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Research Article

Effects of a relined fiberglass post with conventional and self-adhesive resin cement

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ABSTRACT

Objectives: This study was conducted to evaluate the mechanical properties of relined and non-relined fiberglass posts when cemented to root canal dentin using a conventional dual-cure resin cement or a self-adhesive resin cement.
Materials and Methods: Two types of resin cements were utilized: conventional and self-adhesive. Additionally, 2 cementation protocols were employed, involving relined and non-relined fiberglass posts. In total, 72 bovine incisors were cemented and subjected to push-out bond strength testing ($n = 10$) followed by failure mode analysis. The cross-sectional microhardness ($n = 5$) was assessed along the root canal, and interface analyses ($n = 3$) were conducted using scanning electron microscopy (SEM). Data from the push-out bond strength and cross-sectional microhardness tests were analyzed via 3-way analysis of variance and the Bonferroni *post-hoc* test ($\alpha = 0.05$).
Results: For non-relined fiberglass posts, conventional resin cement exhibited higher push-out bond strength than self-adhesive cement. Relined fiberglass posts yielded comparable results between the resin cements. Type II failure was the most common failure mode for both resin cements, regardless of cementation protocol. The use of relined fiberglass posts improved the cross-sectional microhardness values for both cements. SEM images revealed voids and bubbles in the incisors with non-relined fiberglass posts.
Conclusions: Mechanical properties were impacted by the cementation protocol. Relined fiberglass posts presented the highest push-out bond strength and cross-sectional microhardness values, regardless of the resin cement used (conventional dual-cure or self-adhesive). Conversely, for non-relined fiberglass posts, the conventional dual-cure resin cement yielded superior results to the self-adhesive resin cement.

Keywords: Cementation; Dentin; Resin cements; Root canals

INTRODUCTION

The remaining coronal portion of a tooth that has sustained considerable structural damage after endodontic treatment often necessitates the cementation of a fiberglass post (FGP) to increase restorative retention [1]. FGPs offer an aesthetically pleasing option that also provides support, with an elastic modulus similar to that of dentin. This similarity helps to

Other
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distribute stress more evenly within the root canal, thereby reducing the likelihood of root fractures. These fractures can occur when the stress exceeds the dentin's proportional limit, whether from the horizontal, vertical, or oblique direction. Excessive stress can compromise the dentin's ability to resist plastic deformation, leading to simple fractures and the loss of the restoration, or even catastrophic root fractures that render the tooth unrestorable [2,3]. However, the application of FGPs should not be considered a universal solution. One drawback is their prefabricated geometry, which may not align with the shape of a wide or oval root canal. This mismatch can result in poor adaptation and displacement of the restoration [4]. The shape of the root canal also varies, with the cervical and middle thirds having a wider diameter than the apical third, necessitating a thicker layer of resin cement [5].

Marchionatti *et al.* [6] reported that cemented FGP failure was most commonly due to the loss of post retention. To address this clinical issue, some have recommended customizing the FGP by using resin composite, with the goal of enhancing post stability through frictional retention between the FGP and the dentin walls. This approach also aims to reduce the thickness of the resin cement layer and the presence of voids, thereby improving the bond strength of the resin cement [2,5,7-10]. Indeed, relining posts with resin composite produces a uniform resin cement layer, which facilitates controlled biomechanical behavior, such as effective stress distribution along the root canal and increased bond strength compared to non-relined FGPs [8-11]. Furthermore, this technique allows for the formation of resin cement tags in each third of the root canal [9,12].

However, despite the benefits of preventing displacement and poor adaptation with a relined FGP, bonding to radicular dentin during root canal procedures can be difficult. Additional challenges include issues with visibility, access, and light curing of the material [7,13]. Consequently, various types of resin cements with differing properties are available for bonding FGPs to root canal dentin. These include conventional dual-cure resin cements and self-adhesive resin cements, with the primary distinction being their adhesion mechanisms [7].

The key advantage of conventional resin cement is its dual-cure system, which offers 2 distinct polymerization mechanisms: light and chemical activation [14,15]. In areas deep within the tooth where blue light irradiance is diminished, chemical initiators can still polymerize the resin cement, overcoming the limitations posed by scattering and absorption by dental substrates [14,15]. However, the bond strength may be compromised by varying morphologies within the depth of the root dentin. This can result in a resin cement with reduced mechanical properties and diminished bond strength to root dentin, particularly shortly after cementation [5]. Additionally, this type of resin cement necessitates pretreatment with phosphoric acid to demineralize the dentin surface and remove the smear layer, followed by the application of an adhesive system to create a hybrid layer [16]. However, these steps are technique-sensitive and prone to error.

