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ORIGINAL ARTICLE

Comparison of the push-out strength of two fiber post systems dependent on different types of resin cements

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Abstract The purpose of this study was to compare the push-out strength of glass fiber posts dependent on the resin cement. One hundred human teeth were divided into five groups (n=20). Two glass fiber post systems (DT Light SL (DTSL) and RelyX Fiber Post (RF)) were used. DTSL posts were cemented with one "etch & rinse" system (ER) or one of three self-adhesive resin cements (SA). The RF posts were cemented with RelyX Unicem. Afterwards, half of the specimens were thermocycled (TC; 5°C/55°C, 5,000 cycles). All specimens were cut into disks (thickness, 2 mm). The push-out test was performed (crosshead speed, 1 mm/min), fracture types were determined (×25 and ×40 magnification), and statistical analysis was performed (one-way analysis of variance (ANOVA), Scheffe test, $p<0.05$). One-way ANOVA showed a significant influence of the resin cement on the push-out strength of the glass fiber posts before thermocycling ($p<0.001$). After TC, no significant differences were detected. Microscopic evaluation showed mainly adhesive failures between post and cement for ER or mixed fractures for SA. The bond strength of adhesively cemented glass fiber posts is not dependent on the type of resin cement after TC. The use of SA can lead to bond strength values comparable to ER. Self-adhesive resin cements could be used just as well as resin cements with "etch & rinse" adhesive systems for the cementation of glass fiber posts.

Keywords Glass fiber posts · Push-out strength · Root canal filling · Adhesion · Self-adhesive resin cements

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Introduction

The restoration of root canal-treated teeth with an excessive loss of coronal tooth structure frequently requires the use of a post and core. In this case, it should be emphasized that the main function of a root canal post is not physical reinforcement of the remaining endodontically treated tooth structure rather than retention of the final restoration [1, 2]. The restoration of endodontically treated teeth with fiber posts has been widely investigated [3, 4].

The fiber post systems consist of an epoxy resin matrix, which is reinforced with carbon or glass fibers [5–7]. Glass fiber posts consist of glass fibers (65% by weight), which are embedded in a composite- or epoxy resin matrix (about 35% by weight) [8–10]. The main components of the fibers are silicon oxide (50–60%) as well as calcium, boric, sodium, and aluminum oxide. The fibers are mainly responsible for the mechanical properties of the glass fiber posts such as the elasticity and the fracture resistance [8, 11, 12]. On the other hand, it is hypothesized that the matrix can form a chemical bonding with bisphenol A diglycidylether methacrylate (Bis-GMA), which is used in most composite cements [8, 11, 12]. Matrix polymers are commonly epoxy polymers with a high degree of monomer conversion and a highly cross-linked structure [13, 14]. Furthermore, the properties of glass fiber posts may also depend on the diameter of the fibers, their density, the bond between fiber and resin matrix, as well as the external surface of the post [14].

A prerequisite for the use of fiber posts is their adhesive cementation, which creates a bond between the post and the root canal dentin. The combination of an adhesive bond to the root canal dentin with a resin core build-up allows the restoration of nonvital teeth while preserving the remaining tooth structure [15, 16]. The adhesive bond of fiber posts can stabilize the remaining tooth substrate [17]. Another advantage of adhesively cemented fiber posts is the possibility to restore teeth with wide root canals [17].

For the adhesive cementation of fiber posts, either “conventional” composites or self-adhesive resin cements are available. The self-adhesive resin cements are the least investigated group of resin cements. They were introduced to the dental market in 2002 with the advantage that no pretreatment of tooth surface is required [18, 19]. This results in a simplified and time-saving cementation procedure [19–21] with a bonding mechanism based on micromechanical retention and chemical adhesion [22, 23]. The self-adhesive resin cements contain multifunctional hydrophilic monomers with phosphoric acid groups which can react with hydroxyapatite and also infiltrate and modify the smear layer [21, 24–26]. The chemical interaction between the acidic monomers and hydroxyapatite ensures the adhesion of the self-adhesive cements to dentin [27]. The smear layer, which is produced during the post preparation, cannot be removed by self-adhesive resin cements [18, 28–30]. This remaining smear layer could cause a lower bond strength for self-adhesive resin cements compared to an “etch & rinse” adhesive system [28, 31–33]. Furthermore, the smear layer interferes with a deep resin cement infiltration into the collagen substrate impairing the connection of both components [22, 33]. This results in the formation of a thinner hybrid layer and consecutively produces a lower number of resin tags compared to an “etch & rinse” adhesive system [22, 28, 33]. Since the adhesion of resin cements to dentin is also based on micromechanical retention and particularly on the formation of resin tags and a hybrid layer [34–37], an insufficient formation of a hybrid layer after the application of self-adhesive resin cements could explain the low bond strength values determined for this class of resin cements. Several studies showed that the application of self-adhesive cements, specifically RelyX Unicem, did not result in the formation of a hybrid layer and resin tags [36–39].

