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MORPHOLOGICAL ANALYSIS OF GLASS, CARBON AND GLASS/CARBON FIBER POSTS AND BONDING TO SELF OR DUAL-CURED RESIN LUTING AGENTS

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ABSTRACT

Objective: The aim of this study was to evaluate the morphology of glass (GF), carbon (CF) and glass/carbon (G/CF) fiber posts and their bond strength to self or dual-cured resin luting agents. Material and Methods: Morphological analysis of each post type was conducted under scanning electron microscopy (SEM). Bond strength was evaluated by microtensile test after bisecting the posts and re-bonding the two halves with the luting agents. Data were subjected to two-way ANOVA and Tukey's test (α=0.05). Failure modes were evaluated under optical microscopy and SEM. Results: GF presented wider fibers and higher amount of matrix than CF, and G/CF presented carbon fibers surrounded by glass fibers, and both involved by matrix. For CF and GF, the dual-cured material presented significantly higher ($p<0.05$) bond strength than the self-cured agent. For the dual agent, CF presented similar bond strength to GF ($p>0.05$), but higher than that of G/CF ($p<0.05$). For the self-cured agent, no significant differences ($p>0.05$) were detected, irrespective of the post type. For GF and G/CF, all failures were considered mixed, while a predominance of adhesive failures was detected for CF. Conclusion: The bonding between fiber posts and luting agents was affected by the type of fibers and polymerization mode of the cement. When no surface treatment of the post is performed, the bonding between glass fiber post and dual-cured agent seems to be more reliable.

Key words: Scanning electron microscopy. Morphology. Post and core technique. Resin cements. Tensile strength.

INTRODUCTION

The restoration of endodontically treated teeth with fiber posts is widely performed in clinical practice in order to retain a core in teeth with extensive loss of coronal structure. The advantages of fiber post-and-core restorations have been demonstrated *in vitro*[1,13,17-19]. These systems might reduce the incidence of non-retrievable root fractures when compared to metal or conventional cast posts. In addition, retrospective[8,9] and prospective[11,15] clinical studies have shown overall satisfactory performance of endodontically treated teeth restored with fiber post-and-core systems.

Another favorable characteristic of fiber posts is their elastic modulus similar to dentin, resin luting agents and resin core materials[3]. The resulting homogeneous biomechanical post-composite-dentin structure allows a more uniform stress distribution, which better preserves the weakened tooth structure[3]. The clinical success of a post-and-core restoration also depends on the luting material used because materials of different compositions are in intimate contact. Some studies have assessed the bond strength of luting agents to root canal dentin[4,5,10,12]. However, the bonding performance of a fiber post also depends on the adhesion of luting agents to the post itself[2,14].

Carbon fiber (CF) posts were introduced in the early 1990s, but they presented some limitations, such as radiolucency and masking difficulties under all-ceramic or composite

restorations[20]. Later, glass fiber (GF) posts were introduced to overcome these limitations and, more recently, posts that mix glass and carbon fibers (G/CF) were developed. However, while studies concerning the bonding between posts and luting agents usually concentrate in different treatments of the post, there is not much information in the literature about the effect of the fiber type on the bonding ability to resin luting agents, especially regarding the use of G/CF posts. In addition, while conventional microtensile and push-out bond strength tests may assess the bonding of the post to the conical geometry of the root canal walls[12], the actual tensile forces taking place on the interface between the post and the cement/core assembly, as well on the apical portion of the post, are usually neglected.

The aim of this study was to evaluate the morphology of different fiber post types (glass, carbon or glass/carbon) and the bond strength to self or dual-cured resin luting agents using a microtensile bond strength test in which the direction of the forces are applied to the long axis of the post. The null hypothesis tested was that there is no significant differences in bond strength irrespective of the fiber type or the polymerization mode of the cement.

