) minimize tissue sacrifice, especially in the cervical area, so that a ferrule effect can be created, (2) use adhesive procedures at both the radicular and coronal levels to strengthen the remaining tooth structure, and (3) use post and core materials with physical properties close to those of natural dentin.

The principal function of a post is to provide intracoronal retention of the core/crown restoration and to distribute functional loads to a larger area of the remaining tooth structure. However, posts do not strengthen endodontically treated teeth if reinforcement is desired, it should be through incorporating a ferrule into the design of the crown, embracing the circumference of the root to protect the root where maximum force occurs. The ferrule effect is a key factor in the failure threshold of post-treated teeth, but the same ferrule preparation also causes loss of important remaining hard dental tissues. The literature demonstrates that a ferrule is desirable, but should not be provided at the expense of the remaining tooth/root structure.

While the traditional method includes several drawbacks, such as the sacrifice of a considerable amount of sound structure and the longer treatment time necessary for these complex restorations (which makes them costly), adhesive restorations ensure retention and fracture resistance with maximal conservation of dental tissue. Longevity of restorations in stress-bearing posterior cavities depends on many factors, including the materials, the dentist, and the patient. The dental literature reports that annual failure rates of posterior composite resin inlays and onlays range from 0% to 10%, indicating that indirect posterior restorations are a long-lasting alternative in the rehabilitation of large defects.

The development of fiber-reinforced composite resin technologies has increased the field of application of composite resin materials. Glass fibers have demonstrated a significant ability to withstand tensile stress and to stop crack propagation in composite resin materials. The use of fiber-reinforced composite resin (FRC) may prevent undesirable subgingival fracture, and may have a beneficial effect on the failure mode of composite resin restorations and on reparability in the event of a fracture.

To date, only a few studies have been published on this topic. The purpose of this study was to evaluate the fracture strength and the failure mode of endodontically treated posterior teeth restored with composite resin overlays with and without reinforcement with glass fibers in different cavity configurations. The null hypothesis is that the presence or absence of reinforcement and a foundation restoration do not have influence on marginal adaptation and failure modality.

**MATERIALS AND METHODS**

A total of 32 caries-free extracted mandibular molars of nearly identical size with completed root growth were selected. The teeth were extracted due to periodontal disease (patient age range 46 to 79 years) and were stored at 4°C in a solution of 0.02% thymol from the time of extraction up to a maximum of 3 months. Their use complied with the rules of the Commission of Ethics for Research on Humans at the University Hospital of Geneva. The teeth were divided randomly into four equal groups. All teeth were treated endodontically, and the root canal preparations were performed using NiTi rotary instruments, warm gutta-percha (Gutta-percha Points, Denstply Maillefer) in association with intermittent rinsing with 5% NaOCl (Niclor 5, Ogna; Muggiò, Italy). An epoxy sealer (AH Plus, Dentsply De Trey; Konstanz, Germany) and warm gutta-percha (Gutta-percha Points, Denstply Maillefer) in association with a vertical condensation technique (System B, Sybron Dental; Orange, CA, USA) were used to fill the canal system. All specimens were fixed with light-polymerizing composite resin (Filtek Z250, 3M ESPE; Seefeld, Germany) on aluminum bases and immersed in an autopolymerizing resin (Technovit 4071, Heraeus-Kulzer; Hanau, Germany). Provisional restorations of the pulp chamber were made with a temporary filling material (Cavit, 3M ESPE) before cavity preparations.

**Tooth Preparation**

Thirty-two hours after endodontic treatment, the clinical crowns of all specimens were completely removed 2.5 mm above and below CEJ.
from the mesial cusps and 3.5 mm from the distal cusps. The remaining tooth was prepared as follows: rounded 90-degree shoulder, 1.0 mm deep, 1.0 mm above the cementoenamel junction (CEJ) in half the tooth perimeter and 1.0 mm below the CEJ in the other half, using coarse diamond-coated burs (Geneva Prep Set, Intensiv; Viganello, Switzerland) under profuse water-spray cooling (Fig 1).

All dentin surfaces of the pulp chamber and the cavity walls were sealed with a two-step adhesive system (Adhese DC, Ivoclar Vivadent; Schaan, Liechtenstein). Phosphoric acid (Total Etch, Ivoclar Vivadent) was applied to the dentin for 15 s and then rinsed for 30 s. The adhesive system was spread on the dentin with a microbrush without scrubbing. After a minimum penetration time of 20 s, the resin was air thinned and polymerized (Polylight Steril 2, Castellini; Castel Maggiore, Italy) for 20 s at a light intensity of 800 mW/cm². A 0.5-mm-thick composite resin layer (Filtek Z250, 3M ESPE) sealed the canal orifices and the pulp chamber floors in the NFR-NFRC (no foundation restoration, no fiber-reinforced composite resin) and NFR-FRC (no foundation restoration, fiber-reinforced composite resin) groups, whereas in the FR-NFRC (foundation restoration, no fiber-reinforced composite resin) and FR-FRC (foundation restoration, fiber-reinforced composite resin) groups, a 3-mm-thick foundation restoration was placed using the same light-polymerizing composite resin.

