

Comparing the Effect of Relining and Thermocycling on the Push-out Bond Strength of Glass Fibre Posts: An In-vitro Study

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ABSTRACT

Introduction: Endodontically Treated Teeth (ETT) with substantial coronal loss often require post placement for restoration. The adaptation of the post to the root canal is critical for success.

Aim: To evaluate the bond strength and durability of customised (relined) glass Fibre Posts (FP) compared to conventional FP in teeth with non circular root canals.

Materials and Methods: This in-vitro study was conducted at King Abdulaziz University, Jeddah, Saudi Arabia, from January 2024 to December 2024. To create a standardised dentin substrate, healthy adult premolars extracted for orthodontic or traumatic reasons were used. A total of 40 single-rooted teeth with non circular canals with similar root lengths were randomly divided into two groups: 1) conventional FP; and 2) customised (relined) Fibre Posts (FPC). Composite resin was used for relining the FPC group. All posts were luted with RelyX™ Unicem

Aplicap™. Each group was further divided into immediate testing and Thermocycling (TC) (6000 cycles) subgroups before undergoing push-out bond strength tests. Statistical analysis was performed using Two-way ANOVA, followed by Bonferroni post-hoc tests, and $p < 0.05$ was considered statistically significant.

Results: The bond strength of FPC to root dentin was significantly higher than that of FP ($p = 0.006$). Thermocycling did not show a significant impact on the push-out strength for either FP ($p = 0.56$) or FPC ($p = 0.819$).

Conclusion: Relining glass FPs with composite resin significantly increases their bond strength to root canal dentin, whereas thermocycling has no significant effect. Thus, the bond strength of FPs to root canal dentin is markedly improved by relining with composite resin, and no statistically significant reduction in bond strength is observed after thermocycling.

Keywords: Composite resins, Dental bonding, Dental stress analysis, In-vitro techniques

INTRODUCTION

Endodontically treated teeth are frequently encountered in clinical practice, with noticeable coronal tooth structure loss that may compromise tooth restoration [1]. Therefore, following post placement, it is advisable to retain the coronal core and prepare the tooth for coronal restoration if needed [2]. One of the many advantages of FP is its tendency to overcome several drawbacks of using metal posts [3]. As the elastic modulus of the FP resembles that of dentin and tooth modulus of elasticity, it overcomes the catastrophic failure seen with metal posts, which contain a higher elastic modulus than the tooth structure. Anatomically customised posts have the highest fracture resistance [4]. Furthermore, post-space preparation procedures may weaken the root region's remaining tooth structure and may lead to root fracture [5].

The primary reason for post-failures was the de-cementation of the region's interface between luting cement and the root dentin wall. It also causes the loss of glass fibre retention from the canal walls [6]. Nevertheless, a thicker resin-matrix cement layer may result in many flaws, such as pores or cracks, which would weaken the interface and reduce its strength [7]. Therefore, to decrease the occurrence of the failures mentioned above, the proper adhesive procedure is an essential clinical step to consider during FP placement [8]. However, due to the root anatomy and the limited accessibility and visibility, achieving ideal moisture control is a challenging procedure [9].

Additionally, the bonding mechanism between FP and resin cement is a chemical bond that strengthens this interface [10]. Hence, post-space preparation may remove more tooth structure than required for the post and create an uneven cement space [11].

Given the reasons, decreasing the space created around the post may be addressed by applying relining or customisation to the FP. The FP customisation technique demonstrated its ability to capture the root canal anatomy, create a good adaptation, improve retention, and allow for a thinner layer of cement [12].

Testing the customised FP's post is critical in understanding FP's in-vivo performance under occlusal loads [3]. The novelty of this work lies in its direct comparison between conventional posts in extracted human teeth with non circular canals simulating a challenging clinical situation, along with evaluating the impact of TC on bond strength.

Therefore, the current study aimed to compare FP customisation (relining) with composite resin and conventional (un-relined) FP concerning bonding strength, cyclic loading, and durability in extracted human, single-rooted teeth.

