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Communication

Bond Strength Evaluation between Different Glass Fiber Post Systems to Restore Weakened Roots

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Abstract: A new bundled glass fiber-reinforced resin post was developed to be used in post-endodontic restoration. We evaluated the bond strength of a single prefabricated glass fiber post (GFP) and a bundled glass fiber-reinforced resin post (GT), used alone or combined, to restore weakened roots. Fifty bovine incisors roots were weakened with a diamond bur, except for those from the control group. The root canals were endodontically treated (Pro Taper Next system, gutta-percha, and endodontic cement), and the roots were divided into five groups (n = 10): Reb—single prefabricated GFP (Rebilda Post—Voco); GT—bundled glass fiber-reinforced resin post (Rebilda Post GT—Voco); RebGT—association between the prefabricated GFP (Reb) and the bundled one (GT); CP—prefabricated GFP customized with composite resin; and Cont—singular post in a non-weakened root (Control). All posts were cemented using a universal adhesive system (Futurabond U) and dual-cure resin cement (Rebilda DC—Voco). Afterwards, two slices were obtained from each root third (cervical, middle, and apical) and submitted to a push-out bond strength test. Data were analyzed regarding the post system used and the root thirds by two-way ANOVA, followed by Tukey's test ($p < 0.05$). There were higher bond strength means for the RebGT and CP groups, presenting values similar to the control. The Reb and GT groups showed lower values. The adhesion to deeper thirds of the root canal remains a challenge for adhesive dentistry and is not related to the design of the post. Additionally, the rehabilitation of teeth with weakened roots requires the customization of the glass fiber post with composite resin or the association between prefabricated options with multiple posts.

Keywords: fracture resistance; bond strength; glass fiber post; incisor

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1. Introduction

The use of post systems for the rehabilitation of teeth with extensive crown damage is often demanded for the retention and support of future restoration and must be guided by functional, biomechanical, and aesthetical principles [1]. In this context, the use of glass fiber posts (GFPs) with a composite resin core for the restoration of teeth is now widely accepted as a viable alternative to metal cast posts and cores [2]. A clinical trial reported good performances for these posts, with an annual failure rate of around 1.5%, and debonding and root fracture being the most common reasons for failure in the posterior of the teeth [3]. It must be highlighted that debonding might lead to catastrophic root failure due to the wedge effect [2,4], particularly in cases in which the post is not well adapted [5].

As GFPs are prefabricated, their geometry is often cylindrical with or without conicity, presenting a non-ideal design for non-circular root canals [6], which might lead to increasing misfits. This is particularly critical for weakened roots or oval-shaped canals, in which the customization of the posts with composite resin has been described as a viable method to make them more anatomical, reducing the volume of resin cement used [7–10].

Weakened roots present themselves as a challenge in clinical practice and might occur in teeth with incomplete physiological root formation, excessive instrumentation, internal resorption, traumatic dental injuries, and the presence of secondary caries around posts that have already been installed [8,11]. Their root canal is wider, with thinner dentine walls, which are more prone to fracture when compared to situations in which the root is not weakened [12]. Thus, the use of GFPs in these situations often results in a thicker and, consequently, more fragile resin cement layer [8,12]. Prospective and retrospective clinical studies indicate that a higher frequency of debonded glass fiber posts occurs when the thickness of the cement layer is larger [5,13].

To reduce the steps necessary during the placement of the post and the cement layer thickness, different designs of GFP systems have been proposed, such as one composed of multiple independent parallel bundled fibers, reinforced with resin, which are placed and adapted inside the canal, and then filled with the resin cement [12]. As they are composed of multiple thin posts, their adaptation inside weakened canals can be improved compared to the single posts, leading to the reduced thickness of the cement and, consequently, improved bonding, yet studies regarding this are scarce.

In general, polymers are usually filled with blends that have solid particles, such as minerals or glass [14–16]. The role of these particles is to improve the mechanical properties attributed to their uniform distribution of induced shear stress. However, tensile and flexural strains were found to be inversely proportional to the weight percentage of the filler materials used for composites, showing that less ductile composite structures can be produced with higher concentrations of filler materials [14]. However, this information is not available for GFPs for dental application, and the use of more bundles of GFBs instead of a single structure could affect the system's load distribution.

