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Customized Fiber Post Improves the Bond Strength and Dentinal Penetrability of Resin Cementation System to Root Dentin

TP Leandrin • E Fernández • RO Lima • JF Besegato • WG Escalante-Otárola • MC Kuga

Clinical Relevance:

Customized fiber posts when placed with resin cements have the potential to improve bond strength and penetration of the adhesive into root dentin.

SUMMARY

Objective: This study aimed to evaluate the effect of fiber post customization on the bond strength (24 hours and 6 months), resin cement thickness, and dentinal penetrability of Adper Scotchbond Multi-Purpose – RelyX ARC (AS-RA), RelyX U200 (R2), and Scotchbond Universal – RelyX Ultimate (SU-RU) cementation systems to root dentin from the cervical-, middle-, and apical-thirds of the post space.

Methods: One hundred twenty bovine incisors were endodontically treated. After post space preparation, the roots were divided into six groups, according to the luting protocols (AS–RA, R2, SU–RU) and the type of fiber post [noncustomized post (NC) and customized post (C)]. Customization procedures were peformed using a resin composite (Z350 XT). 24 hours (n=60) or 6 months later (n=60), specimens from the cervical-, middle-, and apical-thirds of the post space were submitted to cementation system thickness measurement, bond

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strength evaluation, and dentinal penetrability analysis with Confocal Laser Scanning Microscopy (CLSM). Failure mode was classified as adhesive, cohesive, or mixed. Data were submitted to ANOVA and Tukey tests (α=0.05).

Results: Cementation protocols with customized fiber posts presented the lowest cementation system thickness, regardless of the cementation system or post space-third (p<0.05), and the highest bond strength values (p<0.05), regardless of the third space (p>0.05), for both periods (24 hours or 6 months). The comparison of push-out bond strength values between 24 hours and 6 months showed a reduction in all groups for the cervical-third (p<0.05). For the middle-third, only noncustomized groups showed reduction (p<0.05). For the apical-third, no reduction was observed (p>0.05).

Conclusions: Anatomical customization favored both the bond strength of cements to dentin and the dentinal penetrability, but with lower cementation system thickness, regardless of cement composition and adhesive strategy.

INTRODUCTION

Glass fiber posts are used as an alternative treatment to replace metallic posts in endodontically treated teeth. Their modulus of elasticity is similar to root dentin and resin cements, which promotes more homogeneity of stress distribution in the root and less probability of root fracture. Furthermore, glass fiber posts are more esthetic and avoid dental discoloration by corrosion products from the metallic alloys.[1-3]

However, the post morphology is different from the root canal anatomy. This difference may increase the cement thickness because of poor spatial relationship between them,[4] leading to increased shrinkage and a higher chance of axial displacement due to poor adaptation of the post. As a result, reduction in both degree of conversion and bond strength of the cementation system to root dentin can be observed.[5,6] Therefore, customized posts have been proposed to minimize these effects, since customization using resin composite may improve the post adaptation into the root canal as well as reduce the cement thickness.[7,8]

Furthermore, the type of cementation system may influence the clinical success of the fiber posts in endodontically treated teeth.[2,9,10] Conventional resin cements with etch-and-rinse, self-etching, and self-adhesive systems are the most used cementation systems in luting procedures.[11,12]

Three-step etch-and-rinse adhesive systems (eg, Adper Scotchbond Multi-Purpose) are some of the most effective dentin adhesives.[13] However, their clinical steps must be carefully performed, otherwise, failure may negatively affect the adhesive interface.[14] Moreover, several resin cements have been used with these types of adhesive systems; thus, whether any adhesive failure occurs, the post retention and its clinical longevity may be compromised.[2,13]

Self-adhesive cementation systems have been recommended to minimize the challenges of etch-and-rinse systems.[15] Their adhesion mechanism is related to the acid phosphate monomers that chemically bond to hydroxyapatite from the dentin substrate[16,17]; therefore, the application of adhesive systems is not required during the bonding procedure.[15] On the other hand, the adhesive efficiency is directly related to the clinical conditions of the dentin surface, such as presence of residues and type of endodontic treatment that was previously performed.[16]

Universal adhesive systems combined to conventional resin cements presents better interaction with dentin than self-adhesive cements, since not remove all of the smear layer is removed at adhesive interface, which reduces the common bonding errors associated with etch-and-rinse adhesives systems.[18]

Mechanical retention favors the action of cements and, consequently, improves the post's retention and stability.[7,19,20] Customized fiber posts have been recommended to be used with direct resin composites. By a simple technique, the post customization involves the use of resin composites to fill the space between the post and the root canal.[8] Thus, customization can reduce the cement thickness, which improves the post adaptation into the root canal and the friction retention to the dentin surface.[7,21,22] Although the frictional retention is crucial to the post stability inside the root canal,[19,20] other factors, such as, the anatomy of the root canal, endodontic treatment strategy, and luting system may also affect the stability.[13,15,23-25]

Many questions are still unclear regarding the interaction between the type of cementation system and the post customization on the adhesive interface, and which luting system should be used with customized fiber posts and vice versa.

Therefore, the aim of this study was to evaluate the effects of customized posts on the bond strength, dentinal penetrability, and adhesive failure mode of conventional cementation systems (Adper Scotchbond Multi-Purpose associated with RelyX ARC and Scotchbond Universal with RelyX Ultimate), and self-adhesive (RelyX U200), in the dentin at cervical-, middle-, and apical-thirds of the post space. Push-out testing and confocal laser scanning microscopy (CLSM) to evaluate the bond strength and dentinal penetrability were, respectively, used. The null hypotheses tested were that the customized post does not influence the bond strength or dentinal penetrability of different cementation systems.

METHODS AND MATERIALS

Sixty bovine incisors with similar anatomy and dimension were stored in 0.1% thymol solution (pH 7.0) at 4°C ± 1°C until use.

