Bond Strength of Fiber Posts to Weakened Roots After Resin Restoration With Different Light-Curing Times

Cleonice Silveira Teixeira, DDS, MSc, PhD,[*†] *Yara T. Corrêa Silva-Sousa, DDS, MSc, PhD,*[*] *and Manoel D. Sousa-Neto, DDS, MSc, PhD*[‡]

Abstract

Introduction: This study evaluated the bond strength of translucent fiber posts to experimentally weakened radicular dentin restored with composite resin and polymerized with different light-exposure time. **Methods:** Roots of 60 maxillary incisors were used. Twenty-four hours after obturation, the filling materials of root canals were removed to a depth of 12 mm, and 4 groups were randomly formed. In 3 groups, root dentin was flared to produce a space between fiber post and canal walls. In the control group, the roots were not experimentally weakened. The flared roots were bulk restored with composite resin, which was light-activated through the translucent post for 40, 80, or 120 seconds. Posts were cemented, and after 24 hours, all roots were sectioned transversely in the coronal, middle, and apical regions, producing 1-mm-thick slices. Push-out test was performed, and failure modes were observed. **Results** The quantitative analysis showed significant statistical difference only among groups ($P < .001$). Comparing the weakened/restored groups, composite light-exposure time did not influence the results. Overall, adhesive failures occurred more frequently than other types of failures. Cohesive failures occurred only in the weakened/restored roots. **Conclusions** Intracanal root restoration with composite resin and translucent fiber posts provided similar or higher bond strength to dentin than the control group, regardless of the light-exposure time used for polymerization. *(J Endod 2009;35:1034–1039)*

Key Words

Bond strength, composite resin, light-exposure time, push-out test, root canal

From the *School of Dentistry, University of Ribeirão Preto (UNAERP), Ribeirão Preto, SP; †Dental School, Federal University of Santa Catarina (UFSC), Florianópolis, SC; and ‡School of Dentistry of Ribeirão Preto, University of São Paulo (USP), Ribeirão Preto, SP, Brazil.

Address requests for reprints to Prof Dr Manoel D. Sousa Neto, Rua Célia de Oliveira Meirelles 350, 14024-070 Ribeirão Preto, SP, Brasil. E-mail address: sousanet@forp.usp.br.

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Endodontically treated teeth usually present excessive loss of tooth structure resulting from caries, unnecessary hard tissue removal, previous restorations, and fractures (1–3). Dentin removal at the coronal root third might produce canals with thin tapered walls, in which conventional restorations with metallic posts frequently lead to irreparable root fractures (2). Therefore, these teeth require restorative techniques that reinforce the weakened root structure by increasing the internal thickness (3).

Intracanal restoration with resin materials, which are elastically compatible with dentin, followed by cementation of metallic or fiber posts has been considered an effective technique for root reinforcement (2–4). In addition, it has been observed that the use of intraradicular posts adhered to both dentin and coronal core provide better distribution of forces along the root canal, thus contributing to the tooth reinforcement (2–6).

Although some studies have suggested the cementation of metallic posts after root reinforcement (2, 3), the use of esthetic resin fiber posts (either glass or quartz fiber) has been reported to be particularly advantageous. Fiber posts not only contribute to minimizing the risks of unrestorable root fractures (6, 7) but also enhance the esthetic results of the coronal restoration as a result of their light transmission property (8). The use of light transmitting posts allows composite resin photoactivation to be performed with the same post that will be later cemented into the root canal (9, 10).

Push-out test has been used to evaluate the adhesion between post/resin/cement and root canal dentin by using different types of posts and bonding protocols (11–15). This test might be used to determine the regional adhesive forces after restoration and post cementation in weakened roots. Several studies that investigated bond strength have found lower values in the middle and apical root canal regions (11, 13–16). On the other hand, other authors have reported higher bond strength in apical canal area (17, 18). Although methodologic differences might explain these divergent results, several issues related to the adhesion of root canal dentin remain unclear. In spite of the high-quality outcomes in terms of esthetics and the favorable laboratory and clinical results, the loss of adhesion of fiber posts to root canal dentin is still the main cause of failure of fiber post–retained restorations (19, 20).

