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Glass fiber posts: influence of cementation techniques on push-out bond strength

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Aim: Glass fiber posts are indicated in the rehabilitation of extensively damaged teeth; their cementation represents a critical step in restorative dentistry. The aim of this study was to quantify and compare the push-out bond strength of glass fiber posts cemented by conventional technique, two-step technique with luting agent and two-step technique associating bulk-fill composite and luting agent. **Methods:** Eighty maxillary bovine incisors were endodontically treated and divided into eight groups (n = 10) according to the luting agent (Rely X ARC and Duo-link) and cementation technique (conventional technique; two-step technique with luting agent; and two-step technique associating bulk-fill composite – Filtek Bulk-fill flow or Surefil SDR flow – and luting agent). Samples were submitted to push-out bond strength test, and the fracture pattern was evaluated through scanning electron microscope. Data were submitted to two-way ANOVA and Tukey's test (α = 0.05). **Results:** When Rely X ARC was used, the conventional cementation technique obtained higher bond strength values than the two-step technique associated with Filtek Bulk-fill flow. When Duo-link was used, the two-step technique associated with Filtek Bulk-fill flow presented higher bond strength values than the conventional technique. The most prevalent fracture patterns were adhesive between luting agent and dentin, and adhesive between bulk-fill composite and dentin. **Conclusion:** Two-step cementation technique associated with bulk-fill composite may be promising depending on the luting agent used.

Keywords: Cementation. Composite resins. Dental cements.

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Introduction

Glass fiber posts are indicated for the rehabilitation of extensively damaged teeth in order to ensure higher retention and support to restorative material, as well as better distribution of masticatory stresses[1-4]. Among the advantages of glass fiber posts, one may cite their esthetic appearance, high tensile strength and modulus of elasticity similar to dentin; which provides uniform stress distribution along the post length[3,5,6].

If, on the one hand, glass fiber posts may be promising, on the other hand, their cementation represents a critical step and can be influenced by the post type and shape, dental geometry and luting agent[5,7]. Furthermore, the cavity configuration factor (C-factor) should be considered. Defined first by Feilzer et al.[8] (1987) as the ratio between bonded and unbounded surfaces, the higher the C-factor value, the greater the stress at the adhesive interface. Cementation of fiber posts has been described as the worst possible scenario in relation to C-factor because of the geometric characteristics of the root canal. The root canal is figuratively a very deep class I cavity[9]. Namely, the surface to be cured is deep, reducing the stress relief capacity and increasing the challenge for adhesion.

Post cementation through a two-step technique has been proposed in order to make the C-factor more favorable to adhesion[10,11]. Namely, C-factor reduction should be achieved through layered application of luting agents, instead of the traditional single increment application. Jogsma et al.[10] (2010) explain that in the two-step technique, the unbounded surface is higher than in case of the one-step cementation technique, which could reduce the C-factor from 229 to 1.8. Also, polymerization shrinkage stress should be reduced, generating less microleakage and, thus, increasing the restoration longevity[10,11].

The use of two layers of luting agent in post cementation has not been studied enough. The number of in-vitro studies related to the topic is low[10,11], and to the best of our knowledge a single case report was published so far[12]. However, recently, Bakaus et al.[13] (2018) verified a high bond strength when the root canal was reinforced with bulk-fill composite before cementing the fiber post with traditional luting agent, similarly to the two-step cementation technique. Bulk-fill composites emerged in 2010, when Dentsply produced Surefil SDR Flow; the first composite able to be cured in 4 mm increments[14]. Bulk-fill flowable composites, specifically, should represent a promising alternative to reinforce root canals, since they can be cured at depths of up to 4 mm, without the need to extend the light curing period[15,16]. Additionally, they present reduced polymerization shrinkage and lower modulus of elasticity in deeper layers[15].

Taking into account the lack of studies in respect to the two-step cementation technique, and considering a single study was reported on the use of bulk-fill composite to reinforce root canals before fiber post cementation, further studies are needed to clarify the efficiency of these protocols. The aim of this study was to quantify and compare the push-out bond strength of glass fiber posts cemented by a conventional technique, a two-step technique with luting agent and a two-step technique associating bulk-fill composite and luting agent. The working hypotheses tested were: (1) there would be significant differences in the bond strength of glass fiber posts cemented by different techniques; (2) two-step technique, either solely with luting agent or with bulk-fill composite and luting agent, would generate higher bond strength when compared to the conventional cementation technique.

