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ORIGINAL ARTICLE

Push-out strength of fiber posts depending on the type of root canal filling and resin cement

Maria Dimitrouli · Hüsamettin Günay · Werner Geurtsen · Anne-Katrin Lührs

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Abstract The purpose of this study was to analyze the push-out strength of two fiber post systems/resin cements (RelyX Unicem/RelyX Fiber Post (RLX) and Variolink II/DT Light SL (VL)) depending on the root canal filling (RF). One hundred sixty extracted human teeth were divided into four groups: gutta-percha/AH Plus (GP), gutta-percha/Guttaflow (GF), pre-existing root canal filling (PRF), and without root canal filling (WRF). After root canal treatment, fiber posts were inserted using either RelyX® or Variolink II®/Excite DSC®. Half of the specimens were thermocycled (TC, 5,000 cycles, 5–55°C). All specimens were subjected to the push-out test (crosshead speed 1 mm/min). Three-way ANOVA showed a significant influence of either the RF or the resin cement/post system ($p<0.001$). The highest bond strength was measured for VL-WRF without TC (16.5±6.4 MPa). TC had no significant influence within the RLX groups. For groups PRF and WRF, significant differences were documented between VL and RLX (PRF 16.3±6.0 vs 7.0±2.4 MPa, $p=0.001$; WRF 16.5±6.4 vs 8.0±5.0, $p=0.004$) before TC. No differences were found after TC. The fracture mode analysis for VL showed mainly adhesive fractures between post and cement. For RLX, mixed fractures between post and tooth and between tooth and cement were predominantly determined. The adhesion of resin cements/post systems could be dependent on the type of RF. Higher bond strength values were found for the conventional ("etch and rinse") adhesive than for the "self-adhesive resin cement."

M. Dimitrouli · H. Günay · W. Geurtsen · A.-K. Lührs (✉)
Conservative Dentistry, Periodontology and Preventive Dentistry,
Hannover Medical School,
Hannover, Germany
e-mail: Luehrs.Anne-Katrin@mh-hannover.de

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Introduction

Caries and trauma are the most frequent causes of irreversible pulp damage resulting in a root canal therapy. A variety of concepts exists for the subsequent final restoration of severely damaged root canal treated teeth without sufficient mechanical retention [1, 2].

It should be kept in mind that the main function of a root canal post is not physical reinforcement of the remaining endodontically treated tooth structure but only retention [3, 4]. However, post and cores may secure the long-term retention of a restoration [5].

For many years, cast post and core restorations were the primary option for root canal treated teeth [6]. However, a great variety of disadvantages associated with metallic posts have led to a controversial discussion about these systems. More precisely, the high number of root fractures and the lack of translucency compared to natural teeth are considered to be the main disadvantages. Moreover, corrosive products and the risk of root-perforation during post removal have raised doubts about their use [7–9]. Since cast posts may reduce the fracture resistance of a restored tooth, they should only be used in teeth with little or no remaining mechanical retention [3].

Therefore, new post systems have been developed, e.g., glass fiber posts [1, 6]. The combination of an adhesive bond to the root canal dentin with a resin core buildup allows the restoration of non-vital teeth while preserving the remaining tooth structure [10, 11].The adhesive bond of fiber posts can stabilize the tooth substrate [12]. Another advantage of adhesively cemented fiber posts is the prosthetic reconstruction of wide root canals [12]. For the adhesive cementation of fiber posts, either "conventional" composite or self-adhesive resin cements are available. The self-adhesive resin cements were introduced to the dental market in 2002 with the advantage that no pre-treatment of tooth surface is required [13–15]. This leads to a simplified and time-saving cementation procedure [15–17] with a bonding mechanism based on micromechanical retention and chemical adhesion [18, 19]. The self-adhesive resin cements contain multifunctional hydrophilic monomers with phosphoric acid groups, which can react with the hydroxyapatite and also penetrate and modify the smear layer [17, 20–22]. The chemical interaction between the acidic monomers and hydroxyapatite ensures the adhesion of the self-adhesive cements into dentin [23].