Additionally, composite materials with strong and stiff reinforcing components dispersed as fibers in a continuous resin component allows for load distribution during the reinforcing phase [15]. Despite that, the fiber volume can affect the fracture mode since the fiber bundles can break, with the fragments becoming visible on the fractured surface. During tensile strain, the overload imposed on GFB can modify the fracture plane and promote an easy failure of its structure [17]. A widely used method to assess GFP in the root canal is the push-out test [18–21].

The push-out test is an in-vitro load that is applied in an apical-to-cervical direction until the post is dislodged from the specimen. The push-out strength values are measured at failure and recorded in MPa $\pm$ standard deviation [18]. According to the literature on the bond strength testing of dental biomaterials, the use of small-sized specimens in the push-out bond strength test favors a uniform stress distribution. This approach allows one to calculate the differences in bonding conditions for dental application with a reduced number of specimens per group [19,20].

Therefore, the aim of this study was to assess the adhesive bond strength of single prefabricated glass fiber posts and a novel bundled glass fiber-reinforced resin post, used alone or in association, to restore weakened roots.

2. Materials and Methods

2.1. Experimental Design

The independent variables tested in this study were the different post systems, represented at five levels: Reb—prefabricated GFP (Rebilda Post—Voco); GT—bundled glass fiber-reinforced resin post (Rebilda Post GT—Voco); RebGT—association between the prefabricated GFP and the bundled one (Reb + RebGT); CP—prefabricated GFP customized with composite resin; and Cont—singular post in a non-weakened root (control); and the root third at three levels: cervical, middle, and apical.

Sample size calculation (G Power 3.1—Heinrich-Heine- Universität, Dusseldorf, Germany) was performed based on the means and standard deviation results from a pilot study, with the significance level set at 0.05 and the power test at 0.80. The results indicated n = 10. The materials used in the present study are summarized in Table 1.

Table 1. Materials information used in the present study.

Name/Material	Manufacturer	Composition
Bundled glass fiber-reinforced resin post (Rebilda Post)	VOCO, Cuxhaven, Germany	70% glass fiber, 10% inorganic filler, 20% DMA matrix
Composite resin—GrandioSO	VOCO, Cuxhaven, Germany	Inorganic fillers in a methacrylate matrix (Bis-GMA, TEGDMA)
Futurabond U	VOCO, Cuxhaven, Germany	2-HEMA, BIS-GMA, HEDMA, 10-MDP, UDMA, catalysts, silica nanofillers; ethanol, initiator, catalysts
Condac 37	FGM, Joinville, Brazil	37% phosphoric acid
Ceramic Bond Silane	VOCO, Cuxhaven, Germany	Acetone, 3-methacryloxypropyltrimethoxysilane, and isopropanol

2.2. Specimen Preparation

Fifty sound bovine incisors with complete root formation were acquired from a local slaughterhouse, and were cleaned and stored in distilled water under refrigeration (4 °C). The roots were sectioned into 16 mm lengths, using a diamond disk (KG Sorensen, Barueri, Brazil), and those that were curved, or presented a non-oval canal or open apex were excluded.

Each root was endodontically treated with rotatory instruments (ProTaper Next—X4, Dentsply Maillefer, Ballaigues, Switzerland). The endodontic working lengths were determined visually at 1.00 mm short of the apical foramen, using the 10 K-type root files (Maillefer, Ballaigues, Switzerland). Irrigation was performed after every change of instrument by alternating 1 mL of 2.5% NaOCl solution (Asfer, São Caetano do Sul, Brazil) and 17% EDTA solution (Biodinamica, Ibiporã, Brazil). Final irrigation was carried out using distilled water and the canal was dried with paper points (Dentsply Maillefer, Petrópolis, Brazil). Then, it was filled with gutta-percha and endodontic sealer (Sealer 26, Dentsply DeTrey, Konstanz, Germany) using the single cone technique. The root canals were sealed with glass ionomer cement and stored for 7 days at 37 °C.

