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Original Article

# Comparing the bond strength of fiber post cementation in the root canal using pre- and co-curing procedures with the same self-etching bonding system

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## KEYWORDS

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technique

**Abstract** *Background/purpose:* Self-etching bonding systems are widely used in fiber post cementation. However, no clear guidelines are established for choosing pre- or co-curing procedures. We investigated the bond strength of fiber post cementation using pre-/co-curing methods in self-etching bonding systems and compared them with those of a self-adhesive system.

*Materials and methods:* Post spaces were prepared in 30 single-rooted premolars/canines, and the fiber posts were cemented in three ways (10 specimens per group): using a self-etching bonding system with either a pre-curing or simultaneous co-curing procedure (RelyX™ Ultimate; groups SE-pre and SE-co, respectively) and using a self-adhesive system (RelyX™ Unicem 2, group SA). Each specimen was embedded and sliced perpendicularly to the long axis into three 2.5-mm-thick sections. Microphotographs of the coronal and apical surfaces of each section were acquired, and push-out tests (1 mm/min) were performed. One-way analysis of variance was conducted on the data, followed by Tukey's honestly significant difference post hoc test.

*Results:* The bond strength in the whole root was not significantly different among the three groups. When independently evaluating each portion, group SE-co exhibited significantly lower coronal bond strength. The bond strength varied among root regions only in group SE-pre; the apical region had a significantly lower value.

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**Conclusion:** No cementation method is superior in all portions. Regarding pre-curing methods, clinicians must caution the fit between the post and post space, which may be affected by the pre-polymerized bond layer. The co-curing method used in a larger coronal cement space contributes to the poor bond strength.

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## Introduction

The application of fiber posts in a root canal is a time-efficient and convenient procedure that is widely used in routine clinical practice.<sup>1,2</sup> Cementation directly affects the post retention, thereby playing a crucial role in ensuring successful treatment outcomes. Luting agents are classified based on the adhesion mechanism into self-adhesive systems, total-etching bonding systems, and self-etching bonding systems. There are two approaches for using bonding systems with resin cement: in the first approach, the bond layer is light-cured before cement application, defined as the “pre-curing method”; in the second approach, the polymer bond and cement layers are cured simultaneously, defined here as the “co-curing method.”

Previous studies on fiber post cementation mainly compared self-adhesive cement systems with bonding systems combined with resin cement. For instance, self-adhesive systems have been compared with self-etching systems with either the pre- or co-curing procedure.<sup>1,3,4</sup> However, the differences between the pre- and co-curing procedures in the self-etching bonding systems used with fiber post cementation have not been evaluated to date. Therefore, there are no reliable recommendations that can guide clinicians in choosing a curing procedure.

Regarding the bond strength of composite resin filling, Chapman et al.<sup>5</sup> and McCabe et al.<sup>6</sup> revealed significant differences between pre- and co-curing procedures. Abdelaziz et al.<sup>7</sup> demonstrated that in direct composite resin restorations, the pre-curing method provided better dentin bond strength than the co-curing method. However, using the pre-curing method for cementing fiber posts may affect the fit of the post in the canal space owing to the thickness of the polymerized bond layer, and an ill-fitting post will degrade the bond strength. Therefore, the choice between pre- and co-curing procedures is controversial among clinicians.

This study aimed to determine whether the pre- or co-curing method in self-etching bonding systems can provide stronger bond strength. We focused on self-etching bonding systems instead of total-etching bonding systems because currently, the former is predominantly used. Self-adhesive cement was tested for comparison in the same setting. Furthermore, the differences among the root regions were analyzed. The null hypothesis was that there is no significant difference among the bond strengths achieved using the self-etching bonding system with the pre- or co-curing methods and the self-adhesive system for fiber post cementation.