Due to challenges in root canal access and the complexities of hybridizing radicular dentin, self-adhesive resin cements have been widely adopted for the cementation of FGP to simplify the procedure and reduce clinical time [2,16]. These cements eliminate the need for pre-treatment of the tooth substrate, as their functional acid monomers can demineralize both enamel and dentin. However, the etching aggressiveness of self-adhesive systems on radicular dentin, which is more highly mineralized than coronal dentin, has been a subject of debate [2].

Regarding the mechanisms of action of various resin cements in relation to the adhesive technique and their interactions with the mineralized dentin substrate, it is essential to understand the differences between self-adhesive cementation systems and conventional systems when applied along the root canal. This is particularly important in the context of heterogeneity between the organic and inorganic matrix of the dental substrate and the potential degradation processes of the hybrid layer [17]. Given the interactions between the dental substrate and the various categories of resin cements, as well as the multiple cementation protocols available, this *in vitro* study was designed to evaluate the mechanical properties of relined or non-relined FGP in relation to root canal dentin. The posts were cemented using either a conventional dual-cure resin cement or a self-adhesive resin cement. The null hypotheses tested were: 1) that the technique of relining FGP would not influence the push-out bond strength (POBS), regardless of the resin cement used; and 2) that the thickness of the cementation line would not affect the microhardness measurements.

MATERIALS AND METHODS

Specimen preparation

A total of 72 bovine incisors of similar size and anatomical shape were selected and stored at 4°C in a 0.5% chloramine T solution until use, with storage not exceeding 3 months [1]. The number of samples used in this study was determined after a pilot study and was based on previously published studies employing the same methodology [8,9,13]. Bovine incisors are commonly used in dental research and are considered a validated sample due to their microstructure, which closely resembles that of human teeth [18]. The roots were sectioned 2 mm below the cement-enamel junction, and root canal lengths between 16 and 18 mm were selected to standardize the working length at 15 mm (± 1 mm).

After sectioning of the coronal portion, the root canal was exposed, and the pulp tissue was removed from the bovine roots. The roots were then instrumented with K-files (Dentsply Maillefer, Ballaigues, Switzerland) up to a size 80 K-file, maintaining a working length of 1 mm short of the apex. This was done following the step-back technique, with the canals irrigated with 1% sodium hypochlorite between each preparation step [1,13]. Subsequently, for the obturation process, endodontic cement (AH Plus; Dentsply Maillefer) was mixed in accordance with the manufacturer's instructions and introduced to the root canals using a Lentulo spiral (Dentsply Maillefer). Gutta-percha and accessory cones were then placed using the lateral condensation technique [1,13]. After obturation, the roots were coronally sealed with glass ionomer cement (Fuji II; GC Corporation, Tokyo, Japan). Following a 24-hour storage period in water at 37°C, the root canals were prepared to a standardized depth of 11 mm (± 1 mm) using the designated drill from the FGP manufacturer (Drill #3; FGM, Joinville, SC, Brazil). The coronal dentin thickness of the root canals was then measured mesiodistally and buccolingually using a digital caliper (Mitutoyo, Suzano, SP, Brazil) [5,13].

Luting procedure

Two classifications of resin cements were utilized: a conventional resin cement (RelyX ARC; 3M ESPE, St. Paul, MN, USA) and a self-adhesive resin cement (RelyX Unicem; 3M ESPE). The composition of these materials is detailed in **Table 1**. Additionally, 2 distinct luting protocols were employed: conventional cementation using a non-relined FGP and the relining of the FGP with a resin composite.

Table 1. Composition, manufacturer, and lot number of the materials used

Material	Manufacturer (#Lot number)	Composition
Dual conventional resin cement - RelyX ARC	3M ESPE, St. Paul, MN, USA (#2108900721)	Paste A: silane-treated ceramic, TEGDMA, BIS-GMA, silane-treated silica, reacted polycaprolactone polymer, benzotriazolyl-4-methylphenol, EDMAB, 4-(dimethylamino)-benzeneethanol Paste B: silane-treated ceramic, TEGDMA, BIS-GMA, silane-treated silica, reacted, polycaprolactone polymer, benzotriazolyl-4-methylphenol, benzoyl peroxide
Self-adhesive resin cement - RelyX Unicem	3M ESPE (#2104000687)	Glass, silica, calcium hydroxide, pigment, substituted pyrimidine, peroxy compound, initiator (filler = 72 wt%; average particle size = < 9.5 μm), methacrylated phosphoric ester, dimethacrylate (bis-GMA/TEGDMA), acetate, initiator
Adhesive system - Adper Single Bond 2	3M ESPE (#2102000581)	HEMA, bis-GMA, glycerol 1,3-dimethacrylate, diurethane dimethacrylate, water, ethyl alcohol, photoinitiators, silanized silica, acrylic and itaconic acid copolymer.
Resin composite - Filtek Z250 XT	3M ESPE (#N519660)	Bis-GMA, bis-EMA, UDMA, TEGDMA, silane-treated silica, silane-treated ceramic (5-20 nm, 78.5% by weight)

EDMAB, ethyl 4-dimethyl aminobenzoate; BIS-GMA, bisphenol A-glycidyl methacrylate; TEGDMA, triethylene glycol dimethacrylate; HEMA, 2-hydroxyethyl methacrylate; bis-EMA, bisphenol A diglycidyl methacrylate ethoxylated; UDMA, urethane dimethacrylate.