2.3. Group Division and Post Cementation

The roots were randomly divided into five groups, according to the post system used: Reb (prefabricated GFP—Rebilda Post size 20, yellow, Ref 1774—Voco—length: 19 mm, coronal diameter: 2 mm and apical diameter: 1 mm); GT (bundled glass fiber-reinforced resin post—Rebilda Post GT ø1.4 mm—number of fibers: 12, length: 20 mm, idealized diameter: 1.4 mm); RebGT (association between the Reb and the GT posts); CP (prefabricated GFP—Rebilda Post ø 2.0 mm—customized with composite resin—GrandioSO, Voco); and Cont (singular post in a non-weakened root—Rebilda Post ø 2.0 mm). Figure 1 shows a schematic drawing of the groups.

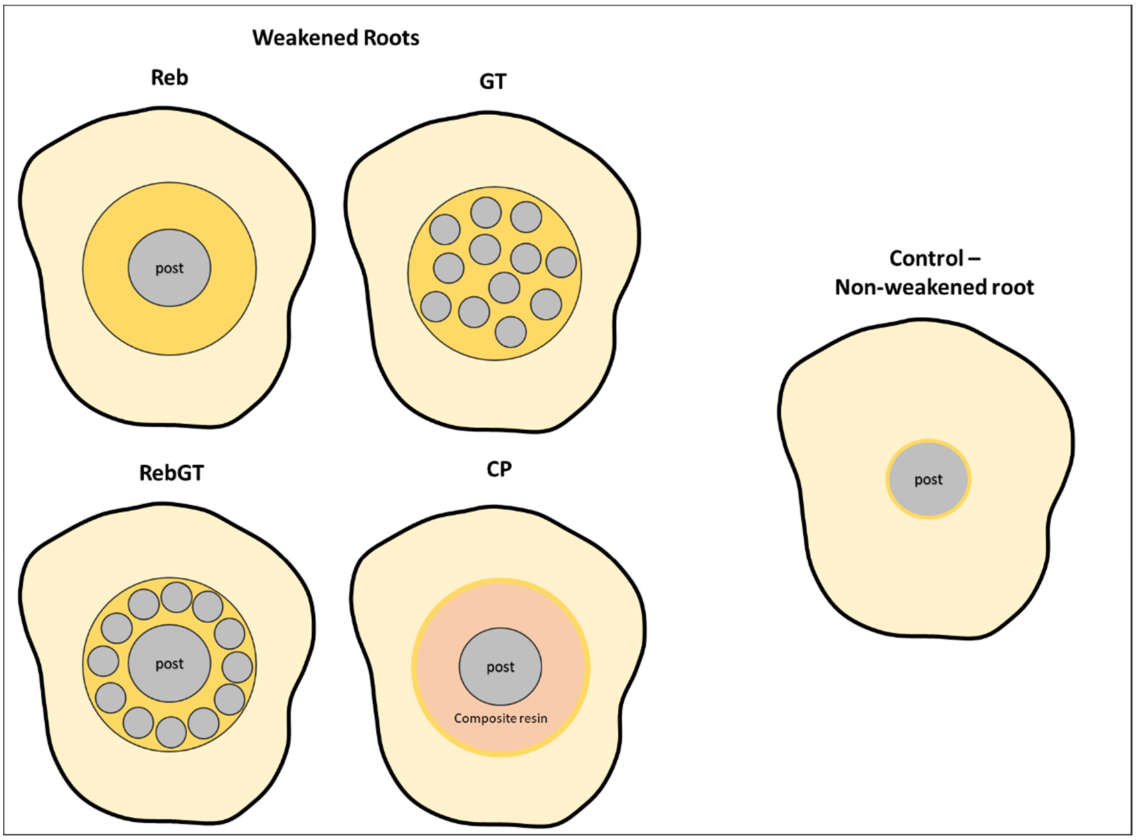

Figure 1. Schematic drawing of the post systems used. The weakened roots were enlarged with a diamond bur, leaving at least 2 mm of remaining dentin wall. In the figure, grey refers to the post, yellow to the resin cement used, and orange to the composite resin used to customize the post in CP group.

The glass ionomer cement was removed with a round diamond bur, and desobturation was performed with Gates–Glidden drills in sequence #4, #3, and #2, up to 12 mm. For the control group (Cont), the canal was also prepared with the specific drill from the post used (Rebilda Drill ø 2.0, Ref 1779, Voco, Cuxhaven, Germany) up to 10 mm. To ensure optimal drilling performance and avoid overheating the dentin, this step was performed with intermittent irrigation of the canal and drill with distilled water.