Material and Methods

Eighty freshly extracted maxillary bovine incisors teeth of similar shapes and sizes, with 18 cm straight root, closed apex and free of cracks were selected and kept in 0.1% Thymol for up to two months. Cleaning of the outer surfaces of the teeth was performed by root scaling, followed by blasting with sodium bicarbonate and water. After cleaning, the crown was separated from the root with the aid of a double-sided diamond disc (KG Sorensen, Barueri, SP, Brazil) under water cooling.

For confection of the samples, the pulp was removed with hand K-files (Dentsply Maillefer, Tulsa, OK, USA) and irrigation with 1% NaOCl solution was performed to suspend any organic matter. Endodontic treatment was manually performed using the crown-down technique with K-files at 17 mm working length, and an apical stop with a #40 file. During instrumentation, the root canal was abundantly irrigated with distilled water so that the irrigation solution did not cause bias to the study[17]. Roots were dried with paper points (Dentsply Maillefer, Ballaigues, Switzerland) and filled by vertical compaction of warm gutta-percha points and Endodontic Cement Sealer 26 (Dentsply, York, PA, USA). Conventional glass ionomer cement (Vitro Fil, Nova DFL, Rio de Janeiro, RJ, Brazil) was used to temporarily seal the root access, and the roots were stored at 37ºC for ten days.

Gates Glidden drills and Peeso reamers #5 and #6 (Dentsply Maillefer, Ballaigues, Switzerland) were used to remove the filling from the root canal at a depth of 12 mm. Intraradicular preparation was performed according to the recommendations of Whitepost DC post manufacturer (FGM, Joinville, SC, Brazil), considering drill #3 for the final calibration.

The roots were then randomly divided into eight groups (n = 10) according to experimental factorial design with independent variables: luting agent (two levels) and cementation technique (four levels), as follows: GROUP 1 – Conventional technique with Rely X ARC (3M Oral Care, St. Paul, MN, USA); GROUP 2 – Two-step technique with Rely X ARC; GROUP 3 – Two-step technique with Filtek Bulk-fill flow (3M Oral Care, St. Paul, MN, USA) and Rely X ARC; GROUP 4 – Two-step technique with Surefil SDR flow (Dentsply Maillefer, Ballaigues, Switzerland) and Rely X ARC; GROUP 5 – Conventional technique with Duo-link (Bisco, Schaumburg, IL, USA); GROUP 6 – Two-step technique with Duo-link; GROUP 7 – Two-step technique with Filtek Bulk-fill flow and Duo-link; GROUP 8 – Two-step technique with Surefil SDR flow and Duo-link. The details of the luting agents and composites used in this experiment are presented in Table 1.

For pre-treating the glass fiber posts, initially, #3 glass fiber posts (Whitepost DC, 3M Oral Care, St. Paul, MN, USA) were selected, cleaned with alcohol and air-dried. Then, a coat of silane-based primer (RelyX Ceramic Primer, 3M Oral Care, St. Paul, MN, USA) was applied for one minute. Finally, a layer of either Adpter Scotchbond Multipurpose Plus Adhesive (3M Oral Care, St. Paul, MN, USA) (Groups 1-4) or All-bond 3 Adhesive (Bisco, Schaumburg, IL, USA) (Groups 5-8) was applied for 20 seconds and air-dried.

