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ORIGINAL ARTICLE

Fracture Resistance of Endodontically Treated Teeth Restored with High-Viscosity Bulk-Fill Resin Composites

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ABSTRACT
Objective: To evaluate the fracture resistance of endodontically treated teeth restored with different high-viscosity bulk-fill resin composites. **Material and Methods:** Forty extracted human upper premolars were endodontically treated and divided into four groups based on the bulk-fill resin composite used: CO: Scothbond Multi-Purpose + Filtek Z350XT; SF: Scothbond Universal + Filtek Bulk Fill; SO: OptiBond All-in-one + SonicFill; and, TT: Tetric N- Bond Universal + Tetric N-Ceram Bulk Fill. Universal adhesive systems were applied using the self-etching technique. After 24 hours, specimens underwent compressive loading at 1mm/min, and fracture patterns were evaluated. Data were statistically analyzed using one-way ANOVA and Tukey's post-test ($p>0.05$), while fracture patterns were assessed with the chi-square test ($p<0.05$). **Results:** Fracture resistance was similar across groups ($p>0.05$), with favorable fractures observed in the CO and SF groups. **Conclusion:** The fracture resistance of endodontically treated teeth restored with bulk-fill resin composites does not differ from those restored with conventional nanohybrid resin composites.

Keywords: Composite Resins; Dental Cements; Dental Restoration Failure; Tooth, Nonvital

Introduction

Successful treatment of teeth undergoing endodontic procedures relies on effective endodontic therapy and appropriate dental restoration [1]. However, endodontic interventions can lead to structural damage or loss, increasing the risk of tooth fractures [2,3]. Thus, resin composite restorations are crucial for enhancing the fracture resistance of endodontically treated teeth [4], ensuring function, aesthetics, marginal sealing, and preservation of the remaining tooth structure [5]. It is known that after pulp removal and endodontic treatment, stress and deformation concentrations are higher in these teeth than in vital teeth. In this sense, restorative procedures with direct composite resin in endodontically treated teeth can restore stress conditions [6].

The dental market offers various direct restorative materials [7], and choosing these materials impacts treatment quality and efficacy, just as the quality of restorations influences long-term clinical outcomes [8]. The major limitation of conventional resin composites is the polymerization shrinkage inherent to the material, which may increase tension at the restoration interface, raising the risk of tooth fracture [9]. Therefore, it is recommended to use the incremental technique to minimize the shrinkage stress, but it demands substantial clinical time, increasing contamination risks and potential inter-increment gaps [10]. Bulk-fill resin composites have been introduced to improve these challenges in molars and streamline clinical procedures [11].

Based on viscosity and composition, bulk-fill resin composites are classified as high or low viscosity. Low-viscosity composites, known as fluid bulk-fill resins, exhibit lower surface hardness and elasticity modulus, requiring a final layer of conventional resin composite. In contrast, high-viscosity bulk-fill composites, containing more inorganic fillers, are ideal for single-step restorations [11], ensuring curing depths of up to 4-5 mm [12]. The restoration of endodontically treated teeth with bulk-fill resin composites remains unclear. Previous studies have evaluated the fracture resistance of non-vital teeth restored with flowable bulk-fill [13-17]. In a systematic review [18], bulk-fill and conventional resin composites behave similarly regarding flexural and fracture resistance, regardless of their viscosity. However, no study has yet evaluated the fracture resistance of endodontically treated teeth restored with different high-viscosity bulk-fill resin composites.

This study evaluated the fracture resistance of endodontically treated premolars restored with different high-viscosity bulk-fill composites and their universal adhesive applied in the self-etching mode. The null hypothesis tested was that there was no statistically significant difference in the fracture resistance of endodontically treated premolars restored with different high-viscosity bulk-fill resins or conventional resin composites.

Material and Methods

Ethical Clearance

The study received approval from the Research Ethics Committee of the Araraquara School of Dentistry, São Paulo State University (Opinion no. 3.743.500).

Sample

Forty non-carious human upper premolars with fully formed apices and similar root and crown anatomy, extracted for orthodontic reasons, were selected. The specimens were immersed in a 0.5% Chloramine-T solution and stored at 4°C until their use.

The average buccal-lingual and mesiodistal widths were 5±1 mm and 6.8±1 mm, respectively. The roots of all specimens were embedded in polyester resin (Maxi Rubber Brasil, Diadema, SP, Brazil) using a PVC matrix

(3 x 2cm – high x diameter) positioned 1mm below the cemento-enamel junction (CEJ). Specimens were left undisturbed for 24 hours until complete polymerization.