It was found that the bond strength of self-adhesive resin cements to enamel can be increased to the same level as “etch & rinse” adhesive systems when an additional phosphoric acid etching is performed [36]. On the contrary, the etching of dentin does not necessarily result in higher bond strengths for the self-adhesive resin cement. Recently, it was documented that the microtensile bond strength to dentin after acid etching was significantly lower than without acid etching [25, 36].

Self-adhesive cements are supposed to be moisture tolerant and to release fluoride at an extent comparable to glass ionomer cements [22, 27]. Additionally, they offer good esthetic and mechanical properties [27]. Because of these positive features, they are used for the adhesive cementation of bridges and crowns as well as posts and inlays. In spite of these advantages, such as the simplification of the luting procedure and the assumed lower technique sensivity, limited information is available about the adhesion of fiber posts in root canals in combination with various adhesive cements.

Therefore, the aim of this study was to analyze the influence of various types of self-adhesive resin cements on the push-out strength of glass fiber posts without and with thermocycling. The null hypothesis, which was set forth, was that self-adhesive resin cements can lead to bond strength values comparable to a resin cement in combination with an “etch & rinse” adhesive system, when used for the adhesive cementation of glass fiber posts.

Materials and methods

One hundred freshly extracted teeth were collected for this study and stored in chloramine solution (1%) at room temperature for no longer than 3 months. Only single-rooted teeth and oral or distal roots from upper and lower molars were used. X-rays of all teeth were taken to identify irregularly formed root canals or calcifications in order to exclude those teeth from the experiments. 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 shaped with Mtwo root canal instruments (VDW, Munich, Germany) up to size 30.05. The canals were rinsed with sodium hypochlorite (NaOCl, 2.5%), chlorhexidine digluconate (CHX, 0.2%), and 0.9% saline solution. All roots were randomly assigned to one of the five groups (n=20) with one control group and four experimental groups. Groups were characterized by the adhesive/resin cement system. Afterwards, the root canals were prepared in order to fit the 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 post cementation. Each canal was rinsed with sodium hypochlorite solution and saline solution and dried with paper points (size 40, VDW, Munich, Germany).

In this study, two different fiber post systems were used: RelyX Fiber Post® (3M ESPE, Seefeld, Germany) for the RelyX groups and DT Light SL® (VW, Munich, Germany) for the other groups. The DT Light SL® posts consist of quartz fibers (64% by volume, 70–80% by weight) which are embedded in an epoxy resin matrix [40]. The DT Light SL post has a double taper design, and the size (blue) used in this study has a diameter of 1.2 mm (apical end) and 2.2 mm (coronal end) [40]. The DT Light SL posts possess an industrial-coated surface. This coating is made of silane and silicate and is applied to the post in a physical vapor deposition process [40]. This coating has a thickness of 10±5 μm, is reproducible and homogenous in production, and does not affect the dimensional aspect of the post since its tolerance is smaller than that of the post diameter itself (20±5 μm) [40].

RelyX Fiber posts consist of glass fibers (zirconia-based, 80–90% by weight) which are also embedded in resin (10–20% by weight, information provided by the manufacturer). Moreover, their glass fibers are oriented parallel and are distributed equally over the surface area [41]. Additionally, during the manufacturing process, the glass fibers are pretensioned for enhanced post stability [41]. According to the information given by the manufacturer, the RelyX Fiber posts exhibit a density from 2.2 to 2.3 g/cm^3 .The used size of RelyX Fiber post (yellow) has a diameter of 0.7 mm (apical end) and 1.3 mm (coronal end) with a taper of 6% [41]. Nevertheless, the RelyX Fiber posts do not possess a coating that is comparable to the DT Light SL posts.