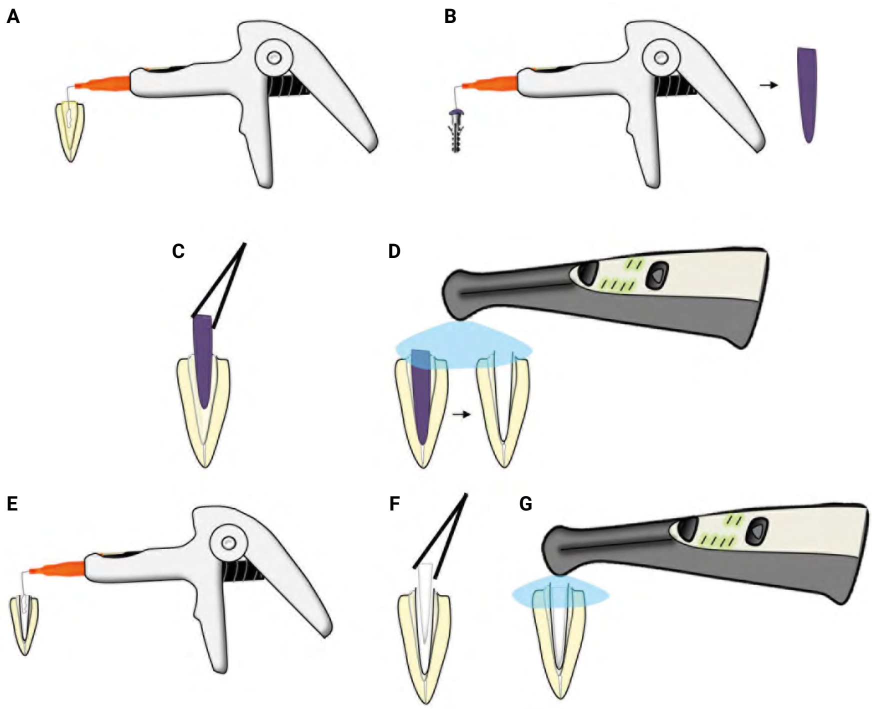
Table 1. Evaluated luting agents and composites and respective manufacturer information.

Material brand name (Classification)	Manufacturer	Composition	Shade
Rely X ARC (luting agent)	3M Oral Care, Dental Products, St. Paul, MN, USA	Paste A: Silane-treated ceramic, TEGDMA, Bis-GMA, silane-treated silica, functionalized dimethacrylate polymer. Paste B: Silane-treated ceramic, TEGDMA, Bis-GMA, silane treated silica, functionalized dimethacrylate polymer (EYFH)	A1
Duo-link (luting agent)	Bisco, Schaumburg, IL, USA	Base: Bis-GMA; TEGDMA; UDMA; glass filler. Catalyst: Bis-GMA; TEGDMA; glass filler	Trans
Filtek Bulk-fill flow (bulk-fill composite)	3M Oral Care, Dental Products, St. Paul, MN, USA	Bis-GMA, Bis-EMA, UDMA, TEGDMA, substituted dimethacrylate, EDMAB, benzotriazol, silate treated ceramic, ytterbium trifluoride	A2
Surefil SDR flow (bulk-fill composite)	Dentsply Caulk, Milford, DE, USA	Modified UDMA, TEGDMA, EBPDMA, barium-aluminofluoroborosilicate glass, strontium-aluminofluoroborosilicate glass	Universal

Abbreviations: Bis-EMA: ethoxylated bisphenol-A dimethacrylate; Bis-GMA: bisphenol-A diglycidyl ether dimethacrylate; EDMAB: ethyl 4-dimethylaminobenzoate; EBPDMA: ethoxylated bisphenol-A dimethacrylate; TEGDMA: triethyleneglycol dimethacrylate; UDMA: urethane dimethacrylate. Data were provided by manufacturers.

The treatment of the root canal was performed as follows: *Groups 1-4* - Root canal was etched with 35% phosphoric acid (Ultra-Echt, Ultradent Products Inc., South Jordan, UT, USA) for 15 seconds, rinsed for 30 seconds and dried with absorbent paper points. A coat of Adper Scotchbond Multipurpose Plus activator, followed by a catalyst, was applied. Excess was removed with absorbent paper points. *Groups 5-8* - Etching, rinsing and drying were performed as previously described. A drop of Part A and a drop of Part B of All-Bond 3 adhesive system were mixed into a mixing well. A coat was applied into the canal and excess was removed with paper points.

