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Original Article

Effect of Post Sizes and Citric Acid Treatment on the Bond Strength of Fiber Posts Using Self-Etch Resin Cement in Calcium Silicate–Based Sealer Treated Teeth

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Abstract

Objectives This study evaluated the effects of different post sizes and citric acid (CA) treatment on the bond strength of fiber posts cemented with self-etch resin cement in teeth obturated with calcium silicate–based sealer.

Materials and Methods Seventy mandibular premolars were collected and randomly distributed to either a control group (no sealer) or experimental groups obturated with calcium silicate–based sealer (iRoot SP). The experimental groups were classified by post sizes—1.25 mm (no. 1), 1.375 mm (no. 2), and 1.50 mm (no. 3)—and the irrigants used (distilled water [DW] or CA). Prefabricated fiber posts were fixed using NX3 self-etch resin cement. Push-out bond strength was tested in the coronal and middle sections of the roots.

Statistical Analysis The data were analyzed using a one-way analysis of variance (ANOVA), followed by a post hoc Duncan test.

Results In the coronal section, post size no. 1 with DW showed significantly lower bond strength compared to the other experimental groups ($p < 0.05$). In the middle section, the larger post sizes (nos. 2 and 3) with CA treatment resulted in a significant increase in bond strength compared to the control group ($p < 0.05$).

Conclusions iRoot SP negatively affected bond strength in the middle section of the canal. However, using larger post sizes (nos. 2 and 3) with CA treatment improved bond strength in the middle section.

Keywords
- bond
- citric acid
- fiber post
- resin cement
- root dentine

Introduction

Root canal–treated teeth often undergo loss tooth structure.[1] Therefore, an intraradicular post is required for restoration to gain a tooth structure replacement and return their functions.[2] Using prefabricated fiber posts that mimic the elasticity of natural teeth facilitates a uniform distribution of force. This reduces the risk of catastrophic failures, such as root fractures, in comparison to metallic posts.[3]

Resin cement adheres to root dentin primarily through micromechanical interlocking, which is facilitated by creating a hybrid layer and allowing tags to penetrate dentinal tubules.[4] This efficacy is influenced by the sealer type, as sealer components can impede the polymerization of the

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resin cement or its penetration into the dentinal tubules.[5] This interference can compromise the bond between prefabricated fiber posts and dentin walls.[6–8]

Recently, calcium silicate–based sealers have gained significant attention for their notable biocompatibility, superior flowability, and ability to chemically bond to dentin.[9] However, several studies indicated that this type of sealer can reduce the adhesive force of self-etch adhesive resin cement systems.[10,11] This reduction may be due to the sealer's deep infiltration into dentinal tubules and its difficulty in being removed from the canal walls, thereby obstructing the infiltration of resin cement into these tubules.[6,12]

Various methods for enhancing the bond strength of prefabricated posts in canals filled with various sealers have been investigated. A prior investigation revealed that post-space preparation following root canal filling with zinc oxide–based and epoxy resin–based sealers enhances intraradicular post retention. This is due to the removal of sealer-occluded dentin surfaces, which enables the resin cement to bond more effectively to the root canal wall.[13]

Citric acid (CA), a chelating compound, is currently employed in root canal irrigation for smear layer elimination.[14] It was noted that pretreating post-space surfaces with 10% CA enhanced the adhesive strength of self-etch resin cement to dentin walls.[15] Furthermore, previous research found that CA can cause pitting on the outer layer of calcium silicate–based cement and alter its surface microhardness.[16] In addition, 10% CA dissolves the inorganic part of the root canal walls, enhancing retreatment efficiency. This acid also interferes with the adhesion of gutta-percha, sealer, and dentin, facilitating more sealer removal and cleaner canal surfaces.[17]

Calcium silicate–based sealers are known for their biocompatibility, but their impact on the bond strength of fiber posts with self-etch resin cements is not well established. CA irrigation has shown potential to improve bonding, but studies on its effect with calcium silicate–based sealers are limited. Similarly, the role of post sizes in enhancing bond strength, particularly with CA treatment, remains unclear. Thus, this study aims to investigate the effects of CA irrigation and post sizes on the bond strength of fiber posts cemented with self-etch resin cement in teeth filled with calcium silicate–based sealers. The null hypothesis of this study is that neither of the aforementioned two variables affects the bond strength of fiber posts cemented with resin cement.