The DT Light SL® posts were cemented with three different self-adhesive resin cements: Maxcem Elite (MC, Kerr, Bioggio, Switzerland), iCem (IC, Heraeus Kulzer, Hanau, Germany), and BifixSE (BF, VOCO, Cuxhaven, Germany; Table 1). For RelyX Unicem (RLX, 3M ESPE, Seefeld, Germany), a post system (RelyX Fiber Post) inherent to the resin cement was used. Twenty roots with the DT Light SL® fiber posts cemented with the "etch & rinse" resin material Variolink II/Excite DSC (VL, Ivoclar Vivadent, Ellwangen, Germany) were used as control. Before post insertion, each post was cleaned 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. Thus, an overdrying of the etched root dentin was avoided according to the moist bonding concept. Afterwards, Excite DSC was applied for 10 s, and the excess was removed with paper points. The root dentin was gently air-dried for 5 s to ensure the solvent evaporation of Excite DSC. Subsequently, the dual-curing cement was mixed in a proportion of 1:1 and applied on the surface of the posts, which were then inserted in the canal, and excess composite was removed with a plastic pellet (Pele Tim, Voco, Cuxhaven, Germany).

In the RelyX Unicem group, the capsule of the self-adhesive cement was first activated for 2–4 s and then mixed (Capmix, 3M ESPE, Seefeld, Germany) for 15 s. The cement was applied using an "elongation tip" (Skin Syringer REF/UP 1681, Ultradent, South Jordan, UT, USA), which was used for the other cements, too. Preliminary tests showed that the placement of the cement with the system's own elongation tip was inferior to the elongation tip the authors used in this study. The post (RelyX Fiber Post®) was inserted into the root canal. Regarding the other three self-adhesive resin cements (Maxcem Elite, iCem, and BifixSE), the cap of each resin cement's double-barrel syringe was removed, and a mixing tip was placed on the automix syringe. To ensure an even

Table 1 Composite cements and their use

Resin cement	Use	Group	Manufacturer
Variolink II®/Excite DSC® (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 Polymerisation for 40 s	Resin cement with etch & rinse adhesive	Ivoclar Vivadent, Ellwangen, Germany
RelyX Unicem® (RLX)	Activation of capsule for 2–4 s Mixing for 15 s Polymerisation for 40 s	Self-adhesive	3M ESPE, Seefeld, Germany
Maxcem Elite™ (MC)	Placement of a mixing tip on the automix syringe Mixing of base and catalyst by using the syringe Dispense 2–3 mm of cement Polymerisation for 40 s	Self-adhesive	Kerr, Bioggio, Switzerland
iCem (IC)	Placement of a mixing tip on the automix syringe Mixing of base and catalyst Dispense 2–3 mm of cement Polymerisation for 40 s	Self-adhesive	Heraeus Kulzer, Hanau, Germany
BifixSE (BF)	Placement of a mixing tip on the automix syringe Mixing of base and catalyst Dispense 2–3 mm of cement Polymerisation for 40 s	Self-adhesive	VOCO, Cuxhaven, Germany

Table 2 Technical data of the two glass fiber post systems

Post	DT light SL	RelyX fiber Post
Post size (color code)	Blue	Yellow
Diameter of coronal post end	2.20 mm	1.30 mm
Diameter of apical post end	1.20 mm	0.70 mm
Composition	Fibers, Quartz, 64% by volume, 70–80% by weight; matrix, epoxy resin	Fibers, glass fibers (zirconia-based) at 80–90% by weight
	Bonding agent, silane	Matrix, composite resin at 10–20% by weight
Diameter of the fibers	12 µm	Not provided/applicable

mix of base and catalyst, 2–3 mm of the cement was dispensed and disposed every time. Afterwards, the post (DT Light SL®) was placed in the root canal. Detailed information about all materials is listed in Table 1. Technical data of the two fiber post systems are listed in Table 2.

The resin cements were polymerized for 40 s with an LED light polymerizing unit (Bluephase II, Ivoclar Vivadent, Ellwagen, Germany; light intensity, >1,000 mW/cm^2, high power modus). The light intensity was regularly monitored with a bluephase meter (Ivoclar Vivadent, Ellwagen, Germany) during the experiments.

For all resin cement systems, the tip of the polymerization unit was placed in direct contact to the coronal end of the post so that the light was transmitted in the root canal by the fiber post. Afterwards, the polymerization was performed for 10 s at all four post surfaces: mesial, distal, vestibular, and oral. This curing pattern was applied in order to standardize the curing and to ensure a high polymerization degree of the cements in apical parts of the root canal. Finally, a composite built-up was placed on all specimens to ensure the tight sealing of the root canal.