For the groups Reb, GT, RebGT, and CP, the roots were weakened with a diamond bur #4137 (KG Sorensen, Barueri, Brazil), up to 10 mm, as described previously [11], leaving at least 2 mm of remaining dentin wall. To allow for standardization, all roots were previously measured towards the mesio-distal and buccal-lingual directions, 2 mm below the cementum-enamel junction, and those presenting a discrepancy of 10% (of the average) were excluded.

After preparation, the roots were rinsed with 1 mL of 2.5% NaOCl solution, followed by distilled water and dried with paper points. For all groups, adhesive cementation was performed with a universal adhesive (Futurabond U, Voco), and a dual cure composite resin cement (Rebilda DC, Voco).

All posts were cleaned with 37% phosphoric acid (Condac 37, FGM, Joinville, Brazil) for (60 s), followed by water-rinsing (30 s) and air-drying (30 s). Then, a silane (Ceramic Bond Silane, Voco) was applied on each post for 60 s and air-dried, following the manufacturer's instructions. This was performed individually and immediately before the cementation.

For the Reb and Cont groups, the canal was filled with the resin cement, using the system cartridge to minimize voids and bubbles. Then the post was placed in position and the set was cured with a blue LED light-curing unit (1400 mW/cm^2—Bluephase, Ivoclar Vivadent, Schann, Liechtenstein) for 40 s in buccal and lingual directions, totaling 80 s.

For the group GT, after filling the canal with resin cement, the post was placed inside the root canal and the plastic holder was removed with the help of clinical tweezers and the fibers adjusted homogenously, as shown in Figure 1. In the RebGT group, the main post was placed in the center of the canal, and the fibers forming the bundled GT post were placed beside it before curing (Figure 1).

Finally, for the CP group, before cementation, the post was customized with composite resin (GrandioSO, Voco). For that, the canal was isolated with water-soluble gel (KY, Johnson & Johnson, São José dos Campos, Brazil) and the post, plus the composite resin assembly, was placed into the root canal and light-cured for 20 s. Additional cure (20 s) was performed after removing the set from the root.

After cementation, the roots were kept immersed in distilled water, at 37 °C for 7 days before testing.

2.4. Push-Out Bond Strength Test

For the bond strength analysis, the roots were sectioned using a precision saw (Isomet 1000, Buehler, Lake Bluff, IL, USA) with a diamond disk and irrigation. The first cut was performed 0.5 mm from the top, to remove the external portion of the post, and discarded. Then 6 slices, of 1 mm thickness each, were obtained, being two per root third (cervical, middle, and apical) (Figure 2).

