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The effect of silane on the bond strengths of fiber posts

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ABSTRACT

Objectives. Esthetic posts have been developed to maximize the foundation of esthetic restorations. The purpose of this study was to evaluate the effect of silane on the bond strength of three fiber-reinforced resin posts (fiber posts).

Methods. Fifty-four extracted human maxillary central incisors and canines were endodontically treated. D.T. Light Post (DT, Bisco), FRC Postec (FR, Ivoclar Vivadent), and ParaPost Fiber White (PP, Coltène/Whaledent) were inserted using the resin adhesive system provided by the respective manufacturer. For half of the specimens in each group, the fiber posts were treated with a silane solution (Monobond S, Ivoclar Vivadent). A push-out test was performed on three different sections of each root to measure bond strengths. Data were analyzed with ANOVA and Bonferroni's post hoc test at $P < 0.05$.

Results. The use of silane did not result in any statistically significant difference at any level of the root. Silane did not result in any significant different bond strengths (MPa) for each of the posts. When the data were pooled, the use of silane did not result in statistically significant different bond strengths at $P > 0.403$: *No silane* = 12.7 ± 8.4; *Silane* = 14.1 ± 7.0. The *coronal* third of the root (17.5 ± 6.7) resulted in statistically greater bond strengths than the *medium* third (12.9 ± 6.8) and than the *apical* third (9.8 ± 7.3) at $P < 0.002$ and $P < 0.0001$, respectively. The *medium* third and the *apical* third resulted in no statistically significant different bond strengths from each other at $P > 0.07$. The type of post did not result in statistically significant different bond strengths at $P > 0.417$: DT = 14.7 ± 6.8 MPa; FR = 13.3 ± 6.6 MPa; PP = 12.2 ± 6.6 MPa.

Significance. The use of a silane coupling agent did not increase the push-out bond strengths of the three fiber posts used in this study. All posts bonded to root dentin at the same magnitude. Bonding is more predictable at the most coronal level of the root.

1. Introduction

Pulpless teeth present challenging restorative problems because of the loss of tooth structure by caries, fracture, defective restorations, and endodontic access preparations. A post fabricated from a carbon fiber-reinforced epoxy resin (Composipost, RTD, Meylan, France) was developed in the early 1990s [1]. The increasing demand for esthetic posts and cores has led to the development of other metal-free, post-and-core systems, specifically zirconia and fiber posts. These new posts have been developed to improve the optical effects of esthetic restorations. Current fiber posts are composed of unidirec-

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tional fibers embedded in a resin matrix in which reinforcing quartz or glass fibers are immersed. Fibers are pre-stressed and subsequently resin, as a filler, is injected under pressure to fill the spaces between the fibers, giving them solid cohesion. In most posts, the resin matrix is made of epoxy resin or its derivatives. The epoxy resin may attach to the BIS-GMA resin through common free radicals in the epoxy resin.

Fiber posts are becoming more popular than their zirconia- or metal-based counterparts as fiber posts result in greater bond strength to radicular dentin than zirconia-based posts [2,3]. An in vitro study suggested that fiber posts are less likely to cause vertical root fractures compared with stainless steel posts [4]. Forces in the tooth restored with a fiber post are apparently absorbed by the core and post and not transferred to the vulnerable root structure. Another study using finite element analysis found that a glass fiber post resulted in the lowest stress inside the root because the stiffness of the post is similar to that of dentin [5]. The metal post and core tested in the same study transferred greater stresses to the root which might cause higher incidence of vertical root fractures. Except for the force concentration at the cervical margin, which may also cause root fractures, the glass fiber composite post induced a stress similar to that of the natural tooth [5]. Two important characteristics of fiber posts are that their modulus of elasticity is similar to that of dentin [6], and these posts and respective core buildups are cemented with an adhesive technique [7].