Post Space Preparation

The root length was standardized at 15 mm length from the root apex. A #15K file (Denstply Maillefer, Petrópolis, RJ, Brazil) was introduced in the root canal until it was visible at the radicular apex. Then, the foraminal opening was sealed with cyanoacrylate resin (Super Bonder; Loctite, São Paulo, SP, Brazil). The root canals were prepared using ProTaper Rotary System technique up to the F5 instrument (Maillefer, Ballaigues, Switzerland) according to the manufacturer's recommendations. Then, irrigation was performed using 5 mL of 2.5% sodium hypochlorite solution (Asfer, São Caetano do Sul, SP, Brazil) at each instrument change.

Final irrigation was performed with 3 mL of 17% EDTA (Biodinâmica, Ibiporã, PR, Brazil) for 3 minutes and 5 mL of 2.5% NaOCl. The root canals were dried using absorbent paper points, obturated with epoxy resin-based sealer (AH Plus, Dentsply) and F5 gutta-percha master cone (ProTaper, Dentsply).[26] After that the roots were kept at 37°C ± 1°C for 7 days.

The intracanal preparation was performed using a #2 bur (White Post DC System, FGM, Joinville, SC, Brazil) at 11-mm length. Afterwards, the root canal was irrigated using 10 mL of distilled water and dried using absorbent paper points.

Sample Size

In this study, bond strength evaluation was considered the main outcome, with a calculated sample size (n=20), considering the comparison between two reported similar fiber post groups[7] [effect size=0.86, power 1-B (0.85), alpha (0.05)].

Experimental Groups

The fiber post surface was cleansed using 95% ethanol (Rinse-N-Dry, Racine, WI, USA). Then, silane (Prosil, FGM) was applied throughout its length. Since this study aimed to evaluate the effects of the customization of fiber posts, noncustomized or customized posts cemented with RA, R2, or RU cementation systems were considered independent variables. Bond strength (24 hours or 6 months), failure mode analysis, cementation system thickness, adhesive interface evaluation, and dentinal penetrability were considered dependent variables.

The specimens were randomly allocated into six groups (n=20), according to the cementation system and post customization.

AS-RA-NC (AS: Adper Scotchbond Multi-Purpose; RA: RelyX ARC; NC: non-customized post)—Dentin was etched with 37% phosphoric acid (Condac 37, FGM, Joinville, SC, Brazil) for 15 seconds, rinsed with distilled water for 30 seconds, and dried using absorbent paper points. Then, both primer and adhesive (Adper Scotchbond Multi-Purpose Plus, 3M Oral Care, St. Paul, MN, USA) were applied throughout the dentin length using a rotary brush (MK Life, Porto Alegre, RS, Brazil) with continuous rotary motion at 500 rpm. Only the adhesive was applied in the fiber post. After that, the adhesive system was light cured for 10 seconds using an LED device (Valo, Ultradent, South Jordan, UT, USA) positioned 1 mm distance from the post surface, with an irradiance of 1000 mW/cm^2 (Standard mode). Afterwards, RelyX ARC cement (3M Oral Care) was inserted using a precision syringe (Maquira, Maringá, PR, Brazil). The post was placed in the root canal, and the whole set was light cured in each root surface for 40 seconds (buccal, mesial, distal, and occlusal).

R2–NC [RelyX U200 (R2); noncustomized post (NC)—The root dentin was rinsed with 5 mL of distilled water and dried using absorbent paper points. The surface was kept slightly moist. Then, self-adhesive resin cement (RelyX U200) was handled and inserted using a precision syringe (Precision, Maquira, Maringá, PR, Brazil). The post was placed in the root canal, and the whole set was light cured, as previously described.

SU–RU–NC [Scotchbond Universal (SU); RelyX Ultimate (RU); noncustomized post (NC)]—The root dentin was rinsed with 5 mL of distilled water and dried using absorbent paper points. Two layers of the Universal adhesive system (Scotchbond Universal; 3M Oral Care) were applied on the post space and light cured for 10 seconds, as previously described. Excesses were removed using absorbent paper points, and the dentin was dried by an air spray. Further, the universal adhesive system was applied on the fiber post and light cured for 10 seconds. Afterwards, RelyX Ultimate cement (3M Oral Care) was inserted using a precision syringe. The post was placed in the root canal, and the whole set was light cured using an LED device for 40 seconds, positioned 1-mm distance from the post surface, as previously described.

AS–RA–C, R2–C, and SU–RU–C [customized post (C)]—The cementation was performed according to the manufacturer's recommendations. However, the fiber posts were previously customized in these protocols. The posts were etched with 37% phosphoric acid (Condac 37, FGM) for 15 seconds, rinsed for the same time, and dried by air spray. Two layers of silane (Prosil, FGM) were applied throughout the post length and dried by air spray. Then, a two-step etch-and-rinse adhesive system (Adper Single Bond 2; 3M Oral Care) was applied on the post length and light cured for 10 seconds.

The post space was lubricated using a water-based glycerin gel (KY Gel; Reckitt Benckiser, Slough, UK). Then, a single increment of resin composite (Z350 XT AT; 3M Oral Care) was applied around the post and inserted into the root canal. Then, the whole set was light cured for 10 seconds. The customized post was removed from the root canal and light cured for 40 seconds on each surface. The post space was irrigated with 10 mL of distilled water to remove the water-based gel and dried using absorbent paper points. Push-out analyses were performed in a period of 24 hours (n=60 specimens) and in a period of 6 months (n=60 specimens) after fiber post cementation.

Table 1 shows the composition of resin cements and adhesive systems used in the cementation protocols.

Rhodamine B (LabSynth, São Paulo, SP, Brazil) was added to the primer of the adhesive system (Adper Scotchbond Multipurpose) and to the universal adhesive system (Scotchbond Universal), in a ratio of 16 μL to 0.4 mL. Rhodamine B was also added to RelyX U200 cement, in a ratio of 0.01% (by mass) in accordance to Bim Júnior and others.[27] Only specimens evaluated at 6 months were subjected to CLSM. The roots were kept in distilled water for 6 months at 37°C ± 1°C. The water was changed every 2 days. After 6 months, push-out testing and dentinal penetrability evaluation were performed.