Cavity Preparation

Endodontic access was carried out with a #FG3131 diamond bur (KG Sorensen, Serra, ES, Brazil) at high speed under constant water cooling. To obtain a standard cavity, the FG1801 PM.82 drill (KG Sorensen, Serra, ES, Brazil) was inserted parallel to the long axis of the teeth. The final shape of the cavity preparation was defined by the shape of the diamond bur. All cavities were standardized to a depth of 4mm and were performed by a single operator.

Endodontic Treatment

After cavity preparation, the root canal was explored using a K#10 endodontic file (Dentsply Maillefer, Ballaigues, Switzerland). The root canals were prepared using the ProTaper rotary instrument sequence (Dentsply Maillefer, Ballaigues, Switzerland) up to size (F3) at the predefined working lengths. At each instrument change, the root canals were irrigated with 3mL of 2.5% NaOCl (Asfer, São Caetano do Sul, SP, Brazil). After biomechanical preparation, the canal was irrigated with 3mL of 17% EDTA (Biodinâmica, Ibiporã, Brazil) for 3 minutes, irrigated with 10mL of distilled water, and then dried with absorbent paper tips (Dentsply-Herpo, Petrópolis, Brazil). The canals were then filled with gutta-percha (Dentsply-Herpo, Petrópolis, Brazil) and epoxy resin-based cement (AH Plus, Dentsply De-Trey, Konstanz, Germany). After completing the filling, a heated instrument was used to remove 3mm of gutta-percha from the root canal, which was filled with light-curing glass ionomer cement (Ionoseal, VOCO GmbH, Cuxhaven, Germany) up to the cemento-enamel junction.

Experimental Groups

The specimens were randomly divided into five groups (n=10) according to the restorative material used:

- CO (Control): Scothbond Multi-Purpose + Filtek Z350XT (3M/ESPE, St. Paul, MN, USA). Dentin etching for 15s with 35% phosphoric acid (Scotchbond Etchant Gel, 3M/ESPE, St. Paul, MN, USA). The three-step Scothbond Multi-Purpose adhesive system was applied according to the manufacturer's instructions. The primer was applied for 20 seconds using a microbrush (KG Sorensen, Serra, ES, Brazil) and dried gently with an air jet for 5 seconds. The adhesive system was applied for 10s, followed by light-curing. Filtek Z350XT nanohybrid resin composite (shade A2, 3M/ESPE, St. Paul, MN, USA) was inserted into the cavity using an incremental technique. The restoration was completed with 2 mm thick oblique resin increments.
- SF: Scothbond Universal + Filtek Bulk Fill (3M/ESPE, St. Paul, MN, USA). The Scothbond Universal adhesive system was used in the self-etching mode. The adhesive was applied for 20 seconds, dried with an air jet, and light-cured for 20 seconds. Filtek Bulk Fill resin (shade A2) was inserted into the cavity in a single 4 mm thick increment. The resin composite was light-cured for 20s.
- OS: OptiBond All-in-one + SonicFill (Kerr Co, Orange, CA, USA). The OptiBond All-in-one adhesive system was used in the self-etching mode. The adhesive system was applied to the cavity with a microbrush for 20 seconds. This application was repeated. Then, the adhesive was dried gently with an air jet for 5 seconds and light-cured for 20 seconds. The SonicFill composite was inserted by sonic activation using a

SonicFill handpiece. A single 4 mm increment was inserted, and the resin composite was light-cured for 20 seconds.

- TT: Tetric N-Bond Universal + Tetric N-Ceram Bulk-Fill (Ivoclar Vivadent AG, Schaan, Liechtenstein). Tetric N-Bond Universal was used in self-etching mode. The adhesive was applied to the dentin for 20 seconds using a microbrush, dried with an air jet for 5 seconds, and light-cured for 20 seconds. Tetric N-Ceram Bulk-Fill resin was inserted into the cavity in a single 4mm thick increment. The resin composite was light-cured for 20s.

Table 1 shows the composition and commercial brand of the materials used in this study. The adhesive systems and resin composite were light-cured using an LED unit (Valo Cordless, Ultradent Products Inc; S. Jordan, UT, USA) with an irradiance of 1000mW/cm^2. The specimens were stored in artificial saliva for 24 hours at 37°C.