In contrast to cast posts, factors like post length, post diameter, or taper of the post do not significantly influence the adhesion and the long-term behavior of glass fiber posts. Taken together, fiber-reinforced posts seem to be superior compared to cast posts, especially regarding their physical properties, for example their modulus of elasticity, that is similar to root dentine [8, 12, 24]. In addition, the parallel bundled fibers may act as a guide for rotating instruments. This may facilitate the removal of glass fiber posts if necessary, e.g., in case of an endodontic revision [2, 5, 12] or after a post fracture [25, 26]. Moreover, glass fiber posts are biocompatible and do not corrode [27]. Finally, an important advantage of fiber posts is the high esthetic appearance, with no risk of gingival discoloration or alteration of the root surface by corrosive products, especially in the anterior region [12].

The aim of this study was to analyze the influence of various types of root canal fillings and of thermocycling on the push-out strength of two glass fiber post/resin cement systems. The null hypothesis, which was set forth, was that neither the type of glass fiber post/resin cement system nor the type of root canal filling nor thermocycling influences the bond strength of the glass fiber posts in root canals of human teeth.

Materials and methods

One hundred sixty freshly extracted teeth were collected for this study and stored in chloramine solution (1%) at room temperature for no longer than 3 months. Single rooted teeth and oral or distal roots from upper and lower molars were used. X-rays of all teeth were taken to identify irregular formed root canals or obliterations in order to exclude those teeth from further treatment. All roots were cut to a length of 12 mm with a diamond bur (No. 837.104.014, Komet, Brasseler Lemgo, Germany) at 200,000 rpm with water spray. Each root canal was treated with Mtwo root canal instruments (VDW, Munich, Germany) up to size 30.05 with the simultaneous shaping technique. The canals were rinsed with sodium hypochlorite (NaOCl, 2.5%), chlorhexidin-digluconate (CHX, 0.2%), and 0.9% saline solution. After drying (paper point size 30, VDW, Munich, Germany), root canals were filled with a well-fitting ("tug back") gutta-percha point (Roeko, Langenau, Germany) in combination with the root canal sealer AH Plus™ (Dentsply DeTrey, Konstanz, Germany) or with Guttaflow (Coltène/Whaledent, Langenau, Germany) using the lateral condensation (AH Plus) or the "single cone" (Guttaflow) technique. Detailed information of all materials is listed in Table 1. All roots were randomly assigned to one of the 16 groups ($n=10$) with four control groups and 12 experimental groups. The study design is shown in Fig. 1. Groups were characterized by the root canal sealer and the post/resin cement system.

Besides 40 roots that were filled with gutta-percha points/AH Plus™ or Guttaflow, another 40 roots revealed a pre-existing root canal filling. The teeth selected for this group were not older than 3 months, and only roots where the root canal filling could be clearly identified as gutta-percha by X-ray and visual inspection were included. Other root canal filling materials for example thermafil, silver-points, or cements were excluded. Forty roots without any filling were used as controls. The parameters of each group are shown in Fig. 1.

Table 1 Composite cements and their use

Resin cement	Use	Group	Manufacturer
Variolink II (VL)	Etching of the root canal dentin for 15 s Activation of Excite DSC Applying of Excite DSC for 10 s Mixing of Variolink Base/Catalyst 1:1 Polymerization for 40 s	Resin cement with etch and rinse adhesive	Ivoclar Vivadent, Ellwangen, Germany
RelyX Unicem (RLX)	Activation of capsule for 2–4 s Mixing for 15 s Polymerization for 40 s	Self-adhesive	3M ESPE, Seefeld, Germany