Bond Strength Evaluation

After 24 hours and 6 months, the roots were vertically centralized inside a PVC matrix (21.3-mm diameter x 20.0-mm length) and checked using a parallelometer (BioArt B2, São Carlos, SP, Brazil). The matrices were filled with polyester resin (Maxi Rubber, Diadema, SP, Brazil), leaving 1.0 mm of the cervical root outside the resin. The whole set was left undisturbed for 24 hours. The specimens were removed from the matrices and then sectioned perpendicular to their long axis using a diamond disk (250 rpm) coupled in a hard tissue cutting machine (IsoMet 1000, Buehler Ltd, Lake Bluff, IL, USA) under water cooling.

Three sections were obtained with 2.0 mm ± 0.1 mm thicknesses from the apical-, middle-, and cervical-thirds of the post space. The cervical, middle, and apical sections were obtained, respectively, from 1.0 mm, 5.0 mm, and 8.0 mm apical to the root cervical face. Section irregularities were removed using 1200-grit silicon carbide sandpaper (Norton, São Paulo, SP,

Table 1: *Composition of Resin Cements and Adhesive Systems used in the Cementation Protocols*

Materials	Manufacturer	Composition
Adper Scotchbond Multipurpose	3M Oral Care	Primer: water, HEMA, copolymer of acrylic and itaconic acid
RelyX ARC	3M Oral Care	Bis-GMA, TEGDMA, silanized zirconia/silica filler 68% functionalized dimethacrylate polymer, triphenyl antimony
RelyX U200	3M Oral Care	Base: glass powder treated silane, 2-propenoic acid, 2-metil 1,1'-[1-(hydroxymetil)-1,2- ethanodlyl] ester, TEGDMA, sodium persulfate and t-butyl per-3,5,5–trimethyl-hexanoate. Catalyst silane-treated glass powder, substituted dimethacrylate, silanated silica, sodium p-toluene sulfonate, 1-benzyl-5-phenyl-baric acid, calcium salts, 1,12-dodecane dimethacrylate, calcium hydroxide and titanium dioxide
Scotchbond Universal	3M Oral Care	MDP phosphate monomer, dimethacrylate resins, HEMA, methacrylate-modified polyalkenoic acid copolymer, filler, ethanol, water, initiators, silane
RelyX Ultimate	3M Oral Care	Methacrylate monomers, radiopaque silanated fillers, initiator components, stabilizers and rheological additives, radiopaque alkaline fillers, pigments, fluorescence dye, dark polymerize activator for SU

Abbreviation: Bis-GMA, bisphenol-glycidyl methacrylate; HEMA, 2-hydroxyethyl methacrylate, MDP, 10-methacryloyloxydecyl dihydrogen phosphate; TEGDMA, triethylene glycol dimethacrylate.

Brazil) under water cooling. The sections were then ultrasonically cleansed for 5 minutes.

The apical-, middle-, and cervical-thirds were demarcated, and the specimens were submitted to a push-out test using an electromechanical testing machine (EMIC, São José dos Pinhais, PR, Brazil), at 0.5 mm/min speed with 5 kN load cell, until the complete displacement of the fiber post and/or cementation system. Punch diameters of 1.2 mm, 0.9 mm, and 0.5 mm for the cervical-, middle-, and apical-thirds of the post space, respectively, were used.

The force (F) required for the displacement of the specimens was obtained in N (newtons) and transformed into bond strength (MPa) by the formula: MPa=F/AD; whereas AD was the adhesion area to dentin and calculated by the formula: $AD=\varpi \cdot (R + r) \cdot g$, where R = cervical root canal radius (mm); r = apical root canal radius (mm); g = relative height of the inverted cone (mm). Cervical and apical root canal diameters were obtained with a stereo microscope at 20× magnification (Leica Microsystems, Wetzlar, Germany). The value of g was obtained using the formula:

$$g = (R - r)^2 + (2.0)^2.$$

Failure Mode Analysis

Afterwards, the cervical surface of each slice, for the 24-hour and 6-month periods, was polished with alumina (0.3 μm and 0.05 μm granulation, Arotec, Cotia, SP, Brazil) and felt disk (FVL, Arotec), driven on a circular polisher (Aropol VV, Arotec) under water cooling. Then, the specimens were rinsed in an ultrasonic tank for 5 minutes.

The perimeter of the adhesive interface was divided into four quadrants, and an image of each quadrant was obtained using a confocal laser microscope (Lext OLS4100, Olympus, Shinjuku, Tokyo, Japan) at ×1024 magnification. The failure mode was classified according to Ramos and others[17] in type 1 (adhesive 1), when it occurred between the post and the cement; type 2 (adhesive 2), between dentin and cement; type 3 (cohesive), within the cement; and type 4 (mixed), when both types of failure were combined. Figure 1 displays the failure mode analyzed with CLSM.

Cementation System Thickness Analysis

In the groups evaluated after 24 hours, the thickness of the cementation system was evaluated before the push-out test (bond strength). The cervical face of each slice was gradually polished with 600-grit and 1200-grit silicon carbide sandpapers (Norton), in a circular polisher (Arotec) under water cooling. The specimens were rinsed in distilled water, and the cervical surface

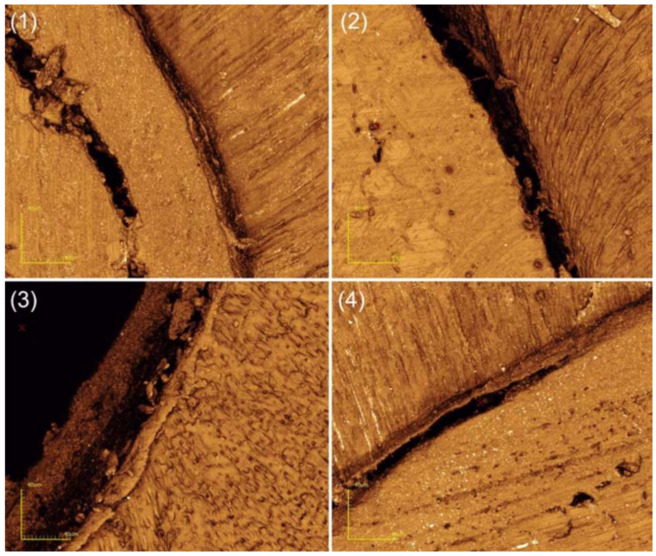


Figure 1. *Representative image of adhesive failure mode: Type 1 (adhesive): When occurring between the post and cement; type 2 (adhesive): Between dentin and cement; type 3 (cohesive): Within cement; and type 4 (mixed): When both types of failure were combined. Scale: 40 μm.*