## Materials and methods

### Sample collection

Thirty caries-free human premolars and canines were collected. The study protocol was reviewed and approved by the institutional review board of Chang Gung Medical Foundation (IRB: 202100369B0). The sample size was determined based on similar previous studies.<sup>8–10</sup> The inclusion criteria were root lengths longer than 15 mm and the absence of root caries and internal or external root resorption. The exclusion criteria were previous endodontic treatment and excessive root curvature determined according to a previously reported measurement method.<sup>11</sup>

### Tooth preparation

To remove the crown, each tooth was sectioned horizontally, 15 mm coronally from the root apex. The canal space was shaped using rotary nickel-titanium instruments (S1 to F4, ProTaper Universal; Dentsply Sirona, Konstanz, Germany) under constant irrigation with 3% NaOCl. Subsequently, the space was enlarged with post drills (RelyX™ Fiber Post Drill sizes 1–2; 3M-ESPE, St. Paul, MN, USA) to a depth of 10 mm. Final irrigation was performed using 10 mL of 3% NaOCl, 1 mL of 17% ethylenediaminetetraacetic acid (EDTA) (MD Cleanser; Meta Biomed Co., Cheongju, South Korea), and 10 mL of distilled water, in sequential order. Passive ultrasonic irrigation was conducted for 1 min using an ultrasonic device (VA970; NSK, Tokyo, Japan) with an Irrisafe tip (IRR 20-21; Acteon Group Ltd, Norwich, UK).

### Post cementation

The root canals were dried with paper points before cementing the posts. Thirty specimens were randomly divided into three groups with 10 teeth per group, and different luting cements and procedures were used for the post cementation in each group (Fig. 1). The materials used are listed in Table 1.

A self-etching bonding system with the pre-curing method (luting agent: RelyX™ Ultimate; 3M-ESPE; self-etching bonding agent: Scotchbond™ Universal Adhesive; 3M-ESPE) was used in the first group (group SE-pre). The bonding agent was applied to canal space using a microbrush (superfine, micro applicators; TPC Advanced Technology, Inc., City of Industry, CA, USA), air-thinned with a 23 G tip attached to a three-way tip, and light-cured for 20 s. A trial was conducted to assess the fit of the fiber post

(RelyX™ Fiber Post 3D Glass Fiber Post #2; 3M-ESPE), and the post length was recorded. The cement was injected into the canal space with an Endo tip attached to a mixing tip (Garant™ Mixing Tips Yellow; 3M-ESPE), after which the post was inserted and light-cured (Monitex LITE Q LED; Fomed Biotech Inc, Taipei, Taiwan) for 20 s.

In the second group (group SE-co), a self-etching bonding system with the same luting agent (RelyX™ Ultimate, 3M-ESPE) and self-etching bonding agent (Scotchbond™ Universal Adhesive, 3M-ESPE) as those in group SE-pre was used. Again, the bonding agent was applied to the canal space with a microbrush and air-thinned with a 23 G tip attached to a three-way tip, but in group SE-co, rather than light-curing, the cement was subsequently injected with an Endo tip attached to a mixing tip. The post was then inserted, and finally, the assembly was light-cured for 20 s.

A self-adhesive cement (RelyX™ Unicem 2 Automix; 3M-ESPE) was used in the third group (group SA). The cement was injected into the canal with an Endo tip attached to a mixing tip. The fiber post was then inserted, held in place for 20 s, and light-cured for 20 s.

All specimens were placed in 100% humidity for 24 h after cementation.

### Specimen preparation

Each specimen was dried with gauze and embedded within bis-acryl resin (Protemp™ 4; 3M-ESPE) in a Teflon mold