Between the individual experimental procedures, teeth were stored in an incubator at 37°C and 100% humidity. Afterwards, half of the specimens (n=10) were thermocycled (TC; 5°C/55°C, 5,000 cycles; dwell time, 30 s), while the remaining specimens (n=10) were stored in an incubator at 37°C for the same time period. All samples were embedded in methacrylate resin (Acryfix, Hersteller, Ort, Deutschland; Fig. 1a, b) and then cut into disks (thickness of 2 mm) at a distance of 0.3 and 2.3 mm from the coronal end of the root (Fig. 1c) with a low-speed diamond saw (Isomet, Buehler, IL, USA). Each slice was marked with a dot on its coronal side and with the sample number on its apical side. The diameter of each post was measured using a computer-aided program (40-fold magnification, Image Access Premium Version 6, Imagic Bildverarbeitung (AG), Glattbrugg, Switzerland), and the surface area of the post was calculated for each slice using the equation in Fig. 2. The push-out test was performed with a universal testing machine (Type 20K, UTS, Ulm) at a crosshead speed of 1 mm/min. All test specimens were loaded until fracture. The push-out strength in megapascals was determined by dividing the "debonding" force by the calculated post area. 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 tooth dentin and the composite cement, (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 one-way analysis of variance (ANOVA) and the Scheffe test (p<0.05, SPSS GmbH Software, Version 15, Munich).

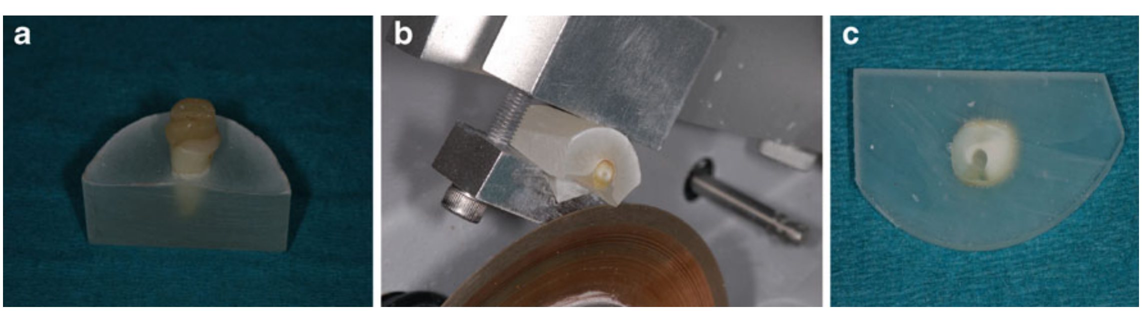


Fig. 1 **a** Embedded root in acrylic resin. **b** Specimen fixed to the low-speed diamond saw. **c** Dentin disk

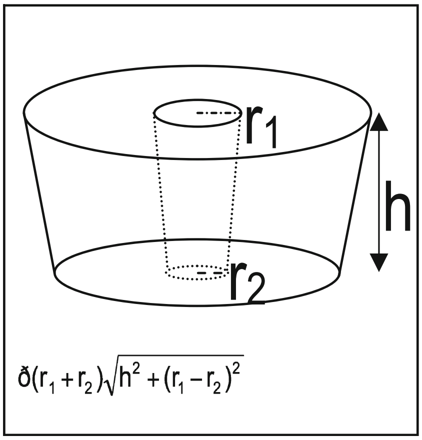


Fig. 2 Calculation of the post surface

Results

The one-way ANOVA indicated a significant influence of the self-adhesive resin cement before TC ($p<0.001$) on the bond of fiber posts in root canal of extracted human teeth (Table 3). After TC, no significant influence was detectable (Table 4).

The highest push-out strength among all cements was measured for BF without TC (22.5±10.4 MPa), which was significantly different to RLX (8.0±5.0 MPa, $p=0.001$) and MC (10.0±5.5 MPa, $p=0.007$). No significant differences between groups could be detected after TC.

Group VL, the only "etch & rinse" system tested, revealed the second highest push-out strength (16.5±6.4 MPa) before TC, which dropped after TC (13.5±14.0 MPa), but without statistically significant difference compared to the self-adhesive resin cements. The lowest values were found for RLX without TC (8.0±5.0 MPa), which increased slightly after thermocycling (11.3±8.8 MPa). For IC, the mean values slightly decreased after TC (14.2±6.1 MPa vs. 13.1±7.1 MPa). The push-out strength for MC was only statistically significant before TC (10.0±5.5 MPa vs. 22.5±10.4 MPa) compared to BF. The mean values of all groups are presented in Table 5. All test results are summarized in Fig. 3.