Table 1. Materials used in this study and their respective manufacturers and chemical composition.

Material	Manufacturer	Composition
ScotchBond Universal Etchant	3M ESPE, St. Paul, MN, USA	Water, phosphoric acid, synthetic amorphous silica, polyethylene glycol, aluminum oxide
Scothbond Multi-Purpose	3M ESPE, St. Paul, MN, USA	Bisphenol A diglycidyl ether dimethacrylate, 2-hydroxyethyl methacrylate (HEMA)
Filtek Z350XT	3M ESPE, St. Paul, MN, USA	Bis-GMA, Bis-EMA, UDMA, TEGDMA, silica and nanoparticulate zirconia
Single Bond Universal	3M ESPE, St. Paul, MN, USA	MDP phosphatase monomers, dimethacrylate resin, HEMA, Vitrebond copolymer, fillers, ethanol, water, initiators, silane
Filtek Bulk Fill	3M ESPE, St. Paul, MN, USA	Bis-GMA, UDMA, Bis-EMA, Procrylat resins; Zirconia/silica, ytterbium trifluoride
OptiBond All-in-one	Kerr Corporation, Orange, CA, USA	Acetone, hydroxyethyl methacrylate (HEMA), ethyl alcohol, disodium hexafluorosilicate
SonicFill	Kerr Corporation, Orange, CA, USA	Bis-GMA, TEGDMA, EBPDMA, silica glass oxide
Tetric N- Bond Universal	Ivoclar Vivadent AG, Schaan, Liechtenstein	Methacrylates, ethanol, water, silicon dioxide, initiators and stabilizers.
Tetric N-Ceram Bulk Fill	Ivoclar Vivadent AG, Schaan, Liechtenstein	Dimethacrylates, filler polymer, barium glass, ytterbium trifluoride, mixed oxide

Fracture Strength Test

The specimens were positioned on a fixed base, in such a way that the incident force took place at an angle of 135° in relation to the long root axis, and submitted to a fracture strength test with a 5kN load cell at a speed of 0.5mm/min in an electromechanical testing machine (EMIC DL 2000; São José dos Pinhais, PR, Brazil). The last force applied (in N) before the crown fracture was recorded.

Fracture Pattern

The specimens submitted to the fracture test were examined under a stereomicroscope (40x) to evaluate the fracture patterns according to the classification described by Fokkinga et al. [19]: repairable fractures above the level of the CEJ (1 mm apical to the cemento-enamel junction) were defined as "favorable failures." In contrast, non-repairable fractures below this level were defined as "unfavorable failures."

Statistical Analysis

Significant differences in fracture resistance values among the groups were verified using a one-way ANOVA test followed by Tukey's post-test since the data had a normal distribution according to the Shapiro-

Wilk test. The analyses were carried out at a significance level of 5% using the statistical software IBM SPSS Statistics (IBM Corporation, Armonk, NY, USA). The differences between the failure modes of each group were analyzed using the chi-squared test ($p<0.05$).

Results

The mean fracture strength values (N) and standard deviations for each group are shown in Table 2. The groups had no statistically significant differences ($p>0.05$). The fracture pattern frequencies (%) for all study groups are shown in Table 3. Fifty-four percent of total failures were favorable fractures. The control group and the SF group showed a higher percentage of favorable fractures, whereas the OS group had more unfavorable fractures.

Table 2. Mean and standard deviation of the experimental groups' fracture strength values (N).

Groups	Mean ± SD (N)
CO	880.78 ± 287.09[a]
SF	759.56 ± 175.34[a]
OS	894.03 ± 231.30[a]
TT	977.525 ± 336.03[a]

[a]Same lowercase letter in the column shows no statistically significant difference ($p>0.05$); CO: Scothbond Multi-Purpose + Filtek Z350XT; SF: Scothbond Universal + Filtek Bulk Fill; OS: OptiBond All-in-one + SonicFill; TT: Tetric N- Bond Universal + Tetric N-Ceram Bulk Fill.

Table 3. Frequency (%) of failure patterns of the experimental groups.

Groups	Favorable Fractures	Unfavorable Fractures
CO	80%	20%
SF	70%	30%
OS	40%	60%
TT	50%	50%

CO: Scothbond Multi-Purpose + Filtek Z350XT; SF: Scothbond Universal + Filtek Bulk Fill; OS: OptiBond All-in-one + SonicFill; TT: Tetric N- Bond Universal + Tetric N-Ceram Bulk Fill.

