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FRACTURE STRENGTH OF SEMI-DIRECT FIBER-REINFORCED COMPOSITE RESTORATIONS ON ENDODONTICALLY TREATED TEETH: AN IN-VITRO STUDY

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Abstract

Restoring endodontically treated teeth (ETT) with semi-direct fiber-reinforced composite (SDFRC) restorations is gaining popularity among the dental fraternity. This study aimed to evaluate the fracture strength and failure modes of the SDFRC restorations with and without cuspal coverage on ETT. Fifty-one sound human maxillary premolars were collected and randomly assigned to 3 groups: Group 1 (sound); Group 2 (SDFRC restorations with cuspal coverage on ETT); Group 3 (SDFRC restorations without cuspal coverage on ETT). SDFRC restorations were fabricated following biomimetic principles and permanently cemented with heated composite. All samples were subjected to artificial aging and statically loaded with a universal testing machine until the final fracture. Data were collected and statistically analysed via one-way ANOVA for fracture strength and Chi-square test for failure modes. Fracture strength of ETT with cuspal coverage SDFRC restorations (647.44N ± 168.43N) were statistically significantly lower than SDFRC restoration without cuspal coverage (849.38N ± 147.40N), $F(2,48) = 5.27$, $p<0.05$. There were no statistically significant differences between the groups for failure modes ($p=0.052$). Minimally invasive biomimetic SDFRC restoration without cuspal coverage is a viable restorative treatment for ETT. Preservation of coronal tooth structure is key to the longevity of the ETT with favourable failure modes.

Keywords: Biomimetic Restoration; Composite Resin; Cuspal coverage; Ribbond; Prosthodontic

1. Introduction

Endodontically treated teeth (ETT) are prone to fractures due to the removal of tooth structure during endodontic procedures, making them more brittle and reducing their longevity (Glazer, 2000; Pantvisai & Messer, 1995). The restoration of pulpless teeth is a complex and controversial topic, with a wide range of techniques and materials recommended (Morgano et al., 2004). Factors such as caries, previous restorations, and access cavities contribute to tooth weakening (Mannocci et al., 2022; Tang et al., 2010) whereas intracanal medicaments and irrigants, such as sodium hypochlorite and calcium hydroxide, can further weaken the tooth structure (Grigoratos et al., 2001). Moreover, dehydration of dentin (Kahler et al., 2003) and collagen alteration during repeated canal irrigation and drying (Morgan et al., 2019) can also affect the biomechanical properties of dentin.

A well-sealed coronal restoration is crucial for the success of non-vital teeth, considering the remaining tooth structure and choice of restoration (Al-Nuaimi et al., 2020; Kimble et al., 2023; Larson, 2006). In a comparative study on the punch shear strength, hardness, toughness, and load to fracture values of endodontically treated teeth (ETT) and vital teeth, it was found that the dentin of vital teeth exhibited a 3.5% higher value compared to ETT. Nevertheless, the study concluded that the biomechanical properties of vital teeth and ETT were similar, indicating that endodontic treatment did not inherently make teeth more brittle. Instead, the cumulative loss of tooth structure was the primary contributing factor to the failure of ETTs (Sedgley & Messer, 1992).

Therefore, endodontic treatment is deemed incomplete until a reliable permanent restoration is applied to the tooth. Various treatment modalities serve as permanent restorations, including traditional post and core, complex amalgam restorations, and direct or indirect casted or milled cuspal coverage restorations (Baba, 2013; Taheri et al., 2021). The need for cuspal coverage after root canal treatment is now debatable, with conservative access cavities and minimally invasive techniques gaining popularity (Bürklein & Schäfer, 2015; Politano et al., 2018). Direct restorations are completed chair-side in a single visit, while indirect restorations are fabricated extra-orally before cementing permanently requiring more than one visit (Bhuva et al., 2021). Apart from direct and indirect composite restorations, semi-direct restorations were introduced to not only reduce polymerization shrinkage through improved curing methods extra-orally but also to reduce cost and time of visit compared to indirect ceramic restorations (Melo et al., 2023). Ribeiro et al. conducted a study comparing direct and semi-direct composite restorations and found that dentin bond strength was better in the latter, while the microhardness ratio was similar between the two (Ribeiro et al., 2022).