The specimens were randomly assigned to 1 of 4 groups ($n = 10$ for each group) according to the type of resin cement and the cementation protocol used, as detailed in **Table 2**. The post surfaces were treated with 35% phosphoric acid (Ultra-etch; Ultradent Products Inc, South Jordan, UT, USA) for 15 seconds, followed by rinsing with water and air-drying. Subsequently, a silane coating was applied (RelyX Ceramic Primer; 3M ESPE) [2]. The Adper Single Bond 2 adhesive (3M ESPE) was then applied and light-cured for 20 seconds. This step was performed only for the groups that included relined FGPs in the cementation protocol and for the FGPs cemented with RelyX ARC resin cement.

For the relined FGP groups, a single layer of Adper Single Bond 2 adhesive (3M ESPE) was applied and light-cured for 20 seconds. Subsequently, a single increment of resin composite (Filtek Z250; 3M ESPE), not exceeding 4 mm in thickness, was placed at the tip of the FGP. The root canal was then lubricated with a water-soluble lubricant, and the FGP was inserted into the canal. Light curing was conducted using a Valo light-curing unit (Ultradent Products Inc) with an irradiance of 1,000 mW/cm^2 for 5 seconds. The FGP was then removed from the canal and subjected to full light curing for 40 seconds. Next, both the root canal and the relined FGP were rinsed with water and dried with paper points. Another layer of adhesive was applied to the relined FGP and light-cured for 20 seconds. Finally, the bonding procedure for the root canals was performed in accordance with the specifications of the resin cement used.

For the conventional resin cement RelyX ARC, the root canals were conditioned with 35% phosphoric acid for 15 seconds, then rinsed with water and dried with paper points. A thin layer of Adper Single Bond 2 adhesive was applied and light-cured for 20 seconds. The resin cement was then manipulated and applied to the root canal using a Centrix syringe (Centrix Precision; Maquira Dental Group, Maringá, PR, Brazil) equipped with elongation tips. This was followed by the insertion of the FGP and another 40 seconds of light curing. For the self-adhesive resin cements, etching the dentin substrate or applying adhesive to the FGP was not necessary, per the manufacturer's instructions. Rely-X Unicem was inserted into the root canal, the FGP was positioned with digital pressure, and the assembly was light-cured for 40 seconds. Subsequently, the specimens were stored at 37°C with relative humidity for 7 days [13].

POBS testing

After 7 days of storage, the roots ($n = 10$) were subjected to a cutting protocol using a high-concentration diamond disc mounted on a precision cutting machine (IsoMet 1000; Buehler, Uzwil, Switzerland). Nine 1-mm-thick slices (3 slices each from the cervical, middle, and apical regions) were cut perpendicularly to the long axis of the teeth. POBS was measured

Table 2. Cementation protocol for each group

Group and technique	Cementation protocol
G1 Fiberglass post + RelyX ARC	Fiberglass post: 1. Apply 35% phosphoric acid. 2. Rinse with water, then dry. 3. Apply silane for 60 seconds. 4. Apply adhesive, followed by light curing for 20 seconds. Root canal: 5. Condition the root dentin with 35% phosphoric acid for 15 seconds. 6. Rinse with water for 15 seconds and dry with paper points. 7. Apply the adhesive, remove any excess with paper points, and light cure for 20 seconds. 8. Manipulate and apply the RelyX ARC into the canal with a Centrix syringe. 9. Position the fiberglass post into the canal with digital pressure. 10. Light cure for 40 seconds.
G2 Relined Fiberglass post + RelyX ARC	Fiberglass post: Repeat steps 1–4 from G1. Root canal: 5. Apply water-soluble lubricant to the canal. 6. Manipulate the resin composite increment onto the fiberglass post and position it into the canal. 7. Light cure for 5 seconds, then remove from the canal and light cure for 40 seconds. 8. Rinse and dry the root canal and the fiberglass post. 9. Apply adhesive in the relined fiberglass post and light cure for 20 seconds. Repeat steps 5–10 from the G1 cementation protocol.
G3 Fiberglass post + RelyX Unicem	Fiberglass post: 1. Apply 35% phosphoric acid. 2. Rinse with water, then dry. 3. Apply silane for 60 seconds. Root canal 4. Manipulate and apply the RelyX Unicem into the canal with a Centrix syringe. 5. Position the fiberglass post into the canal with digital pressure. 6. Light cure the resin cement for 40 seconds on each side.
G4 Relined Fiberglass post + RelyX Unicem	Fiberglass post: Repeat steps 1–3 from G3. 4. Apply adhesive and light cure for 20 seconds. Root canal: 5. Apply water-soluble lubricant to the canal. 6. Manipulate the resin composite onto the fiberglass post and position it into the canal. 7. Light cure for 5 seconds, then remove from the canal and light cure for 40 seconds. 8. Rinse and dry the canal and the fiberglass post. Repeat steps 4–6 from G3.

using a universal testing machine (Instron, Norwood, MA, USA). A force of 500 N and a crosshead speed of 1.0 mm/min were applied at the center of the FGP in the apicocervical direction until bond failure was observed [1,5,8,9,13].