MATERIAL AND METHODS

Morphological Analysis

Dental posts (Reforpost; Angelus, Londrina, PR, Brazil) measuring 1.1 mm in diameter and 20 mm in length and presenting different types of fibers (GF, GF and G/CF) were tested. In order to evaluate their morphology, three specimens for each fiber type were embedded in epoxy resin (Buehler, Lake Bluff, IL, USA) polished wet in an automatic polisher (APL-4; Arotec, Cotia, SP, Brazil) with 600-, 1200- and 2000-grit SiC papers, followed by a final polishing using 3-, 1- and 0.25-µm diamond pastes (Buehler). The specimens were sputter coated with gold and examined with a scanning electron microscope (JSM5600LV; Jeol Inc., Peabody, MA, USA).

Bonding Procedures

Twenty posts of each fiber type were divided into two subgroups, according to the resin luting agent tested: dual-cured (RelyX ARC; 3M/ESPE, St. Paul, MN, USA) or self-cured agent (Cement-Post; Angelus). The composition of the luting agents is shown in Figure 1. In order to obtain a thin, clinically relevant cement film thickness, a novel method to obtain specimens for the microtensile bond strength test was carried out. Each post was sectioned perpendicular to the long axis of the specimen into two halves, using a water-cooled double-faced diamond disc (KG Sorensen, Barueri, SP, Brazil). The non-sectioned surface of each half was then used for bonding. The surfaces were cleaned using 37% phosphoric acid for 15 s, washed with air-water spray for 15 s, and dried with air stream for 15 s. A silane coupling agent (RelyX Ceramic Primer; 3M/ESPE) was applied to the post surfaces and air-dried for 10 s, followed by application of a layer of unfilled resin (Scotchbond; 3M/ESPE).

After light-activation of the unfilled resin for 20 s using a quartz-tungsten-halogen curing unit (Optilight 600; Gnatus, Ribeirão Preto, SP, Brazil – 500 mW/cm^2), the halves were bonded to each other using one of the two resin luting agents. The specimens were repositioned on the metal support with a constant 0.5 mm distance between them, and a thin layer of cement was applied to both surfaces using a dental spatula. The metal support also allowed a standard pressure to be applied and sustained in order to approximate the halves as close as possible, and create a thin cement film. The excess cement was removed, and the sets were left undisturbed for 10 min. For the dual-cured resin cement, light-activation was conducted for 20 s with the light guide perpendicular to the bonding interface. All materials were used in accordance with the manufacturers' instructions.

Bond Strength Evaluation

The microtensile test was conducted in a mechanical testing machine (DL2000; EMIC, São José dos Pinhais, PR, Brazil). The specimens were loaded at a cross-head speed of 0.5 mm/min until failure. Bond strength means were calculated in MPa. Data were subjected to two-way ANOVA (fiber type vs. luting agent) followed by *post-hoc* Tukey's test at 5% significance level.

Failure Mode Analysis

Fractured specimens were examined under an optical microscope (HMV-2; Shimadzu, Tokyo, Japan) at 200x magnification. Failure modes were classified as follows: adhesive failure or mixed failure involving bonding agent, luting cement and post. Additionally, representative fractured specimens were sputter coated with gold and subjected to SEM examination.

Luting agent	Manufacturer	Composition*
Cement-Post	Angelus	*Base*: Bis-GMA, TEGDMA, Ba glass particles, silica, co-initiators *Catalyst*: Bis-GMA, TEGDMA, Ba glass particles, silica, benzoyl peroxide
RelyX ARC	3M ESPE	*Base*: Bis-GMA, TEGDMA, prepolymers, ceramic particles, silica, camphorquinone, co-initiators *Catalyst*: Bis-GMA, TEGDMA, prepolymers, ceramic particles, silica, benzoyl peroxide

FIGURE 1- Resin luting agents used in the study
*Information supplied by the manufacturers.

RESULTS

SEM micrographs of the morphology of each post type are shown in Figure 2. The GF post presented wider fibers and higher amount of organic matrix involving the fibers compared with the CF post. The G/CF post presented carbon fibers in the center surrounded by glass fibers, and both fibers were involved by organic matrix.