MATERIALS AND METHODS

The in-vitro study was conducted at King Abdulaziz University, Jeddah, Saudi Arabia, from January 2024 to December 2024 and received ethical approval from the relevant institutional review board (124-10-18). The current study adhered to the guidelines present in the Declaration of Helsinki.

Sample size calculation: Based on previous evidence showing that relined posts exhibit significantly higher mean push-out bond strength than non relined posts (6.7 ± 3 MPa vs. 4.1 ± 1.8 MPa) (13), the sample size for the present study was calculated using the OpenEpi program with a 95% confidence level and 80% power.

$$n = \frac{2(Z_{\alpha/2} + Z_{\beta})^2 \times \sigma^2}{d^2}$$

Where:

- $Z_{\alpha/2}=1.96$ (for 95% confidence)
- $Z_{\beta}=0.84$ (for 80% power)
- σ =pooled standard deviation from the previous study;
- d =expected difference between groups (2.6 MPa) [13].

The minimum required sample size was 30 specimens; however, to account for possible specimen loss during preparation and testing, the final sample size was increased to 40 teeth.

Following preparation, the 40 teeth were randomly assigned to one of two primary groups using a computer-generated random number table:

- Group FP (n=20): Conventional (non relined) glass FP
- Group FPC (n=20): Customised (relined) glass FP

Based on the sample size calculation and comparable prior research [14] assessing the push-out bond strength of FP, 10 specimens per subgroup were deemed to be an appropriate sample size, divided as follows:

- Subgroup immediate (n=10 specimens): tested 24 hours after cementation;
- Subgroup thermocycled (n=10 specimens): subjected to 6000 cycles of TC before testing.

Inclusion criteria: The study included single-rooted human premolars extracted for orthodontic reasons, with intact roots that, when examined under a stereomicroscope 40x magnification, showed no signs of fractures, fissures, or caries, a minimum of root length of 14 mm, measured from the Cemento-enamel Junction (CEJ) to the apex, and complete root development with closed apices.

Exclusion criteria: Teeth that had undergone root canal obturation or endodontic therapy, teeth with internal or external root resorption; and teeth in which craze lines or cracks were detected during the methylene blue dye penetration test were excluded from the study.

Study Procedure

The root length of each tooth was measured from the CEJ to the apex, with a mean length of 15 mm. A digital calliper (accuracy 0.01 mm; Mitutoyo, Japan) was used to measure root length from the CEJ to the apex. Subsequently, tooth decoronation was performed at the CEJ, and the teeth were stored in normal saline solution at 25°C. At the CEJ, a diamond disc under continuous water cooling was used for decoronation.

Preparation of teeth: The root canals were instrumented properly up to size X3 file until the working length was reached. To prevent extrusion of irrigating solution or luting cement beyond the apex, the apical 1 mm of the root canals was left unprepared. Irrigation of the root canals was performed between each filing step using 5.25% NaOCl (1 mL), followed by the obturation of the canals using gutta-percha points (Sure-Endo, Seoul, Korea) and AH Plus® sealer (Dentsply Sirona, York, PA, USA). The obturated roots were stored in saline solution at 37°C. The 8 mm of gutta-percha from the obturated root canals was then removed three days later. Gates Glidden drills were used to prepare the post space (Dentsply Malliefer, Switzerland). Gates Glidden drills (#2, #3, and #4) were used successively to extract gutta-percha. The final post spacing was created with a #3 post drill (RelyX™ Fibre Post System) at 800 rpm under saline irrigation. Finally, the #3 post drill at low speed (RelyX™ fibre post system, 3M™ ESPE., Germany) was used to enlarge the root canals and create uniform post spaces.

Post-relining and cementation: Normal saline (5 mL) was used to irrigate the root canals for 60 seconds using a plastic syringe (10 mL, 25-gauge tip). Paper points (Sure Endo, Korea) were used to remove excess irrigating solution and water from the canals. The roots were then randomly divided into two groups, with each group receiving a different treatment. Post-relining and cementation

procedures were performed on all 40 teeth. Twenty teeth from each of the two main groups (FP and FPC) were then randomly assigned to either the TC subgroup or the immediate testing subgroup. Thus, different teeth were used for every testing condition.