Materials and Methods

Calculating Sample Size

The sample size was calculated using G*Power software (version 3.1.9.7) based on a pilot study; the statistical power was estimated at 0.80, with a significance level set at $\alpha = 0.05$. A minimum of eight teeth per group was required, and 10 samples were used for each experimental group to ensure reliable results.

Specimens Preparation

The experimental protocol of this study was approved by the Human Experimentation Committee, Faculty of Dentistry, Chiang Mai University, Thailand (No. 5-6/2566). Seventy extracted human mandibular premolars with mature apices, extracted for orthodontic reasons, were collected. The teeth had no carious lesions, restorations, cracks, or fractures, and were radiographically evaluated to confirm the presence of a single canal and no prior endodontic treatment. After cleaning the roots, the samples were stored at room temperature in a 0.1% v/v solution of thymol.

The root specimens were standardized to a length of 14 mm by transversely sectioning samples at the cementoenamel junction using a diamond disk. The working length (WL) was set at 1 mm shorter than the apical foramen, and the access cavities were subsequently created for each specimen. Specimens were excluded if their canal size was larger than an ISO 25 K-file at the WL. The canals were mechanically prepared using Mtwo NiTi rotary files (Mtwo, VDW GmbH, Munich, Germany), reaching a size 40 with 0.06 taper. Throughout this process, 20 mL of sodium hypochlorite at a concentration of 2.5% was used for irrigation, a 27-gauge close-ended needle was positioned 2 mm from the apex. The canals were irrigated for 1 minute with 5 mL of ethylenediaminetetraacetic acid (EDTA; 17%) to eliminate the smear layer. The canals were then flushed with 5 mL of DW and dried using paper points. Subsequently, the canals were obturated using size 40 gutta-percha cones with a 0.06 taper and a calcium silicate-based sealer (iRoot SP; Innovative BioCeramix Inc., Vancouver, BC, Canada) in accordance with the manufacturer's instructions (single cone technique). The control group, however, was obturated using the warm vertical compaction technique without the use of canal sealer. The excess filling materials were removed from the canal orifice and condensed. Following obturation, radiographs were acquired for each specimen to assess the integrity of the root canal obturation. The pulp chamber was then sealed with temporary filling (Caviton; GC, Tokyo, Japan), and the samples were stored at 37°C for 14 days.

Post Preparation and Cementation

After the incubation period, the 60 experimental specimens were divided randomly, by the diameter of the prefabricated post, into three groups (FibreKleer 4x tapered; Kerr, Orange, CA, United States): 1.25 mm (no. 1), 1.375 mm (no. 2), and 1.50 mm (no. 3). An additional control group of 10 specimens was assigned to the 1.25-mm post-space diameter (►**Fig. 1**).

Following the removal of the temporary filling, the obturation materials were removed using a size 1 Peeso reamer, followed by a FibreKleer post drill with diameters of 1.25, 1.375, or 1.50 mm (20 specimens per group), and the remaining 4 mm of gutta-percha was preserved in order to keep the apical seal. For the control group, a 1.25-mm post-space drill was used. Each experimental group of 20 specimens was then subdivided into two subgroups based on the irrigants used: DW and CA.

- ***DW*** subgroup and control group: 2 mL of DW was used to irrigate the canals for 2 minutes.
- ***CA*** subgroup: The canals were irrigated for 1 minute with 10% CA and then rinsed for 1 minute with DW.