Failure mode analysis

The debonded specimens were examined using a stereomicroscope (EK3ST; Eikonal Equip. Ópticos e Analíticos, São Paulo, SP, Brazil) at a magnification of 40×. The failures were classified into the following categories: I, adhesive failure at the interface between the FGP and the resin cement; II, adhesive failure at the interface between the resin cement and the dentin; III, cohesive failure within the resin cement; IV, cohesive failure within the FGP; and V, mixed failure, which is a combination of 2 or more failure modes [13].

Cross-sectional microhardness (Knoop hardness number; KHN)

Twenty root canals (n = 5) were isolated and processed as outlined in **Table 2**. After 7 days of storage, the samples were sectioned under cooling conditions, using a precision cutting machine to cut perpendicularly to the longitudinal axis of the root. This process was continued at the midpoint of the FGP until 2 halves were produced. The specimens were then embedded in epoxy resin and polished using a rotary polisher (Aropol 2V; Arotec S/A, Cotia, SP, Brazil). The polishing sequence involved the use of abrasive papers with grit sizes of 600, 1,200, 2,000, and 4,000, each for a duration of 1 minute. Subsequently, final polishing was carried out using diamond paste with particle sizes of 1 and 1/4 µm. To complete the preparation, the specimens were rinsed with distilled water in an ultrasonic cleaner for 10 minutes. The evaluation of cross-sectional microhardness was conducted using a microhardness tester with a diamond indenter (HMV-2000; Shimadzu, Kyoto, Japan). A static load of 50 × *g* was applied to the resin cement for 10 seconds. Three indentations were made in each third of the root canal (cervical, middle, and apical), aligned with the long axis and spaced 1 mm apart [19].

Interface analysis

The roots of another set of 12 bovine incisors ($n = 3$) were separated and processed as outlined in **Table 2**. Subsequently, the samples were prepared following the protocol detailed in Section 2.5. After being polished, the specimens underwent a dehydration process using a series of ethanol solutions at concentrations of 25%, 50%, 75%, 95%, and finally 100%, each for a duration of 10 minutes. They were then left to dry overnight in a desiccator at 37°C. The final step involved sputter-coating the samples with gold (MED 010; Bal-Tec, Balzers, Liechtenstein) before examining them under scanning electron microscopy (SEM) (JSM-5600LV; JEOL, Tokyo, Japan) at a magnification of 35× [20].

Statistical analyses

The Shapiro-Wilk and Levene tests were employed to confirm the normal distribution and homoscedasticity of the POBS and cross-sectional microhardness data. Three-way analysis of variance was used along with the Bonferroni *post-hoc* test. All statistical analyses were performed using SPSS (version 21.0; IBM Corp., Armonk, NY, USA), with the significance level set at 5%. The results of the SEM evaluation were examined with descriptive analysis. The power test was conducted using GPower 3.1.9.7 (ASA Group, Autenzell, Bayern, Germany), considering the variables of the study (POBS and KHN) ($\beta > 0.9$, $\alpha = 0.05$).

RESULTS

POBS testing

The power of the test exhibited values exceeding 0.9934 (99%) across all methodologies used, indicating a high level of confidence in the sample values.

Table 3 presents the means and standard deviations for the POBS test, measured in megapascals (MPa), across the tested groups. The analysis considered 3 distinct variables: root third ($p < 0.001$), resin cement ($p < 0.001$), and cementation technique ($p < 0.001$). Additionally, interactions between these variables were examined: root third and resin

Table 3. Push-out bond strength (in MPa) according to resin cement, fiberglass post (FGP) individualization, and root third

Material	Conventional cementation technique			Relined FGP		
	Cervical	Middle	Apical	Cervical	Middle	Apical
Rely-X ARC	$37.75 \pm 3.3^{Aa*}$	30.99 ± 10.3^{ABa}	$24.97 \pm 10.1^{Ba*}$	$48.77 \pm 11.5^{Aa*}$	34.09 ± 3.1^{Ba}	$32.33 \pm 8.0^{Ba*}$
Rely-X Unicem	$27.67 \pm 8.9^{Ab*}$	$17.58 \pm 4.7^{Bb*}$	$12.38 \pm 2.5^{Bb*}$	$41.04 \pm 9.5^{Aa*}$	$34.61 \pm 9.6^{Aa*}$	$25.09 \pm 10.3^{Ba*}$