The surface analysis of the fractured specimens showed mainly adhesive failures between post and cement for group VL, whereas mixed fractures were predominantly determined for self-adhesive resin cements (Fig. 4). Group RLX revealed more adhesive failures between post and cement before TC, whereas after TC, mainly mixed fractures between tooth and cement and post and cement were detected. The same failure mode was also observed for group BF. MC group revealed predominately mixed fractures between tooth and cement and post and cement before and after TC as well. Nearly half of the IC specimens exhibited either adhesive failures between post and cement, or mixed fractures between tooth and cement, or post and cement before and after TC.

Discussion

The aim of this study was to determine if the bond strength of glass fiber posts to root canal dentine was dependent on the type of cement used (self-adhesive vs. resin cement with "etch & rinse" adhesive). The null hypothesis that was set forth has to be rejected because the push-out strength of fiber posts was significantly influenced by the resin cement before TC.

Regarding materials and methods, all root canals were rinsed with sodium hypochlorite (2.5%) and sterile saline solution (0.9%) after preparation and before post cementation. NaOCl may impair the bond strength of resin cements to root canal dentin [42–46]. The irrigation of root canals with 5% NaOCl reduced the bond strengths of adhesive cements [42, 45]. Wattanawongpitak et al. [47] found similar effects of NaOCl and EDTA/NaOCl on dual-curing resin composites which could be caused by oxygen-enriched dentin surface after NaOCl application that might inhibit the polymerization of resin materials [42]. However, NaOCl is the most frequently used endodontic rinsing solution because of its ability to remove the smear layer [44, 48] and therefore was used in the present study. The study protocol followed the manufacturers' instructions for RelyX Unicem (3M ESPE, Seefeld, Germany), which recommends the irrigation of the root canal with NaOCl followed by water. Alternatively, the root canal could be irrigated with CHX or sterile saline solution before post cementation in order to prevent a potential negative effect of NaOCl on the adhesive bond to dentine [43]. In this study, saline solution was used as final irrigant before post cementation according to the manufacturers' instructions.

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

Table 3 One-way ANOVA before TC

	Sum of squares	*df*	Mean square	*F*	Sig.
Between groups	1304.530	4	326.133	6.744	.000
Within groups	2176.050	45	48.357		
Total	3480.580	49			

Table 4 One-way ANOVA after TC

	Sum of squares	*df*	Mean square	*F*	Sig.
Between groups	145.420	4	36.355	.344	.847
Within groups	4754.300	45	105.651		
Total	4899.720	49			

microtensile bond strength and the push-out test. By using the push-out test, the risk of a premature loss of samples during the manufacturing of the specimens is reduced [49]. Furthermore, the micro push-out test allows the measurement of bond strength to very small areas such as the interior of a root canal [49].

The conditions of the oral cavity were simulated by TC and by storing the specimens in an incubator at 37°C and 100% humidity. TC, which simulates not only the variation of the oral temperature but also thermal stress, may influence the bond between post, resin cement, and dentin [50, 51]. Moreover, TC was used for accelerating the aging process as it is a way of artificial aging of the specimens [52]. TC could be used to study the long-term clinical bonding behavior of the adhesively luted glass fiber posts [53]. TC can be a method to assess the results of prolonged water exposure (within a shorter time period) [54]. During thermal cycling, the specimens are subjected to thermal changes and also to additional exposure to water [54].The main cause for the reduction in bond strength by thermocycling is believed to be the possible effect of hydrolysis at the interfaces of the bonding resin and hybrid layer [54]. Water molecules are absorbed during TC into composite resin and fiber posts by diffusion, which is a time-dependent process [55, 56].

In the present study, no significant differences between the cements could be detected after TC. Bitter et al. [53] and Mazzoni et al. [57] observed a significant influence of TC on the bond strength of composite cements to root canal dentine. However, in another study by the same authors, the bond strength was not affected by thermocycling [58], which is contradictory to our results.