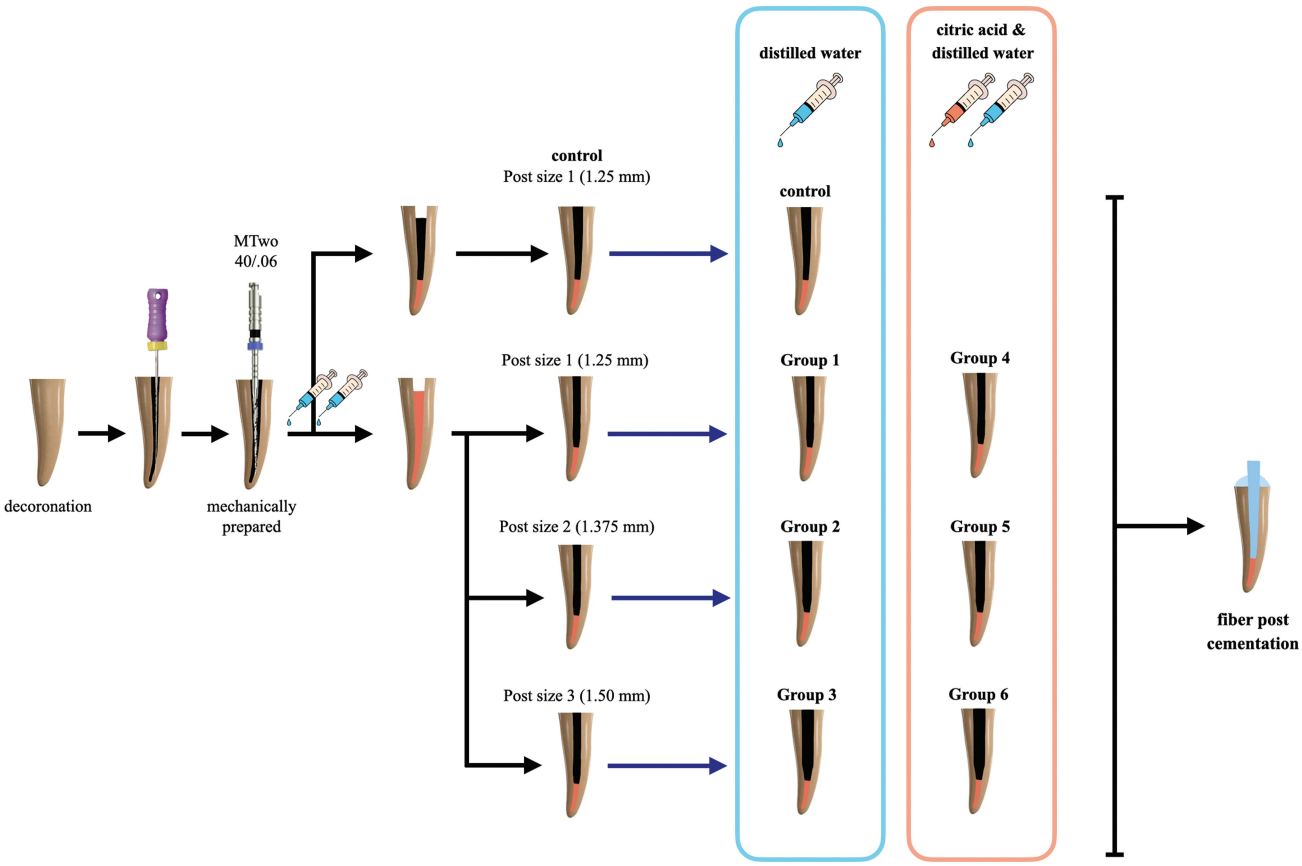

Fig. 1 Schematic diagram representing the experimental procedures.

After the post space was dried, a prefabricated tapered fiber post corresponding to the size of the prepared space was cemented using a self-etch dual-cured resin cement system (NX3 and OptiBond Universal, Kerr) following the instructions provided by the manufacturer. The specimens were then stored for 7 days at 37°C.

Push-Out Bond Strength Test

After 7 days of incubation, roots were securely installed in acrylic resin and oriented along its longitudinal axis via a surveyor. A water-cooled IsoMet 1000 Precision Saw (Buehler, Lake Bluff, IL, United States) operating at a slow speed sectioned them across their longitudinal axis. Two slices with 1-mm thickness were cut at 7 and 12 mm above the root apex, representing the middle and coronal sections, respectively. The thickness of the slices was precisely verified using a digital caliper. The push-out test is done by applying cylindrical pluggers with a diameter of 0.8 mm from the apical end of each slice using an Instron 5566 UTM (Instron Engineering Corporation, Norwood, MN, United States). A steady load was applied at a 1 mm/min crosshead speed. The maximal load at fiber post that becomes dislodged was noted in newtons (N) and then adjusted to megapascals (MPa) using the equation $MPa = F/A$, where F indicates the bond strength (N) and A is the post/dentin interface area (mm^2), calculated for each section following Coniglio et al's method[18]: $A = \pi(R + r)\sqrt{h^2 + (R - r)^2}$. The thickness of the root slice is denoted by h, while R and r represent the coronal and apical intraradicular post radius, respectively.