The cementation of the fiber posts was then performed, as described: *Conventional technique* - Luting agent was mixed in 1:1 ratio according to the manufacturer's instructions, and was inserted into the root canal with the aid of a needle tube (Centrix, Shelton, CT, USA). The glass fiber post was then positioned. Light curing was performed by a poly-wave light-emitting diode curing unit (VALO, Ultradent Products Inc., South Jordan, UT, USA) in the high power mode: 1400 mW/cm² for 40 seconds. *Two-step technique with luting agent* – The luting agent was mixed in 1:1 ratio according to the manufacturer's instructions and was applied to the root canal with a needle tube (Figure 1A). After, a non-stick simulated post, made of polyether-based impression material (Impregum Soft, 3M Oral Care), was placed inside the root canal in order to establish space for the definitive post cementation. The simulated post dimensions were standardized as follows: Polyether-based material was manipulated according to the manufacturer's instructions and applied into an S4 nylon plug fixing (Fischer, São Paulo, SP, Brazil) with the aid of a needle tube, resulting in a post slightly larger than that of #3 glass fiber post (Figure 1B). After the setting time, the simulated post was removed from the plug fixing and placed into the root canal along with the first layer of luting agent (Figure 1C), which was light-cured for 20 seconds. The simulated post was then removed from the root canal, and the first layer of luting agent was light-cured for 40 seconds more (Figure 1D). Finally, the second layer of luting agent was manipulated, applied to the root canal (Figure 1E) and the glass fiber post was positioned (Figure 1F). Light curing was performed for 40 seconds (Figure 1G). *Two-step*



* A – application of first layer of luting agent to the root canal; B – application of polyether-based material to nylon plug fixing and obtainment of simulated post; C – placement of simulated post into root canal along with luting agent; D – light curing of first layer of luting agent; E – application of second layer of luting agent to root canal; F – placement of glass fiber post; G – light curing of second layer of luting agent and glass fiber post.

Figure 1. Illustrative scheme of the two-step technique for glass fiber post cementation.

technique associating bulk-fill composite and luting agent - The same procedures of the previous technique were performed. Nevertheless, the first layer of luting agent was replaced by bulk-fill composites, which were applied by their own dispensing tips.

After seven days of storage in distilled water at 37°C, the roots were fixed to acrylic plates with sticky wax (ASFER Ind., São Caetano do Sul, SP, Brazil). The set was stabilized to a metallographic precision cutter (Isomet 1000, BUEHLER, Lake Bluff, IL, USA) in which a diamond blade (Isomet Diamond Wafering Blades, Buehler Ltd., Lake Buff, IL, USA) performed serial sections with water-cooling at 250 rpm, from the cervical to apical direction, to obtain three slices of 1 mm thick from cervical, middle and apical third.

The samples were then submitted to push-out bond strength test, conducted at a crosshead speed of 1 mm/min, with the load applied to the apical-cervical direction using a metal tip of 1.2mm diameter, until failure (Universal Testing Machine, EZ Test L, Shimadzu, Japan). The maximum failure load was recorded in Newtons (N) and converted into MPa by dividing the load by the root canal area (A). The area was calculated through the formula: $A = 2\pi r.h$, where π is the constant 3.14; r the radius of the post #3; and h the root slice thickness. Measurements of r and h were performed using a digital calliper (Mitutoyo Corporation, Tokyo, Japan).

A mean push-out bond strength, in MPa, was calculated for each root from the values obtained by each slice.

Sample patterns of fractures were evaluated using scanning electron microscopy (SEM) (JEOL-JSM 5600LV, Tokyo, Japan) in 1) adhesive fracture between glass fiber post and luting agent; 2) adhesive fracture between first and second layers of luting agent; 3) adhesive fracture between luting agent and composite; 4) adhesive fracture between luting agent and dentin; 5) adhesive fracture between composite and dentin; 6) cohesive fracture in glass fiber post; 7) cohesive fracture in luting agent; 8) cohesive fracture in composite; 9) mixed fracture. Cohesive and adhesive fractures were considered when at least 70% of the total area was composed of the same pattern. Mixed fracture was stated when there was more than one pattern, and none prevailed.