The “push-out test” was first described for use in dentistry in 1970 [8]. The use of the push-out test for studying bonding to root canal dentin was later reported in 1996 [9]. The push-out test provides a better estimation of the bonding strength than the conventional shear test because with the push-out test the fracture occurs parallel to the dentin-bonding interface, which makes it a true shear test [10]. Additionally, the push-out test has been considered more dependable than the microtensile test for bonded posts [11].

Silane coupling agents are hybrid organic–inorganic compounds that can mediate adhesion between inorganic and organic matrices through an intrinsic dual reactivity [12]. The silane coupling agent most commonly used for dental applications is a pre-hydrolyzed monofunctional γ-methacryloxypropyl-trimethoxysilane (γ-MPS) diluted in an ethanol–water solution with a pH between 4 and 5. The use of silanes to improve the bonding of fiber posts is a controversial subject. One study reported that the use of a silane alone with ParaPost Fiber White (Coltène/Whaledent, Altstätten, Switzerland) did not increase the bond strengths when ParaPost Cement (Coltène/Whaledent) or Panavia F (Kuraray Medical, Osaka, Japan) were used as resin cements [13]. In another study by the same research group, when ParaPost Fiber White was sandblasted and silanated the retention strength was not significantly different from that obtained when the posts were only sandblasted [14]. A more recent study found that the application of a silane solution increased the microtensile bond strengths of two fiber posts to flowable composite resins [15]. Taking into consideration that the most frequent cause of failure of bonded fiber posts is debonding [16], the purpose of this study was to evaluate the use of silane on the bond strength to root dentin of three fiber posts. The null hypotheses tested in this study were: (1) the use of a silane coupling agent does not affect the bond strengths of fiber posts; (2) there is no measurable difference in bond strength at different levels of the root for each post; (3) there is no difference in bond strength among three current fiber post systems.

2. Materials and methods

The sample size was determined from data of previous studies carried out in the same laboratory which utilized the push-out setup using a power analysis set at 90%. Fifty-four extracted human maxillary central incisors and canines stored in 0.2% chloramine at 4 °C up to 3 months were endodontically treated. The crown of each tooth was removed 2 mm coronal to the CEJ with a 0.15 diamond-wafering blade (Buehler Ltd, Lake Bluff, IL) in an Isomet 1000 slow-speed saw (Buehler Ltd) with distilled water refrigeration. Endodontic access was made with a tapered fissure bur (Brasseler USA, Savannah, GA) with a high-speed handpiece and water spray. For working length calculation, 1 mm was subtracted from the total length of the file inside the root canal. A crown down technique was used for instrumentation with Gates Glidden (Union Broach, York, PA) #2 to #4 drills and then rotary files (Profile .06 Taper Series 29, Dentsply Maillefer, Tulsa, OK) were used incrementally up to a #35 file/.06 taper. The teeth were irrigated between each instrument and the canal space was filled with irrigant during the instrumentation phase. For each tooth, 2 ml of 5.25% solution of sodium hypochlorite (The Clorox Co, Oakland, CA) was delivered with a Monoject (Sherwood Medical Co, St. Louis, MO) syringe and a 27-gauge needle. Following the final irrigation, the canal spaces were completely dried with absorbent paper points (Dentsply Maillefer, Tulsa, OK). The prepared canals were coated with AH26 (Dentsply Caulk, Milford, DE) root canal sealer, by using paper points dipped into the sealer. The lateral condensation technique was accomplished with Obtura II (Texceed Corp, Costa Mesa, CA) gutta-percha and AH26 (Dentsply Caulk) sealer. After endodontic treatment was completed, teeth were stored in 100% humidity in black film containers for 7 days.

Post holes were prepared to depths of 8 mm from the CEJ, leaving a minimum apical seal of 4–5 mm of gutta-percha in the canal space after post preparation. Gutta-percha was removed with a warm plugger (Union Broach) to the appropriate depth. The roots were instrumented with the mandrels from the respective post manufacturer (Table 1). A final flushing of the canal space was accomplished with sterile water, and then the canals were dried with paper points. The specimens were randomly assigned to three fiber posts (Table 1): D.T. Light Post size 1, a quartz-fiber post (DT, Bisco Inc, Schaumburg IL); FRC Postec size 1, a glass-fiber post (FR, Ivoclar Vivadent, Schaan, Liechtenstein); and ParaPost Fiber White size 1, a glass-fiber post (PP, Coltène/Whaledent).