Three-way analysis of variance and Bonferroni *post-hoc* test ($\alpha = 5\%$). Values are presented as mean ± standard deviation.
Uppercase letters indicate a statistical difference between the root thirds of each resin cement. Lowercase letters indicate a statistical difference between the resin cements in each root third. Asterisks (*) indicate a statistical difference between cemented and relined fiberglass posts of each root third and of each resin cement.

cement ($p = 0.629$), root third and cementation technique ($p = 0.799$), resin cement and cementation technique ($p = 0.019$) and the interaction among all variables ($p = 0.272$). The findings indicate that the type of resin cement system significantly influenced the POBS for the conventional cement. Rely-X ARC exhibited higher POBS values than Rely-X Unicem across all root thirds ($p < 0.008$). These values (in MPa) were as follows: cervical, 37.75 vs. 27.67; middle, 30.99 vs. 17.58; and apical, 24.97 vs. 12.38. However, the relined technique yielded comparable results between the 2 resin cements in all root thirds ($p > 0.05$), with respective values of 48.77 vs. 41.04 for the cervical third, 34.09 vs. 34.61 for the middle third, and 32.33 vs. 25.09 for the apical third.

For each resin cement, the POBS values decreased from the cervical to the apical third ($p < 0.011$), with the following results (in MPa) for the cervical, middle, and apical thirds respectively: Rely-X ARC showed values of 37.75, 30.99, and 24.97, while Rely-X Unicem had measurements of 27.67, 17.58, and 12.38 for the conventional cementation technique. For the relined FGP technique, Rely-X ARC had values of 48.77, 34.09, and 32.33, and Rely-X Unicem displayed measurements of 41.04, 34.61, and 25.09. The middle third did not differ significantly from the cervical or apical thirds for Rely-X ARC using the conventional technique ($p > 0.05$). However, the middle third (POBS = 34.09 MPa) did significantly differ from the cervical third (POBS = 48.77 MPa) for Rely-X ARC with the relined FGP, as well as for Rely-X Unicem with the conventional technique ($p = 0.001$ and $p = 0.008$, respectively), with the cervical POBS for Rely-X Unicem at 27.67 MPa and the middle POBS at 17.58 MPa. Additionally, the middle third was statistically different from the apical third for Rely-X Unicem with the relined FGP ($p = 0.11$). Finally, across all radicular thirds, the relined FGP technique yielded higher POBS values for both resin cements compared to the conventional cementation technique ($p < 0.004$), with the exception of the middle third for Rely-X ARC resin cement ($p > 0.05$).

Failure mode analysis

Failure modes (types I to V) are depicted in **Figure 1**, categorized according to the type of resin cement and the cementation protocol used. For the conventional resin cement Rely-X ARC, type II failure was the most common mode for both the conventional and relined techniques (62.6% and 71.3%, respectively), followed by type V (20.1% and 18.5%, respectively). Notably, the relined FGP technique showed a higher incidence of type I failure (5.2%) compared to the conventional technique (2%). The resin cement Rely-X Unicem also exhibited type II as the predominant failure mode (76.5% and 76.27% for conventional and relined techniques, respectively), followed by type III (12.3% and 6.23%, respectively), regardless of the cementation technique employed. Similar to Rely-X ARC, the relined technique for the FGP with Rely-X Unicem displayed a higher occurrence of type I failure (5.2%) compared to the conventional technique (0%).

Cross-sectional microhardness test (KHN)

Table 4 presents the means and standard deviations for Knoop microhardness along the root canal for the groups tested, considering 3 distinct variables: root third ($p < 0.001$), resin cement ($p < 0.001$), and cementation technique ($p < 0.001$). Additionally, their interactions were examined: root third and resin cement ($p < 0.001$), root third and cementation technique ($p = 0.066$), resin cement and cementation technique ($p < 0.001$), and the interaction among all variables ($p = 0.120$). The findings indicate that the type of resin cement system significantly impacted the Knoop microhardness. Rely-X ARC exhibited higher KHN values compared to Rely-X Unicem across all root thirds ($p < 0.017$), with the following values for the conventional cementation technique: cervical, 61.35 vs. 51.47; middle, 46.59 vs. 44.04;