Following the test, a 40x magnification phase contrast inverted microscope (Olympus, Tokyo, Japan) was used to visually inspect each section of the specimens in order to identify the mode of failure. The following six failure pattern were considered: failure of adhesion at the dentin–cement interface (type 1); failure of adhesion at the post–cement interface (type 2); failure of cohesive in dentin (type 3); failure of cohesive in cement (type 4); failure of cohesive in fiber post (type 5); mixed failure or encompassing both types mentioned previously (type 6).

Statistical Analysis

The data were statistically analyzed using the SPSS v.25.0 program (SPSS Inc., Chicago, IL, United States) to evaluate differences in bond strengths among the groups, using a one-way analysis of variance (ANOVA) followed by Duncan's test with a 95% confidence interval.

Results

►**Table 1** presents the average bond strengths and their standard deviations for each experimental group. For the coronal section, the bond strength values of group 1 (post no. 1/DW) did not show any significant differences compared to the control group ($p = 0.903$). The bond strengths of group 2 (post no. 2/DW), group 3 (post no. 3/DW), group 4 (post no. 1/

Table 1 The average push-out bond strengths (MPa) ± standard deviation of fiber posts in groups with varying post-space preparations and root canal surface treatments

	Control	Distilled water (DW)			Citric acid (CA)		
		Post no. 1	Post no. 2	Post no. 3	Post no. 1	Post no. 2	Post no. 3
		Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Coronal	5.32 ± 0.60^{a}	5.20 ± 0.46^{a}	7.53 ± 0.52^{b}	8.44 ± 0.87^{bc}	8.42 ± 0.86^{bc}	9.47 ± 0.92^{bc}	10.09 ± 0.66^{bc}
Middle	3.16 ± 0.55^{B}	1.07 ± 0.89^{A}	4.11 ± 0.55^{B}	4.12 ± 0.49^{B}	2.63 ± 0.36^{B}	6.04 ± 0.74^{C}	6.94 ± 0.75^{C}

Note: Different lowercase letters indicate a statistically significant difference between rows of the coronal part of the root canal, according to Duncan's test results ($p < 0.05$).
Different uppercase letters indicate a statistically significant difference between rows of the middle part of the root canal, according to Duncan's test results ($p < 0.05$).

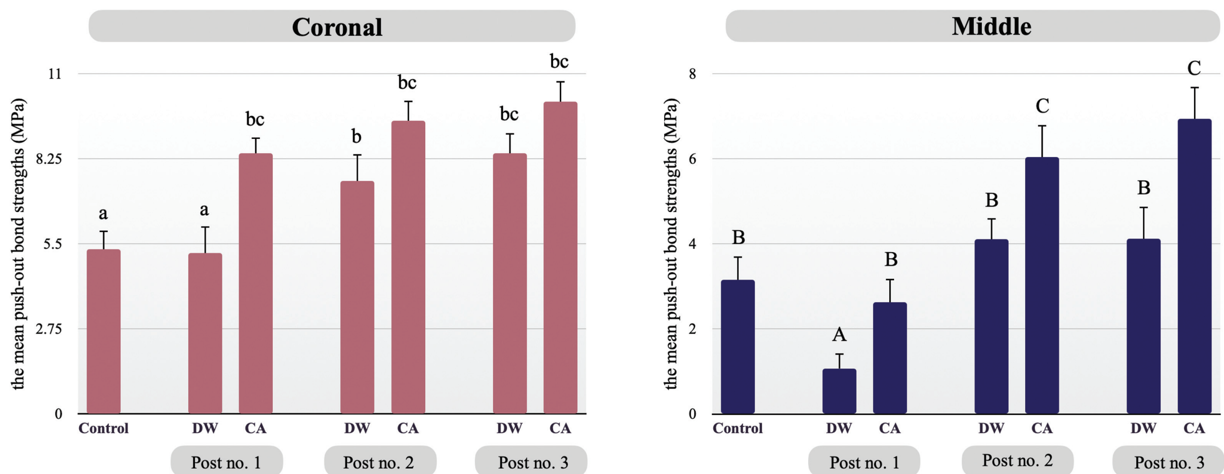

Fig. 2 The bond strength tests were obtained from all experimental groups (left) coronal sections and (right) middle sections. CA, citric acid; DW, distilled water.

CA), group 5 (post no. 2/CA), and group 6 (post no. 3/CA) were determined to be statistically comparable but had a significantly higher bond strength than the control group and group 1 ($p < 0.05$).