Internal and external cavity finishing lines were finished with a diamond bur (25 μm grain size, no. 3113 NR, Intensiv) using water cooling under a stereomicroscope. Impressions were made using polyether material (Permadyne, 3M ESPE) with a simultaneous mixing technique, according to the manufacturer’s instructions. Provisional restorations were made with a temporary filling material (Permifil N, Ivoclar Vivadent) and inserted without provisional cement, analogous to the clinical procedure.

**Laboratory Manufacturing Process**

NFR-NFRC and FR-NFRC groups were restored with composite resin overlays (Adoro, Ivoclar Vivadent) whereas NFR-FRC and FR-FRC groups were restored with fiber-reinforced composite resin overlays (Adoro/Vectris Frame, Ivoclar Vivadent) (Fig 2). Adoro is a microfilled resin composite veneering system containing UDMA as monomer. Vectris Frame consists of several layers of fiber wafers and woven fiber bundles embedded in an organic polymer matrix. Vectris Frame consists of dimethacrylate (44 to 46 wt%), glass fibers (49 to 51 wt%), and silicon dioxide (5 to 6 wt%). An impression of the gypsum model with transparent polyvinyl siloxane (Memosil 2, Ivoclar Vivadent) paste was taken for each cavity preparation in the FR-NFRC and FR-FRC groups to form a mold. Four layers of a pre-impregnated sheet of woven-fiber “frame” were placed on the gypsum model and condensed in a deep-drawing, polymerization process using the transparent polyvinyl siloxane. After a cycle of the vacuum-forming process followed by light polymerization (VS1 unit, Ivoclar Vivadent) for 10 min according to the manufacturer’s recommendations, excess FRC was removed with a carbide bur to the vertical cavity wall. The FRC base was airborne-particle abraded (Rocatec system, 3M ESPE) with 80-μm particles at 0.25 MPa for 10 s and treated with silane (Monobond S, Ivoclar Vivadent, Schaan, Liechtenstein). For all groups, the composite resin (Adoro, Ivoclar Vivadent) was added incrementally. The final polymerization/tempering was performed in a light-polymerizing unit (Lumamat 100, Ivoclar Vivadent) using 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 previously sealed with bonding were airborne-particle abraded (CoJet system, 3M ESPE) with 30-μm particles at 0.2 MPa for 2 s. Only the enamel
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Tests were performed using a universal testing machine (Instron Model 4301, Instron; Canton, MA, USA) after fatigue loading. A spherical stainless steel punch of 5.0-mm diameter was applied perpendicular to and in the middle of the occlusal surface of the specimens. The crosshead speed was 1.0 mm/min and the load was applied until the specimen fractured. The stress-strain curves were recorded with computer software (Instron 8.2). Three fractured gold-sputtered (SCD 030, Provac; Balzers, Liechtenstein) specimens for each group were observed at various magnifications with SEM (XL20, Philips; Eindhoven, The Netherlands) to qualitatively analyze the fracture patterns. Means, medians, and 25th/75th percentiles of the fracture resistance values were calculated. The data for fracture resistance were subjected to parametric statistical analyses using two-way ANOVA and Tukey's test. The level of significance was set at $\alpha = 0.05$.

RESULTS

All restorations were in place after completing the fatigue test. Thus, the retention rate was 100% in all groups. The fracture test results are reported in Fig 4.

Two-way ANOVA revealed differences between pairs of means and an interaction between the glass-fiber infrastructure and the presence of a 3.0-mm pulp core made with composite resin ($p < 0.05$). The pairwise comparison of the four groups (post-hoc Tukey's test) showed statistically significant differences between the pairs: NFR-NFRC/FR-FRC ($p = 0.001$), NFR-FRC/FR-FRC ($p = 0.001$), and FR-NFRC/FR-FRC ($p = 0.001$). No statistically significant differences were detected between the pairs: NFR-NFRC/FR-NFRC ($p = 0.754$), NFR-NFRC/NFR-FRC ($p = 0.580$), and FR-NFRC/NFR-FRC ($p = 0.899$). The mode of failure observed was considered instantaneous in all groups, since it was not possible to detect the value of the initial failure in the stress-strain curve, but only the value of the fracture load.

Six vertical root fractures and two overlay fractures were recorded on the NFR-NFRC group (Fig 5), whereas in the FR-NFRC group, there were eight vertical root fractures. In the NFR-FRC group, four overlay fractures and four vertical root fractures were found, whereas eight overlay fractures occurred in the FR-FRC group (Fig 6). In the FR-FRC and NFR-FRC groups, delaminations at the interface of reinforcing fibers/composite resin veneering material mainly occurred (Fig 7). The fractures started on the occlusal surface at the level of the composite resin.

DISCUSSION

This study compared the fracture strength and the modality of fracture in endodontically treated molars restored with composite resin overlays. Differences between groups included the presence or absence of reinforcement in the prosthetic restoration and the presence or absence of a
foundation restoration. The results obtained showed that fiber reinforcement and foundation restoration can affect the fracture strength and the pattern of fracture; thus, the null hypothesis was rejected.