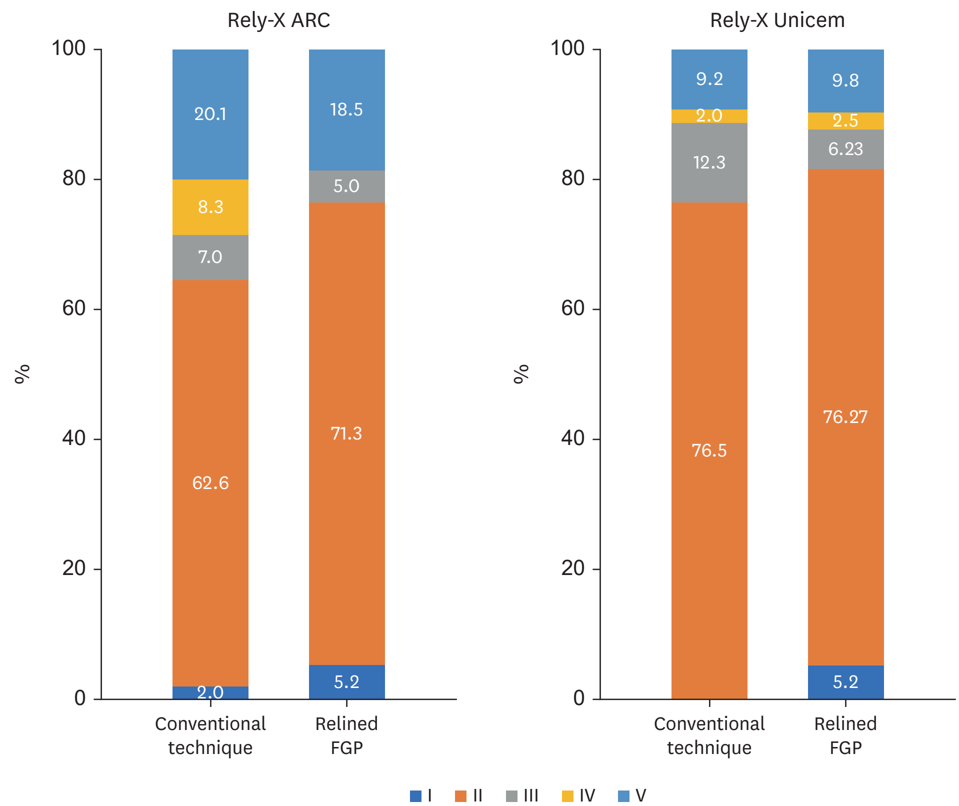

Figure 1. Distribution of failure mode according to the resin cement and cementation protocol.
Here, I (dark blue) indicates adhesive failure between the fiberglass post (FGP) and resin cement. II (orange) represents adhesive failure between the resin cement and dentin. III (gray) corresponds to cohesive failure of the resin cement, while IV (yellow) denotes cohesive failure of the FGP. Finally, V (light blue) indicates mixed failure. The percentages (in parentheses) reflect the proportion of each failure mode observed.

and apical, 39.21 vs. 31.50. For the relined FGP technique, the values were: cervical, 71.08 vs. 61.03; middle, 54.01 vs. 47.35; and apical, 44.55 vs. 36.33. When examining the root thirds for each resin cement, a decrease was noted in KHN values from the cervical to the apical region ($p < 0.001$). Additionally, across all radicular thirds, the relined FGP technique demonstrated higher KHN values compared to the conventional cementation technique ($p < 0.002$).

Interface analysis

Figure 2 displays representative SEM images of the internal adaptation of FGPs cemented using different techniques within the root canal. The conventional technique (**Figure 1**) exhibited a thick layer of resin cement, marked by defects such as voids and bubbles. In contrast, when the FGP was relined (**Figure 2**), the resin cement layer appeared thinner and was free of observable defects.

Table 4. Knoop microhardness (Knoop hardness number) along the root third according to different cementation techniques and resin cements

Material	Conventional cementation			Relined FGP		
	Cervical	Middle	Apical	Cervical	Middle	Apical
Rely-X ARC	61.35 (0.9)^{Aa*}	46.59 (3.0)^{Ba*}	39.21 (1.3)^{Ca*}	71.08 (2.4)^{Aa*}	54.01 (1.2)^{Ba*}	44.55 (1.2)^{Ca*}
Rely-X Unicem	51.47 (3.6)^{Ab*}	44.04 (3.0)^{Bb*}	31.50 (2.1)^{Cb*}	61.03 (1.7)^{Ab*}	47.35 (1.9)^{Bb*}	36.33 (3.6)^{Cb*}

Three-way analysis of variance and Bonferroni *post-hoc* test (α = 5%).
FGP, fiberglass post.
Uppercase letters indicate a statistical difference between the root thirds of each resin cement. Lowercase letters indicate a statistical difference between the resin cements in each root third. Asterisks (*) indicate a statistical difference between cemented and relined fiberglass posts of each root third and of each resin cement.