was polished with alumina (30-μm granulation; Arotec). Then, they were rinsed with distilled water. After drying, each specimen was analyzed with CLSM (Lext OLS4100) using an specific software (Olympus Stream, Olympus) at 1024× magnification. To obtain the images, the perimeter of the root canal was divided into four quadrants. From each quadrant, an image was obtained and ten measurements were performed (in micrometers) on this image using the Image J (National Institutes of Health, Bethesda, Maryland, USA) program. The arithmetic average of the forty measurements was considered as the mean of the thickness of the cementation system in each section.

Adhesion Interface Evaluation

Thirty-six roots received the post preparation and were randomly distributed in the six groups evaluated (n=6), as previously described, to evaluate the characteristic of the adhesion interface between the dentin and the cementation system, in the cervical-, middle-, and apical-thirds of the post space. After 4 hours, sections were made, and the specimens were polished with 1200-grit silicon carbide (Norton) sandpaper under water cooling and rinsed in an ultrasonic tank with distilled water for 3 minutes.

Then, the specimens were immersed in 18% hydrochloric acid (6N), for 30 seconds, rinsed in distilled water for 1 minute, immersed in 2.5% sodium hypochlorite solution (Asfer, São Caetano do Sul, SP, Brazil) for 10 minutes, and rinsed again in distilled water for 10 minutes. After drying the specimens, the cervical face of each specimen was molded with polyvinyl siloxane (Express XT; 3M Oral Care), and epoxy resin-based replicas were obtained (Buehler).

The resin specimens were individually mounted on metallic stubs and coated in gold-palladium (Bal-Tec, Balzers, Liechtenstein) at 20 mA for 180 seconds. Representative images of the adhesion interface were obtained using SEM (JEOL; Peabody, MA, USA) at 2000× magnification. Figures 2 and 3 show the representative images of the adhesion interface between the cementation system at the post space thirds for noncustomized and customized posts, respectively.

Dentinal Penetrability Evaluation

After 6 months, 60 specimens (10 per group) were submitted to CLSM (LSM5; Zeiss, Jena, Germany) analysis. The images of the root canal diameter were divided into four quadrants. An image of each quadrant of the adhesive interface perimeter was obtained at 10× magnification. 10 measurements of dentinal penetrability were considered in each quadrant—a total of 40 measurements. The arithmetic average of the quadrant measurements was considered as the mean of each specimen. The measurements of the cement penetration into the dentinal tubules were performed in each quadrant using the Image J program.

Statistical Analysis

Bond strength (24 hour and 6 month), cementation system thickness, and dentinal penetrability data were submitted to Shapiro–Wilk testing. Then, the data were subjected to two-way ANOVA followed by Tukey post-hoc tests (α=0.05). The failure mode data were classified according to their incidence in the post space third.

RESULTS

Bond Strength Evaluation

24 Hours—In all thirds, the protocols with customized fiber posts (AS-RA-C, R2-C, and SU-RU-C) showed the highest bond strength (p<0.05) but similar to each other (p>0.05). In the cervical- and middle-thirds, R2–NC presented the lower bond strength (p<0.05), but AS–RA–NC and SU–RU–NC presented similar values (p>0.05). In the apical-third, the protocols without a customized fiber post presented similar bond strength between them (p>0.05).

6 Months—The protocols with customized fiber posts (AS–RA–C, R2–C, and SU–RU–C) presented the highest bond strength, regardless of the dentin-third and the luting system (p<0.05), and they were similar among them (p>0.05).

The analysis by thirds showed that R2–NC and SU–RU–NC protocols presented the lowest bond strength in the middle- and apical-thirds (p<0.05). Moreover, in the cervical-third, bond strength was similar to the AS–RA–NC protocol (p>0.05).

The customized variable was significant in all groups, and the variable thirds were only significant in groups R2–NC and SU–RU–NC (p<0.05).

Table 2 shows the mean and standard deviation of the bond strength values of the cementation system to dentin according to the customization protocol, post space thirds, and periods of evaluation.

24 Hours × 6 Months—Push-out bond strength was compared between the periods of 24 hours and 6 months exclusively within each group. In the cervical-third, all groups presented a reduction in bond strength after 6 months. In the middle-third, a reduction in bond strength was only observed after 6 months in the noncustomized fiber post groups (p<0.05). In the apical-third, no reduction was observed, regardless of the group (p>0.05).