Although this study has some limitations with respect to its clinical relevance, the mean fracture resistance for all four groups (ranging from 1438 N [SD ± 262 N] to 3000 N [SD ±688 N]) suggests that composite resin restorations can withstand posterior mastication forces, which can range from 800 to 1000 N. Thus, adhesive restorations may represent a valid alternative to the traditional approach.

An important factor may be the direction of the load: in this experiment, axial forces were applied to the middle of the specimens’ occlusal surfaces, simulating a normal occlusal situation on a molar. Because fracture resistance depends on the angle of the applied load, future work should examine how nonaxial forces change the outcome.
The fracture is deflected by fibers without affecting the root.

Fig 8 SEM image of a specimen from the FR-FRC group (foundation restoration, fiber-reinforced composite resin).

compared to that in this study. Moreover, the lack of thermocycling simultaneously performed with occlusal loading represents another limitation of this study. In fact, it has been suggested that thermocycling may further stress and weaken the adhesive bond, decreasing fracture strength and increasing microleakage. The different failure modes of the groups suggest that the absence of a foundation restoration did not predispose to root fracture in groups restored with composite resin overlays without reinforcement with glass fibers (NFR-NFRC and FR-NFRC groups), whereas it significantly reduces the incidence of this kind of fracture in groups restored with composite resin overlays with glass fiber reinforcement (NFR-FRC and FR-FRC groups). The NFR-NFRC group exhibited six vertical root fractures and two overlay fractures; in the FR-NFRC group, eight vertical root fractures were observed; four overlay fractures and four vertical root fractures were observed in the NFR-FRC group, and in the FR-FRC group, eight overlay fractures were recorded. These results may be due to the disposition and position of the glass fibers in the specimens with a foundation restoration, which permits a coronal deflection of the vertical fracture line. Position and fiber orientation influence the loads at initial and final failure. The positioning of fibers occlusal to the CEJ, as in the FR-FRC group, seemed to be more effective in avoiding irreparable root fracture. The fracture resistance of specimens without a foundation restoration (the mean fracture strength of the NFR-FRC group was 1438 N) was not significantly different from that of the groups restored with composite resin overlays without glass-fiber reinforcement (the NFR-NFRC group fractured at a mean of 1677 N, the FR-NFRC group at a mean of 1498 N), and differences were seen in the mode of failure. The NFR-FRC group, despite having the lowest fracture strength, showed fewer root fractures than did the NFR-NFRC or FR-NFRC group. In contrast, the FR-FRC group showed the highest fracture strength (3000 N). In addition, the FR-FRC group only resulted in reparable fractures. The distance between the fibers and crack initiation may explain this different behavior. In the FR-FRC group, which had a foundation restoration, the distance between the fibers and the occlusal surface, where the crack began, is reduced; for this reason, the fibers can withstand tensile stress and stop crack propagation (Fig 8). In the NFR-FRC group, the distance and the amount of composite resin between the fibers and the occlusal surface were greater, so the fibers could not prevent fracture propagation. NFR-FRC and FR-FRC groups showed a more favorable manner of failure compared with the groups restored with composite resin overlays without glass-fiber reinforcement. This may be explained by the glass-fiber arrangement, which results in greater fracture resistance and better transmission of the stresses. These results confirm the ability of glass-fiber reinforcement to deflect a crack, preventing unfavorable propagation in a cervical direction, and facilitating re-restoration in the case of fracture. Nevertheless, it should be emphasized that the results obtained in this study may have been influenced by the lack of a simulated periodontal ligament. In fact, Soares et al found that this factor can significantly affect the fracture mode of bovine teeth in vitro.

Magne et al found that vital molars with a compromised cusp can be reinforced using a composite resin onlay, but that a polyethylene fiber patch did not affect the pattern of fracture. Thus, in vivo, the presence of fiber reinforcement does not seem to be essential in small restorations carried out on vital teeth. A study by Brunton et al showed that specimens with FRC produced fewer fractures of the tooth substrate than specimens without FRC. In fact, glass fibers are known to be able to withstand tensile stress and to stop crack propagation in composite resin material. The results of this study, however, are consistent with those of Dere et al. These authors demonstrated that fiber-reinforced overlays, besides achieving higher fracture toughness values, induced more favorable patterns of fracture in vitro. Fibers may produce a sort of ferrule effect, surrounding the remaining gingival tooth structure. These results suggest that the incorporation of glass fibers, in association with a foundation restoration, can increase the load-bearing capacity of molars with cusp-replacing restorations.

CONCLUSIONS

Within the limitations of this in vitro study, the results demonstrated that the use of composite resin overlays represents a conservative approach to rehabilitation of endodontically treated teeth. The fracture strength of all composite resin overlays was higher than the likely bite forces. The incorporation of glass fibers increased fracture resistance and had a positive effect on the failure mode and thus on the re-restorability in case of fracture. The arrangement of fiber reinforcement occlusal to the CEJ enabled an increase in the fracture strength and a reduction in the risk of root fracture.
REFERENCES


Clinical relevance: The use of fiber-reinforced overlays is a possible alternative to prosthetic crowns in endodontically treated teeth and can prevent irreparable root fractures.