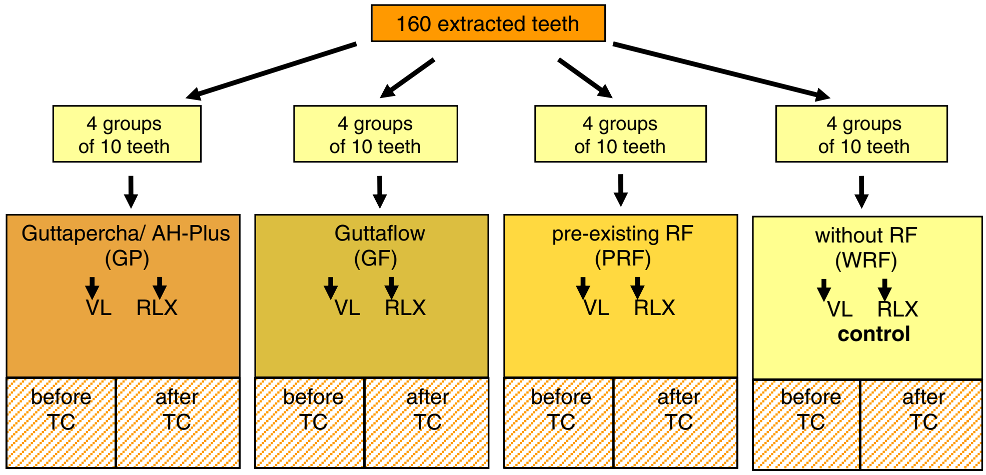


Fig. 1 Study design and test groups

The root canal filling in all test groups was removed after 24 h, and the canal was prepared in order to fit the appropriate post using the root canal drills according to the manufacturers' instructions. The preparation depth for each post was 8 mm, which was checked for each root by taking another set of X-rays before cementation of the post. Each canal was rinsed with sodium hypochlorite solution and saline solution and dried with paper points (size 40, VDW, Munich, Germany).

The fiber posts used in this study were DT Light SL® (VDW, Munich, Germany) and RelyX Fiber Post® (3 M ESPE, Seefeld, Germany). The resin materials Variolink II®/Excite DSC® (VL, Ivoclar Vivadent, Ellwangen, Germany) and RelyX Unicem® (RLX, 3 M ESPE, Seefeld, Germany) were used for post cementation (Table 1). Before insertion, each post was disinfected with ethanol (99.8 vol.%) for 60 s and then thoroughly air-dried.

For Variolink II/Excite DSC, the root dentin was etched with 37% phosphoric acid for 15 s, followed by rinsing with water for 10 s. The water excess was removed with absorbent paper points. With this procedure, an overdrying of the etched canal root dentin could be avoided because the canal wall surface was left slightly moist due to the moist bonding concept. Afterward, Excite DSC was applied for 10 s, and the excess was again removed with paper points. The root dentin was gently air-dried for 5 s to ensure the solvent evaporation of the Excite DSC. Subsequently, the dual-curing cement was mixed in a proportion of 1:1 and applied onto the surface of the posts, which were inserted into the canal, and surplus was removed with a plastic pellet (Pele Tim, Voco, Cuxhaven, Germany).

Regarding the RelyX Unicem group, the capsule of the self-adhesive cement was first activated for 2–4 s and then mixed (Capmix, 3 M ESPE, Seefeld, Germany) for 15 s. The cement was applied using an "elongation tip" (Skin Syringer REF/UP 1681, Ultradent, South Jordan, UTAH, USA). Preliminary tests showed that the placement of the cement with the system's immanent elongation tip was inferior to the elongation tip the authors used in this study. The post was inserted into the root canal.

The resin cements were polymerized for 40 s with an LED light polymerizing unit (Bluephase II, Ivoclar Vivadent, Ellwagen, Germany, light intensity = above 1,000 mW/cm^2, high power modus, checked with bluephase meter (Ivoclar Vivadent, Ellwagen, Germany) during treatment).

For both post systems, the tip of the polymerization unit was placed in direct contact to the coronal end of the post, so that the light could be transmitted into the root canal by the fiber post. Afterward, the polymerization was performed for 10 s at all four root surfaces: mesial, distal, vestibular, and oral. Finally, a composite buildup was placed onto all specimens to ensure the tight sealing of the root canal.

In between the experimental steps, teeth were stored dry in an incubator at 37°C and 100% humidity.