Because of their ease of handling, incremental insertion, and control of working time, light-activated composite resins are a better option for intracanal reinforcement than chemically activated resins (9, 10). However, when light-activated composite resins are placed in deeper regions or regions with a thickness greater than 2–3 mm, polymerization might be affected and, consequently, the material hardness (21, 22). It has been reported that the access to the resin material, light-curing tip distance, and power density of the curing light might influence composite resin hardness (9, 21–23) and negatively affect the mechanical properties (24). Conversely, some authors have observed that a longer light-exposure time might compensate the lower light density and promote adequate polymerization (10, 25, 26). However, the influence of light-exposure time on the adhesion of composite resins used with fiber posts for root reinforcement has not yet been evaluated.

The purpose of this ex vivo study was to evaluate the bond strength of a quartz fiber post (DT Light Post; DT-Bisco Inc, Schaumburg, IL) to root dentin previously weakened and restored with composite resin (Light Core; LC-Bisco Inc) by using the push-out test.

TABLE 1. Materials Used in the Experimental Procedures, with the Respective Manufacturer Information, Composition, and Batch Number

Product (manufacturer)	Composition	Batch no.
AH Plus (Dentsply DeTrey, Konstanz, Germany)	*AH Plus Paste A:* bisphenol-A epoxy resin; bisphenol-F epoxy resin; calcium tungstate; zirconium oxide; silica; iron oxide pigments	0603002042
	AH Plus Paste B: dibenzyldiamine; aminoadamantane; tricyclodecane-diamine; zirconium oxide; silica; silicone oil	
All-Bond 2 (Bisco Inc, Schaumburg, IL)	*UNI-ETCH:* 32% phosphoric acid, benzalkonium chloride, and xanthum gum thickener	0600001033
	Primer A: NTG-GMA, acetone, ethanol, and water	0600001076
	Primer B: BPDM, acetone, ethanol, and photoinitiator	0600001077
	D/E Resin: Bis-GMA, UDMA, HEMA, photoinitiator (CQ), and amine activator	0600000717
Light-Core (Bisco Inc, Schaumburg, IL)	Bis-GMA, ethoxylated bisphenol A dimethacrylate, glass frit (>60%)	0600004829
Duolink (Bisco Inc, Schaumburg, IL)	*Base*: Bis-GMA, TEGDMA, UDMA, glass filler	0600004680

NTG-GMA, Na-N-tolylglycine glycidylmethacrylate; BPDM, biphenyl dimethacrylate; Bis-GMA, bisphenol A diglycidyl methacrylate; UDMA, urethane dimethacrylate; HEMA, 2-hydroxyethyl methacrylate; TEGDMA, triethylene glycol dimethacrylate; CQ, camphorquinone.

The null hypothesis tested was that different light-exposure times for resin polymerization through translucent fiber post might not affect the interfacial bond strength.

Material and Methods

Tooth Selection and Preparation

Sixty extracted noncarious human maxillary central incisors were stored in 0.1% thymol solution at 4 °C, pH 7, and used within 3 months after extraction. The crown of each tooth was removed 2 mm from the cementoenamel junction in coronal direction with a 0.15 diamond saw at slow speed (Isomet 1000; Buehler, Lake Bluff, IL). Working length was established at 1 mm from the apical foramen. Root canal preparation was performed according to the crown-down technique by using #2 to #4 Gates Glidden drills (Union Broach, York, PA), and then rotary files (ProFile .04 taper; Dentsply Maillefer, Tulsa, OK) were used incrementally up to a #50 file/.04 taper. Root canals were irrigated with 2 mL of 1% sodium hypochlorite at each change of instrument. After final irrigation, root canals were completely dried with absorbent paper points (Dentsply Maillefer) and then obturated with AH Plus sealer (Dentsply DeTrey, Konstanz, Germany) (Table 1) and gutta-percha cones (Dentsply Maillefer). Root canal obturation was carried out according to the hybrid technique of Tagger et al (27). After vertical compaction and placement of provisional restorations (Citodur; Dorident, Vienna, Austria), roots were stored in 100% relative humidity at 37 °C for 24 hours.