With technological advancements, dentistry is transitioning towards conservative and adhesive-focused approaches. Biomimetic restorative dentistry exemplifies this shift, emphasizing maximum bond strength, long-term marginal seal, improved pulp vitality, and reduced residual stress. Following strict rubber dam isolation, a variety of protocols are used to minimize polymerization stresses and create a final fail-safe restoration. These protocols include caries removal endpoint, immediate dentinal sealing (Alleman & Magen, 2012), resin coating (Sema Belli et al., 2007), deep margin elevation (Aldakheel et al., 2022), incorporations of polyethylene fibers, and stress-reducing composite layering or indirect final restorations (Deliperi et al., 2017). With the use of fiber-reinforced composite, these biomimetic restorations were found to have an increase in fracture resistance (Shah et al., 2022). Many studies observed that linear woven ultra-high molecular weight polyethylene fiber ribbons act as stress breakers, effectively distributing and transferring stress to reinforce the restoration and prevent crack propagation (Sema Belli et al., 2006; Sema Belli et al., 2007; Ozsevik et al., 2016). Ribbond is a commercially available non-impregnated fiber ribbon made of polyethylene (Eliguzeloglu Dalkılıç et al., 2019a) which have shown to increase the fracture strength of endodontically treated mandibular molars with mesio-occlusal-distal cavities (Belli et al., 2005; Khan et al., 2013). However, there was limited research conducted both in vitro and in vivo on treatment modalities that combine most of these protocols (Magne & Douglas, 1999; Eshani H Shah et al., 2021).

2. Objective

This research aimed to investigate the fracture strength and failure modes of fiber-reinforced semi-direct cuspal and non-cuspal composite restorations on endodontically treated premolars.

3. Methodology

3.1 Material preparation

The core material for this study was the Ribbond fiber reinforced composite (Ribbond® - THM, Seattle, WA, USA) used in constructing semi-direct composite restoration. Materials used in the study are listed in Table 1. Sample size calculation was done using G*power 3.1.9.7. Considering a = 0.05, p = 0.5, and d = 0.25, it was determined that the total sample size was 51, distributed among three groups, with each group containing 17 samples.

Fifty-one sound maxillary premolars with complete root formations were collected, cleaned, and stored in 4°C saline. Only premolars with single roots and radiographically identified two canals were included whereas teeth with caries, root resorption, or fracture lines were excluded. The selection of teeth samples was done by two calibrated operators (C.J.D.W. and Y.A.) who are trained in restorative dentistry. All samples were randomly divided into 3 groups with 17 teeth each; Group 1 as the control group was sound premolars with no procedure initiated; Group 2 was endodontically treated and restored with SDFRC cuspal coverage restoration and Group 3 was similar to Group 2 without cuspal coverage restoration.

A simulated mesio-occluso-distal (MOD) cavity and palatal cusp reduction up to 2mm above cementoenamel junction (CEJ) with pulpal exposure were prepared for Groups 2 and 3. Preparation was performed using depth orientation burs of 2mm, course, and fine-grit diamond burs (NTI Diamond bur FG KR Taper, Modified Shoulder 850KR 018M and SF, Kahla, Germany) making sure the buccal wall thickness remained 3mm at the occlusal surface and 4mm at the CEJ in the buccolingual direction (Figure 1).