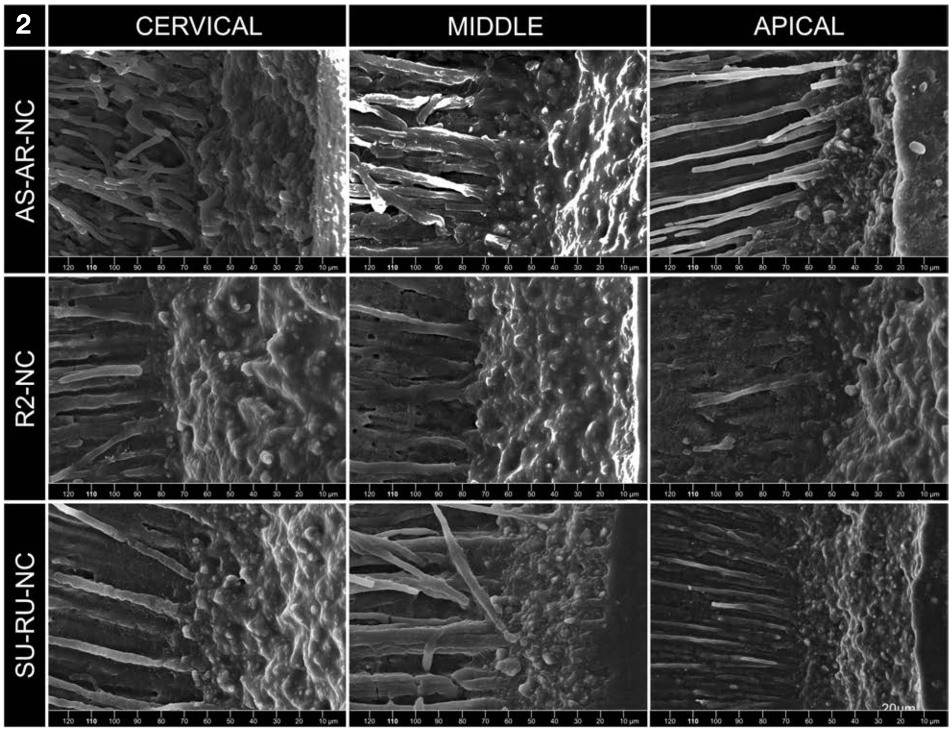
Failure Mode Analysis

24 Hours—Type 4 (mixed) failure mode was the most frequent in all groups for cervical- and apical-thirds. However, for the middle-third, type 3 failure mode was more frequent in noncustomized post groups, while type 4 was more frequent in customized post groups protocols. Figure 4 shows the failure mode in all protocols in the 24-hour period.

6 Months—Type 4 (mixed) failure mode was higher in the noncustomized posts protocols, regardless of the post space third and luting system. On the other hand, the customized posts protocols showed that type 4 failure mode was more frequent in the cervical-third, whereas type 1 failure (post/cement) presented the highest incidence in the middle- and apical-thirds. Figure 5 shows the failure mode in all protocols in the 6-month period.

Cementation System Thickness Analysis

In all thirds, customized post protocols presented the lowest cementation system thickness, regardless of the cementation system or post space third (p<0.05). However, these protocols presented similar measures between them (p>0.05). On the other hand, there were no differences in cementation system measures between noncustomized (NC) post protocols (p>0.05). Table 3 shows the mean and standard deviation of the cementation system thickness according to customization protocol and post space thirds.



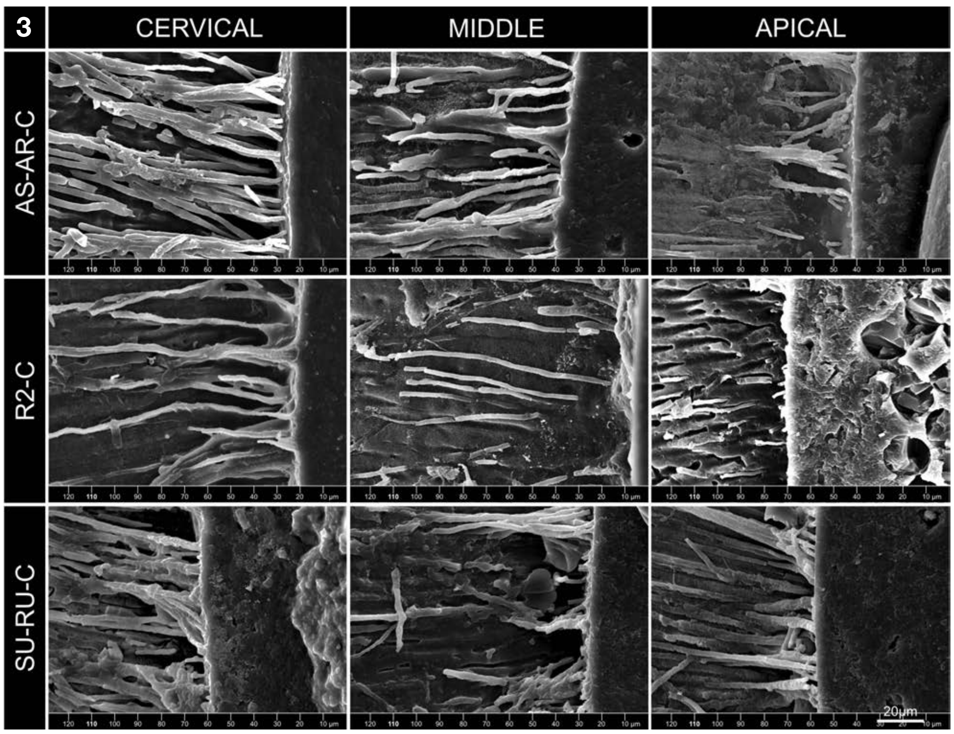


Figure 2. *Representative image of the adhesion interface among cementation system with noncustomized fiber post and radicular dentin, in "space post thirds." The ruler is only for reference. Magnification: 2000×; scale: 200 μm (24 h). AS, Adper Scotchbond Multi-Purpose; C, customized post; NC, noncustomized post; R2, RelyX U200; RA, RelyX ARC; RU, RelyX Ultimate; SU, Scotchbond Universal.*

Figure 3. *Representative image of the adhesion interface among cementation system with customized fiber post and radicular dentin, in "space post thirds." The ruler is only for reference. Magnification: 2000x; Scale: 200 μm (24 h). AS, Adper Scotchbond Multi-Purpose; C, customized post; NC, noncustomized post; R2, RelyX U200; RA, RelyX ARC; RU, RelyX Ultimate; SU, Scotchbond Universal.*

Table 2: *Mean and Standard Deviation (MPa) of the Bond Strength Values of Cementation Protocols, According to Time Evaluation, the "Space Post-third" and Resin Cements*[a]