Discussion

This study revealed no significant differences in fracture resistance among the groups, suggesting that the choice of high-viscosity bulk-fill or conventional nanohybrid resin composites does not impact the fracture resistance of endodontically treated premolars. Thus, the null hypothesis was accepted.

Teeth with extensive coronal loss are more prone to fractures [4]. Consequently, preserving tooth structure favors a better prognosis of the restorative treatment [3]. Arya et al. [20] suggested that endodontically treated molars with loss of one marginal ridge restored with direct composite resin without cusp coverage would reveal lower stress values in the tooth structure and restorative material based on finite element analysis. Thus, if the cusp is preserved, the clinical performance of the filled teeth is better. According to Reeh et al. [21], endodontic procedures reduce the stiffness of tooth structure by 5% through the coronary access procedure. Therefore, this study evaluated the influence of restorative materials used to seal the coronary access in terms of fracture resistance.

After completion of the endodontic treatment, it is crucial to restore the tooth with a material capable of absorbing and resisting impacts. Teeth sealed with temporary material or not restored produce a wedge effect between the buccal and palatal cusps, reducing resistance to fracture and the high risk of catastrophic fracture. In this context, resin composites have become the material of choice for posterior restorations, and bulk-fill resin composites are attractive to clinicians since they reduce operative time [22,23].

Studies have evaluated the performance of bulk-fill resin composites mainly in Class II cavities [14,24-26]. However, no study has evaluated different high-viscosity bulk-fill resin composites and their respective adhesive systems. A previous study highlighted that the choice of material for restoring class II MOD cavities (high viscosity bulk-fill, flowable bulk-fill, fiber reinforced, and conventional resin composites) did not exert significant differences among the groups [27]. The results corroborate with previous studies that showed no significant differences in fracture resistance between teeth restored with high-viscosity bulk-fill and conventional resin composites [22,28,29]. Thus, high-viscosity bulk-fill resin composites can safely restore endodontically treated teeth, demonstrating fracture resistance comparable to incrementally placed conventional nanohybrid resin composites [23]. Martins et al. [29] observed that bulk-fill filling techniques resulted in less stress and strain on the cusps than the incremental filling with conventional resin composite.

The use of universal adhesives with high-viscosity bulk-fill composites has the potential to simplify the sealing of endodontically treated teeth. In terms of fracture resistance, this combination proved favorable, as it did not compromise the mechanical strength of the restored teeth when compared to the control group, which employed an adhesive system in the etch-and-rinse strategy with conventional resin composite. Consequently, our results suggest that high-viscosity bulk-fill resin composites with universal adhesives offer a time-saving and less discomforting procedure for tooth restoration.

Apart from serving as a single-step filling material, high-viscosity bulk-fill resin composites offer additional advantages, including high inorganic filler content and low polymerization shrinkage and stress [30]. Han and Park [30] have claimed that using a flowable bulk-fill resin composite to fill the cavity can result in inferior internal adaptation compared to the same high-viscosity material.

The classification of fractures in this study considered the depth, extension, and degree of difficulty in restoring fractured teeth. Thus, the failures were divided into favorable (above the JCE) and unfavorable (below the JCE). In the study by Isufi et al. [14], more than 70% of the restored teeth had "unfavorable" fractures, and the authors attributed the severity of cusp fractures to the removal of cervical dentin. In this study, only the group restored with SonicFill resin (OS) presented a higher percentage of unfavorable fractures (60%), while the other groups showed fractures above the CEJ (favorable fracture). In contrast, Rauber et al. [28] observed that both conventional resin composite incrementally-placed and bulk-fill resin composites presented unfavorable fractures.

However, some limitations of this study include using static loads rather than dynamic fatigue stresses, which are more representative of oral conditions, and only one cavity type and sound-extracted teeth without any prior intervention. Future studies should explore these variables under more representative conditions, using other restorative strategies such as fiber-reinforced composite and other tests such as finite element analysis, bond strength, and clinical performance.

Conclusion

Endodontically treated premolars restored with high-viscosity bulk-fill resin composites exhibit fracture resistance similar to those restored using the incremental technique with conventional nanohybrid resin composite. These findings suggest that high-viscosity bulk-fill resin composites can be effectively used to restore endodontically treated teeth, offering a time-efficient alternative to conventional methods.

Authors' Contributions

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All authors declare that they contributed to a critical review of intellectual content and approval of the final version to be published.		

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None.

Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

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