Afterward, half of the specimens were thermocycled (TC, 5°C/55°C, 5,000 cycles, dwell time 30 s), while the remaining specimens were stored in an incubator at 37°C for the same time period. All specimens were cut into disks with a thickness of 2 mm at a distance of 0.3 and 2.3 mm from the coronal end of the root (Fig. 2a) with a low-speed diamond saw (Isomet, Buehler, IL, USA). The diameter of each post was measured under 40-fold magnification using a computer-aided program (Image Access Premium Version 6, Imagic Bildverarbeitung (AG), Glattbrugg, Switzerland, Fig. 3), and the surface area of the post for each slice was calculated using the equation in Fig. 4. The push-out test was performed in a universal testing machine (Fig. 2b, type 20 K, UTS, Ulm) with a crosshead speed of 1 mm/min. The push-out strength in MPa was calculated by dividing the "debonding" force by the calculated post area. All test specimens were loaded until fracture. The type of fracture was subsequently determined at ×25 and ×40 magnification (microscope: Wild M3Z Type-S, Heerbrugg, Switzerland) and classified according to the following criteria: (1) adhesive failure between dentin and the composite cement,

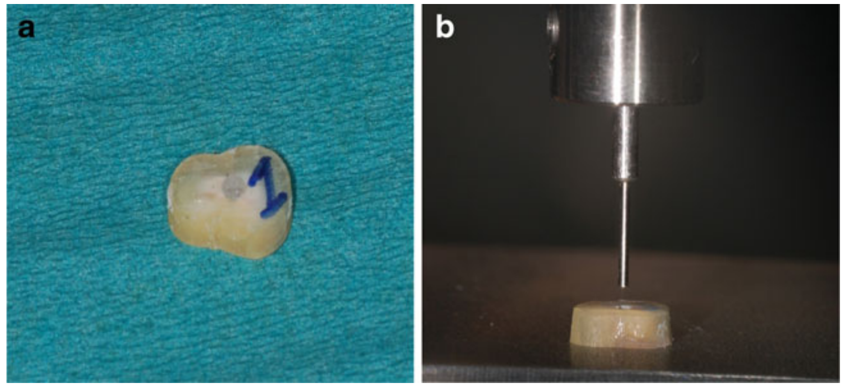


Fig. 2 **a** Dentin disk, **b** specimen in the universal testing machine

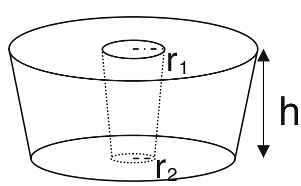
(2) adhesive failure between composite cement and the post, (3) cohesive failure within the post, (4) mixed failure of (1) and (2), (5) mixed failure of (2) and (3), and (6) mixed failure of (1) and (2) and (3). Because no cohesive fractures in either root dentin or cement occurred, these fracture modes were not included into the classification.

Statistical analysis was performed using three-way ANOVA and the *t* test ($p<0.05$, SPSS GmbH Software, Version 15, Munich). The following factors were included in the three-way ANOVA statistical analysis: (1) fiber post/resin cement system, (2) type of root canal filling, and (3) thermocycling.

Results

The three-way ANOVA indicated a significant influence of either the factors root filling material or fiber post/resin cement. The adhesion of both post systems was not significantly influenced by TC (Table 2). Therefore, the first part of the null hypothesis concerning the root filling material and the fiber post/resin cement is rejected. The null hypothesis was confirmed for the TC.

VL-WRF without TC revealed the highest push-out strength (16.5±6.4 MPa). After TC, bond strength values dropped, but were not significantly different compared to non-thermocycled specimens (13.5±14.0 MPa). Lower values were found for RLX-WRF without TC (8.0±5.0 MPa). The bond strength slightly increased after thermocycling, but differences were not statistically significant (11.3±8.9 MPa). In group VL-GF, TC caused a significant reduction in bond strength, resulting in the lowest bond strength of all groups investigated in this study (9.5±3.2 vs 5.3±2.4 MPa, $p=0.005$). The RLX groups were not significantly influenced by TC.



$$\pi(r_1+r_2)\sqrt{h^2+(r_1\ \ r_2)^2}$$

Fig. 3 Calculation of the post surface

Furthermore, it was observed that the combination post system/resin cement influenced the bond strength. Without TC, groups PRF and WRF showed significant differences between VL and RLX (PRF 16.3±6.0 vs 7.0±2.4 MPa, $p=0.001$; WRF 16.5±6.4 vs 8.0±5.0 MPa, $p=0.004$) that diminished after TC (PRF 11.5±6.5 vs 7.2±3.6 MPa; WRF 13.5±14.0 vs 11.3,±8.8 MPa). Group GF without TC revealed slight differences between VL and RLX, but without statistical significance before (9.5±3.3 vs 6.5±3.5 MPa, $p=0.059$) and after TC (5.4±2.4 vs 6.0±4.4 MPa). The mean values of all groups are shown in Table 3. All test results are summarized in Fig. 4a, b.