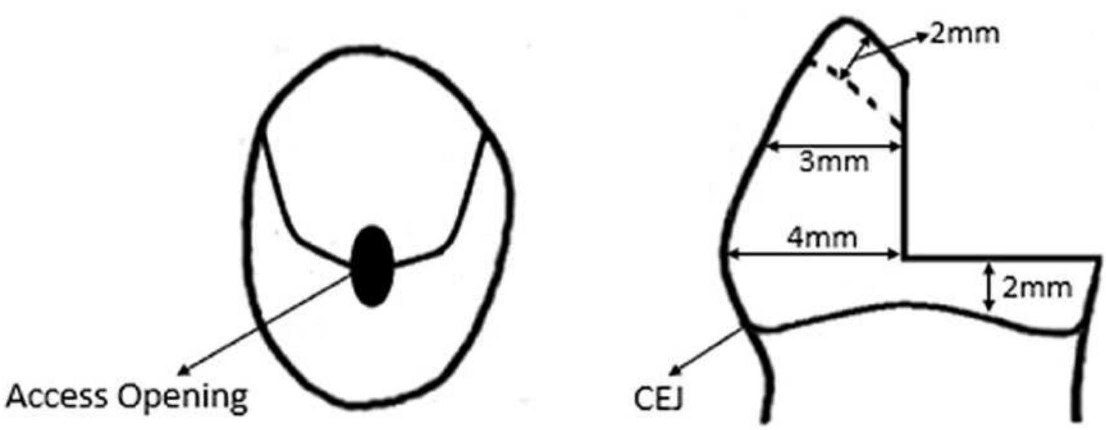

Figure 1 Dimensions of the tooth preparation with pulpal involvement

Cavities were accessed following the principles of cavity preparation for a maxillary premolar with both buccal and palatal canals cleaned and shaped up to the visible working length using rotary Ni-Ti files (AurumBlue, MetaBiomed, Korea). Irrigation with 5.25% sodium hypochlorite and normal saline was performed. Teeth were obturated with a hydraulic condensation technique with a single gutta-percha cone (25/06) and bioceramic sealer (CeraSeal, MetaBiomed, Korea). The gutta-percha was sheared off 1mm below CEJ and vertically compacted. The cavities were temporized with self-curing temporary filling material (CavitTM, 3M ESPE, Deutschland, Germany) to prevent contamination during mounting.

The roots of all the samples from all 3 groups were soaked in a wax bath of 100°C to obtain even wax thickness around the roots up to CEJ and embedded in a freshly mixed polymethyl methacrylate (PMMA) (Kemdent, Wiltshire, UK). The PMMA acrylic was contained in a silicone mold of 2 x 2 cm. The wax spaces were then replaced with polyvinyl siloxane (PVS) impression material (3M ™ Imprint ™, 3M ESPE, Deutschland, Germany) to simulate the presence of periodontal ligament.

TABLE 1. Materials used in this experiment

Material	Brand	Manufacturer
NiTi Rotary Files	Aurum Blue	MetaBiomed, Korea
Root canal sealer	Ceraseal	MetaBiomed, Korea
Fine grit diamond burs	NTI	Kahla, Germany
Alginate	Kemdent	Wiltshire, UK
Polyvinyl siloxane	3M ESPE	Deutschland, Germany
OptiBond FL	Kerr	California, USA
Flowable composite	ENA HRi Flow, Micerium	Genova, Italy
Short fiber reinforced composite	EverX Flow, GC	Tokyo, Japan

3.2 Fabrication of semi-direct composite restoration

Temporary filling materials were removed and samples from Group 2 underwent 2mm of buccal cusp reduction with a butt joint margin. The tooth preparations for Groups 2 and 3 were refined with fine-grit diamond burs ensuring the elimination of undercuts to receive a semi-direct restoration (Figure 2A and B). The prepared surfaces were then sealed with a two-bottle primer and adhesive system (OptiBond FL, Kerr; Orange, California, USA). After immediate dentinal sealing, a thin layer of 0.5mm flowable composite resin (ENA HRi Flow, Micerium, Avegno, Genova, Italy) was coated onto the entire preparation, cured for 20 seconds, and underwent decoupling process for 5 minutes. Then, polyethylene fibers (5 x 3mm) (Ribbond - THM, Ribbond Inc., Seattle WA, USA) were prepared and coated with adhesive resin which was then placed onto the tooth preparation surface in a bucco-palatal direction covering both the cusps for Group 2 and only the palatal cusp for Group 3 (Figure 2C and D). A thin layer of short fiber-reinforced flowable composite (EverX Flow, GC, Tokyo, Japan) was placed over the fiber to prevent exposure and light-cured completely.