Post Space Preparation

After 24 hours, gutta-percha was removed with heated endodontic pluggers (Sybron Dental Specialties, Romulus, MI), maintaining at least 4 mm of filling material in the apical third. Post spaces were prepared to a depth of 12 mm measured from the sectioned surfaces by using the specific drills supplied with the fiber post system. Final irrigation was accomplished with distilled water, and post spaces were dried with paper points. The fiber post (DT Light Post size 2; Bisco Inc) was tested to fit the canal space. Each post was sectioned perpendicularly to its long axis 4 mm above the coronal border of the root by using a doubled-faced diamond disk (911H; Brasseler, Savannah, GA) at low speed under air/distilled water spray cooling.

The specimens were randomly assigned to 4 groups (n = 15). In the 3 experimental groups, the thickness of radicular dentin walls was reduced by using diamond burs (#4137; Vortex Indústria e Comércio de Ferramentas Diamantadas Ltda, São Paulo, SP, Brazil and KG PM717 G; KG Sorensen, São Paulo, SP, Brazil) under air/water spray coolant to produce a circumferential space between the fiber post and circumjacent dentin walls (Fig. 1). In the control group, roots were not experimentally weakened.

Intracanal Restoration with Composite Resin

Before composite resin restoration, the canals of the flared roots were irrigated with 10 mL of distilled water and dried with absorbent paper points. Intracanal dentin was etched with 37% phosphoric acid (Uni-Etch; Bisco) for 15 seconds, rinsed with distilled water for 30 seconds, and gently dried with absorbent paper points. A 3-step total-etch adhesive system (All Bond 2; Bisco) was applied to the moist dentin with disposable microbrush tips (3 M/ESPE, St Paul, MN), according to the manufacturer's instructions. The material was photoactivated by positioning the tip of the light-curing unit (Curing Light 2500; CL, 3 M/ESPE; 550 mW/cm^2 light intensity) at the canal entrance for 20 seconds.

For the intracanal restoration, the canal space was filled with a translucent composite resin (Light Core; Bisco) (Table 1). The composite resin was incrementally inserted into the root canal against the palatal wall and compacted apically with hand compactor (Dentsply Maillefer) until filling the canal space completely. In each canal, a DT Light Post (Bisco) coated with a thin layer of petroleum jelly (Vimak Produtos Químicos Ltda, São Paulo, Brazil) was centrally inserted into the resin mass along the whole post space extension. After the removal of the excess resin, the tip of the light-curing unit was placed over the post, and the device was activated according to different light-exposure times: G_{40s} = 40 seconds, G_{80s} = 80 seconds, and G_{120s} = 120 seconds. After composite resin polymerization, the post was clamped with needle-nose pliers and removed from the canal.

Post Cementation

The root canals of all groups (weakened/restored and control) were reprepared with the drills of the post system kit (D.T. Light Post size 2; Bisco), washed with 10 mL of distilled water, and dried with absorbent paper points. After the removal of the petroleum jelly coating, the posts were rinsed with distilled water and dried in a mild air stream. Primer B (AB; Bisco) was applied to the post surface, gently air-thinned, and light-cured for 10 seconds. The root canals were etched with phosphoric acid (Uni-Etch), applied with disposable microbrush tips (3 M/ESPE), and left for 15 seconds, rinsed with distilled water for