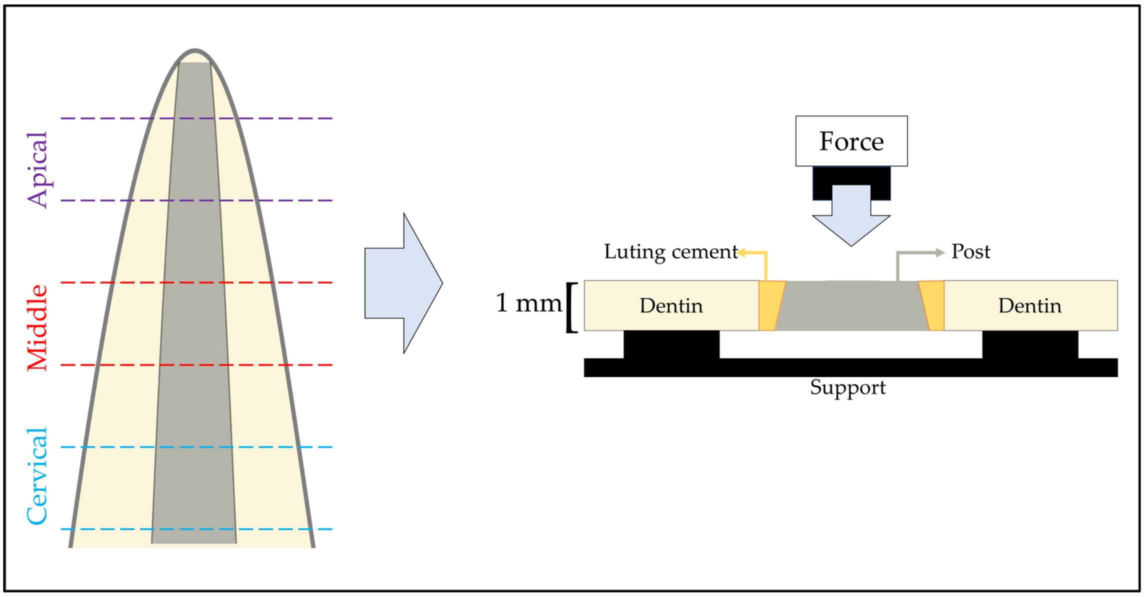

Figure 2. Distribution of the root slices with six 1-mm-thick slices (two per third) obtained from each root sample. Diagram of the push-out test procedure on the tooth slices.

A digital caliper (Mitutoyo Corporation, Tokyo, Japan) was used to measure the thickness of the slices and both sides were photographed with an optical microscope at 20× magnification to measure the coronal and apical diameter of each slice. Measurements were made with the software Image J (National Institutes of Health; Bethesda, MD, USA).

The push-out bond strength test was performed in a universal testing machine (DL500; EMIC, São José dos Pinhais, Brazil), with a crosshead speed of 0.5 mm/min, with the load applied in the apical-coronal direction until failure. A push-out cylindrical plunger, with different diameters, was used for the 15 different root thirds as follows: 1.8 mm for the cervical third, 1.0 mm for the middle and for the apical thirds. The failure load was recorded in Newtons (N) and converted into MPa by dividing the applied load by the bonded area using the formula of a truncated cone [11].

A single operator performed the specimen preparation, post cementation, and push-out bond strength procedures.

2.5. Statistical Analyses

Data were checked for normality assumption (Shapiro-Wilk), followed by two-way analysis of variance (2-way ANOVA) testing (post system x root third), with a 5% significance level. Tukey's test was performed for multiple comparisons among the groups. The statistical analysis was performed using the GraphPad Prism software (San Diego, CA, USA).

3. Results and Discussion

Data from the bond strength analysis are presented in Table 2. The two-way ANOVA showed significant differences for the post system (p = 0.00001), the root third (p = 0.00001), and their interaction (p = 0.00001). Regarding the posts, the RebGT and CP groups were similar to the Cont group and higher than the Reb group. Only in the cervical third were the RebGT, CP, and Cont groups higher than the GT group.

Table 2. Bond strength (MPa) mean and SD values for all groups tested.

Group	Cervical		Middle		Apical	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
GT	4.41	(±1.33) Aa	8.41	(±2.43) Bab	3.75	(±1.67) Aab
Reb	7.15	(±1.55) Aab	6.01	(±2.32) Aa	2.67	(±0.71) Ba
CP	9.63	(±1.86) Abc	9.47	(±2.37) Ab	5.64	(±2.43) Bab
RebGT	9.14	(±2.37) Abc	7.45	(±2.59) Aab	4.09	(±1.71) Bab
Cont	10.32	(±2.03) Ac	7.69	(±1.85) ABab	6.76	(±2.68) Bb

Uppercase letters show significant differences within the lines for the root third factor, and lowercase letters show differences within columns for the post system.

For the root third factor, the cervical and middle thirds presented similar values, and both were higher than the apical, except for in the GT group.

According to the results obtained, the null hypotheses tested were rejected since the design of the posts interfered with the bond strength, and there was a significant difference between the root thirds. Although the biomechanical behavior of GFPs makes them the option of choice for the rehabilitation of teeth with extensive coronal loss [22–25], roots with enlarged canals are challenging in clinical situations [8,12,26]. Under these conditions, the use of a singular GFP is not recommended, as there is often no adaptation in the cervical and middle thirds, promoting a thick resin cement interface, which is unfavorable to bonding and resistance, as discussed in previous studies [8,12,27,28]. The results of this study corroborate these findings (Table 2) since the group restored with a single post (Reb) presented lower values of bond strength than the other groups (with the exception of the GT group). The groups representing the customized post (CP) and the association between single posts and the bundled fibers from the GT system (RebGT) presented higher adhesive bond strength values (Table 2), being similar to the control (non-weakened). The promotion of a thinner cementation line reduces the shrinkage stress, as well as the formation of bubbles or voids, and consequently adhesive failures in this region [4], reducing the chances of loss of retention associated with these factors [11,13].