The surface analysis of the fractured specimens showed for groups VL mainly adhesive failures between post and cement, whereas for groups RLX, fractures between tooth and cement and post and cement were mainly found (Fig. 5).

Discussion

The aim of this study was to determine if the bond strength to the root canal dentine was influenced by either the fiber post system/resin cement, by the type of root canal filling, or by thermocycling. Regarding the results, the null hypothesis of the present study was confirmed that thermocycling did not influence the bond strength of glass fiber posts. The first part of the null hypothesis regarding the influence of glass fiber post/resin cement systems and the root canal filling on the push-out strength was rejected.

Referring to materials and methods, all root canals were rinsed with sodium hypochlorite (2.5%) and sterile saline solution (0.9%) after preparation and before the post was cemented adhesively. In current scientific literature, the adverse effect of sodium hypochlorite (NaOCl) on the bond strength of resin cements to root canal dentin was described [28–32]. It was demonstrated that the irrigation of root

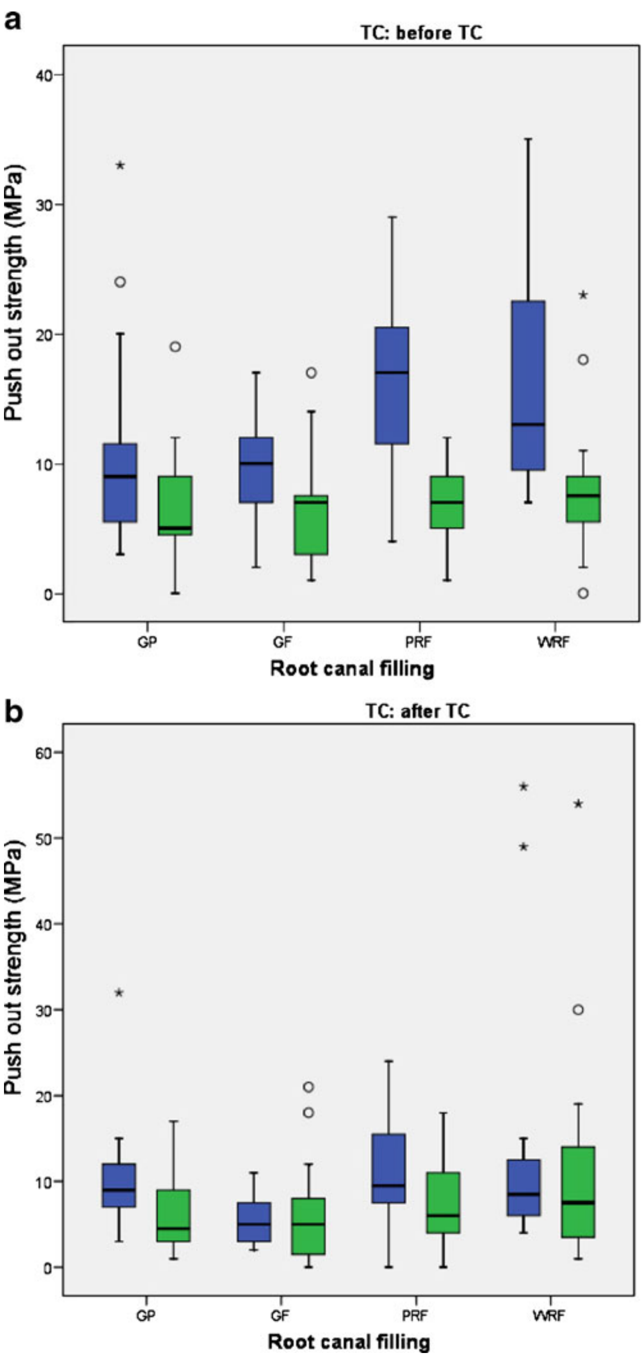


Fig. 4 a, **b** Test results before and after TC: groups gutta-percha (*GP*), Guttaflow (*GF*), pre-existing root canal filling (*PRF*), without root canal filling (*WRF*), *blue* VL, *green* RLX