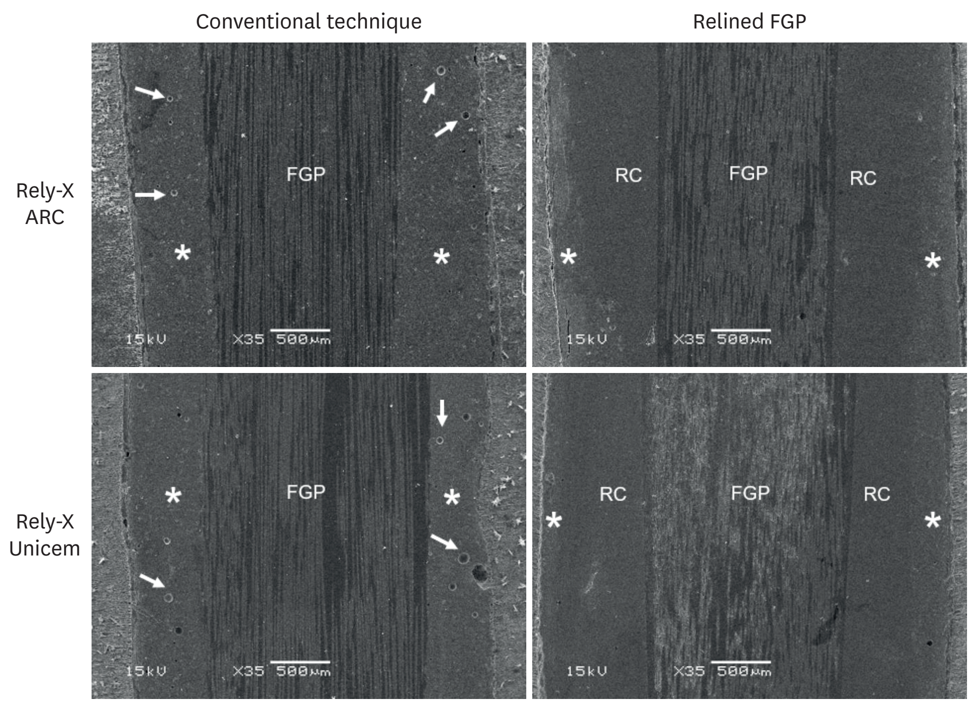

Figure 2. Scanning electron microscopy images (×35) showcasing the interface analyses.
*, resin cement; RC, resin composite; FGP, fiberglass post; arrows, bubbles.

DISCUSSION

Numerous studies have examined the mechanical properties of FGPs; however, the lack of standardization in materials and techniques has led to considerable variations in mechanical characteristics. Consequently, the aim of this *in vitro* study was to assess the mechanical properties and adhesion of relined and non-relined FGPs when cemented with either a conventional dual-cure resin cement or a self-adhesive resin cement. Based on the findings, the initial null hypothesis—that the technique of relining FGPs would not influence the POBS values, regardless of the resin cement used—was rejected.

Although Gomes *et al.* [21] demonstrated in an *in vitro* study that FGP cementation techniques with fewer steps yield more favorable bond strength results between root dentin and resin cement, the data in **Table 3** indicate that the conventional resin cement Rely-X ARC exhibited higher bond strength values compared to the simplified resin cement Rely-X Unicem. This discrepancy may be due to the capacity of conventional resin cements to demineralize the substrate, create a hybrid layer, and form resin tags, thereby enhancing the bond strength [5,14].

In contrast, the adhesion mechanism of Rely-X Unicem stems from the functional acid monomers included in its composition [22]. These monomers are characterized by their low pH and hydrophilicity, which allow them to partially demineralize the smear layer, resulting in an adhesion mechanism more akin to that of glass ionomer cements than to conventional resin cements [23]. However, the smear layer produced during root canal preparation is denser and thicker than that on coronal dentin, which impacts the interaction between the acid monomers of the self-adhesive resin cement and the underlying dentin. This explains the lower POBS values observed with self-adhesive resin cement compared to conventional resin cement, which employs traditional phosphoric acid etching to remove the smear layer

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and demineralize the dentin [22-24]. Nevertheless, when the technique of relining the FGP was employed, no significant difference in bond strength was noted between the resin cements. This suggests that reducing the thickness of the resin cement layer can enhance frictional retention and lead to better adaptation within the root canal [4,5].

Nonetheless, it is important to emphasize that a lack of continuous and homogeneous interlocking between materials or substrates can lead to various types of failures. As depicted in **Figure 1**, a higher rate of type I failure (adhesive failure between the resin cement and the FGP) was observed when the FGP was relined, regardless of the resin cement used. These results may be attributed to the multiple layers that could introduce operator errors or complex chemical interactions between the post surface, silane, adhesive resin, and resin composite. However, the incidence of this type of failure is low relative to the benefits of a thin layer of resin cement. **Figure 2** illustrates that relining the FGP resulted in thinner layers of resin cement with fewer defects, such as bubbles and voids, which can lead to cracks, reduce adhesion, and shorten the longevity of the treatment [7,20].