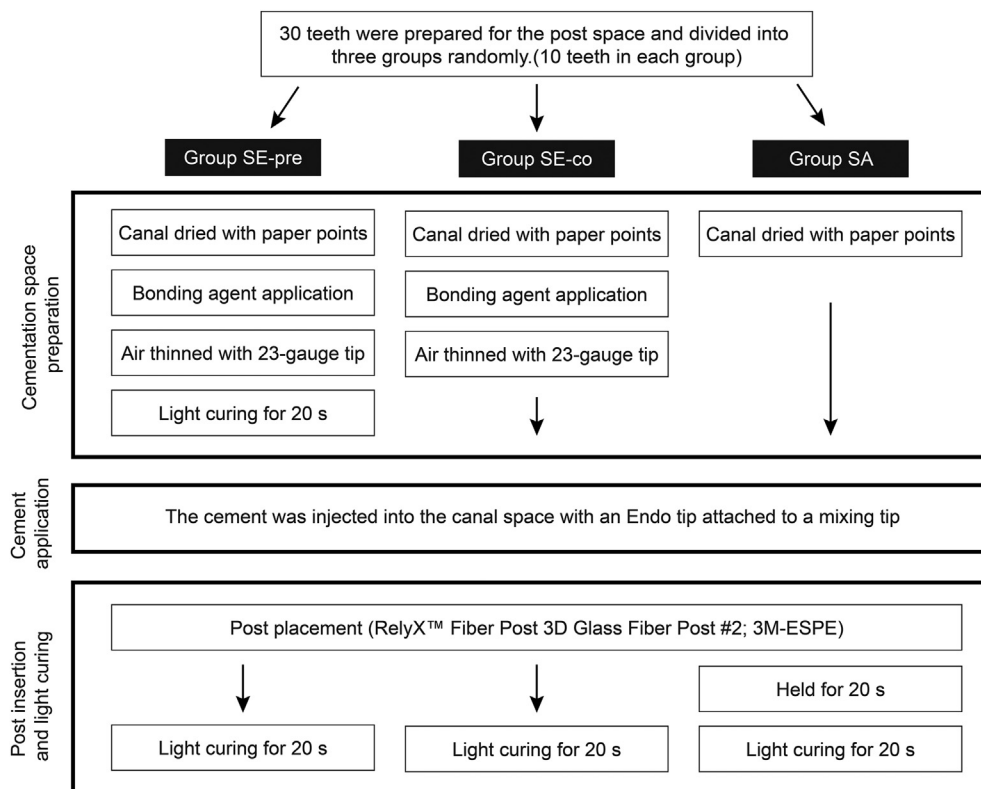
(Fig. 2). Each specimen-embedded resin block was sliced into three 2.5-mm-thick sections perpendicular to the long axis (Fig. 2D) using a sectioning machine (CL50; TOP TECH, Taichung, Taiwan) with a diamond saw (WB-0060LC; PACE Technologies, Tucson, AZ, USA).

### Push-out test

Microphotographs (coronal and apical surfaces) of each section were captured using a stereomicroscope (Leica M320; Leica Microsystems, Wetzlar, Germany) at a magnification of 40x for further measurements. Subsequently, the push-out test was performed using a universal testing machine (JSV-H1000; JISC, Kanagawa, Japan) at a cross-head speed of 1 mm/min and with a customized tip (stainless steel, diameter, 0.8 mm; length, 3 mm (Fig. 3)). The maximum failure load was recorded.

### Statistical analysis

All statistical analyses were performed using JMP software (Version 15.0; SAS Institute, Cary, NC, USA). One-way analysis of variance (ANOVA) was conducted to analyze the mean bond strength between groups within a whole root, between different regions of the root in the same group, and between different cementation types in the same root region. The main effect of each independent variable was analyzed through Tukey's honestly significant



All specimens were placed in 100% humidity for 24 h after cementation.

**Figure 1** Specimen preparation procedures for fiber post cementation in the three experimental groups. SE-pre, self-etching system with pre-curing method; SE-co, self-etching system with co-curing method; SA, self-adhesive system.

**Table 1** Materials used.

	Manufacturer	Chemical composition
RelyX Unicem 2 Automix	3M-ESPE, St. Paul, MN, USA	Base paste: methacrylate monomers containing phosphoric acid groups, methacrylate monomers; Catalyst paste: methacrylate monomers; Fillers: alkaline (basic) fillers, silanated fillers; Initiators: sodium toluene-4-sulphinate, sodium persulfate, tert-butyl 3,5,5-trimethylperoxyhexanoate
RelyX Ultimate	3M-ESPE	Base paste: phosphoric acid modified methacrylate monomers, bifunctional methacrylate; Catalyst paste: methacrylate monomers; Fillers: alkaline (basic) fillers, silanated fillers; Initiators: sodium toluene-4-sulphinate, disodium peroxydisulphate, tert-butyl 3,5,5-trimethylperoxyhexanoate
Scotchbond™ Universal Adhesive	3M-ESPE	Methacrylated phosphoric acid, dimethacrylate resins, HEMA, ethanol, water, silane treated silica, 2-propenoic acid, copolymer of acrylic and itaconic acid, initiators, silane
RelyX™ Fiber Post 3D Glass Fiber Post #2	3M-ESPE	Epoxy resin matrix: 32% Glass fibers: 67%, zirconium and strontium fillers

Abbreviation: HEMA, hydroxyethyl methacrylate.

difference (HSD) post hoc test. The level of statistical significance was set at  $P < 0.05$ .