Interestingly, an unfavorable bonding performance was found within the GT group, which presented lower bond strength values. The idea of these multiple post systems (Rebilda Post GT) was conceived to favor adhesive post cementation by allowing its better adaptation to the root canal, especially in non-oval or weakened roots. Also, it is expected that this system improves the stress distribution along the root, modifying its biomechanical behavior [12]. However, according to the present study, the bond strength of this group can be considered a disadvantage.

Therefore, in theory, the possibility of arranging the fibers in a more homogenous way inside the canal in these bundled fiber systems does improve the adaptation of the post, and therefore a better bonding strength behavior would be expected. However, the results of the present study showed lower values for bond strength in the cervical (Table 2) section for the GT group, opposing what is generally found in the literature for this region. This might have happened due to the greater volume of resin cement in this region due to the greater space between the fibers, therefore promoting more strain and stress by high polymerization shrinkage in the adhesive interface [29]. The approximation of the fibers in the middle third and the reduction of resin cement volume in this region contributed to the increase in bond strength found for this group (Table 2). Finally, for the apical third, it was observed that it had lower MPa values, similar to the cervical section, and although the volume of resin cement was smaller, the difficulty in achieving a proper cure of resin cement in this region is extensively reported in the literature [30,31]. An interesting fact also observed in this group was that fewer fibers reached the apical third region (usually 9 or 10 from the 12), and therefore the conical posts are usually preferable. Difficulties in placing accessory posts in this region were also discussed by Latempa et al. (2015) [29].

Still, regarding these bundled fibers post systems (GT), it is important to note that their use, although innovative, is not as simple as is claimed by the manufacturer. The removal of the plastic rod that holds the fibers together during cementation is challenging and often promoted the removal of the post from inside the canal, which might increase the formation of bubbles in the interface when the post was reinserted into the canal. During the execution of the present study, an option found and suggested was the removal of the plastic holder prior to the cementation and insertion of the fibers individually in the root canal.

Although the use of the multiple post system (group GT) did not show satisfactory bond strength results for weakened roots, its association with the single post (RebGT group) showed favorable and similar results to the control group (Cont). In this technique, the GT system functioned as auxiliary posts, reducing the cement volume and improving the distribution of root stresses to the dentin when more fibers were used [22]. The use of accessory posts to reinforce enlarged roots has been reported in the literature as an option to increase the adaptation of prefabricated posts [12,29,31–34]. Previous investigations [33,34] reported increased resistance to root fracture, while other reports [29,32] showed improvements in adhesive strength when using accessory posts in fragile roots.

However, it is necessary to consider that the use of accessory posts might be more expensive, given the need to use two systems. This study showed similar results between the customized post (CP) and the association of posts (RebGT), indicating that the customization with composite resin can be favorable in this respect, given the lower cost of the composite resin. In addition, the use of composite resin for post relining allows it to be cured outside the root canal, reducing the risk of deficient polymerization in deeper regions; this also allows composite shrinkage to happen outside the mouth, reducing shrinkage stresses in the adhesive interface [5,11,13].

Finally, with respect to the root thirds, the bond strength was higher in the cervical and middle thirds compared to the apical (except for GT). This aspect is continually reported in the literature [30,31,35] and associated with the difficulty of properly curing the resin cement in deeper regions, even when a dual-cure cement is used [36–39]. Besides, adhesion to apical dentin is less predictable due to the substrate composition; thus, this issue still presents itself as a challenge for adhesive dentistry.

4. Conclusions

It can be concluded that for weakened roots, higher bond strength values were found when customizing the GFPs with composite resin or when associating them with thinner fibers, such as the bundled glass fiber-reinforced resin post. In addition, adhesion to deeper thirds of the root canal remains a challenge for adhesive dentistry and is not related to the design of the post.

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