		AS–RA–NC	**R2–NC**	**SU–RU–NC**	**AS–RA–C**	**R2–C**	**SU–RU–C**
24 hours	Cervical	7.51 ± 0.34 bA	6.83 ± 0.54 bA	7.57 ± 0.90 bA	8.62 ± 0.35 aA	8.61 ± 0.36 aA	8.66 ± 0.43 aA
	Middle	6.76 ± 0.31 bA	5.12 ± 0.55 bA	6.83 ± 0.74 bA	7.79 ± 0.49 aA	7.63 ± 0.45 aA	7.75 ± 0.45 aA
	Apical	5.71 ± 0.57 bA	5.63 ± 0.33 bA	5.78 ± 0.45 bA	7.52 ± 0.47 aA	7.45 ± 0.51 aA	7.57 ± 0.63 aA
6 months	Cervical	5.58 ± 0.39 bB	5.07 ± 0.73 bB	5.27 ± 0.54 bB	7.66 ± 0.36 bB	7.32 ± 0.58 bB	7.39 ± 0.40 bB
	Middle	5.52 ± 0.57 bB	4.66 ± 0.64 cB	4.73 ± 0.35 cB	7.46 ± 0.67 aA	7.29 ± 0.60 aA	7.25 ± 0.29 aA
	Apical	5.50 ± 0.36 bA	4.49 ± 0.72 cA	4.43 ± 0.93 cA	7.21 ± 0.61 aA	7.08 ± 0.47 aA	7.13 ± 0.66 aA

Abbreviation: AS, Adper Scotchbond Multi-Purpose; C, customized post; NC, noncustomized post; R2, RelyX U200; RA, RelyX ARC; RU, RelyX Ultimate; SU, Scotchbond Universal.

[a] *Different lowercase letters on the same line indicate significant differences in the bond strength (p<0.05). Different uppercase letters in the same column and third indicate significant differences in the bond strength (p<0.05)*

Dentinal Penetrability Evaluation

AS–RA protocols presented the greatest dentinal penetrability, regardless of the dentin third and post customization (p<0.05). In contrast, the R2–NC protocol (RelyX U200 cement with noncustomized post) showed the lowest dentinal penetrability (p<0.05); however, the R2–C protocol with customized posts presented dentinal penetrability similar to Scotchbond Universal/RelyX Ultimate protocols (p>0.05).

Table 4 shows the mean and standard deviation of dentinal penetrability values of the cementation system to dentin according to the customization treatment. Figures 6 and 7 display representative images of dentinal penetrability of the cementation systems in the post space thirds, using both noncustomized and customized posts.

DISCUSSION

Customized posts luted with traditional protocols using alternative resin cements presented a positive effect on the bond strength and dentinal penetrability. The lowest cement system thickness was observed when conventional resin cement with etch-and-rinse, universal, and self-adhesive systems were used. Therefore, the null hypotheses were rejected.

Proper sealing of the root canal is essential for successful endodontic treatment. The use of customized anatomical fiber post during the rehabilitation procedure ensures better adaptation to the walls of the root canal, decreases the risks of axial displacement, and, consequently, the risks of adhesive failures and reinfection of the root canal.[7,8]

After 24 hour and 6 month immersion in distilled water, the cementation systems in the customized posts presented similar bond strengths. In addition, customized fiber posts presented the highest push-out values. These results may be explained by two factors: higher frictional retention of the fiber posts and lower thickness of the cement layer.[21,28,29] These data are in accordance to Macedo and others[7] who observed that customization increased fiber post retention due to the improved contact between the cement and adhesive.

The customized fiber post with resin cement presented low shrinkage stress, since the volume and layer of cement were reduced.[29-31] This study showed that the bond strength values were in accordance to D'Arcangelo and others,[32] although, the luting systems presented different bonding strategies, as shown in Table 1.

The bonding between dental materials and root dentin is commonly assessed using push-out tests.[15,33-35] Despite it not showing the real clinical behavior of resin cements, push-out testing is one of the most used methods to evaluate the bonding of dental materials.[2,17,36,37] However, many variables may affect the bond strength results, such as, the material stiffness, specimen position in relation to the load force application, and the diameter of the root canal and punch.[36] The bond strength may also be affected when the material under evaluation undergoes deformation.[37] Nevertheless, it was not relevant in this study, since the whole set (cementation system/fiber post) was rigid and, practically, did not suffer plastic deformation during the push-out test.

Misalignment during the inclusion of the specimens in polyester resin results in deviation of the load application, causing significant variation in bond strength values.[36] The adhesive area is obtained using the following formula:

$$A=\pi \bullet g \bullet (R+r),$$

where g is obtained from the formula $g=(R-r)^2+(h)^2$. If the h value (circular straight cone trunk height) is not constant due to the lack of uniformity in the specimens, the bond strength values will be severely compromised.[34,35] In order to avoid this, the specimens

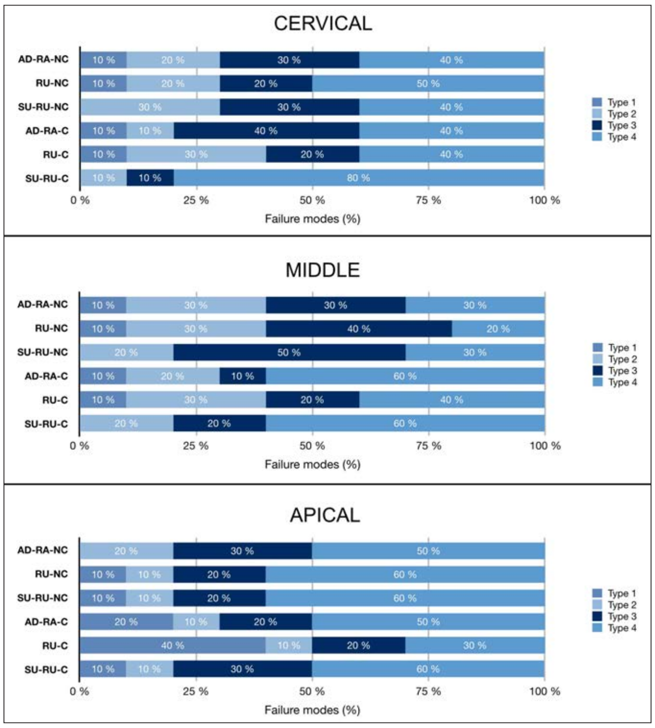


Figure 4. *Incidence of the failure mode according to the cementation protocols and post space thirds (24 hours).*