The posts were placed using the resin adhesive systems provided by the respective manufacturer (Table 1). For half of the specimens, the fiber posts were treated with a silane solution (Monobond S, Ivoclar Vivadent) using a disposable brush and gently air dried for 5 s. After completing the application of the respective bonding agent, the posts were placed into the canal with slight pressure and excess luting material was removed with a disposable brush. After 4 min, the roots with

Table 1 – Materials used in study

Post (diameter[a])	Dentin adhesive	Resin luting agent	Manufacturer
D.T. Light Post #1 (1.50/0.90 mm) Lot 400001142	One-Step Lot 400000437 (LC[b])	Post Cement Hi-X Base, Lot 300014553 Post Cement Hi-X Catalyst, Lot 300014554 (SC[b])	Bisco Inc
FRC Postec #1 (1.47/0.82 mm) Lot GL0015	Excite DSC Endo Lot E32533 (DC[b])	Variolink II A1 Base, Lot F50938 Variolink II Transparent Low Visc Catalyst, Lot E58704 (DC[b])	Ivoclar Vivadent
ParaPost Fiber White #1 (1.07 mm) Lot MT-10193	ParaPost Adhesive Lot MK979 (SC[b])	ParaPost Resin Cement, Lot MK979 (SC[b])	Coltène/Whaledent
Monobond S, Lot D51336 (pH 4), MPS 1.0%, 52% ethanol, 47% water (MPS = monofunctional γ-methacryloxypropyltrimethoxysilane or 3-trimethoxysilylpropyl methacrylate)			Ivoclar Vivadent

[a] Diameter of posts measured with a Mitutoyo digital caliper (Mitutoyo Corp, Kanogawa, Japan).
[b] DC = dual-cured; LC = light-cured; SC = self-cured.

their cemented posts were stored in sterile saline in a black film canister. Teeth were preserved in distilled water for 1 week at 37 °C.

The roots with cemented posts were fixed to phenolic ring forms filled with acrylic resin (Dentsply/Trubyte, York, PA). The posts were kept parallel to the acrylic resin table and fixed with sticky wax. Three segments per root (Fig. 1), apical to the CEJ, were obtained by sectioning the root under distilled water coolant. The sections were 2.0 ± 0.1 mm in width. Each specimen was marked on its coronal side with an indelible marker, and the thickness of each specimen was measured by using a Mitutoyo absolute digital caliper (Mitutoyo Corp, Kanogawa, Japan) with an accuracy of 0.001 mm and the value was recorded. The sections (total = 162 sections) were stored individually in black film canisters with sterile water.

Each section was attached to the push-out jig (Fig. 1) with cyanocrylate adhesive (ZapIt Base and Accelerator, Dental Ventures of America, Inc, Corona, CA), ensuring that the coronal surface faced the jig and the post was centered over the hole in the jig. The push-out jig was placed on an Instron 4204 (Instron Co, Canton, MA) universal testing machine. Care was taken to center the push-out pin (diameter = 0.90 mm) on the center of the post surface. The crosshead was lowered at 1.0 mm per minute until the post was dislodged. Push-out bond strengths were calculated for each section by using the following formula:

$$\frac{\text{debond stress} = \text{debonding force (Kg)}}{A}$$

where: A = area of post/cement interface. Debond stress values were converted to megapascals (MPa). After testing the post segments were analyzed under a stereomicroscope to determine the type of failure. The type of failure was classified in five categories:

1. adhesive between post and resin cement (no resin cement visible around the post);
2. mixed with resin cement covering 0–50% of the post diameter
3. mixed with resin cement covering between 50 and 100% of post surface;
4. adhesive between resin cement and root canal (post enveloped by resin cement);
5. cohesive in dentin.

