Evaluation of Static Load-bearing Capacity and the Failure Mode of Endodontically Treated Maxillary Incisors Restored with Complete Crowns Made of Experimental Composite Resin with Short Fiber Fillers, With and Without Root Canal Posts

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Abstract

Background: Indenture base materials, a semi-interpenetrating polymer network (semi-IPN) matrix based on polymethyl methacrylate has been employed. Semi-IPN polymer matrix is also used in several dental products. However, no research has been done on dental restorative composite resin with a semi-IPN polymer matrix and glass fibers. The goal of this *in vitro* study was to assess the static load-bearing capacity and failure mode of endodontically treated maxillary incisors restored with complete crowns made of experimental composite resin (FC) with short fiber fillers, with and without root canal posts, in endodontically treated maxillary incisors. **Material and Methods:** 22.5 wt. % short E-glass fibers (3 mm in length) and 22.5 wt. % semi-IPN resin was mixed with 55 wt.% silane-treated silica fillers to make the experimental composite resin (FC). At the cementoenamel interface, the clinical crowns of thirty human removed maxillary incisors were sectioned. Group A: made from particulate filler composite resin (PFC) (Grandio Caps, VOCO, control), Group B: PFC with fiber post (everStick, StickTeck), Group C: made from PFC with everStick fiber post and Fiber-reinforced composite FRC-substructure, Group D: made from FC, Group E: made from FC with FRC-substructure, Group F: made from FC with FRC-substructure. The root canals were cleaned, and resin cement was used to cement the posts in place (ParaCem Universal). All restored teeth were maintained in room temperature water for 24 h before being statically stressed at 1.0 mm/min till breakage. ANOVA ($P = 0.05$) was used to evaluate the data. Visually, failure modes were explored. **Results:** ANOVA demonstrated that experimental fiber composite resin restorations had a better load-bearing capability (349 N) than control restorations ($P = 0.05$). (173 N). The load-bearing capability of restorations strengthened with FRC-substructure and those without were not significantly different ($P > 0.05$). **Conclusions:** Restorations built with short glass fiber-containing composite resin with IPN–polymer matrix outperformed those constructed with plain PFC or PFC reinforced with fiber post in terms of load-bearing ability.

Keywords: Fiber-reinforced composite, Load-bearing capacity, Fiber composite complete composite crown fiber post

Introduction

Vertical root fractures still occur in daily clinical practice, despite attempts to repair an endodontically treated tooth. Minimal tooth preparation in endodontic and restorative operations, on the other hand, is known to be a useful technique for minimizing vertical root fractures in pulpless teeth.[1-3] Different kinds of fiber-reinforced composite (FRC) resin posts have been created in the latest days as an option to molded or prefabricated metal supports for the restoration of endodontically treated teeth because the elastic moduli

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of these fiber posts are closer to that of dentin than metal posts.[1,2]

In compared to other types of posts, many investigations on the mechanical strength of pulpless incisors restored using FRC resin posts have revealed fewer rates of root fractures. Even if teeth are severely damaged, it is crucial to preserve strategically important teeth when rebuilding severely damaged dentition. Root-filled teeth can be restored without the use of traditional crowns in some cases using adhesive techniques and particle filler composite resin as both the core and veneering material. On a sound tooth structure, a full crown with a 2 mm ferrule modified the distribution of forces to the root and post-and-core complex.[3,4]

A prior study found no significant difference in strength between post-and-core restorations with a ferrule and those without a ferrule when bounded resin was used on structurally compromised roots. Although some clinical findings imply that the direct composite resin crown is a viable alternative to traditional treatment procedures, failure has also been linked to fracture of the restorative composite resin. Because of these types of failures, the use of restorative composite resins in large, high-stress bearing applications such as direct full crowns is still debatable. Current composite resins are still limited in their usage in these big stress-bearing restorations due to their high brittleness and low fracture toughness. Improvements to restorative composite resins have been studied.[5,6]

Changes in the kind or size of fillers, as well as their silanization, have been attempted by altering the polymerization kinetics of resins and modifying the degree of monomer conversion. Glass fiber reinforcement, FRC resin substructure, whiskers, particulate ceramic fillers (dense and porous), and filler content optimization are some of the technologies that have been investigated. Additional features of indirect laboratory-made composite resins, such as post-polymerizing to improve composite resin strength and toughness, have been examined. Glass fibers have been studied for over 30 years as a way to reinforce dental polymers.[2,7]

In comparison to carbon or aramid fibers, glass fibers have demonstrated reinforcing effectiveness and good esthetic properties. The resins used, the quantity of fibers in the resin matrix, the length of fibers, the form of fibers, the orientation of fibers, fiber adherence to the polymer matrix, and fiber impregnation with the resin are all factors that influence the efficiency of fiber reinforcement. Indenture base materials, a semi-interpenetrating polymer network (semi-IPN) matrix based on polymethyl methacrylate (PMMA) has been employed. Semi-IPN polymer matrix is also used in several dental FRCs. However, no research has been done on dental restorative composite resin with a semi-IPN polymer matrix and glass fibers.[8,9]

The study's first goal was to look into the load-bearing capacity of anterior crowns composed of experimental short FRC resin with semi-IPN matrix. The second goal was to look into the strengthening influence of FRC-substructure on the restoration failure mode.