Results for the microtensile bond strength for all groups are shown in Table 1. The two-way ANOVA showed that the factor 'fiber type' did not affect significantly the bond strength ($p = 0.111$). On the other hand, the factor 'luting agent' was significant: the dual-cured material showed overall higher bond strength than the self-cured agent ($p<0.001$). In addition, the

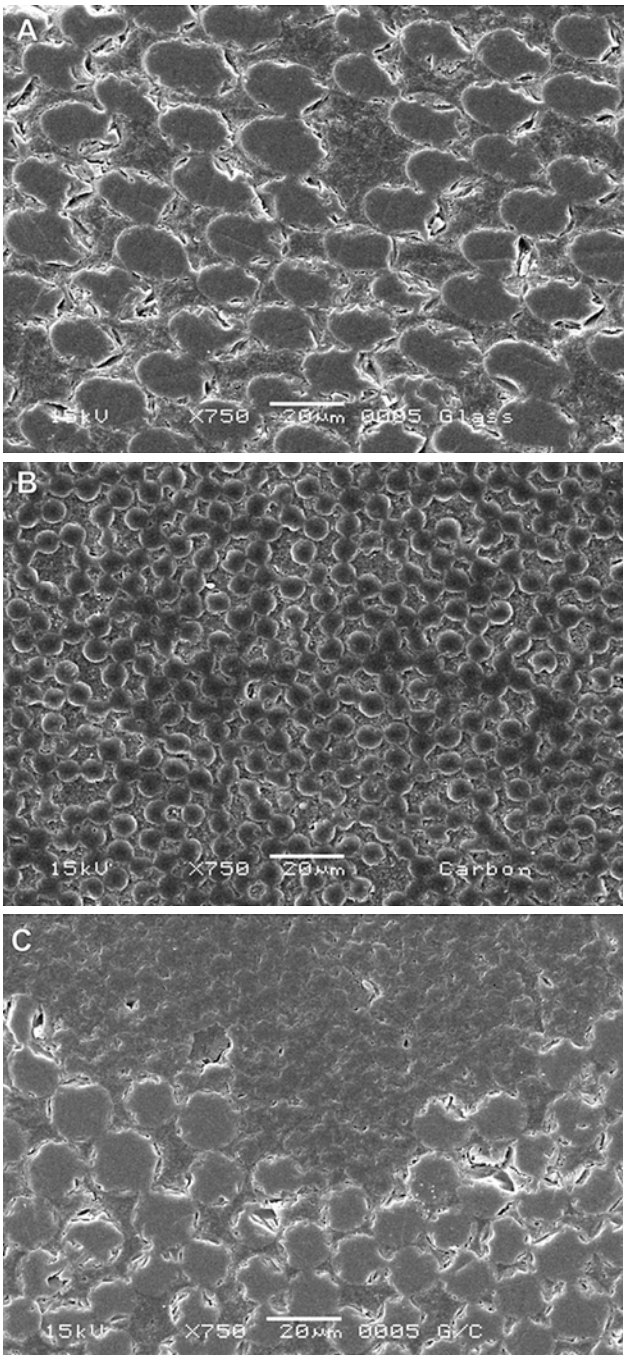

FIGURE 2- SEM micrographs of the morphological appearance of each post type. The glass fiber post (A) presented wider fibers and higher amount of organic matrix involving the fibers compared with the carbon fiber post (B). The glass/carbon fiber post (C) presented carbon fibers in the center, surrounded by glass fibers, and both fibers were involved by organic matrix