Data were tabulated and statistically analyzed using SPSS 21.0 Software (SPSS Inc., Chicago, IL, USA). The results were submitted to normality and equality of variances tests (Shapiro-Wilk and Kolmogorov-Smirnov, $p > 0.05$), followed by parametric two-way ANOVA and Tukey's post-hoc test ($\alpha = 0.05$).

Results

The results of push-out bond strength (MPa) for both variables, luting agent ($p = 0.932$), cementation technique ($p = 0.744$) and their interaction ($p < 0.001$) are presented in Table 2.

Rely X ARC obtained higher bond strength than Duo-link when a conventional cementation technique was performed ($p = 0.002$). Conversely, when associated with Filtek bulk-fill, Duo-link obtained higher bond strength than Rely X ARC ($p = 0.005$). Both luting agents, associated with Surefil SDR flow, obtained similar bond strength values ($p > 0.05$). Also, bond strength values presented by the two-step technique with Rely X ARC and the two-step technique with Duo-link were not statistically different ($p > 0.05$).

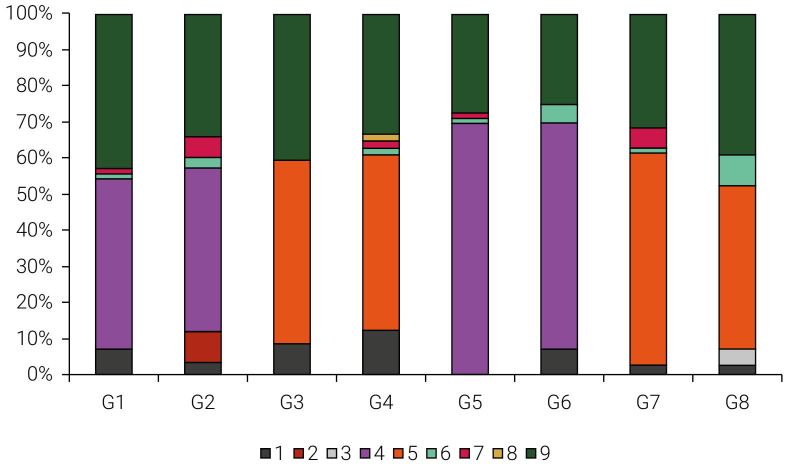
When Rely X ARC was used, conventional cementation technique obtained higher bond strength values than two-step techniques associated with Filtek Bulk-fill flow ($p = 0.027$). Two-step techniques with Rely X ARC and two-step techniques with Surefil SDR flow did not differ statistically from other groups ($p > 0.05$).

When Duo-link was used, in turn, the two-step technique associated with Filtek Bulk-fill flow presented higher bond strength values than the conventional technique and the

Table 2. Mean (standard deviation) push-out bond strength (MPa) of glass fiber posts cemented by different techniques.

Cementation technique	Luting agent	
	Rely X ARC	Duo-link
Conventional	4.55 (1.56) Aa	3.23 (1.16) Bc
Luting agent + Luting agent	4.15 (1.33) Aab	3.86 (1.12) Abc
Filtek Bulk-fill flow + Luting agent	3.62 (1.44) Bb	4.81 (1.43) Aa
Surefil SDR flow + Luting agent	3.78 (1.40) Aab	4.29 (1.53) Aab

Mean values followed by distinct letters (uppercase in horizontal and lowercase in vertical) differ from each other ($p \leq 0.05$). n=10 specimens / group.



* 1 - adhesive fracture between glass fiber post and luting agent; 2 - adhesive fracture between first and second layers of luting agent; 3 - adhesive fracture between luting agent and composite; 4 - adhesive fracture between luting agent and dentin; 5 - adhesive fracture between composite and dentin; 6 - cohesive fracture of glass fiber post; 7 - cohesive fracture of luting agent; 8 - cohesive fracture of composite; 9 - mixed fracture.

Figure 2. Failure pattern (%) of glass fiber posts cemented by different cementation techniques.

two-step technique with Duo-link ($p = 0.0001$ and $p = 0.025$, respectively). The two-step technique associated with Surefil SDR flow presented higher bond strength than the conventional technique ($p = 0.012$). However, the same technique did not differ neither from the two-step technique associated with Filtek Bulk-fill flow nor from the two-step technique with Duo-link. The values obtained by the two-step technique with Duo-link did not differ from the values obtained by the conventional technique ($p > 0.05$).