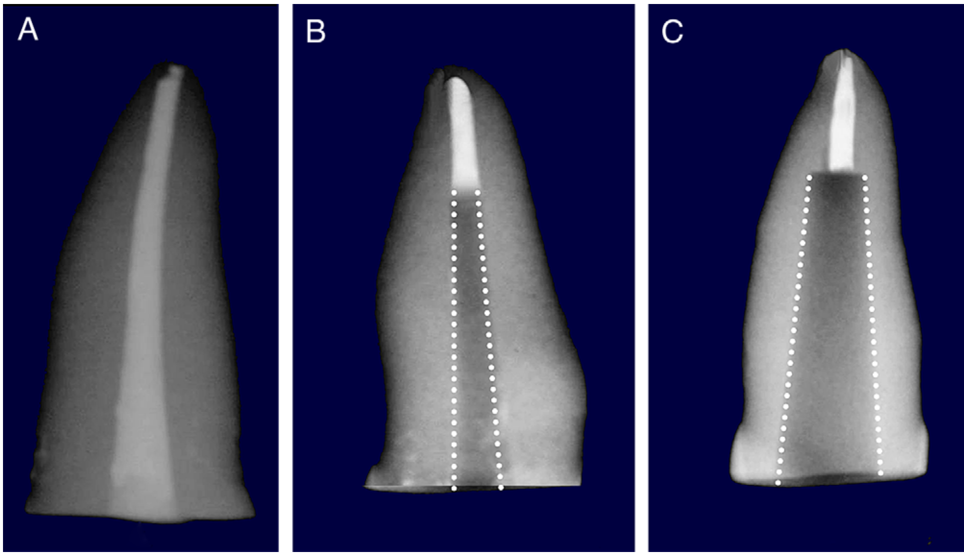

Figure 1. Root canal and post space preparation. Images of radiograph obtained after root canal obturation (*A*), with the root canal emptied to a depth of 12 mm and prepared to the fiber post (*B*), and after the flaring of the dentin walls to simulate weakness in the experimental groups (*C*).

30 seconds, and gently dried with absorbent paper points. Two consecutive drops of primer B were applied, and the excess was removed with absorbent paper points. Equal amounts of Duolink resin cement (Bisco) were mixed, and the material was taken to the canal with a lentulo spiral. Each post was seated into the respective canal by applying gentle pressure, excess cement was removed with a microbrush tip, and the material was light-activated for 40 seconds. After 4 minutes, the specimens were placed in black light-proof containers and stored in 100% relative humidity at 37°C for 24 hours.

Push-out Test: Specimen Preparation, Post Dislodgment, and Failure Pattern Analysis

The specimens were individually taken to a precision cutting machine (Isomet 1000) and serially sectioned perpendicular to the long post axis by using a water-cooled diamond saw (South Bay Technology, San Clement, CA). Approximately 1.0-mm-thick (±0.1 mm) slices were obtained from the coronal, middle, and apical regions of the restored root. One specimen of each region was selected at 2-, 6-, and 10-mm depths, respectively, and specimen thickness was measured with a Mitutoyo absolute digital caliper (Mitutoyo, Kanogawa, Japan), with an accuracy of 0.001 mm.

Each section was marked on its apical side and fixed in a stainless steel base (Fig. 2), with a central hole attached to the lower portion of a universal testing machine (Instron Model 4444; Instron, Canton, MA). Each specimen was positioned to the machine, ensuring that the coronal surface faced the metallic base and the resin/cement/post was centered over the hole in the base. Care was also taken to ensure that the contact between punch tip and post section occurred over the most extended possible area to avoid any notching effect of the punch tip into the post surface (11). The push-out test was performed by applying a compressive load to the apical aspect of each slice by using a 0.6-mm-diameter cylindrical plunger attached to the upper portion of the Instron machine. A crosshead speed of 0.5 mm/min was applied until bond failure occurred.

To express the bond strength in megapascals (MPa), the load at failure recorded in newtons (N) was divided by the area (mm^2) of the post/dentin interface.

To calculate the bonding surface, the area of the post/dentin interface was measured by using the formula of the lateral surface area of a conical frustum (28), considering the top and bottom circles of the dislodged bonded assembly along with the height of the slice.

For the fracture analysis, a careful visual examination was first performed at 4× magnification (Illuminated magnifying glass, Tokyo, Japan), and the debonded area was examined with a stereomicroscope at 20× to 40× magnifications (SZ60; Olympus, Tokyo, Japan). Failure was considered as the following: adhesive between fiber post and cement/composite resin set; adhesive between cement/composite resin set and root dentin; mixed (failure occurring at fiber post/resin cement interface and at cement or composite resin/root dentin interfaces in the same specimen); cohesive in the resin if the fracture occurred only in the resin; and cohesive in dentin if the fracture occurred in the dentin. Failure modes were recorded as percentages.

Data were analyzed by using analysis of variance (ANOVA) with SPSS 13.0 for Windows (SPSS Inc, Chicago, IL) statistical software. Post hoc tests were calculated by using Tukey multiple comparison test at $\alpha = 0.05$.

Results

Bond strength means and standard deviations are given in Table 2. Two-way ANOVA showed that only the comparison between the groups resulted in statistically significant difference ($P < .001$). Neither the post/canal region (coronal, middle, and apical) nor the interaction between the groups and regions had a significant influence on the results ($P > .05$).