For the middle section, the bond strength in group 1 was significantly lower than that in the control group ($p < 0.05$). Groups 2 and 3 exhibited bond strengths that were statistically similar to the control group ($p = 0.083$). However, groups 5 and 6, treated with CA, exhibited significantly higher mean bond strengths than the control group ($p < 0.05$).

From ►**Fig. 2**, within the coronal section, the CA-treated group exhibited an increase in bond strength exclusively in the subset where post-space preparation no. 1 was conducted. Meanwhile, in the middle section, irrigation of the post space with CA significantly enhanced bond strength compared to DW across all experimental groups.

Mixed failure (type 6) is the most commonly observed failed pattern. The next common failed pattern is type 2 failure, in both the coronal and middle parts of the root canal, as shown in ►**Fig. 3**. ►**Fig. 4** illustrates the failure patterns observed in this study.

Discussion

Clinical procedures that optimize adhesion to the dentin surface are directly related to the successful retention of posts in the root canal. Previous studies have consistently indicated that calcium silicate–based sealers do not impact the bond strength of posts cemented with self-adhesive resin cements.[6,19] On the contrary, these sealers adversely affect the bonding efficiency of self-etch resin cements, leading to reduced fiber post retention.[10,11] This discrepancy can be attributed to the distinct bonding mechanisms inherent to these two resin cement systems.[6,8] Based on our findings, in the middle third section, the use of calcium silicate–based sealers notably decreased bond strength compared to the control group, specifically for the smallest post size (1.25 mm with DW), which is consistent with several prior studies.[6,10,20] This indicates that the sealer can penetrate the dentinal tubules and react with phosphate ions on the root dentin surface to form hydroxyapatite and tag-like structures that are difficult to remove completely during post-space preparation.[21] Moreover, acidic monomers in the bonding system might not efficiently modify the dentin surface, thereby impeding the process of creating adhesive/resin tags and the hybrid layer created by self-etch resin cements.

In addition, the post-space diameter is smaller and narrower in the middle third of the canal in group 1 (post no. 1/DW). Therefore, it is possible that the sealer-contaminated dentine surface is not adequately removed. This includes the challenges of accessing the region with various tools for

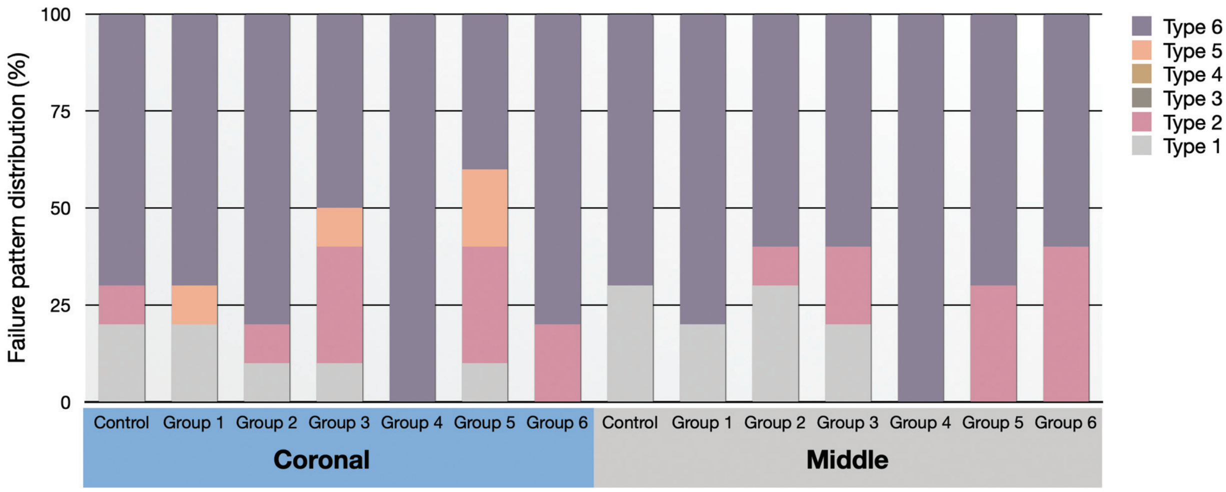

Fig. 3 Failure pattern distribution (%) for all experimental groups.