canals with 5% NaOCl reduced the bond strength of resin cements to dentin [28, 31]. Wattanawongpitak et al. [33] found similar results regarding the effect of NaOCl and EDTA/NaOCl on the microtensile bond strength (MTBS) of dual-curing resin composite. After irrigating the root canal with EDTA followed by NaOCl, the MTBS of a resin composite to the intrapulpal dentin was reduced. This could be explained by an oxygen-enriched dentin surface after application of NaOCl, which could act as a polymerization inhibitor of resin materials [28]. However, NaOCl is the most commonly used irrigant because it has the ability to remove the smear layer, which is created on the dentin surface during the post space preparation [30, 34]. The removal of the smear layer, which contains organic and inorganic components, sealer and gutta-percha remnants, microorganisms, and infectious deteriorated dentin is necessary for the penetration of the adhesive system and resin cement into the dentin tubules [31, 34, 35].The ability of NaOCl to remove the smear layer was the reason for selecting NaOCl as an irrigant within the present study. In addition, the study protocol followed the manufacturers' instructions of RelyX Unicem (3 M ESPE, Seefeld, Germany), which recommend the irrigation of the root canal with NaOCl followed by water. In general, the root canal should be irrigated with CHX or sterile saline solution before post cementation in order to eliminate the negative effect of NaOCl on the adhesive bond to dentine [29]. In this study, saline solution was used as the last irrigant before post cementation according to the manufacturers' instructions.

The conditions of the oral cavity were simulated by TC and by storing the specimens in an incubator at 37°C and 100% humidity in the present study. By using these two techniques, the results of our study can predict the clinical behavior of the two tested post systems and the investigated resin cements.

Various methods are available to analyze the adhesive bond of composite cements and the bond strength of fiber posts. The two most commonly used techniques are the MTBS and the push-out test. Most scientists prefer the push-out test for the analysis of fiber posts' bond strength to root dentin because it has been documented that the results of this test are more reliable for fiber posts compared to the MTBS test [36]. By using the push-out test, the premature loss of samples during the manufacturing of the specimens is reduced [36]. Furthermore, the micro push-out test enables the measurement of bond strength to very small areas such as the interior of a root canal [36].

In this study, four different types of root canal fillings were examined in order to investigate the influence of various endodontic materials including pre-existing gutta-percha root fillings. These "pre-filled" specimens were included in our examination in order to investigate the influence of an immediate (groups GP, GF, and WRF) or delayed post cementation (group PRF) on the bond strength of fiber posts.

Our findings clearly indicate that the type of root canal filling influenced the bond strength of the investigated fiber post/resin cement significantly. In contrast to our findings, Kurtz et al. [37] documented that AH Plus had no influence on the adhesive bond of glass fiber posts. Teixeira et al.

Table 2 Three-way ANOVA

Source	Sum of squares	df	Mean square	*F*	Sig.
Fiber post/Resin cement (PR)	711.914	1	711.914	18.990	0.000
Thermocycling (TC)	51.189	1	51.189	1.365	0.245
Root filling material (RF)	679.242	3	226.414	6.039	0.001
PR×TC	143.452	1	143.452	3.826	0.052
PR×RF	171.642	3	57.214	1.526	0.210
TC×RF	53.792	3	17.931	0.478	0.698
PR×TC×RF	53.455	3	17.818	0.475	0.700
Total	21,750.750	160			

[38] however revealed that the root filling material can influence the bond strength of the resin cement. The obturation with a resin-based sealer (EndoREZ) provided higher bond strength values in coronal and middle root thirds compared to a calcium hydroxide-based sealer (Sealapex) and a zinc oxide-eugenol-based sealer (Endo Fill).