Comparison of all groups (Table 2) showed that the groups with root reinforcement resulted in statistically similar (G_{80s}) or higher (G_{40s} and G_{120s}) bond strength means compared with the control group (GC).

Comparing the experimentally weakened/resin-restored groups (G_{40s}, G_{80s}, and G_{120s}), it was observed that the increase in composite light-exposure time did not result in statistically significant difference in bond strength ($P > .05$). Likewise, when the post/canal regions (coronal, middle, and apical) were compared, the use of different light-exposure times did not have a statistical effect in the mean bond strengths ($P > .05$).

Table 3 shows the failure modes observed in each group and post/canal region. There was a predominance of adhesive failures in the weakened/restored groups as well as in the control group. In the resin-reinforced specimens, either the cement had completely

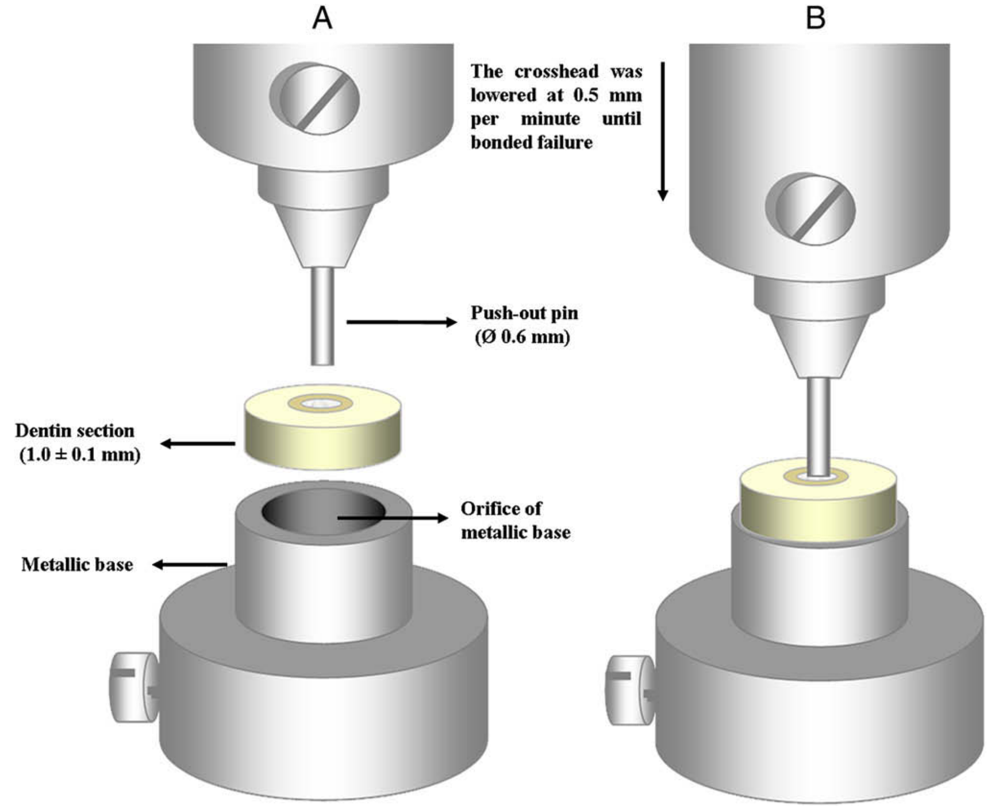

Figure 2. Schematic illustration of the push-out test (*A*); specimen fixed to the metallic device during the test (*B*).

dislodged from the post, or the post/cement/resin set had dislodged from the dentin. In the control group, adhesive failures between the post and cement were the most frequent observed followed by mixed failures. Cohesive failures were predominant in the apical region and were observed only in weakened/restored groups.

Discussion

The use of composite resin for intracanal restoration of weakened roots before cementation of prefabricated, fiber, or metallic posts has been shown to increase root resistance to fracture (2, 3). However, there are few published data referring to the bond strength along the root canal in these cases (3). The present study evaluated the regional bond strength of quartz fiber posts cemented to radicular dentin walls previously restored with a composite resin photoactivated with different light-exposure times.