Following the manufacturer's instructions, the FP for the first group (FP) was coated with RelyX™ Unicem Aplicap™ (3M™ ESPE, USA). For the second group (FPC), the posts were relined incrementally with flowable composite Z350 XT (3M™ ESPE, St. Paul, MN, USA). During the relining process, a hydrosoluble gel (Gel-in, Techno, Vilamalla, Spain) was used to lubricate the canal walls to prevent resin composite adhesion to the root dentinal walls. At the end of the relining procedure, the FP was coated with a combination of composite resin and flowable composite and then placed in the canal to replicate the canal shape.

All excess resin was removed, and the relining layer was cured. The curing procedure involved two stages. First, the post underwent a 10-second light-activation period to initiate polymerisation, with the light-curing unit tip in direct contact with the post. Next, to complete polymerisation of the relined post, the post was removed from the canal by clamping it with a needle-nose plier, and an additional 20 seconds of light activation was applied. Before proceeding with FP cementation in the root canal, the lubricant gel placed in the canals during the relining step was removed by copious rinsing, followed by thorough drying of the canals using paper points. RelyX™ Unicem Aplicap™ was then used to cement the FP, following the manufacturer's instructions.

Thermocycling: Lastly, the teeth were uniformly separated into two groups; within each group, half were assigned directly to the push-out test 24 hours after the luting step (labelled, immediate group, or direct group). At the same time, the other half of the group was subjected first to TC.

Push-out test: Specimen preparation: The push-out bond strength was assessed using an established thin-slice push-out test protocol as described by Goracci C et al., in 2004 [15]. This test used 10 specimens with FPC. First, the roots were mounted in a cylindrical rubber mould and embedded in clear ortho resin (Techno Sin Pro Techno, Vilamalla (Girona), Spain). The roots were stabilised vertically, and the cold-cured acrylic monomer and polymer were mixed in the recommended proportions, following the manufacturer's instructions, and poured into the rubber mould on a vibrator and left to polymerise. Once polymerisation was complete, cylinders were sectioned horizontally, from the coronal to the apical end of the root, with a diamond saw disc under water cooling (ALLIED, TECHCUT 4™, USA), ensuring that they remained vertically positioned along the post's long axis. The slices used in the study were the first three coronal slices of the post space. Thirty slices were initially obtained from each subgroup (10 specimens ×3 coronal slices). Five slices were excluded due to specimen preparation or testing-related defects; therefore, 25 slices per subgroup were included in the final analysis.

Post dislodgment and failure pattern analysis: In the universal testing machine, the slices were fixed on a metal support with the apical aspect of each slice facing the loading plunger. The custom-made plunger was positioned to contact only the post and the bonded interface during loading, thereby introducing shear stresses. The push-out test was performed by applying force to the post from the apical toward the coronal end of the slice until failure occurred, at a crosshead speed of 0.5-1 mm/min [15].

The bond strength was calculated by dividing the load at failure by the bonding surface area and expressed in MPa. A digital calliper with an accuracy of 0.01 mm (Mestra, Spain) was used to measure the post diameter at each cut surface and the slice thickness. The failure mode was evaluated by examining the specimen surfaces under a stereomicroscope at 40x magnification. In addition, a further examination was performed after the push-out test.

Scanning Electron Microscopy (SEM) analysis: Two samples from each group were collected for SEM assessment to evaluate the homogeneity and thickness of the conventional and customised posts to the root canal wall (Model EVO MA10, Carl Zeiss, Germany), equipped with INCA Energy Dispersive Spectroscopy (Oxford Instruments, UK). SEM photographs were also taken (original magnification: 50x).

STATISTICAL ANALYSIS

Statistical analysis was performed using IBM SPSS Statistics software (version 28.0, IBM Corp., Armonk, NY, USA). Two-way analysis of variance (ANOVA) was used to assess both Push-out bond strength data (in MPa), the effects of post type (conventional vs. relined) and TC (immediate vs. thermocycled). Bonferroni's post-hoc test was used for pairwise comparisons if significant differences were noted. A p-value <0.05 was considered statistically significant.