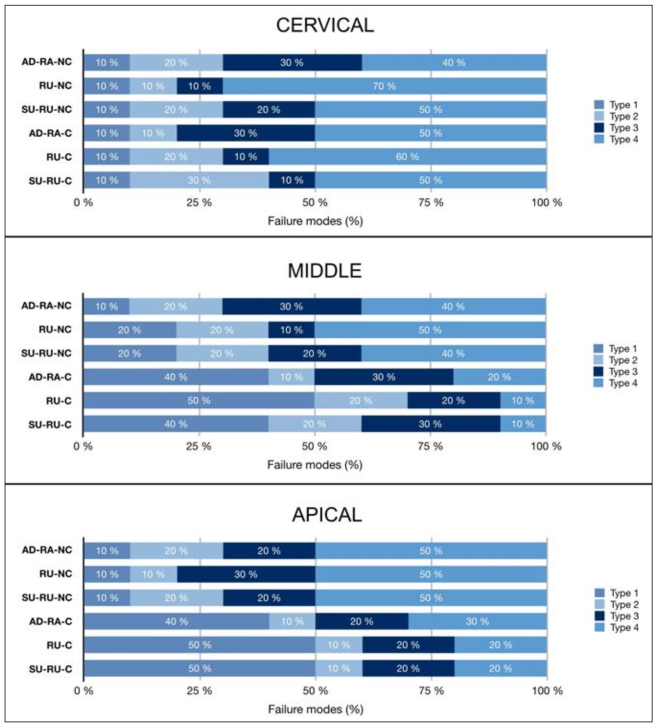


Figure 5. Incidence of the failure mode according to the cementation protocols and post space thirds (6 months).

were included in vinyl resin using a parallelometer. Then, they were transversely sectioned to their root axis with the same thickness and individually checked with a caliper (0.01 mm).

The punch diameter should be between 50% to 83% of the root canal diameter.[36,38] Thus, this study used a punch with compatible diameters for each post space third, in order to avoid any influence on the bond strength values. The diameters of 1.2 mm, 0.9 mm, and 0.5 mm for the cervical-, middle-, and apical-thirds, respectively, were used. Additionally, it avoided friction with the root dentin and plastic deformation of the material.

The bond strength values are also associated with the type of cement, its thickness, and its polymeric degree of conversion.[7,39] Noncustomized posts placed in wide root canals increase the cement thickness and, depending on the cement composition, may affect the its polymerization in deeper regions, reducing the bond strength and the dentinal penetrability.[39]

In all root-thirds, customized fiber posts presented the lowest cement system thickness, but no differences between the cementation protocols were observed due to the adaptation in the root canal.[21,28,29] On the other hand, the cementation system thickness in the groups of noncustomized fiber post were similar to each other, because the post space was subjected to conformation with the DC#2 bur, which has a similar taper to the fiber post used in this study. In the push-out analysis, all noncustomized groups showed lower bond strength values than customized groups, except in the cervical-third for the 6 month evaluation. However, in that

Table 3: *Mean and Standard Deviation (in micrometers) of the Cementation System Thickness According to Customization Protocol and "Space Post-thirds"*[a]

	AS–RA–NC	R2–NC	SU–RU–NC	AS–RA–C	R2–C	SU–RU–C
Cervical	53.53 ± 3.96 b	54.84 ± 4.07 b	53.04 ± 2.37 b	8.65 ± 1.55 a	8.66 ± 1.21 a	8.31 ± 0.92 a
Middle	28.88 ± 1.52 b	29.33 ± 1.39 b	28.43 ± 1.28 b	7.45 ± 0.49 a	7.58 ± 0.45 a	7.41 ± 0.37 a
Apical	14.57 ± 1.01 b	14.62 ± 0.82 b	14.18 ± 0.67 b	4.57 ± 0.68 a	7.28 ± 0.25 a	4.47 ± 0.34 a

Abbreviations: AS, Adper Scotchbond Multi-Purpose; C, customized post (6 minutes); NC, non-customized post; R2, RelyX U200; RA, RelyX ARC; RU, RelyX Ultimate; SU, Scotchbond Universal.

[a] *Different lowercase letters on the same line indicate significant differences in the cement system thickness (p<0.05).*

Table 4: *Mean and Standard Deviation (mm) Values of Dentinal Penetrability According to Space post-third and Type of Cementation System[a]*

	AS–RA–NC	R2–NC	SU–RU–NC	AS–RA–C	R2–C	SU–RU–C
Cervical	383.22 ± 27.08 a	123.27 ± 14.80 c	217.17 ± 20.85 b	377.70 ± 16.72 a	209.45 ± 10.52 b	216.6 ± 14.18 b
Middle	376.97 ± 12.95 a	84.09 ± 13.06 c	208.82 ± 9.22 b	375.89 ± 13.92 a	203.74 ± 11.06 b	207.20 ± 12.85 b
Apical	369.87 ± 11.30 a	82.57 ± 10.98 c	206.74 ± 6.21 b	370.84 ± 9.05 a	199.81 ± 12.77 b	203.88 ± 11.45 b

Abbbreviations: AS, Adper Scotchbond Multi-Purpose; C, customized post (6 minutes); NC, noncustomized post; R2, RelyX U200; SU, Scotchbond Universal; RA, RelyX ARC; RU, RelyX Ultimate.

[a] *Different lowercase letters on the same line indicate significant differences in the dentinal penetrability (p<0.05).*

situation, the mixed failure mode was the most frequent and indicates that the rupture probably occurred directly in the resin cement. Therefore, due to this phenomenon, the results were similar regardless of the cementation system thickness.