## Results

The mean bond strengths of group SE-pre, SE-co, and SA were  $7.79 \pm 2.62$ ,  $6.93 \pm 1.92$ , and  $7.13 \pm 2.07$  MPa, respectively. When all root regions in the canal were included, there was no significant difference in the bond strengths between the three groups ( $P = 0.877$ ). The push-out test values obtained for each root region or cementation type are presented in Table 2 and Fig. 4.

Comparing the bond strength of different regions within the same cementation group, significantly lower bond strength values were observed only in group SE-pre ( $P = 0.002$ ) for the apical region compared with those for the middle and coronal regions ( $P = 0.004$  and  $0.009$ , respectively; Tukey-HSD).

When evaluating each region independently with different cementation groups, only the bond strength in the coronal region was significantly affected by the cement type ( $P = 0.002$ ). Post hoc tests revealed a higher value in group SE-pre than in group SE-co ( $P = 0.018$ ; Tukey-HSD).

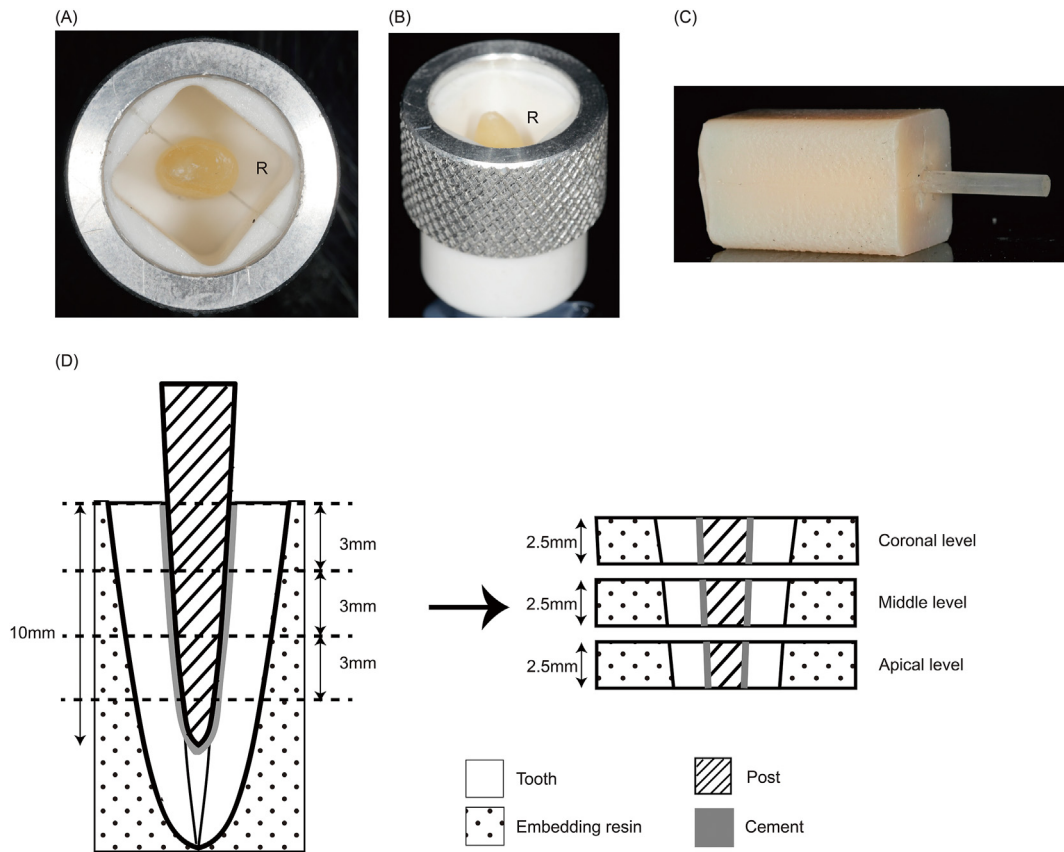
## Discussion

The study aimed to evaluate the differences in the bond strength achieved with either a pre- or co-curing procedure using a self-etching bonding system compared with those achieved using a self-adhesive system. No significant differences in the overall bond strength were observed. Therefore, the null hypothesis was accepted. However, in the coronal region only, group SE-pre showed significantly higher bond strength than group SE-co. When the bond strength was evaluated in different regions within each group, the apical region of group SE-pre showed a significantly lower value than the coronal and middle regions.