Data were analyzed by using analysis of variance (ANOVA) with SPSS 11.5 for Windows (SPSS Inc, Chicago, IL) statistical software. Post hoc tests were calculated using the Bonferroni's multiple comparison test at $\alpha = 0.05$.

3. Results

For each post, the use of silane did not result in any statistically significant difference at any level of the root (Table 2). When data were computed for root region, the use of silane for each of the posts did not have a statistical effect in the mean bond strengths. Overall, the use of silane did not result

Table 2 – Mean push-out bond strengths by post and surface treatment in MPa

Surface treatment	N	Mean ± S.D.	Mean ± S.D.
DT Light Post			
Silane	27	15.2 ± 6.9	14.7 ± 6.8
No silane	27	14.1 ± 6.7	
FRC Postec			
Silane	27	13.0 ± 5.9	13.3 ± 6.6
No silane	27	13.7 ± 7.2	
ParaPost Fiber White			
Silane	27	13.9 ± 6.9	12.2 ± 6.6
No silane	27	10.5 ± 6.5	

For each column means are not statistically different at $P < 0.05$.

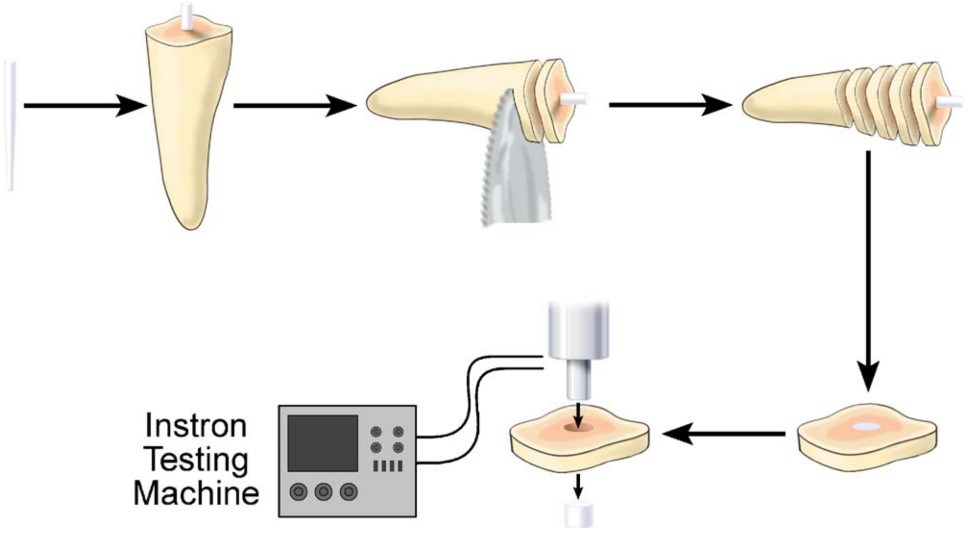

Fig. 1 – Diagram showing the preparation and testing of specimens for push-out bond strength.

Table 3 – Mean push-out bond strengths by post and root section in MPa

Root section	N	Mean ± S.D.
DT Light Post		
Coronal	18	$17.5^{a} \pm 6.3$
Medium	18	$15.3^{ab} \pm 5.7$
Apical	18	$11.3^{bc} \pm 7.0$
FRC Postec		
Coronal	18	$17.1^{a} \pm 6.1$
Medium	18	$13.7^{abc} \pm 5.9$
Apical	18	$9.3^{c} \pm 5.4$
ParaPost Fiber White		
Coronal	18	$18.1^{a} \pm 7.5$
Medium	18	$9.8^{c} \pm 5.0$
Apical	18	$8.6^{c} \pm 5.5$

Means with same superscript letter are not statistically significantly different at $P < 0.05$.

in statistically significant different bond strengths at $P > 0.403$: *No silane* = 12.7 ± 8.4; *Silane* = 14.1 ± 7.0 MPa.