The dentinal penetrability evaluation using CLSM images can quantify the cementation system diffusion into the dentinal tubules and the collagen matrix.[15,27] This study used a conventional cementation system with etch-and-rinse (Adper Scotchbond Multi-Purpose), Universal (Scotchbond Universal), and self-adhesive systems. Rhodamine pigment was added to the adhesive system using a ratio of 16 μL to 0.4 mL of primer (Adper Scotchbond Multi-Purpose) or Universal adhesive (Scotchbond Universal), and 0.1% (mass/mass) in the self-adhesive cement (RelyX U200) to be analyzed by CLSM.[2,16,17] Although the fluorescent pigments may reduce the monomer conversion and the bond strength of resinous compounds to dentin, the concentrations used in this study presented no effect on the polymerization, the dentinal penetrability, and the bond strength of resin-based materials.[27,29,40]

Adhesive interface analysis using CLSM presents an advantage over scanning electron microscopy (SEM), since CLSM enables the preservation of the specimens and does not require a vacuum during image processing, which avoids technical artifacts, such as cracks and false areas of misadaptation.[28,29] Thus, this study has used surface laser confocal microscopy (Lext OLS4100) to analyze the adhesive failure mode, after identification with the CLSM evaluation.

According to our results, dentinal penetrability occurs according to the dentin substrate and the adhesive system, in addition to the pressure exerted on the

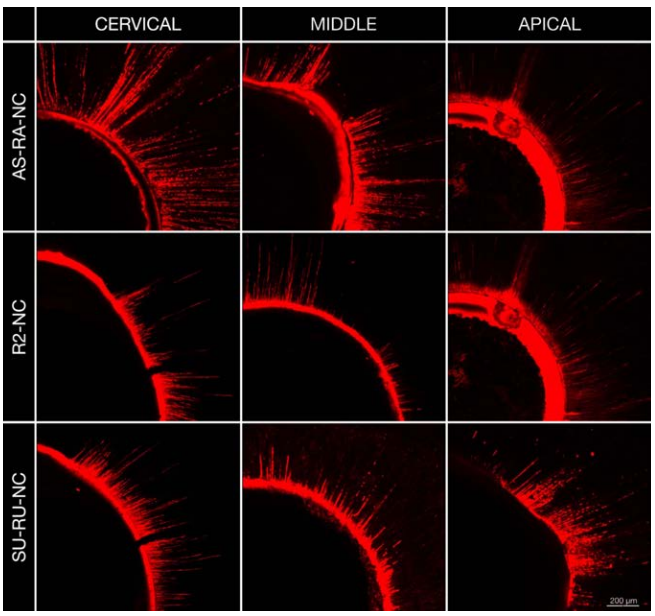


Figure 6. *Representative image of the cementation system penetration in dentin, according to the protocol using non-customized posts and root third. Scale: 100 µm (6 mm). AS, Adper Scotchbond Multi-Purpose; RA, Relyx ARC; R2, Relyx U200; SU, Scotchbond Universal; RU, Relyx Ultimate; NC, non-customized.*

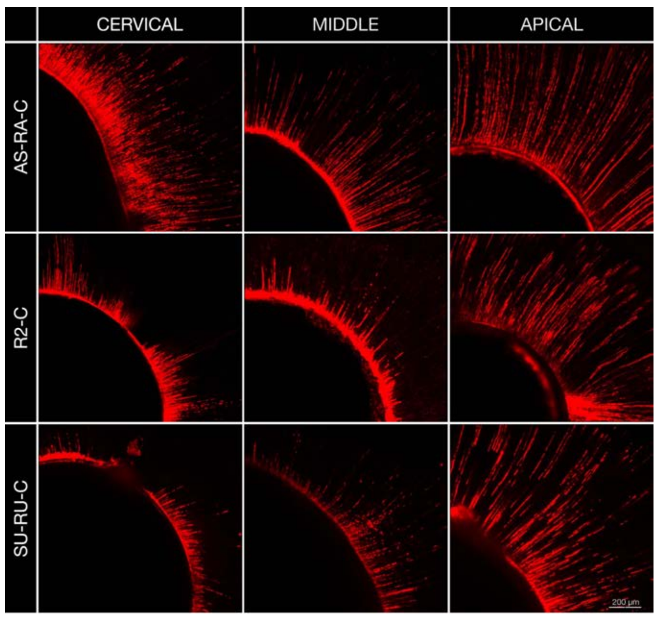


Figure 7. *Representative image of the cementation system penetration into the post space dentin, according to the protocol with customized posts and root third. Scale: 100 µm (6 mm). AS, Adper Scotchbond Multi-Purpose; NC, non-customized; RA, Relyx ARC; R2, Relyx U200; SU, Scotchbond Universal; RU, Relyx Ultimate.*

walls. Although the self-adhesive resin cement system does not have a greater penetrability, it shows relative adhesion mainly by a chemical process.[7,18] A three-step etch-and-rinse adhesive system showed higher dentinal penetrability than a one-step self-etching system (Universal) and a self-adhesive cementation system (RelyX U200), due to its primer, presenting lower surface tension.[13,15]

Conventional cementation systems presented higher dentinal penetrability than self-adhesives, because fluorescent pigment was added to the most fluid substance, such as, into the primer (Adpter Scotchbond Multi-Purpose) or directly in the Universal adhesive (Scotchbond Universal). However, it did not show a direct relation to the post retention in the root canal, according to Lorenzetti and others.[2]

Customization provides a smaller volume of cement and, due to the better adaptation to the fiber post space, possibly also provided greater pressure during the insertion of the post, which may influence the similarity of results regarding dentinal penetrability.[7] On the other hand, the polymerization of self-adhesive resin cement and consequently its bond strength to dentin may have been compromised due to the interference of residual acid monomers on the tertiary amines in the dentin area of the prosthetic space triggered by incomplete photoactivation.[39]

Therefore, resin customization appears to be a viable alternative to minimize the risks of axial displacement of the fiber posts and to improve the clinical longevity of restorative procedures in endodontically treated teeth. However, further studies should be conducted in order to improve and complement this study, such as, which type of resin composite should be used in the customization procedure and the photoactivation timing of cementation systems.

CONCLUSIONS

Customized fiber posts presented better bond strength of the cement, enhanced dentinal penetrability, and a lower cementation system thickness than noncustomized posts, regardless of the cementation protocol tested.

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Regulatory Statement

This study was approved by the Ethical Committee in Animal Use from the Araraquara School of Dentistry (23/2019).

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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