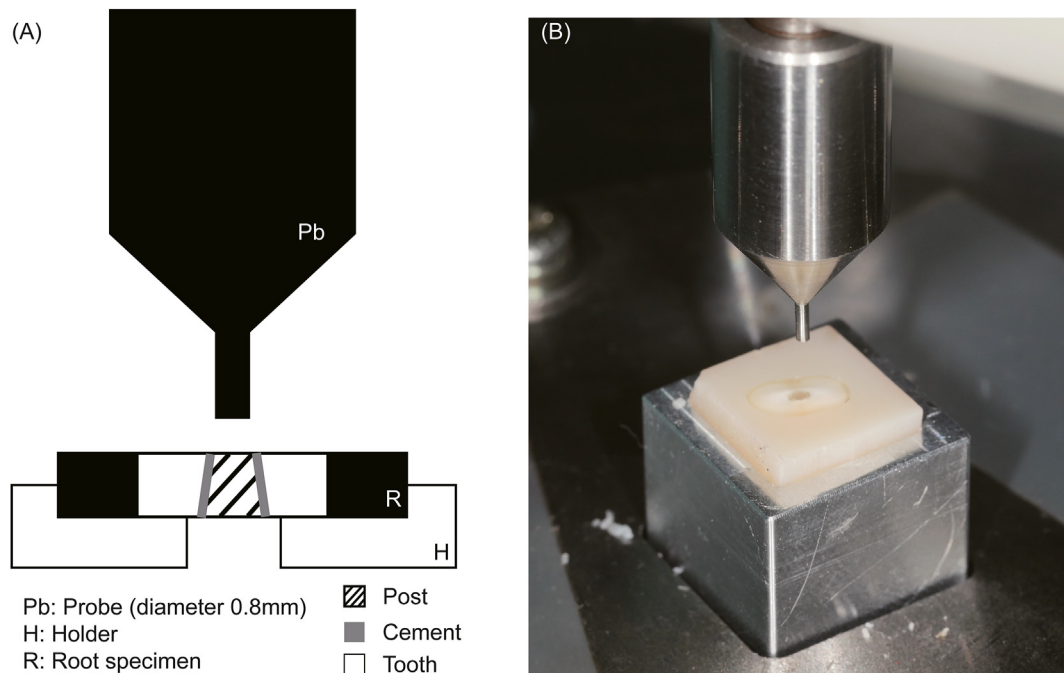
Several factors are responsible for the different results reported in various studies. Therefore, it is difficult to compare these findings directly and objectively with previously reported results, given the variations in experimental settings, such as the use of different brands of cements,<sup>3,4,9</sup> different methods of smear layer removal,<sup>12–14</sup> and some operational details.<sup>15,16</sup>

First, the present study only used one brand of cement system to avoid the complication of comparing different types of cement and to ensure consistent product quality, delivery, and mixing tip system. Previously, the same brand of cement system was used to test the bond strength in bovine teeth, and no difference was observed between RelyX Ultimate with the co-curing procedure and RelyX Unicem,<sup>17</sup> which is consistent with our study's findings. Bitter et al.<sup>18</sup> compared several different brands of cement with the co-curing method and proposed that Panavia F (resin cement; Kuraray, Osaka, Japan) has higher bond strength in the apical region than in the middle and coronal region. However, such differences were not observed with other cement brands. To avoid the potential risk of uncontrolled factors by simultaneously using multiple brands with multiple cementation procedures, we used the same brand in this study.

The smear layer might play an important role in influencing the bond strength owing to decreasing dentin permeability.<sup>19,20</sup> Alaghemand et al.<sup>12</sup> achieved higher bond strength upon removing the smear layer, although the difference was not significant. Similarly, Kambara et al.<sup>13</sup> concluded that removing the smear layer before using a self-adhesive cement increased the bond strength. However, Tani et al.<sup>14</sup> observed no significant improvement in the bond strength with smear layer removal before using a self-etching system. Considering the results obtained in previous studies, we used 17% EDTA and an ultrasonic device to remove the smear layer in the present study, resulting in a similar root dentin surface to that after standard endodontic treatment.