For each post the apical third (Table 3) resulted in statistically lower bond strengths than the coronal third. When the means were pooled (Table 4), the *coronal* third (17.5 ± 6.7) resulted in statistically greater bond strengths than the *medium* third (12.9 ± 6.8) and than the *apical* third (9.8 ± 7.3) at $P < 0.002$ and $P < 0.0001$, respectively. The *medium* third and the *apical* third resulted in no statistically significant different bond strengths at $P > 0.07$.

Table 4 – Mean push-out bond strengths by root section in MPa

Root section	N	Mean ± S.D.
Coronal	54	17.5 ± 6.7^{a}
Medium	54	12.9 ± 6.8^{b}
Apical	54	9.8 ± 7.3^{b}

Means with same superscript letter are not statistically significantly different at $P < 0.05$.

The three posts did not result in statistically significant different bond strengths at $P > 0.417$: DT = 14.7 ± 6.8 MPa; FR = 13.3 ± 6.6 MPa; PP = 12.2 ± 6.6 MPa.

There were no cohesive failures in dentin (Table 5). For categories 1 and 2 (failure predominantly adhesive between post and cement), 43 failures occurred with silanated posts versus 55 in posts that were not silanated. Overall, 98 failures (60.5%) were in categories 1 or 2. The remaining 39.5% were in categories 3 or 4 (failure predominantly adhesive between the cement and root dentin).

4. Discussion

The ideal post provides retention to the core, supports the core to prevent loosening of the cemented crown, and dissipates stresses to prevent root fracture [6] The modulus of elasticity of fiber posts is similar to the modulus of elasticity of dentin [6]. Post systems with a modulus of elasticity similar to dentin show promise in that the post may fracture prior to the tooth. Stainless steel posts with a high modulus (approximately 20 times that of dentin, which is 18.3 GPa^{5}) cause stress concentration in the less rigid tooth resulting in a greater incidence of catastrophic root fracture [4,5,17]. As far as zirconia posts, they result in catastrophic irreparable fractures in vitro as opposed to either D.T. Light Post or ParaPost Fiber White, which display more favorable fractures [18].

Conventional methods for bond strength testing have used flat dentin or enamel surfaces ground with sandpaper [19]. However, it has been shown that flat surfaces result in increased bond strength of resin-based materials as compared with confined spaces [20]. The restricted spaces, which are more clinically relevant, include one-surface cavity preparations and the curved walls of endodontic access preparations, which are less favorable to bonding as a result of a high ratio of bonded surfaces to unbonded surfaces, or C-factor [21]. When

Table 5 – Type of failure

Fiber post	Location of disc	Silane	1	2	3	4	5
DT Light Post	Coronal	No silane	5	3	1	0	0
		Silane	8	0	0	1	0
	Medium	No silane	0	6	0	3	0
		Silane	2	5	1	1	0
	Apical	No silane	0	3	4	2	0
		Silane	2	2	1	4	0
Fiber White ParaPost	Coronal	No silane	2	4	3	0	0
		Silane	1	6	1	1	0
	Medium	No silane	1	4	1	3	0
		Silane	1	2	2	4	0
	Apical	No silane	2	3	1	3	0
		Silane	2	1	5	1	0
FRC Postec	Coronal	No silane	7	2	0	0	0
		Silane	4	1	2	2	0
	Medium	No silane	2	5	0	2	0
		Silane	0	1	8	0	0
	Apical	No silane	4	2	2	1	0
		Silane	1	4	4	0	0

the restoration has more free surfaces, more flow occurs which results in relaxation of stresses occurring within the polymerizing resin [21,22]. Fiber posts have been reported to result in bond strengths of over 14 MPa when using the push-out method [3]. The reduction in bond strength found with the push-out test as compared with conventional shear or tensile tests may be caused by internal stresses resulting from polymerization shrinkage that pulls the bonded restoration away from the dentin walls [9]. In fact the C-factor associated with a thickness of 150 μm of resin cement around the post may reach a value of 200, which is 40× higher than the C-factor of an occlusal composite restoration [23].