In the present study, the push-out test was performed with 1-mm-thick serial root slices, which allowed a more uniform application of the shearing force over the adhesive interface, with less interference of tensile forces (11, 14). The use of this methodology was particularly important because it permitted an evaluation of the efficacy of the composite resin reinforcement in a specific area, indicating precisely the sites where failures occurred. In addition, because the push-out test is based on the application of extrusion shear forces, the confined root canal space might be more reliably simulated than in the conventional shear and microtensile strength tests (11, 12).

The findings of the conducted research showed that regardless of the light-exposure time of the composite resin used for root reinforcement, bond strength means were either higher than or similar to those obtained for the control specimens. Coronal and middle regions had statistically similar bond strength means to those of the apical region in all groups. These results might be due to the following events: easier application of the adhesive system to the artificially flared root dentin walls; adhesive system used; total light-curing time of resin restoration and post cementation; and materials used for root restoration (light transmitting post and translucent composite resin). Other previous investigations that assessed bond strength in different regions of the cemented post by using different methodologies found lower bond strength in the middle and apical thirds (11, 13–15).

TABLE 2. Bond Strength Means (MPa) and Standard Deviations for the Different Groups and Post/canal Regions

	Post/canal region			
Group	Coronal	Middle	Apical	Overall
G_{40s}	10.39 (3.41)^{ABC}	11.15 (2.89)^{AB}	9.54 (2.61)^{ABC}	10.36 (2.99)^{a}
G_{80s}	8.91 (2.37)^{ABC}	8.75 (2.76)^{ABC}	9.44 (3.04)^{ABC}	9.03 (2.69)^{ab}
G_{120s}	11.77 (2.90)^{A}	9.13 (2.93)^{ABC}	9.95 (3.24)^{ABC}	10.28 (3.16)^{a}
GC	8.35 (2.52)^{BC}	7.78 (2.28)^{C}	7.679 (3.49)^{C}	7.94 (2.78)^{b}

G_{40s}, G_{80s}, and G_{120s} are weakened/restored groups with different composite resin light-exposure times (40 s, 80 s, and 120 s, respectively). GC is the nonflared/nonreinforced control group. Different superscript letters indicate a statistically significant difference at the 5% level.

TABLE 3. Failure Modes Observed on the Debonded Specimens of the 3 Experimental Groups (n = 15) and Control Group (n = 15) after the Push-out Test

Groups	Regions	Adhesive failure/ post (%)	Adhesive failure/ dentin (%)	Mixed failure (%)	Cohesive failure/ dentin (%)	Cohesive failure/ resin (%)
G_{40s}	Coronal	66.7	20.0	—	13.3	—
	Middle	66.7	26.6	—	6.7	—
	Apical	60.0	—	—	33.3	6.7
G_{80s}	Coronal	46.7	53.3	—	—	—
	Middle	60.0	40.0	—	—	—
	Apical	40.0	33.3	—	20.0	6.7
G_{120s}	Coronal	53.3	40.0	—	6.7	—
	Middle	53.3	40.0	—	6.7	—
	Apical	46.7	20.0	6.7	13.3	13.3
GC (control)	Coronal	73.3	6.7	20.0	—	—
	Middle	66.7	—	33.3	—	—
	Apical	66.7	6.7	26.6	—	—

G_{40s}, G_{80s}, and G_{120s} are weakened/restored groups with different composite resin light-exposure times (40 s, 80 s, and 120 s, respectively). GC is the nonflared/nonreinforced control group. Adhesive failure/post, failure between fiber post and resin cement; adhesive failure/dentin, failure between dentin and composite resin (in the weakened/restored groups) or failure between dentin and cement (in the control group); mixed, failure occuring at fiber post/resin cement interface and at cement or composite resin/root dentin interfaces in the same specimen; cohesive failure/dentin, if the fracture occurred in the dentin; cohesive failure/resin, if the fracture occured only in the resin.

In our study, experimental root weakening (root dentin flaring) might have facilitated the access to deeper areas of the post space, thus enhancing the adhesive procedures. It is known that resin-based material, especially when it is nonuniformly adapted or incompletely polymerized, might negatively affect the dentin bonding and decrease the longevity of the adhesive interface (29, 30).