Furthermore, our data reveal that the bond strengths of the tested self-adhesive cements (RelyX Unicem, Maxcem Elite, iCem, Bifix SE) were not statistically different compared to the "etch & rinse" adhesive system (Variolink II/Excite DSC) after TC. A possible reason for that could be the moisture sensitivity of the self-adhesive resin cements. TC findings of the present study are contrasting to those documented by Mazzoni et al. [57], who examined one "etch & rinse" system (XP Bond/CoreXFlow2), one self-etch system (Panavia F2.0/ED primer), and one self-adhesive composite cement (RelyX Unicem). No difference was observed between the groups before TC. After TC, the groups of "etch & rinse" system and of self-adhesive resin cement showed higher bond strength compared with the group with the self-etch adhesive. On the other hand, our results after TC are concordant with Zicari et al. [23] and Bitter et al. [59], who found that the push-out strength of a self-adhesive composite cement was similar to the "etch & rinse" system Variolink II.

In our study, no significant differences could be detected between the "etch & rinse" system and the self-adhesive cements neither before nor after TC. In contrast to these findings, an "etch & rinse" system exhibited a higher bond strength value (Variolink II, 3.5±0.6 MPa) than the self-adhesive composite cement (RelyX Unicem, 2.2±1.0 MPa) without TC [7]. Wang et al. [29], Rathke et al. [60], and Goracci et al. [28] also showed the superiority of the "etch & rinse" adhesive system regarding the push-out strength of fiber-reinforced posts when compared to self-adhesive resin cements, which is contradictory to our results. Another study about the adhesion of glass fiber posts reported higher bond strength for RelyX Unicem compared to other composite resin cements, which also disagrees with our results [53].

Compared to the current literature, the bond strength values obtained for the adhesive cements are controversial. It is difficult to compare the push-out strength values of the resin cements obtained in the present study to those of other similar protocols. This is due to the fact that every study is performed with different devices as well as with different operators. For this reason, the data and the obtained values can be compared only inside the same study. Our study indicated a significant difference between the self-adhesive resin cements (BF, RLX, and MC) before TC, which was not detectable anymore after

Table 5 Push-out strength (megapascals) before and after TC

	VL	RLX	MC	IC	BF
Before TC	16.5±6.4a,b	8.0±5.0a	10.0±5.5a	14.2±6.1a,b	22.5±10.4b
After TC	13.5±14.0A	11.3±8.8A	9.4±12.8A	13.1±7.1A	9.5±6.5A

Same lowercase and uppercase letters indicate no statistical difference

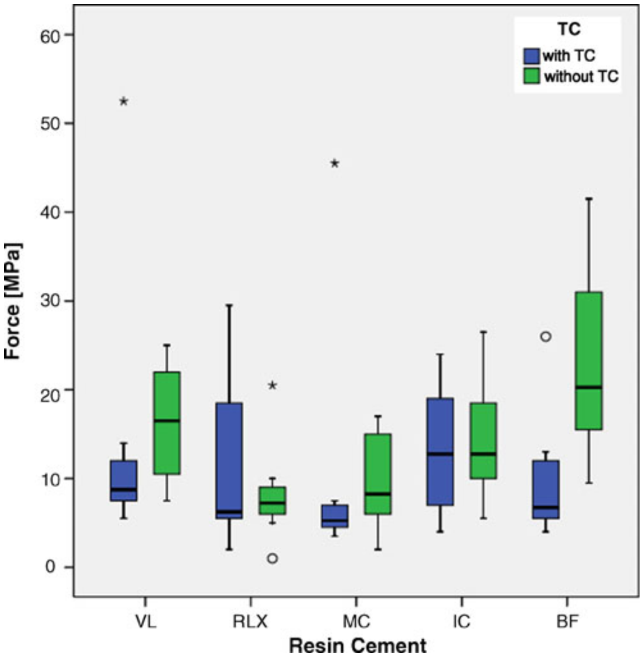


Fig. 3 Test results without and with TC: groups *VL* Variolink II, *RLX* RelyX Unicem, *MC* Maxcem Elite, *IC* iCem, *BF* BifixSE