Notably, type II failure (adhesive failure between the resin cement and the dentin) was the most prevalent for both types of resin cement and both cementation techniques. This phenomenon may be associated with the shrinkage stress of the resin cement. When resin cements are light-cured, polymer chains form through the conversion of carbon bonds. This process can lead to the accumulation of stress, particularly due to the high C-factor of root canals, which may result in debonding from the dentin [13,19].

Another key factor that may be linked to the failure mode is the quality of the light-cured resin cement. The literature indicates that light-activated materials achieve a degree of conversion between 50% and 80%; however, the apical third of a root canal receives less light than the coronal third. This can leave uncured residual monomers that may affect the mechanical properties and accelerate the degradation process [19,25]. Some researchers have found that microhardness testing correlates with Fourier-transform infrared spectroscopy analysis, suggesting that as the degree of conversion increases, so does hardness, and vice versa [19,26,27]. Consequently, this study assessed microhardness measurements along the root canal. Based on the findings presented in **Table 4**, these authors rejected the second null hypothesis that the thickness of the cementation line would not influence microhardness values.

The present study demonstrated that, regardless of the cementation technique and type of resin cement used, the microhardness values were significantly higher in the coronal region than in the apical region of the root canal. These findings are consistent with those of previous studies and may be attributed to the fact that the apical third receives less light irradiation compared to the coronal region [7,27,28]. Moazzami *et al.* [25] evaluated the reduction in light intensity after it passed through various depths of FRC posts and confirmed that even the middle third does not receive the minimum light irradiation required for adequate polymerization. However, the capacity of the post to transmit light must be considered and is dependent on the material's composition [29]. Factors such as the variability of fiber orientation, fillers, and matrix can influence reflection and absorption quality [30]. Therefore, the translucency of the glass in glass fiber posts is preferred over zirconia ceramic posts [29,30]. Despite the influence of light irradiation, Knoop microhardness values can also be affected by the composition of the resin cements, including the organic and inorganic matrix, particle shape and size, and adhesion mechanism [11,31].

In the present study, when comparing resin cements, the conventional resin cement exhibited higher microhardness values than the self-adhesive resin cement.

Dual-cure resin cements contain dimethacrylate molecules within their organic polymeric matrix. Upon exposure to optical radiation, these molecules release free radicals that harden the resin material [32,33]. Subsequently, amines react with peroxides to complete the polymerization process at unreacted carbon double bond sites, ensuring the polymerization of the material even in deep areas that receive insufficient light intensity [32-34]. In contrast, to achieve adhesion to tooth structure, new methacrylate monomers with phosphoric acid groups have been incorporated into self-adhesive resin cements [22]. This results in a lower pH compared to conventional resin cements. However, the alkaline components of the filler content, namely glass fillers and colloidal silica, can neutralize this reaction [22,23,35]. This may explain why Rely-X Unicem contains a higher percentage of filler particles (72% wt) compared to Rely-X ARC (67.5% wt). Nevertheless, due to the challenges of light curing within the root canal, the neutralization of the residual acid monomers in self-adhesive resin cements may not be complete. This incomplete reaction could act as a plasticizer, potentially reducing the microhardness [16].

Apart from the need for a high number of particles to neutralize the reaction of self-adhesive resin cements, the shape and size of the fillers may also influence the extent of polymerization. This is because mechanical stress is typically concentrated on protuberances, angles, and irregularities of the filler/matrix interface; this targeted stress can lead to the initiation of cracks at these locations, resulting in lower Knoop microhardness values [14,35]. Additionally, the viscosity of the material plays a role. Rely-X ARC has a comparatively low filler content, suggesting that this resin cement is more viscous than Rely-X Unicem. Consequently, it can be inferred that the conventional resin cement, when combined with acid etching, may penetrate deeper into the substrate, leading to better micromechanical retention. This is particularly relevant in the apical third, which lacks a high density of dentinal tubules [14,15,24,34,36,37].

Thus, despite the demand to reduce procedural steps to save time, it is essential to consider the chemistry, bonding, mechanical requirements, and limitations of the materials for each clinical scenario. A simple additional step, such as the relining technique protocol for the FGP, may enhance the bond strength to radicular dentin and potentially improve post stability [34,36,37]. However, the present study has limitations due to the absence of fatigue/thermo-aging or exposure to the oral environment, which complicates the understanding of long-term behavior. Therefore, long-term *in situ* studies and clinical trials are necessary.

CONCLUSION

The use of a relined FGP can improve mechanical integration into the root canal by creating a thin, defect-free resin cement layer. This results in higher POBS and microhardness values compared to those of a non-relined FGP, irrespective of the type of resin cement used. Additionally, the cementation protocol for non-relined FGPs revealed the presence of bubbles and voids within the cement layer for both types of resin cements. However, conventional resin cement demonstrated superior POBS and Knoop microhardness results relative to self-adhesive resin cement.

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