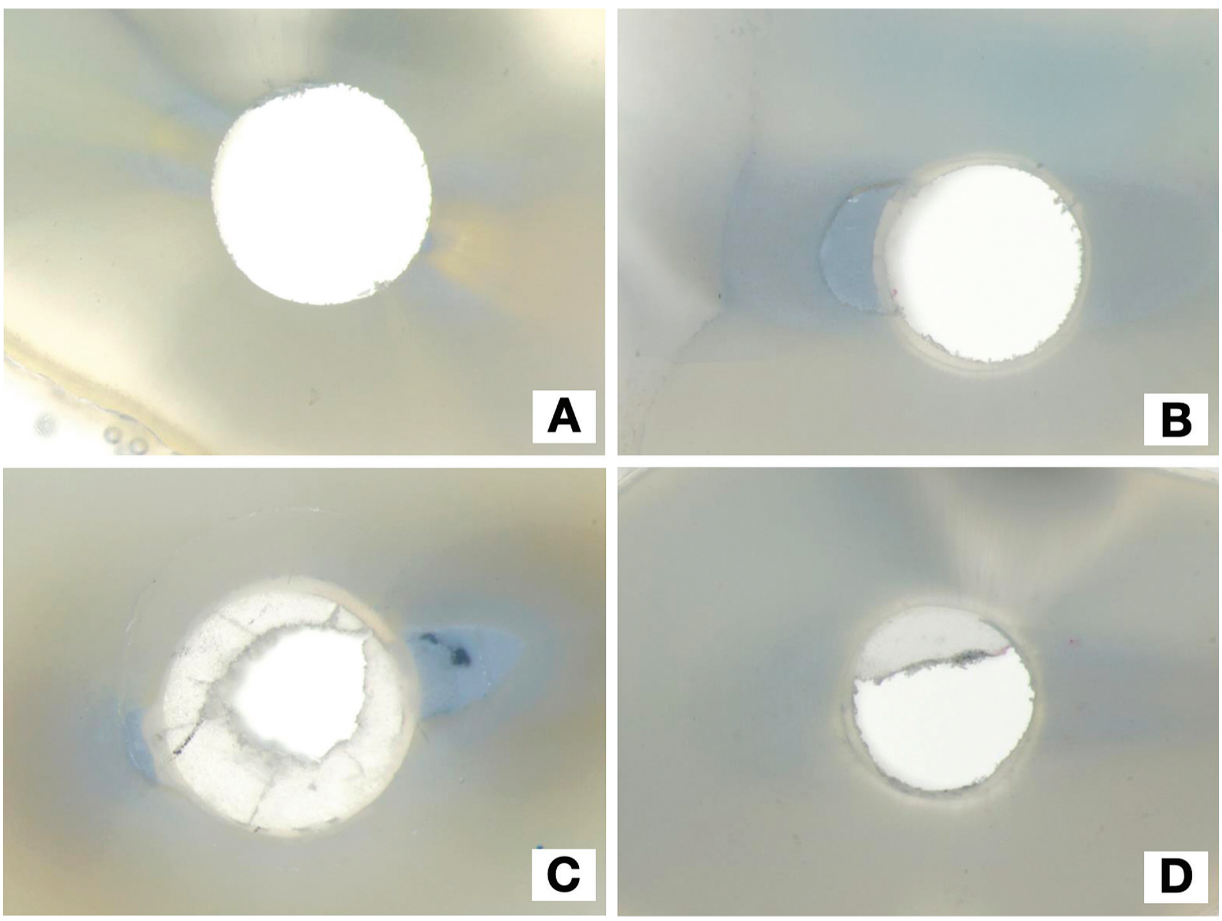

Fig. 4 Representative image of failure pattern observed in this study. (**A**) Type 1: adhesive failure at the dentin–cement interface. (**B**) Type 2: adhesive failure at the post–cement interface. (**C**) Type 5: cohesive failure in the post. (**D**) Type 6: mixed failure.

applying bonding agents or resin cements, as well as difficulties in light curing for polymerization. Such factors may compromise adhesion in this particular region.[22]

In the coronal region, this study found that the iRoot SP sealer did not negatively impact the adhesive strength of fiber posts when used in conjunction with self-etch dual-cured resin cement (5.20 ± 0.46 MPa in group 1 and 5.32 ± 0.60 MPa in the control group without sealer use). This may be attributed not only to the higher diameter and density of dentinal tubules in the coronal region, which can enhance bonding, but also to other factors such as the larger bonding surface area and improved access for light curing. These conditions may make the coronal region more suitable for adhesion, potentially reducing the impact of the materials used.[23] Dibaji et al,[10] on the other hand, stated that the bond strength of fiber posts fixed with self-etch resin cement in calcium silicate sealer–obturated canals decreased in the coronal part of the fiber post. Differences in methodology, including the length of time after root filling or post fixation, and variances in obturation techniques (such as the use of a single cone method vs. warm vertical compaction) may contribute to these disparate results.