Most fiber posts on the market contain epoxy resin as the matrix connecting the individual fibers. When fiber posts are made of methacrylate resin in lieu of epoxy resin, the degree of water sorption induces greater dimensional changes than when an epoxy resin is used [24]. Glass- and quartz-reinforced posts have demonstrated superior physical characteristics when compared to the previous generation of posts [25,26]. Quartz fibers have, however, a higher tensile strength than glass fibers (3600–6000 MPa versus 2000 MPa, respectively) [27]. The microstructure of each fiber post is based on the diameter of the single fibers, on their density, and on the quality of adhesion between the fibers and the resin matrix [28]. When FRC Postec or FR, a glass-fiber post, was compared with other posts (ceramic and gold) cemented with Syntac and Variolink, FR showed a mechanical behavior comparable to that of other post systems when composite cores were used [29]. FR has a stiffness similar to that of dentin; therefore, it behaves mechanically like the natural tooth [5]. In another in vitro study [30], several dentin adhesives were used. Excite DSC, the dual-cured one-bottle dentin adhesive also used in the present study, contains small particles of catalyst incorporated into the bristles of the application brush. The hybrid layer formed by Excite DSC when used to bond FR fiber posts has been shown to be more uniform in the apical third than that formed with the light-cured version of the same adhesive, Excite [30]. However, the bonding system used may not influence the bond strengths obtained with FR, as the resin cement may play a more important role. In a previous study different bonding systems were used with FR which did not result in any statistically significant difference in bond strengths [31].

The similarity in physical properties between FR and DT has been confirmed clinically. A clinical study showed that the 2-year clinical performance of DT bonded with One-Step was excellent and comparable to the clinical performance of FR bonded with Excite DSC [16]. DT has demonstrated a higher fracture resistance than Cosmopost, a zirconia post, and PP, a glass-fiber post [18]. This fracture resistance may be a result of the number of fibers per surface area of DT [28]. DT ranked first among eight posts in fiber density (32 fibers/mm^2) while PP ranked last (18 fibers/mm^2) [29]. In the same study FR ranked in the middle (25 fibers/mm^2). DT also resisted 2 million fatigue cycles without any failure. FR resisted an average of 1.8 million cycles, while PP only resisted 85,000 cycles. This poor performance for PP may be a result of its serrations which may function as areas of stress concentration during the fatigue test. The difference in fatigue resistance does not seem to translate in lower adhesion strengths for PP. At least in vitro, PP is retained effectively in the root canal [3] and withstands fatigue longer than a prefabricated titanium post or a cast gold post [32].

Because it is a light-polymerized adhesive, the performance of One-Step was expected to be compromised at the apical third of the root. As opposed to other light-polymerized one-bottle dentin adhesives, the acetone-based One-Step adhesive is compatible with auto-polymerized composites [33]. A previous study has also demonstrated that One-Step performs well at any level of the root, despite being light-polymerized [3].