Materials and Methods

22.5 wt. % short E-glass fibers (3mm in length, 15 mm in diameter, and coated with PMMA and BisGMA matrix) were mixed with 22.5 wt. % photopolymerizable dimethacrylate resin matrix, and then 55 wt. % SiO_2 filler particles (3 2 mm in size) (Aldrich, Steinhein, Germany) were gradually added. For 5 min, a high-speed mixer was used to mix the ingredients (SpeedMixer, DAC, Germany, 3500 rpm). The silica filler particles were silane treated before being integrated into the resin matrix, as previously described.

Thirty extracted human maxillary incisors with straighter roots and fully developed apices were chosen because they had similar root diameters, no cavities in the root, a crown up to 2 mm above the cementoenamel junction (CEJ), and no apparent fracture lines in the root. The teeth were placed in water until they were ready to be processed. Root lengths were measured from the CEJ on the facial surface with a digital caliper (Tamoline, Helsinki, Finland) with a precision of 0.01 mm, and mesiodistal widths were measured between the proximal surfaces at the CEJ. The clinical crowns were removed from the CEJ up to 1.5 mm above it.

Five groups of teeth (n = 6) were formed from the prepared teeth. Crowns made of direct composite resin were made according to the groups to which they belonged. Group A (control group) is made of ordinary particulate filler composite (PFC) (Grandio) with no post. Group B: PFC reinforced with individually formed glass FRC post (everStick post, diameter 1.2 mm), Group C: PFC reinforced with post and two layers of continuous bidirectional E-glass FRC substructure (thickness = 0.12 mm), Group D: plain FC composite resin, Group E: FC composite resin with two layers of bidirectional FRC substructure. Over the flattened incisal surface, FRC-substructure layers were applied. The two fiber layers were oriented in the opposite direction.

Burs (Gates Glidden; Dentsply Maillefer, Ballaigues, Switzerland) up to size 4 were used to prepare the post space over the whole length of the canal (4000 cycles min^{-1} with water cooling). The manufacturer's instructions were followed for preparing the individually shaped glass FRC posts. A 16-mm-long bundle of pre-impregnated glass fibers was cut. The bundle was placed in the canal and light polymerized for 20 s using an Optilux-501 hand light-curing equipment. The post was then removed from the canal and light polymerized for 40 s. An extra bundle of pre-impregnated glass fibers was placed along and fastened to the post after it was pushed into the canal and initially light polymerized for 20 s.

After that, the FRC post was taken out of the canal and light polymerized for 40 s. The FRC post system's surface was then wetted with resin (Stick Resin) and shielded from light by a lightproof box (3 M-ESPE, Germany) until it was cemented.

The pole was seated after cement (ParaCem Universal, Switzerland) was poured on it. Before crown building, excess cement was removed and each specimen was stored in distilled water for 1 h.

The teeth's dentin surfaces were etched for 20 s with a 37% phosphoric acid etch-gel (3 M Scotchbond, USA), washed, and air-dried gently. The manufacturer's instructions were followed for applying the dentin prep and glue (3 M Scotchbond, USA). A translucent template matrix (Memosil, Heraeus Kulzer, Germany) of an appropriately shaped crown was employed to help crown manufacturing for all groups in order to reduce variability in specimens. Polymerization was done gradually for 40 s on both sides utilizing a light polymerization machine (Optilux-501, Kerr, CT, USA). The light source was put in close proximity to the crown surface (1–2 mm). The visible light (halogen) had a wavelength of 380–520 nm, with a maximum intensity of 470 nm and a light irradiance of 800 mW/cm^2.

Finally, diamond stone and polishing tips were used to finalize the composite resin crown's cervical shape and the restoration's surface (40,000 cycles min 1 with watercooling). The teeth were placed onto acrylic resin (Palapress; Heraus Kulzer, Wehrheim, Germany block (diameter 2.5 cm) after the restorative treatment was completed. The acrylic resin level was approximately 1.5 mm above the flattened incisal root surface (to simulate bone). The teeth were kept wet during the procedure and then stored in distilled water at room temperature for 24 h before being tested.

A universal testing equipment was used to apply a static stress to the recovered teeth. The acrylic block containing the reconstructed tooth was firmly attached to the inclined metal base, resulting in a 458 angle between the tooth's palatal surface and the loading tip (spherical 2.0 mm). The loading event was recorded until each tooth fractured, and the failure mode for each specimen was visually analyzed and classified into two types of failures: favorable above the CEJ (adhesional failure at bonding surface) with an easy repair possibility, and unfavorable below the CEJ (vertical root fracture) with a difficult repair possibility. The fracture load data were statistically evaluated using SPSS version 10 software (SPSS Inc., Chicago, IL, USA).