Impressions were made with a custom tray and alginate impression (Kromopan, Florence, Italy). The working models were fabricated using light-bodied PVS (3M ™ Imprint ™, 3M ESPE, Deutschland, Germany) where the nano-hybrid composite resin (FILTEK Z250, 3M ESPE, 3M Deutschland, Germany) was used to build up the final SDFRC restoration (Figure 2E and F). The final occlusal anatomy was performed using the stamping technique and standardized for all restorations with a stamp acquired from the occlusal anatomy of the sound tooth. After curing thoroughly, the restorations were heat-treated in an oven (120°C) for 7 minutes. The restorations were then placed onto the samples for margin fitting and adjustments.

The intaglio surface of the semi-direct restorations and the tooth-prepared surfaces were air-abraded with 50-µm aluminum oxide at a bar pressure of 2.0 for 10 seconds (Danville MicroEtcher ERC Micro-Sandblaster Air Abrasion System, Chicago, USA). Etching of both surfaces was performed using 37% phosphoric acid (Ultra-Etch - Etchant, Ultradent, South Jordan) for 30 seconds, rinsed for 30 seconds, and air dried before the application of silane agent. OptiBond FL adhesive was applied on the entire tooth surfaces without light curing and the semi-direct restorations were cemented using preheated composite resin (Enamel Plus HRi, Micerium, Avegno, Genova, Italy). Excess luting cement was removed and light cured completely for 60 seconds. The restorations were finished and polished with the Diacomp EVE Polishing system (EVE DiaComp Plus Twist, Smart, Israel) (Figure 3A and B).

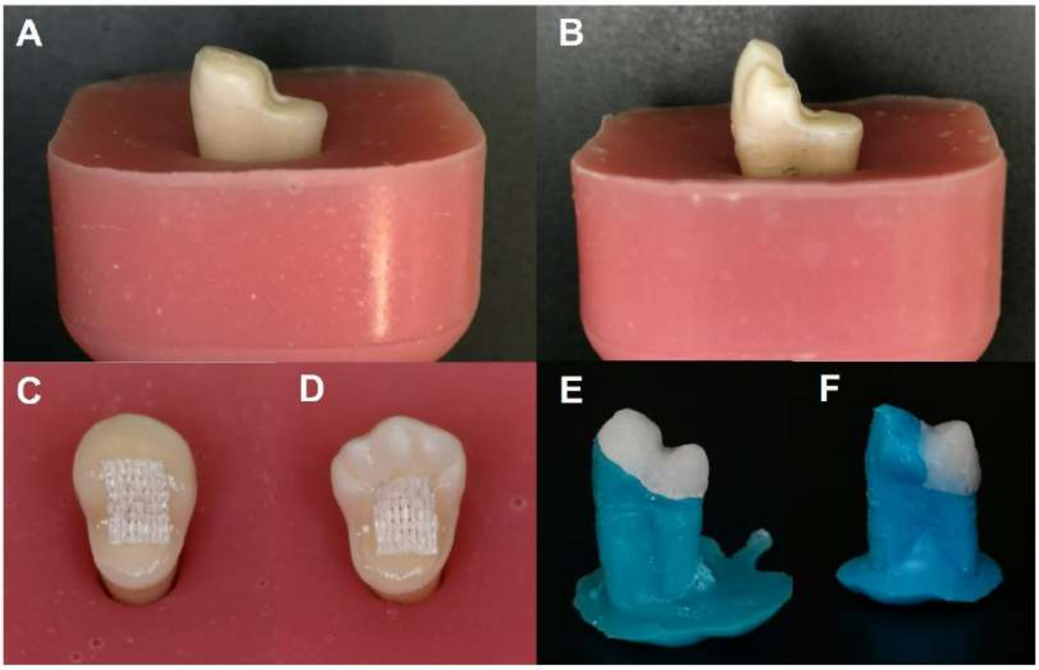

Figure 2 (A) Cuspal reduction in Group 2; **(B)** Non-cuspal reduction in Group 3; **(C)** Ribbond placement on both buccal and palatal cusps for Group 2; **(D)** Ribbond placement on palatal cusp only for Group 3; **(E)** SDFRC restoration with cuspal coverage; **(F)** SDFRC restoration without cuspal coverage