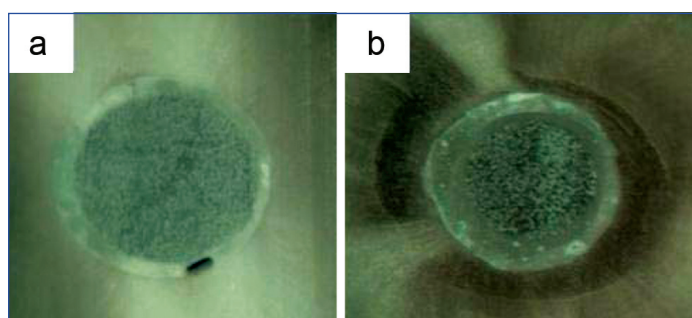
RESULTS

The 40 samples included were healthy human premolars taken from patients receiving orthodontic treatment who were between the ages of 18 and 30 years. Relined FPC had higher bond strengths to root canal dentin than conventional FP ($p=0.006$). However, TC did not significantly impact the push-out strength of FP to the root canal walls ($p=0.560$ for FP and $p=0.819$ for FPC). Bonferroni's post-hoc test also indicated that FPC had higher bond strengths (19.32 ± 0.7 MPa) compared to the FP group (10.69 ± 0.4 MPa), (p -value= 0.006) [Table/Fig-1].

Post-group	Immediate (24 hours)	Thermocycled (6000 cycles)	p-value (Effect of Ageing)
FP (Conventional)	10.69±0.4	10.42±0.5	0.560
FPC (Relined)	19.32±0.7	19.10±0.6	0.819
p-value (Post type)	0.006*	0.005*	-

[Table/Fig-1]: Mean push-out bond strength values (MPa) for conventional (FP) and relined (FPC) glass Fibre Posts (FP), immediate testing and after 6000 thermal cycles. Statistical tests applied: ANOVA followed by Bonferroni's post-hoc test for pairwise comparisons. Results are expressed as Mean±SD. *denotes a statistically significant difference where $p<0.05$. *FP: conventional fibre post, FPC: customised fibre post

Stereomicroscopic evaluation at 40x magnification demonstrated that all 40 specimens (100%) across all four subgroups (FP Immediate, FP Thermocycled, FPC Immediate, and FPC Thermocycled; $n=10$ each) exhibited adhesive failure at the cement-dentin interface. No cohesive or mixed failures were detected in any group [Table/Fig-2].



[Table/Fig-2]: The stereomicroscopic evaluation presented adhesive failure of the post-test between the cement layer and canal wall.

DISCUSSION

The application of relining, a customised treatment method for excessively flared and non circular canals, would broaden the scope of restorative dentistry in teeth with non circular canal anatomy [13]. The technique of cast metal posts and core systems has demonstrated several drawbacks, such as increasing the chances of root fractures (catastrophic failure) when compared with FP. This has been supported in earlier research documenting higher root fracture rates with cast metal posts versus FP [16].

The present study assessed the push-out bond strength of conventional and relined glass FP to root canal dentin in both

immediate and thermocycled conditions. The results showed that the bond strength of relined FPC was significantly higher than that of conventional posts (FP) ($p=0.006$). Nevertheless, neither group's bond strength was significantly affected by TC (6000 cycles) ($p>0.05$). For all cementation processes, RelyX™ Unicem, a self-adhesive resin cement, was utilised in accordance with the manufacturer's recommendations. The findings aligned with research on stress distribution and showed that mechanical cycling did not significantly reduce the binding strength of FP to root canal dentin [17].

The higher bond strength observed in the relined group may be related to improved adaptation and a thinner cement layer, potentially reducing void formation. The similarity to dentin absorbs the created stresses and decreases the possibility of vertical root fracture [17]. However, disadvantages of resin cement include void formation, fissures, and polymerisation shrinkage [18]. Moreover, the relining procedure for the glass FP improves the post's frictional retention in the canal and decreases the chances of defect formation in the cement layer [19].