Results

The mean fracture loads and standard deviations for the five test groups are summarized in Tables 1 and 2. ANOVA found that experimental fiber composite resin restorations had a considerably better load-bearing capability (349 N) ($P = 0.05$) than plain PFC (control) restorations (173 N). The research revealed that crowns with additional post reinforcement have a higher load-bearing capacity than crowns without post reinforcement. There was no statistically significant difference in load-bearing capability comparing restorations with and without FRC-substructure ($P > 0.05$). The difference in failure mode, on the other hand, was obvious. Fracture pattern analysis indicated that 70% of the failures in groups without FRC were unfavorable, whereas in groups with FRCsubstructure the failures were all favorable (debonding)

Discussion

The findings of this study backed up the idea of combining short E-glass fiber fillers and FRC-substructure to enhance composite resin restorations to withstand direct full incisor crown loads. The worst-case scenario of endodontically treated maxillary incisors with badly damaged crowns was recreated in this study. A metal post-and-core and a full crown would have been the standard treatment. Clinical research on the failure of metal post and core restorations, on the other hand, frequently revealed the occurrence of root fracture. Alternative core materials would have been composite resin or amalgam.[10,11]

Endodontically treated teeth restored with a fiber post and composite resin core in combination with dentin bonding had a good long-term clinical performance. However, another study found decreased long-term survival rates, with fracture of the composite resin restoration being the predominant cause of failure, particularly in high-stress locations. Short E-glass fiber fillers were used to support the composite resin repair in order to preserve direct entire crown loads.[12,13]

Stress transfer from the polymer matrix to the fibers is required for the fiber to operate as an effective reinforcement for polymers, and this is achieved by having fiber length equal to or greater than the critical fiber length. Based on this understanding, fiber fillers with a length of 3 mm were used in the current study. In theory, the fiber fillers' reinforcing action is based on both stress transfer from the polymer matrix to the fibers and individual fiber activity as stress breakers. Data on the behavior of direct composite resin crowns with and without a post was also collected as part of this study.[14,15]

In general, our findings are consistent with earlier laboratory research that found that the post had a considerable impact on

Table 1: Mean fracture load values (n) with standard deviations (S.D.) of test specimens

Group	Mean (*n*)	S.D
A (plain PFC, control)	17.3	89
B (PFC+post)	25.8	134
C (PFC+post+FRC)	22.9	109
D (FC)	34.9	146
E (FC+FRC)	30.9	126

Table 2: Failure modes distribution of test specimens

Group	Favorable failures	Unfavorable failures
A (Plain PFC, control)	1	5
B (PFC+post)	2	4
C (PFC+post+FRC)	6	0
D (FC)	2	4
E (FC+FRC)	6	0

the restoration's fracture resistance. Furthermore, the bulk of the specimens had been fractured in an unsatisfactory manner (root fracture). Root fractures start in sites with high-stress concentrations and spread through the repair by seeking mechanically weak areas. Fractures could have started at the adhesive junction between the core and root dentin and spread to the post, indicating a lack of dentin bonding.[16,17]

These findings back with a prior finite element analysis study that indicated that an oblique force was conveyed to the entire crown and stress were distributed to the crown's cervical margin and post-dentin interface. Given this, its critical to look for alternate treatments to avoid failures of this nature. The study's second hypothesis was that using FRC-substructure would prevent root fractures. It was discovered that groups with the FRC-substructure had more favorable failure modes and had a lower load-bearing capability.[18,19]

This is in line with the findings of Fokkinga *et al*., who discovered that continuous bidirectional FRC produced a stiffer structure and hence the ability to block or arrest fracture growth, resulting in a beneficial failure mode. A 458 angle between the palatal surface of the tooth and the loading tip was used in this *in vitro* study to provide lateral forces to the occlusal surface. In order to imitate clinical situations, lateral forces, as well as axial forces and fatigue loading, should be considered. In addition, aging mechanisms such as alternative thermal stress, mechanical stress, wear, and water storage must be considered.[20,21]

The stress that is imparted to the teeth and dental restorations is usually mild and repetitive, rather than isolated and damaging. The compressive static test, however, provides vital information about load-bearing capability due to a linear relationship between fatigue and static loading. It is important to note that using FC composite or FRC-substructure with a composite resin crown is not a substitute for metal post-and-core and complete ceramic crown restorations. The findings of this study imply that using FC composite or FRC-substructure as a composite restoration alternative in high-stress-bearing applications could be a viable option.[22,23]

Conclusion

In comparison to traditional particle filler restorative composite resin, short glass fiber reinforced semi-IPN composite resin displayed improved load-bearing ability. At the interface between composite resin crown and dentin, a continuous bidirectional glass FRC substructure may help prevent crack propagation and root fractures.

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