Regarding the fracture analysis, it should be emphasized that the group VL showed mainly adhesive failures between post and cement, whereas the RLX groups showed mainly fractures between tooth and cement or post and cement. This may indicate that within the VL groups, the weak link was the bond between the resin cement and the post, but not between the resin cement and the root canal dentin. The failure modes described by Kececi et al. [39] and Toman et al. [15] are in contrast with our findings and showed mainly adhesive failure between dentin and resin cement in the group of Variolink. Also, Kececi et al. [39] detected higher bond strength values for Variolink in comparison to RelyX Unicem, which revealed mixed failures between dentin and resin cement and cohesive failures for Variolink. In our study, RLX revealed mixed fractures between tooth and cement and post and cement. The RLX group in the study of Bitter et al. [40] showed mainly an adhesive failure mode between post and cement.

Moreover, it may be also speculated that the higher bond strength of the VL group compared to RLX was achieved due to a lower share of fibers in DT Light SL posts in comparison to RelyX Fiber Post [7]. Unfortunately, no information about the fiber content in RelyX posts was provided by the manufacturer. The fibers are mainly responsible for the mechanical properties, such as elasticity and fracture strength. On the other hand, it is hypothesized that the matrix can form a chemical bond with Bis-GMA, which is used in most composite cements [7, 41, 42]. Also, DT light SL posts are visually more translucent in comparison to the RelyX Fiber Post. The higher photoconductivity of the DT Light SL compared to RelyX Fiber Posts could increase the light transmission during polymerization directly into the root canal and thus enhancing the photo-polymerization process of the composite within the root canal [6, 43–45].

Independently from the type of root canal filling or the type of sealer, the smear layer, which is created by the drill bur during the post space preparation, can act as insulation against any kind of adhesive material intended to bond to the root canal dentin [35, 46].This smear layer contains sealer and gutta-percha remnants and is plasticized by the heat of friction of the drill [34]. In the present study, the bond strength in the group WRF (i.e., VL-WRF before TC=16.5±6.4 MPa) was higher compared to the push-out strength of the other groups (VL-GP before TC 10.4±7.2 MPa).This confirms that this layer can act as a barrier, which interferes with the adhesive agents [47].

Furthermore, the remnants of gutta-percha and sealer may diminish the chemical action of the orthophosphoric acid [34], which interferes with a clean bonding substrate in the root canal [48]. In the present study, the GF group revealed the lowest bond strength after TC. With GF containing silicone, the smear layer produced during the removal of that material may also contain silicone, which could render the smear layer more resistant to acid etching. The different compositions of the smear layer produced by the same bur for every fiber post/resin cement system after removing different types of sealers could be another explanation for the varying bond strength values. Because no information about silicone remnants in smear layers are available in current scientific literature, further research is needed on this topic.

Table 3 Push-out strength of the composite cements in MPa before and after TC

	VL+GP	RLX+GP	VL+GF	RLX+GF	VL+PRF	RLX+PRF	VL+WRF	RLX+WRF
Before TC	10.4±7.2	6.6±3.4	9.5±3.2	6.5±3.5	16.3±6.0	7.0±2.4	16.5±6.4	8.0±5.0
After TC	10.2±5.1	6.6±5.0	5.3±2.4	6.1±4.4	11.5±6.5	7.2±3.6	13.5±13.9	11.3±8.8