3.3 Fibroblast-like Synoviocytes and Joint Destruction

All samples were subjected to aging via boiling in deionized distilled water (100°C) for 16 hours (Gil-Castell et al., 2014; Wang et al., 2023). After drying, aluminum foil of 0.3mm thickness was placed over the samples to reduce excessive stress forces. The samples were then statically loaded using the Universal Testing Machine (AGS-X, Shimadzu, Japan) with a bar-shaped stainless steel horizontal indenter (4mm in diameter). The load was continuously applied along the long axis of the tooth with a crosshead speed of 1mm/min until the final fracture and recorded as Newton (N). All the fracture sites were observed under a dental microscope (Leica Micro-system Imaging Solutions, Cambridge, UK) at 20x magnification to categorize the type of fractures. Fracture lines extended below the CEJ were considered unfavorable which is non-repairable.

Figure 3 (A) Semi-direct restoration for Group 2 and Group 3 **(B)** cemented and polished

3.4 Data Analysis

All the data collected were tabulated in Microsoft Excel and statistically analyzed using SPSS vs27. One-way analysis of variance (ANOVA) test was used to assess the differences among groups and the Fisher exact test for the mode of failure.

4. Results

The fracture strength of each group was summarized in Table 2. It was observed that statistically significant differences were found between the groups with p-value = 0.009. Posthoc comparison found that ETT with SDFRC cuspal coverage restoration had significantly lower fracture strength than SDFRC without cuspal coverage restoration (p = 0.007), whereas SDFRC without cuspal coverage restoration had no significant difference with sound tooth (p = 0.563). In terms of the failure mode analysis, the Fisher exact test (Table 3) showed no significant difference between the 3 groups (p = 0.0529).

TABLE 2. Results of Fracture Strength (N).

Group	n	Mean ± SD (N)	Minimum (N)	Maximum (N)	*p*-value
Sound	17	784.07±229.62[a]	296	1215	F (2,48) = 5.27, $p = 0.009$
SDFRC with cuspal coverage on ETT	17	647.44±168.43[ab]	364	898	
SDFRC without cuspal coverage on ETT	17	849.38±147.40[ac]	572	1151	

Data presented in mean ± standard deviation (SD). P-value calculated using one-way ANOVA. The similar letter indicates statistically similar groups.

TABLE 3. Results of Failure Mode between Groups

Group	Mode of Failure		Pearson Chi-Square Value
	Favourable	**Unfavourable**	
Sound	10 (58.8)	7 (41.2)	1.275 (2) $p = 0.0529$
SDFRC with cuspal coverage on ETT	13 (76.5)	4 (23.5)	
SDFRC without cuspal coverage on ETT	12 (70.5)	5 (29.4)	

5. Discussion

Restoring endodontically treated teeth has always been a topic of interest for the past few decades. In the current study, restoring ETT with semi-direct restoration following the biomimetic principle presented comparable results with sound teeth. Group 3 without cuspal coverage performed significantly better than the group with cuspal coverage (Group 2) and had no significant differences with intact teeth (Group 1). The result was in contrast with Fennis et al. (2004) where the group with cuspal coverage had higher fracture resistance compared to non-cuspal coverage (Fennis et al., 2004). However, Fennis et al. investigated Class II cavities with palatal coverage and did not involve the buccal cusps as shown in this study. Having both the cusps reduced could have jeopardized the fracture resistance of the tooth, which was not an uncommon feature in a tooth with little coronal tooth structure. This explained the significant differences between Groups 2 and 3. The importance of remaining coronal tooth structure was studied extensively in the past. Multiple in-vitro studies demonstrated that the loss of coronal tooth structure had a significant reduction in fracture resistance (Reeh et al., 1989; Sornkul & Stannard, 1992; Steele & Johnson, 1999), whereas many clinical studies thereafter showed that the survival rates of teeth were affected by cuspal coverage restoration (Hansen et al., 1990; Mannocci et al., 2002; Nagasiri & Chitmongkolsuk, 2005; Scotti et al., 2015).