Figure 2 shows the fracture patterns obtained by each group. The most prevalent fracture patterns were adhesive between the luting agent and dentin (groups 1, 2, 5, 6) and the adhesive between the composite and dentin (groups 3, 4, 7, 8), although mixed fractures also stood out.

Discussion

In order to increase the bond strength of glass fiber posts to radicular dentin, several strategies have been proposed by dental material manufacturers and researchers to reduce luting agent thickness: posts individualization, roots reinforcement with restorative materials and layered application of luting agents by a two-step cementation technique[10-13,17-19]. The aim of this study was to quantify and compare the push-out bond strength of glass fiber posts cemented by a conventional technique, a two-step technique with luting agent and a two-step technique associating bulk-fill composite and luting agent. The luting agents tested in this study were Rely X ARC and Duo-link, whereas the bulk-fill composites used in this study were Filtek Bulk-fill flow and Surefil SDR flow.

The first hypothesis, that there would be significant differences in the bond strength of glass fiber posts cemented by different techniques, was accepted. Nevertheless, the second hypothesis, that the two-step technique would generate higher bond strength compared to the conventional cementation technique was rejected. Interestingly, Rely X ARC and Duo-link obtained opposite performance results. When Rely X ARC was used, the conventional cementation technique obtained higher bond strength values than two-step techniques with Filtek Bulk-fill flow. Conversely, when Duo-link was used, the two-step technique with Filtek Bulk-fill flow presented higher bond strength values than the conventional technique. Although both luting agents are dual-cured, the amount of auto- and light-polymerizing components varies between the products. Such variation may result in differences in the polymerization characteristics[20]. Rely X ARC is a luting agent with a rapid response to light exposure, but low potential of cure when chemically activated[20]. Namely, in the conventional cementation technique, despite the increase of luting agent volume, there is a single compound of cement, so light is able to be transmitted through the whole thickness and activate the high content of photo-initiators, which yield high degree of conversion and consequently high bond strength. Conversely, when the two-step technique is applied, especially with bulk-fill composite, luting agent may depend more on chemical activation, since light may be attenuated by the different constituents of the root canal filling. Arrais et al.[20] (2009) found that in the auto-polymerizing mode, Rely X ARC takes longer than Duo-link to initiate polymerization and its maximum rate of polymerization is lower. This explains the low bond strength values obtained by Rely X ARC when it was associated with Filtek Bulk-fill flow.

When Duo-link was used, in turn, the two-step technique associated with Filtek Bulk-fill flow presented higher bond strength values than the conventional technique. Several points may be considered to explain the result. The two-step technique enables a thinner cementation layer, which provides: First, reduction of the polymerization shrinkage, generating less stress at the adhesive interface. Second, decrease of incorporation of failures such as voids. Third, increase of frictional retention, through the intimate contact between post and dentin. All these features should increase the adhesion[21-23]. The results may also demonstrate the influence of bulk-fill associated with a luting agent on fiber post cementation. According to the manufacturer's information, the resin system of Filtek Bulk-fill flow produces low polymerization shrinkage associated with a low modulus that results in low shrinkage stress. Low shrinkage stress provided by the composite should reinforce even more the bond to dentin and create a more uniform structure at the dentinal walls[10]. Also, the semi-translucence of the composite enables light transmission and complete curing through the whole layer[16,24]. Lastly, it is relevant to consider that the bond between Filtek bulk-fill flow and Duo-link might be uniform and high enough to provide high bond strength results. Such speculation may be confirmed by the pattern of fracture analyses, which show that in the two-step technique associated with Filtek bulk-fill flow and Duo-link, no fracture between the luting agent and composite was observed. The results of this study are somewhat in accordance with the reports of Bakaus et al.[13] (2018), who found out that the bond strength of fiber posts cemented into roots reinforced by bulk-fill composite was not the highest in their study, but was constant. Namely, bulk-fill composite was the only material able to maintain high bond strength values from the cervical to apical root third[13].