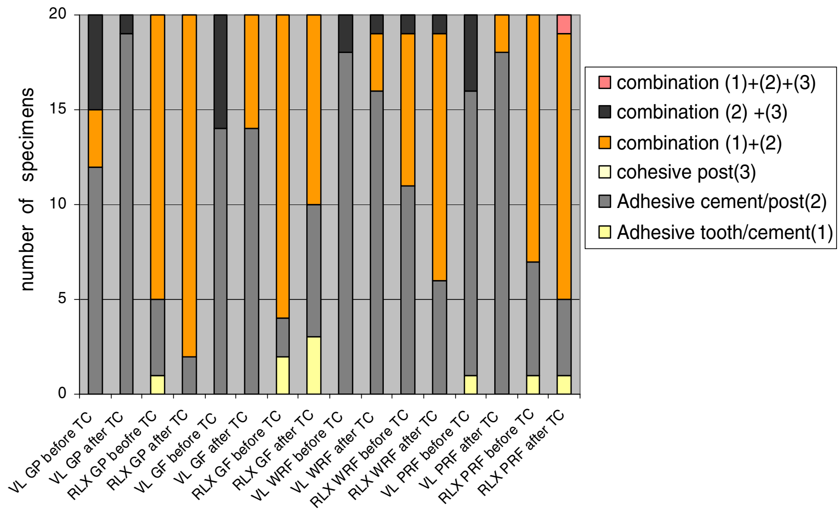


Fig. 5 Outcome of the fracture analysis

In our study, the post was inserted after 24 h, in order to avoid a coronal infiltration of bacteria. According to the results of the present study and considering that materials used for temporary coronal sealing do not inhibit, but only decrease bacterial infiltration, it could be beneficial to perform an immediate post cementation after root canal preparation. This procedure might reduce the risk of coronal leakage. In addition, the restoration (adhesive restoration or buildup) could be done in a single session [47].

Furthermore, our data revealed that the resin cement in combination with an etch-and-rinse adhesive (Variolink II/ Excite DSC) results in higher bond strength values than the self-adhesive resin (RelyX Unicem). The etching of the root canal dentin with dissolution of the smear layer may result in an increased adhesion of Variolink [49]. The acid-resin monomers of RelyX Unicem, which are used in this material for the etching of the tooth's enamel and dentine, were possibly not as effective as phosphoric acid [36, 49]. This led to the lower bond strength values of RelyX compared to Variolink. The findings of the present study are consistent with Durâo et al. [50] found that Variolink II had the highest bond strength out of three investigated products. These findings were also confirmed by Kececi et al. [39], who examined two fiber-reinforced posts in combination with four different composite cements including Variolink II and RelyX Unicem. In contrast to our results, Bitter et al. [51, 52] found higher bond strength values for RelyX compared to Variolink II [51, 52]. Moreover Zicari et al. [19] found higher push-out strength values for the self-etching cements (Clearfil Esthetic 14.6±3.6 MPa; Panavia 21 12.6±2.5 MPa) compared to the conventional etch and rinse composite cement Variolink II (11.1±4.1 MPa) and the self-adhesive cement RLX Unicem (11.3±4.31 MPa). In contrast to the results of the present study, the push-out strength of Variolink II was equal to the self-adhesive composite cement. Based on our data, it may be concluded that the use of an adhesive system may result in higher bond strengths independent of the used root filling material.

It has also been discussed that TC, which simulates the variation of the oral temperature and the thermal stresses, could influence the bond between post, resin cement, and dentin [53, 54]. In the present study, TC did not affect the push-out strength of the investigated fiber post systems/resin cements. This contrasts with Bitter et al. [51], who observed a significant influence of TC on the bond strength of RLX to root canal dentin. In another study accomplished by the same authors, the bond strength was not affected by thermocycling [55]. In our study the bond strength was reduced after TC for the Variolink groups, while the values for the RLX groups were not affected (GP, GF, and PRF) but were increased (WRF). Moreover, Drummond and Bapna [56] found that all fiber post systems analyzed in their experiments showed significant lower bond strength values after TC, which is also in contrast to our results.

Several aspects, however, need further research. Composite cements shrink during polymerization, which may cause stress within the composite layer. Composite resins also undergo hydrolytic degradation, and their coefficient of thermal expansion is different to natural tooth structure and ceramic materials [5]. Furthermore, a smear layer is present after preparation of the root canal dentin, which can be removed effectively with different solvents in combination with EDTA [57, 58]. The effects of these parameters and possible interactions with irrigations after root canal preparation on the long-term stability of glass fiber posts should be analyzed in future studies.

Conclusion

Our data indicate that the bond of adhesively cemented glass fiber posts may be dependent on the type of the root canal sealer. In addition, higher bond strength values may be expected with a conventional ("etch and rinse") composite-based material compared to a self-adhesive cement.

Conflict of interests The authors declare that they have no conflict of interests.

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