Interestingly, no significant differences were observed in the modes of failure among the groups. It could be due to the usage of FRC in both groups that aid in the prevention of crack propagation. A recent systematic review stated that the usage of both polyethylene and short FRC showed greater fracture resistance when compared to restorations without reinforcement (Eshani H. Shah et al., 2021). The authors also claimed that favourable and adhesive fractures were most commonly seen, occurring at the level of enamel and dentin. Reinforcing restorations with polyethylene fibers not only changes, distributes, and transfers stress patterns, but also acts as shock absorbers and effectively reduces the negative effects of polymerization shrinkage when used in combination with flowable resin (S. Belli et al., 2006; S. Belli et al., 2007). Ribbond® possesses a 3-dimensional structure of leno woven fibers, providing a lock stitch feature and improving the mechanical interlocking between resin and composite resin on different planes. Polyethylene fibers which have a high modulus of elasticity and low flexural modulus, can modify the effects of interfacial stresses that are presented on the etched enamel and resin boundary. Embedding polyethylene fibers under a large composite restoration was observed to increase the fracture strength and tensile bond strength of dentin and reduce microleakage (Eliguzeloglu Dalkılıç et al., 2019b). Short FRC, which was EverXFlow used in this study is a new material having multidirectional and discontinuous fibers which also helps to increase the load-bearing capacity and fracture resistance, act as a dentin substitute, and prevent crack formation (Vallittu, 2015). This explains the failure modes for both groups with semi-direct restoration reinforced with FRC.

Polymerization shrinkage is inevitable in a direct composite restoration, where stress can develop at the tooth-restoration interface leading to multiple unfavourable complications such as microleakage, secondary decay, pulpal sensitivity and irritation, and marginal discolouration. The degree of monomer conversion is directly proportional to the physical and mechanical properties of composites. Unreacted monomers and inadequate polymerization compromise and affect the performances of composite, increasing their wear and decreasing their longevity. Semi-direct and indirect techniques were good ways to alleviate this issue. Studies have shown that treating large cavities with unfavourable configurations when restored with semi-direct restorations had better long-term clinical outcomes when compared to direct restorations (Machado & Anchieta, 2020; Spreafico et al., 2005; Torres et al., 2020). Heat-treated composite restorations were proven to be greatly beneficial in monomer and polymer conversion, thus increasing the physical and mechanical properties of a restoration. Up to 95% of double-bond conversion reduces residual monomers thus increasing cross-linking between polymer chains and more homogeneous network (Asmussen, 1982; Chung & Greener, 1988). The above-mentioned methods were used in this study to improve the bonding of the semi-direct restoration to the tooth substrate. With surface treatment and silanization, the restorations could achieve comparable strength to sound teeth.

In-vitro evidence stated that immediate dentinal sealing (IDS) and resin coating improve the bond strength of resin-based restorations regardless of which strategy of adhesion was employed (Braga et al., 2006; Hardan et al., 2022; Magne et al., 2005). These individual protocols that are presented in biomimetic restorative protocols were proven to provide successful clinical results, but more research has to be done with long-term clinical follow-ups so that biomimetic restorations can be advocated for daily application.

There were several limitations in this study which can be addressed in future studies. Natural teeth and only maxillary premolars were collected for this experiment which varied in size and shape, so, the results cannot be generalized. An improved aging process such as thermal cycling and dynamic loading can be performed to simulate the usage of the restoration intra-orally.

5. Conclusion

Reinforcing composite restorations with fiber-reinforced composite increases the fracture strength of the semi-direct restorations even without cuspal coverage. Preservation of peri-cervical and remaining dentinal coronal tooth structure was observed to be beneficial. Therefore, strict protocols should be followed when prescribing a semi-direct restoration for ETT, and the maintenance phase should be emphasized to observe the possible failures that can be repairable.

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CONFLICT OF INTEREST

There are no conflicts to declare

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