Most failures in the relined group often happened where the root dentin and cement meet. Furthermore, the restoration of teeth with weak roots necessitates the use of composite resin to customise the glass FP or the combination of prefabricated solutions with several posts [20]. Due to dentin's morphological and histological features and the smear layer on the sliced dentin surface, bonding to dentin is more challenging. Variables that might affect the degree of adhesion at the cement-dentin interface include hydration conditions, dentin collagen degradation, and regional variations in dentinal tubule density [21].

On the other hand, in the non reinforced group, the post/cement interface was where most failures occurred. Because the Glassix FPs was not given any surface treatment in this investigation, the bond between cement and dentin appeared stronger than the bond between cement and post. Relining Glassix FPs with composite resin produced stronger bonds at the post-composite interface than the non relined group, transferring the failure to the cement-dentin interface and resulting in noticeably higher push-out bond strength values than the non relined group. Chemical bonding plays a significant role in the strong connection between the post and the composite resin used for relining, although the post's surface was untreated [15].

According to several studies, thick resin cement between the post and root dentin makes the post more susceptible to debonding from the canal walls due to polymerisation shrinkage stresses [11,22,23]. Likewise, operator skills and experience are essential when bonding FPs to root dentin. Under a stereomicroscope, the point of failure occurred between the canal wall and the resin cement layer. According to quantitative analysis, 100% of the specimens in both groups showed adhesive failure. The cement-dentin interface is still the weakest link in this restoration complex, as shown by the absence of cohesive failures inside the post or dentin [24].

Several studies have reported that adhesive failure is the most likely mode of failure [23-26]. Analysis of all debonded samples under the stereomicroscope suggests that this may be related to the complex biological and structural characteristics of root dentin, compared with coronal dentin, as well as to the specific conditions under which bonding occurs.

Another relevant factor is the high C-factor in the root canal, where polymerisation shrinkage in the luting cement increases interface stresses. Studies have shown that customised glass FPs with flowable composites improve intra-canal adaptation in teeth with compromised root canals [27]. The present study's customisation of glass FPs using flowable composite resin resulted in greater push-out bond strength.

The push-out bond strength was not significantly affected by TC. After 6000 cycles, both groups maintained similar bond strength values (FP: 10.42 ± 0.5 MPa; FPC: 19.10 ± 0.6 MPa), consistent with a prior investigation reporting resistance to TC-induced degradation [28]. However, studies have reported inconsistent effects: Bitter K et al., found a significant reduction after 5,000 cycles [6], while

Mazzoni A et al., observed a reduction after 40,000 cycles [29]. These discrepancies likely reflect differences in TC protocols.

The samples undergo temperature changes and increased water exposure during thermal cycling. Hydrolysis at the bonding interfaces may explain bond strength reduction, though no statistically significant change were observed in the current study [15].

Limitation(s)

The present study has limitations due to its in-vitro design. First, the relatively small sample size. Second, though TC was performed in the study, the dynamic mechanical fatigue loading (chewing simulation), which can precisely predict clinical lifespan, was not investigated. Third, it is challenging to normalise the diversity in dentin sclerosis as natural teeth were used. Fourth, because only one operator carried out all procedures, operator variability and the technique-sensitive nature of post-cementation could not be assessed. Fifth, only one type of FP, composite resin for relining, and resin cement (RelyX™ Unicem) were evaluated, limiting the generalisability of the findings to other materials. Sixth, the binding strength at the post-cement interface may have been impacted by the FPs' lack of surface treatment before relining or cementation.

Therefore, in order to validate the current study in-vitro findings, future research should focus on long-term randomised clinical studies and incorporate dynamic fatigue testing.

CONCLUSION(S)

Based on the results of the study, the practice of relining FPs is a valuable clinical technique that may potentially help improve the FP bonding strength to root canal dentin. However, the current study findings also show that the FP-bonding strength remained unaffected by cyclic loading. The improved bond strength observed with relined posts is likely attributable to better adaptation to the canal anatomy, resulting in a thinner and more uniform cement layer with fewer voids. The cement-dentin interface showed adhesive failure in every specimen, indicating that it is still the weakest component of the repair complex. Clinically, teeth with non circular or flared root canals, where traditional posts cause uneven cement thickness, may benefit most from relining.

Authors' contribution: Both the authors contribute equally towards the study.

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