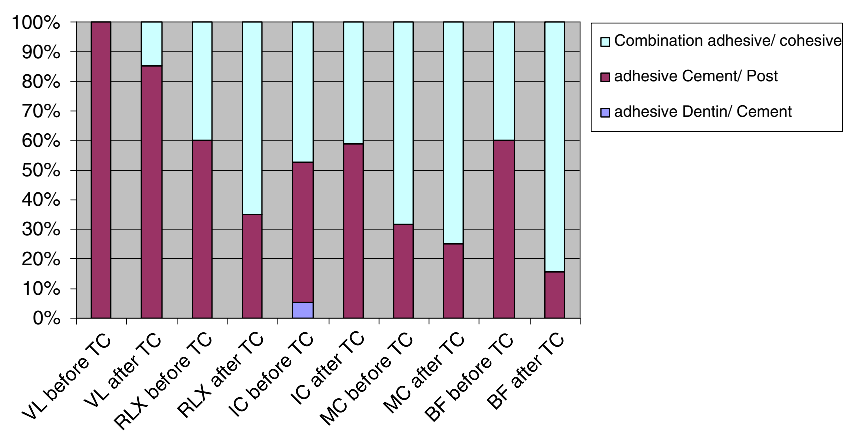
TC. The "etch & rinse" adhesive system revealed no significant difference compared to the self-adhesive resin cements neither before nor after TC.

The influence of the type of fiber post on the push-out strength of the resin cements was not examined in the present study. Nevertheless, the values obtained with the DT Light SL posts in combination with the "etch & rinse" based system lead to higher bond strength values when compared to the RelyX Fiber post but without being statistically significant. It may be speculated that this was achieved due to a lower share of fibers in DT Light SL (70–80% by weight) posts in comparison to RLX Fiber post (80–90% by weight) [61], meaning that the DT Light fiber posts contain a higher amount of matrix (ca. 10%) which can form a chemical bonding with Bis-GMA, which is used in most composite cements [8, 11, 12]. Another possible explanation for the higher bond strength of DT Light SL posts could be their Safety Lock-coated surface. According to the manufacturer, the Safety Lock coating increases the bond strength by 50% and provides stability to the system in hydrolytic conditions [40]. This coating is polymerised with composites made of Bis-GMA and/or UDMA [40] and can lead to high bond strength values between the resin cements and the posts. In contrast to that, the surface of the RLX Fiber post is not coated with a protective layer. For this reason, the Safety Lock coating of DT Light SL posts could be a differentiating factor compared to RLX Fiber post.

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 photopolymerisation process of the composite within the root canal [62–65]. Our findings agree with those of Kececi et al. [7], who also found higher bond strength for the DT Light and DT Light SL posts in comparison to other glass fiber posts. In the same way, Kremeir et al. [66] revealed a higher bond strength for the DT Light post compared to the glass fiber post Luscent Anchor. In contrast, Kurtz et al. [67] and Perdigao et al. [68] did not observe significant differences among different types of fiber posts. Considerably less data are available in the literature regarding differences among fiber posts compared to differences among luting materials.

The fracture mode analysis showed mainly adhesive failures between post and cement in group VL, whereas the self-adhesive resin cements (RLX, MC, IC, and BF) revealed mainly mixed fractures between tooth and cement or post and cement. This may indicate that in group VL, the weak link was the bond between the resin cement and the post due to the higher bond strength values to dentin, but not between the resin cement and the root canal dentin. These findings are supported by Rathke et al. [60], who

Fig. 4 Results of the fracture analysis



found mainly adhesive failures between the post and the luting agent for the “etch & rinse” adhesive system. The Safety Lock coating of DT Light SL posts used in the group of VL could be another explanation for the different failure modes. This coating ensures a chemical and mechanical resistance to the post as described above [40]. Mazzoni et al. [57] observed no differences in failure modes for one “etch & rinse,” one self-etch system, and one self-adhesive composite cement, which differs from our findings. The fracture mode for most specimens demonstrated adhesive failures between dentin and the luting agent. In our study, the self-adhesive resin cements revealed mixed fractures between tooth and cement and post and cement. The results of our study differ from those of Bitter et al. [30], who found mainly adhesives failures between post and cement for the self-adhesive resin cement group (RLX). Zaitter et al. [69] also showed that the self-adhesive resin cements and the self-etch systems revealed adhesive failures between dentin and cement and to lower extent adhesive failures between post and cement.

Several aspects, however, need further research. Composite cements shrink during polymerisation, which may cause stress within the composite layer. They also undergo hydrolytic degradation, and their coefficient of thermal expansion is different compared to natural tooth substance and ceramic materials [70]. 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 [71, 72]. The effects of these parameters and possible interactions with various irrigation protocols 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 strength of adhesively cemented glass fiber posts is not dependent on the type of resin cement. A self-adhesive resin cement system can result in bond strength values that are comparable to a conventional “etch & rinse” adhesive system.

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

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