**Figure 2** (A) Top view of the Teflon mold with the prepared tooth placed inside and secured with a metal ring. (B) Side view of the Teflon mold. (C) Resin block after removal from the mold. (D) Resin block is sequentially sectioned from a point 3 mm from the top, into three 2.5-mm-thick specimens. R: Bis-acryl resin injection space.



**Figure 3** (A) Push-out tests performed using a universal testing machine with the apical surface of the specimen facing upwards. (B) Photograph showing the push-out test set-up.

**Table 2** Mean bond strengths (MPa) of different cementation groups in different root regions.

Region	SE-pre	SE-co	SA
C	8.50 ± 1.98 <sup>Bb</sup>	5.93 ± 1.99 <sup>Aa</sup>	7.21 ± 1.90 <sup>ABa</sup>
M	9.59 ± 1.57 <sup>Ab</sup>	7.26 ± 1.78 <sup>Aa</sup>	7.54 ± 2.31 <sup>Aa</sup>
A	5.12 ± 2.09 <sup>Aa</sup>	7.81 ± 1.59 <sup>Aa</sup>	6.53 ± 2.09 <sup>Aa</sup>

Values are presented as mean ± standard deviation. Thirty teeth were divided into three groups and 10 samples were assigned for each group.

SE-pre, self-etching system with pre-curing method; SE-co, self-etching system with co-curing method; SA, self-adhesive system; C, coronal level; M, middle level; A, apical level.

Different letters indicate statistically significant differences verified by Tukey's honestly significantly different test ( $p < 0.05$ ). Uppercase letters indicate comparisons of groups in rows (cementation types); lowercase letters indicate comparisons of groups in columns (root regions).

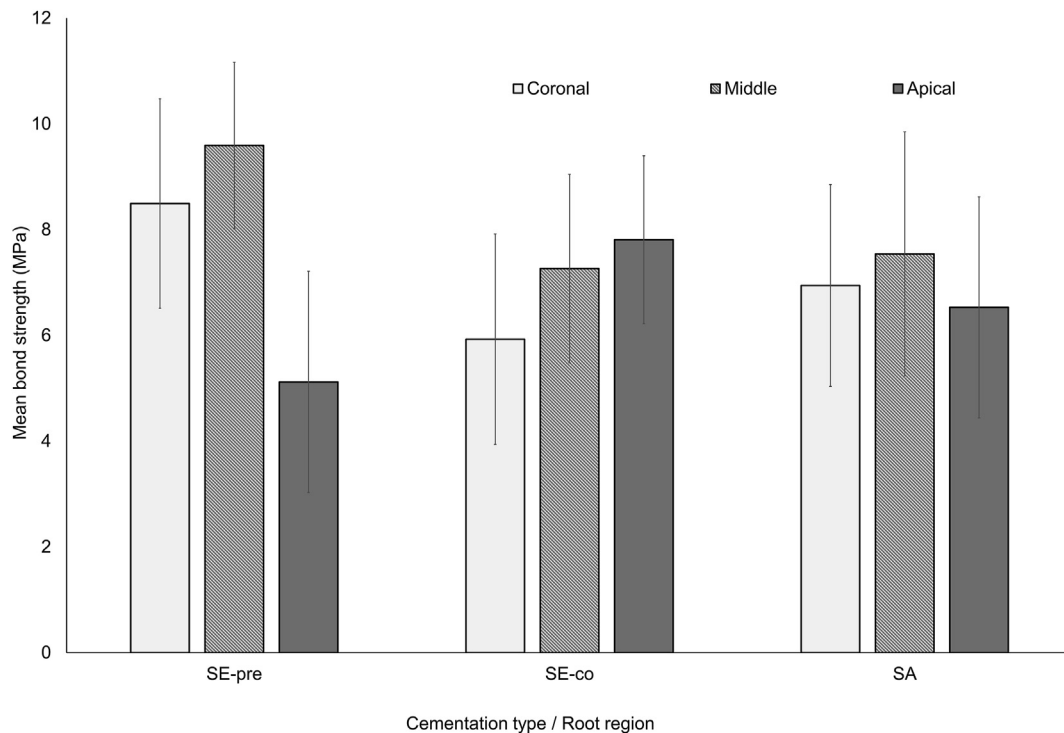
Moreover, there are two operational details in our study. We applied the bond material with microbrushes, which would significantly increase the amount of the resin–dentin interdiffusion zone in the apical region.<sup>15</sup> Further, the Endo tip connected to the mixing system was used as suggested previously<sup>16</sup> to prevent insufficient cement in the apical region.