After the enlargement of the post space aiming for the effective removal of residual materials on the root canal walls, it was noted that in the middle part of the canal, increasing the post space from group 1 (diameter 1.25 mm) to group 2 (diameter 1.375 mm) increased the bond strength to levels equivalent to the control group. This is possibly a result of the iRoot SP sealer infiltrating the dentinal tubules to an approximate depth of 0.1 to 0.25 mm when applied in conjunction with the single cone obturation technique.[24] When preparing the post space in group 2, the canal walls are prepared by approximately 0.30 mm all around from the original root canal diameter. Consequently, enlarging the post space in the middle third of the root canal effectively removes most of the dentin contaminated with sealer. This results in cleaner dentin, which in turn improves the adhesion between the dentin and the cement.

An increase in fiber post bond strength has been observed with larger post diameters in the cases where zinc-oxide-eugenol-based sealers are used during obturation. This not only facilitates removing sealer-contaminated dentin but also increases the bonding surface area.[25] However, according to the findings of this study, enlarging the post-space diameter from 1.375 to 1.50 mm did not result in an improvement in bond strength. This may be because the bond strength of the post depends predominantly on the thickness of the resin cement layer.[22,26] This is because this factor correlates with the cavity configuration (C-factor), which affects the distribution of the internal stress within the material. By preparing a post space with a larger diameter and using a post of the same size, the resin cement layer's thickness remains relatively consistent, leading to no statistical difference in bond strength.[26]

When comparing the experimental groups that were rinsed with DW to those with CA after preparing the post space, it was found that CA tended to yield a higher bond strength than the group irrigated with DW. Dąbrowska et al[16] found that CA can dissolve some surfaces of the calcium silicate cement and remove inclusions from the matrix, resulting in a porous and rough texture on the material surface. This is similar to the surface of etched dentine, which might enhance the adhesion of the resin cement. Additionally, CA acts as a chelating agent, capable of removing the smear formed on the canal wall during post-space preparation.[27] This allows the resin cement to penetrate and form a hybrid layer in the acid-etched dentin, potentially increasing the bond strength.[28]

In terms of canal regions, the adhesive strength in the coronal part of the canal was found to be higher than that in the middle section. Apart from the high density of tubules in the coronal region of canals, which facilitates effective micromechanical retention from the resin cement, the use of light curing with dual-cured resin cement further amplifies polymerization in the coronal section of the roots.[29] This might potentially enhance the bond strength. This contradicts the findings of Yuanli et al,[30] who found that the bond strength in the middle or apical part of the fiber post was higher than that in the coronal section. This discrepancy might be attributed to their use of self-adhesive resin cement. Their study primarily relied on the chemical reaction between the cement and the hydroxyapatite-enriched dentin surface, which is more prevalent in the apical portion of the root canal.[31] Therefore, this led to higher bond values in the apical portion for the mentioned cement group.

The most commonly observed failure pattern was mixed failure. Additionally, in groups that were rinsed with CA, an adhesive breakdown occurred in the contact between the post and the cement, evident in both the coronal and middle sections of the canal. This suggests a trend of enhanced bonding between the cement and the surface of the dentin.

In this present investigation, the single cone obturation method was used in conjunction with the iRoot SP sealer. Yang et al[24] and Casino Alegre et al[32] investigated the infiltration of calcium silicate–based sealers used with various root canal filling techniques. The authors discovered that the continuous wave compaction technique enabled deeper invasion of the sealer into dentinal tubules compared to the single cone technique. Consequently, further research examining the performance of the iRoot SP sealer with alternative root canal obturation methods or the impact of chelating agents or other substances on the bond strength of resin cement could provide valuable insights for advancing dental procedures.

Conclusion

Within the limitations of this in vitro study, iRoot SP reduced the bond strength of fiber posts cemented with self-etch dual-cured resin cement in the middle third of the canal. However, using a post size of 1.25 mm with CA irrigation restored the bond strength, while using larger post sizes (1.375 or 1.50 mm), along with CA pretreatment, resulted in an enhancement of the bond strength.

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Conflict of Interest
None declared.

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