Silanes improve the bonding of composite resins to porcelain by 25% [34]. The use of silane solutions to improve the bond between new composite resin and existing composite is controversial. There are not many studies testing the use of silane solutions for bonding posts to root canal dentin. Silanes improved the bonding between new composite and an existing fiber-reinforced composite framework, similar to the structure used in fiber posts [35]. In a study measuring microtensile bond strengths, the silane solution was found to improve the bond strengths of a glass-fiber post and a quartz-fiber post [36], which does not agree with the findings of our study. However, the study by Aksornmuang et al. [36] used a two-component silane system (Clearfil PhotoBond + Clearfil Porcelain Bond Activator, Kuraray Medical), which contains a resin adhesive system and is not pre-hydrolyzed. The solution used in our study, Monobond S, is a single phase pre-hydrolyzed solution containing 1.0% monofunctional γ-methacryloxypropyl-trimethoxysilane (γ-MPS), 52% ethanol, and 47% water. In another study, Goracci et al. [15] used Monobond S with FR and with DT and found that the silane solution improved the microtensile bond strengths for both posts. These two fiber posts contain epoxy resin, therefore they have no functional groups to react with the silane solution. The authors concluded that the mechanism by which the silane enhanced the bonding of FR and DT is not understood. Besides using a different testing method, Goracci et al. [15] used light-cured flowable composites as the intermediate resin material, which may wet the posts more efficiently than the resin cements used in or study. On the other hand Sahafi et al. [13] found that silane did not increase the bond strength of ParaPost Cement to ParaPost Fiber White, one of the combinations used in our study. These authors explained the inefficiency of silane by a weak or absent bond of the silane functional group to the epoxy resin, a nonsilicate-based material.

In our study, the greatest difference in the diameter of the posts was between the FR and the PP posts (1.47 mm versus 1.07 mm, respectively, Table 1). The shape of both posts is cylindrical, except for the apical third of the FR post where it decreases sequentially in diameter. The DT post has a double-tapered shape; therefore the diameter of the post inside the root canal does not reach the maximum of 1.5 mm measured at the occlusal tip of the post. Wider posts result in a greater interfacial debonding area, but these differences are accounted for when the bond strength are calculated. Therefore, the small differences in the diameter of the posts might not influence the push-out bond strengths. The post diameter may play, however, an important role in the strength of the final restoration as a result of variations in the load-bearing ability of posts of different diameters [37]. For example a carbon posts with a diameter of 1.4 mm has a load-bearing capacity of 85 N while a similar post of 2.1 mm has a load-bearing capacity of 200 N [37].

It has been shown that the number of dentinal tubules decreases moving from the crown to the root apex [38]. Because the post retains and stabilizes the respective core, it is important to evaluate different levels of adhesion of the post. Consequently, one of the objectives of the present study was to evaluate the bond strength at each level of the root. The difference in the number of tubules may explain why the strongest adhesion occurred in the most coronal sections. Tubule density is greater in the coronal and middle thirds than in the apical part of the root [39]. Because adhesion may be enhanced by penetration of resin into the tubules, if there were a greater number of tubules per mm^2 a stronger bond would be expected [40]. Additionally, dentin hybridization is not uniform in the apical third and lateral branches of resin tags and the characteristic truncated-cone shape of the neck of the resin tags are not observed in the apical part of the interface post-adhesive system [39]. Another factor that may play a role in the difference in push-out bond strengths between the coronal third and the apical third is the accessibility of the coronal portion of the canal, making it easier to etch and more thoroughly apply the adhesive agents.

The specimens in the present study were not subjected to thermal fatigue or to mechanical fatigue. It has been shown that thermocycling results in a significant decrease on the flexural strength of fiber posts [10]. Also, mechanical fatigue increases the microleakage for all types of posts [41]. However, it has also been demonstrated that mechanical fatigue does not change the bond strengths for fiber posts [42,43].

Most failures were predominantly adhesive between the fiber post and the resin cement. This raises the question as to how long the seal of the canal will survive. Coronal leakage is known to occur after post space preparation in endodontically-treated teeth [44] and that short root canal fillings provided a much inferior seal than intact root canal fillings [45]. Further studies should analyze the ability of the post systems (adhesive, resin cement, and fiber post) to provide a tight seal to the root dentin. A long-term survival rate of different modalities for restoration of pulpless teeth should also be carried out.

5. Conclusions

Two of the null hypotheses were accepted. Within the limitations of this in vitro study the following conclusions are made:

(1) The use of a silane coupling agent may not provide increased bond strength between the fiber posts and the resin cement.
(2) The coronal third of the root bonds more reliably to the post than either the medium or the apical third.
(3) The type of fiber post used may not significantly affect the bond to root structure.

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