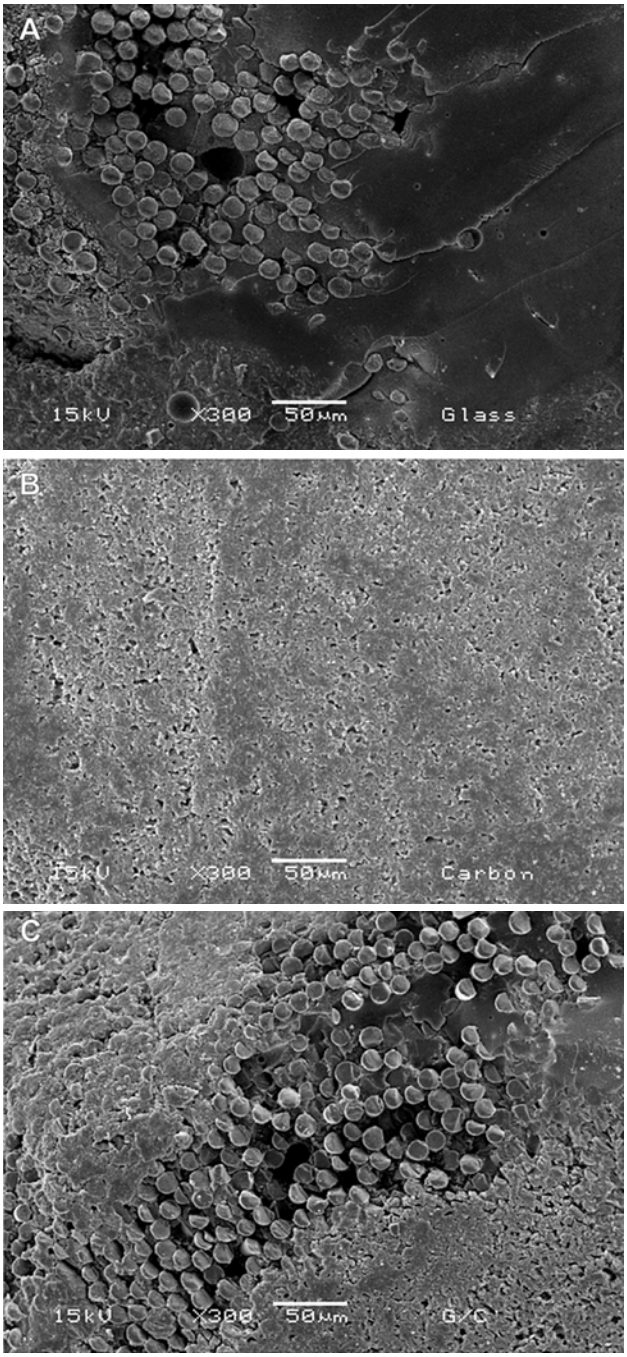

FIGURE 3- SEM micrographs for the failure modes. For the glass fiber post (A), all failures were considered mixed: note the remnants of bonding agent and luting cement on the post surface. Likewise, all failures were considered mixed for the glass/carbon fiber post (C), but the carbon fiber surfaces generally presented no remnants of adhesive or luting agent. For the carbon post (B), a predominance of adhesive failures was observed, characterized by post surface without adhesive or luting agent

TABLE 1- Microtensile bond strength means (standard deviations)

Post type	Luting agent	
	Dual-cured	Self-cured
Carbon fiber	20.1 (4.0) A,a	14.4 (1.8) B,a
Glass fiber	19.2 (3.9) A,ab	16.6 (2.1) B,a
Glass/carbon fiber	16.6 (1.8) A,b	15.5 (1.7) A,a

Means followed by different uppercase letters in the same row and lowercase letters in the same column were significantly different at p<0.05. Values are expressed in MPa.

TABLE 2- Results of the failure mode analysis

Post type	Dual-cured agent		Self-cured agent	
	Adhesive	Mixed	Adhesive	Mixed
Carbon fiber	70%	30%	60%	40%
Glass fiber	-	100%	-	100%
Glass/carbon fiber	-	100%	-	100%

interaction between the two factors tested was significant (p = 0.032). For CF and GF, the dual-cured presented significantly higher bond strength than the self-cured material (p<0.001 and p = 0.044, respectively), although similar bond strengths between both cements were observed for G/CF (p = 0.397).

Moreover, when luted with the dual-cured agent, CF showed similar results to GF (p = 0.740), but significantly higher bond strength than G/CF (p = 0.017). No significant differences were detected for G/CF and GF luted with the dual-cured material (p = 0.100). For the self-cured agent, no significant differences were detected, irrespective of the post type (p > 0.05). Results for the failure analysis are shown in Table 2. For GF and G/CF, all failures were considered mixed, involving bonding agent, luting cement and post (Figure 3). In contrast, a predominance of adhesive failures (Figure 3) was detected for CF.