In addition, All Bond 2 three-step total-etch adhesive system, used before the Duolink resin cement, might have successfully hybridized apical root dentin, even in the control group. In deeper root canal regions, drying of the acid-etched dentin is more critical than in coronal regions. Because of its acetone and alcohol-based composition, this system can act well on moist or slightly wet dentin, increasing bond strength. Akgungor and Akkayan (13) investigated the influence of dentin bonding agents and polymerization modes on the bond strength between translucent fiber posts and 3 dentin regions within a post space and found similar results in all regions when a self-etching adhesive system was used. These authors suggested that bond strength in deeper regions might be attributed not only to the access difficulties but also to the chemical composition and application technique of the tested adhesive systems.

It was also verified in the present study that light-exposure time did not influence the bond strength in the post/resin-restored groups. However, when the DT Light Post was cemented to the canal, dual resin cement was photoactivated for additional 40 seconds to control its setting time and thus facilitate specimen handling. Therefore, in these groups the total light-exposure time ranged from 80–160 seconds. This might explain, in part, the similar bond strength recorded within the post space in the depths of 2, 6, and 10 mm, regardless of the time of light exposure.

The light-activated composite resin used for root restoration (Light Core; Bisco, Inc) might also have affected the results because according to the manufacturer, its translucency provides a curing depth of up to 5 mm, which is considerably greater than that recommended for photoactivation of nontranslucent resins (2-mm-thick increments).

The cementation of light-transmitting fiber posts simultaneously with composite resin restoration (single-step technique) seems to be easier and faster than the 2-step root restoration technique used in our study, whereby the adhesive system applied to dentin was light-activated before resin placement and fiber post cementation. A previous scanning electron microscopic study (29) found that simultaneous light-curing of the adhesive system to dentin during fiber post cementation might produce a thinner hybrid layer and less resin tag formation, especially in the apical post space region. Other authors have stated that resin cement application and post seating might damage the unpolymerized adhesive system layer applied to root canal dentin (13). More recently, a study with an experimental model similar to that of the present study observed that different light-exposure times used for composite resin polymerization during root canal reinforcement with fiber posts did not affect significantly the formation and quality of the dentin/adhesive/composite resin bonding interface (31). Furthermore, they observed formation of a hybrid layer, resin tags, and lateral branches in all regions of the reinforced root.

The cavity configuration factor (C-factor) is the ratio of the bonded surface area in a cavity to the unbonded surface area (8). It is known that when a cavity to be restored has more free than bonded surfaces, there are greater material flow and less internal stress during the curing process (8, 9, 11–14). During polymerization, unbonded surfaces can move and flow, thereby relieving shrinkage stresses. However, as the unbonded surface area decreases, as in a long, narrow root canal, there are insufficient stress relief and a high likelihood of debonding of 1 or more bonded areas (8, 14, 32). In addition, cavities with a greater C-factor, restored with composite resin, presented a larger number of interfacial failures/gaps (32). It might be assumed that in our study, post cementation carried out after composite resin restoration of the root structure decreased the bonded-to-unbonded surface ratio during resin photoactivation, which might have provided a higher material flow and, consequently, lower composite polymerization shrinkage.

The analysis of the failure modes after the push-out test (Table 3) showed a higher percentage of adhesive and mixed failures between the post and the cement, mainly in the control group. In the weakened/restored groups, there were adhesive failures between resin and dentin, but they were still in a lower percentage than that of the adhesive failures in the post. Furthermore, some specimens in these groups showed dentin fracture (cohesive failure in the dentin), mainly in the apical third. This seems to suggest that although composite resin root restoration provides similar or superior bond strength to that recorded for specimens in the control group, it does not guarantee that restored dentin will have the same resistance as that of the original dentin with greater thickness. In other words, although the restoration of weakened roots with light-activated composite resin increases their fracture strength, it cannot be categorically stated that the original condition of the removed dentin is re-established (2, 3).

Within the limits of this study, it might be concluded that the use of different light-exposure times for resin polymerization through translucent fiber post did not affect significantly the interfacial bond strength evaluated by the push-out test. Also, in the weakened/restored groups, the use of longer light-exposure times (80 and 120 seconds) did not provide increased bond strength between fiber post and resin-restored dentin, regardless of the region analyzed (coronal, middle, and apical).

The findings of the present study cannot be directly correlated with those of other materials because of the structural differences existing among the diverse types of composites and posts. Finally, further bond strength studies with weakened/restored roots after longer periods of storage and under clinical conditions should be conducted.

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