The two-step technique associating Surefil SDR flow and Duo-link presented similar bond strength values to two-step techniques associating Filtek Bulk-fill flow and Duo-link, which point out once again the promising influence of bulk-fill composites associated with a luting agent on fiber post cementation. Giovannetti et al. (2012) tested Surefil SDR flow as a luting agent to cement fiber posts[25]. The authors found out that Surefil SDR flow yielded post retentive strengths similar to those of the luting agent tested as the control. Although the present study did not test bulk-fill composites exactly as luting agents, high bond strength results might be due to the same reasoning. Surefil SDR flow is a flowable bulk-fill composite of high translucency. A high translucency associated with low filler volume, typical of flowable composites, enhance light transmission, enabling complete curing and increasing bond strength[24]. Additionally, Surefil SDR flow features a photo-initiator group, which is a modulator of polymerization reaction in urethane dimethacrylate (UDMA). The polymerization modulator reacts with camphorquinone, leading to the formation of polymers with low elastic modulus and decreased polymerization stress[25-27]. Indeed, low polymerization stress should enhance the bond to dentin[10,22].

Unlike the two-step technique associating bulk-fill composite and luting agent, the two-step technique solely with luting agent presented overall intermediate bond strength values. The inherent shrinkage of luting agents after the setting reaction may justify the results since gaps at the interface between the layers of luting agent could be developed. The findings are not in accordance with the reports of Jongsma et al.[10] (2010). Yet, it should be highlighted that their study did not compare two-step technique solely with luting agent to two-step technique with bulk-fill composite and luting agent. Comparing both techniques, the use of a bulk-fill composite in a two-step cementation procedure should yield higher bond strength of the fiber posts since bulk-fill composites exhibit singular composition that reduces polymerization shrinkage. Assuming, however, that the layered application of both luting agents by the two-step technique yielded a statistically similar bond strength than those applied by the conventional technique, the use of such a protocol should be pondered.

Analyzing the pattern of fracture, although mixed fracture pattern was prominent among the groups, indicating homogeneity between the composite and/or luting agent-post-dentin composition, it is worth noting that failures occurred mainly between the luting agent and dentin or bulk-fill composite and dentin. Based on these findings, it may be assumed that the bond between the fiber post and luting agent was higher than the bond between the luting agent or bulk-fill composite and dentin. This result is in accordance with previous studies[28]. Shrinkage is inherent in resin-based cements, and such shrinkage may pull the resin cement away from dentin, resulting in weaker bond[10]. Also, several factors may affect the luting agent-dentin bond strength: the presence of moisture in the root canal to allow the penetration of adhesive monomers, the number and diameter of dentin tubules relative to the portion of the root canal, and certainly the procedures related to endodontic treatment, post space preparation and post cementation[9,23]. The association between inherent shrinkage of the luting agent and the unfavourable features of the root canal may lead to failures at the luting agent/composite–dentin interface[9,28,29]. Pre-treatment of the post may have also played a role in the pattern of the fracture results, as the bond strength between the glass fiber post and luting agent was maximised. According to Machado et al.[30] (2015), the application of both silane and adhesive improve post retention since the adhesive allows a compatible and strong chemical interaction between the silanized post and luting agent.

It is important to emphasise that, although the two-step cementation technique associating bulk-fill composites and a luting agent seems promising to enhance the bond strength of glass fiber posts, additional studies that evaluate a greater variety of bulk-fill composite and luting agent combinations are necessary to consider this protocol superior in relation to a conventional cementation technique. Also, the present study was performed under ideal laboratory conditions. Thus, further studies may contribute to making the protocol feasible, so that the several steps involved in the technique can be clinically practicable. Finally, glass fiber post cementation is considered a complex technique, usually performed in clinical environment, whose increased protocol steps appears to have limited benefits.

Within the limitations imposed by this *in vitro* study, it can be concluded that Rely X ARC performance was better when using a conventional cementation technique. Conversely, Duo-link bond strength was higher when it was associated with bulk-fill composites. Findings suggest that two-step cementation technique associated with bulk-fill composite may be promising depending on the luting agent used.

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