DISCUSSION

The results of the present study show that the fiber type did not interfere with the overall bond strengths, partially confirming the hypothesis tested. The bond between fiber posts and luting agents relies on the diffusion of resin monomers of the cement into the organic matrix involving the fibers, and the composition of the resin matrix of the post might affect the ability of resins agents to penetrate between the fibers and achieve micromechanical adhesion. Although the morphological analysis showed that GF posts presented higher amount of organic matrix involving the fibers, this group did not present higher bond strength compared to the other post types. This observation is in line with the findings of Bell, et al.[4] (2005), who stated that the resin matrix between the fibers is highly cross-linked and sometimes even non-reactive due to the high degree of conversion, which in some situations might even impair its bonding ability to resin luting agents.

On the other hand, the dual-cured material presented significantly higher bond strength than the self-cured cement. Dual-polymerizable agents conciliate the favorable characteristics of self and light-cured cements, that is, a material with extended working time theoretically capable of reaching proper polymerization in either the presence or absence of light. The probable explanation for the present results is the fact that only for the dual-cured material the photo-polymerization reaction takes place, which is more effective when compared with the chemical polymerization[6], enhancing the conversion of double bond and thus the bond strength to the post[21]. In corroboration, Goracci, et al.[12] (2004) reported lower bond strength for self-cured compared with dual-cured materials.

For the G/CF post, however, similar results were observed for both luting agents. Although the overall bond strength values were similar among all types of posts, this result suggests that, in addition to the polymerization mode of the luting agent, the microstructure of the post may also interfere with bonding. Parameters such as the diameter of individual fibers, their density, embedment of resin matrix around the fibers, and quality of the entanglement between the glass and carbon fibers, might affect the bond strength to posts that mix glass and carbon fibers. In light of this, it could be speculated that a concentration of stress may have occurred in the interface between the different fibers during the tensile testing, leading to similar bond ability for both dual and self-cured agents. However, this effect needs further investigation to be confirmed.

With regard to failure mode analysis, GF and G/CF posts presented only mixed failures, whereas a predominance of adhesive failures was detected for CF. Correspondingly, Bell, et al.[4] (2005) reported that GF posts did not show any adhesive failure between the post and the cement, while CF posts showed mainly complete or partial adhesive failures. A probable explanation for this result is the higher amount of organic matrix detected in the SEM analysis for the GF compared with the CF post. As the adhesion is theoretically enhanced for GF, failures involving post, luting agent and adhesive are generated. For

CF, as shown in Figure 1, the smaller diameter and higher surface area of the fibers may decrease the amount of organic matrix available for bonding, generating mainly adhesive failures.

Previous studies describe distinct methods to obtain specimens for evaluating the bond strength between fiber posts and resin luting agents[2,14,16], usually using experimental designs in which the resulting cement film thickness is not clinically relevant. The current study proposes a novel method to obtain specimens for microtensile bond test with film thickness similar to clinical conditions. The present method may also have limitations, as the forces applied during the tensile test might be different from the forces occurring at the conical geometry of the root canal. However, while bonding to root canal might rely mainly on the friction of the post to the canal walls[12], the present method may reflect the direction of forces taking place at the interface between the post and the cement/core assembly in the crown, and at the apical portion of the post as well.

The present results have clinical implications, as the selection of both fiber post and luting material were shown to be important for bonding. Despite the non-significant differences in bond strength, the mechanism of bonding to carbon posts seems to be less efficient compared with posts presenting glass fibers. Nonetheless, the application of surface treatments may provide an opportunity to increase bond strength to any fiber post, and this issue still warrants investigation. In addition, the dual-cured luting agent presented significantly higher bond strength than the self-cured material. However, it should be highlighted that the dual-cured agent was photo-activated in an ideal scenario, that is, with direct exposure to light. Under clinical conditions, the middle and apical thirds may receive lower energy doses, which could interfere with the bond strength to the post itself or to the root canal walls. Moreover, it has been demonstrated that the translucency of fiber posts might interfere with the polymerization of the luting agent[7], and different results might be expected for GF and CF posts. Therefore, further clinical and laboratory studies are necessary.

CONCLUSION

The bonding between fiber posts and resin luting agent might be affected by both the type of fibers and polymerization mode of the cement. Based on bond strength measurements and failure analysis, when no post surface treatment is performed, the adhesion between glass fiber post and dual-cured resin luting agent seemed to be more efficient compared to the other tested conditions.

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