The analysis of different root levels within the same group suggests the bond strength varies with root regions only in group SE-pre. Specifically, the apical region of group SE-pre showed a significantly lower bond strength than the coronal and middle regions. In groups SE-co and SA, no difference in the bond strength was noted at any of the

three levels. We observed that the try-in procedure in group SE-pre after polymerizing the bonding agent was relatively more difficult than that in the other two groups. For the three specimens in group SE-pre, the tried-in post was approximately 0.5 mm shorter than the entire length of the post space. We consider that the pre-cured bond layer adversely affected the fit between the post and the post space; the post space became narrower, in which made the try-in procedure more difficult. These negative effects might be most severe in the apical portion and could have adversely influenced the bond strength.

Most previous studies evaluated the apical bond strength after fiber post cementation using the co-curing method. These studies reported different results; some reported lower apical bond strength owing to improper cleaning procedures,<sup>21,22</sup> whereas some neglected to perform operational details.<sup>15,16</sup> Conversely, other studies<sup>8,18</sup> reported higher apical bond strength resulting from the distribution and aperture of the dentinal tubules. The present study performed proper cleaning, thoroughly dried the canal, and used Endo tips for cement injection. In group SE-co, the apical bond strength was not significantly different from the other area-specific strengths; however, we noted a significant difference in group SE-pre. To date, the pre-curing method has not been evaluated in detail; thus, we believe our findings will provide a useful reference for clinicians.

According to the comparison of the same regions between the groups, only the coronal level in group SE-pre was significantly higher than that in group SE-co. As studies evaluating the two procedures in self-etching bonding systems are rare, our inferences are based on experimental observations and other research investigating different methods.



**Figure 4** Histogram showing mean bond strength (MPa) and standard deviation of each cementation system and root region. SE-pre, self-etching system with pre-curing method; SE-co, self-etching system with co-curing method; SA, self-adhesive system.

In the micrographs, a large cement volume appears in the coronal regions, implying poor adaption. Moreover, a significantly lower strength was detected in the coronal region in group SE-co. Macedo et al.<sup>23</sup> demonstrated that conventional resin cement impairs the bonding to the root dentin owing to its high polymerization shrinkage, and it increases the dependency of post retention on the mechanical properties of cement, which is in line with our findings. The coronally larger cement space in group SE-pre compared with that in group SE-co also corresponds with previous findings.<sup>5–7</sup> Therefore, the pre-curing method might be an appropriate choice if the post space is more extensive.

The present study closely simulated a clinical situation,<sup>24,25</sup> and thus, it was able to show differences in bond strength among root levels by the push-out test, which is more reliable than the microtensile technique for measuring bond strength of luted fiber posts.<sup>24</sup> However, there are some limitations. First, to focus on the bond strength of cement to the post and dentin wall, only single-rooted teeth were used. Thus, outcomes in teeth with complex root canal anatomies, such as a flat root canal or type II canal, or a canal combined with pulp chamber, should be investigated in a future study. Second, this study tested a single cement brand in all methods. Although this brand holds a high market share, clinicians should be cautious in generalizing the results to different commercial brands, even if these brands employ the same adhesion mechanisms; this would require further investigation.

In conclusion, the results of this study demonstrated that when self-adhesive systems are used, thorough cleaning of the post space and removal of the smear layer can yield good bond strength in the entire root region. The use of self-etching systems with the pre-curing method in a deep and narrow post space should be avoided. Operators must consider the clinical situation and be careful to ensure good fit between the fiber post and post space, which may be detrimentally affected by the pre-polymerized bond layer, particularly in terms of apical bond strength. Meanwhile, the co-curing method should not be used when there is poor adaption between the post and dentin wall. Clinicians should be aware of the differences between the three methods with the cementation of prefabricated fiber posts, particularly when the root canal is wide coronally and narrow apically. In such conditions, a combined technique that uses a self-etching system with the pre-curing method over the coronal region and the co-curing method over the apical region should be considered.

### Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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