Original Article

Bond Strength and Failure Mode of Glass Fiber Posts with Different Surface Treatments Prior to Silanization: An *In Vitro* Comparative Study

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ABSTRACT

Aim: The use of chemical agents in the surface treatment of glass fiber posts can improve their bond strength to the root canal. The aim of this study was to assess the bond strength and failure mode of glass fiber posts that received different surface treatments prior to silanization. **Materials and Methods:** In this cross-sectional and *in vitro* experimental study, 50 human lower premolar roots were randomly divided into five groups and subsequently prepared to receive the cementation of a fiberglass post prior to silanization. They were distributed as group 1 (with 24% hydrogen peroxide), group 2 (with 37% phosphoric acid), group 3 (with 1.23% acidulated phosphate fluoride for 2 minutes), group 4 (with 1.23% acidulated phosphate fluoride for 6 minutes), and group 5 (without pretreatment). After cementation, the roots were sectioned into two discs for each cervical, middle, and apical region. Bond strength was assessed using the *push out* technique. Adhesive, mixed, and cohesive failure modes were also assessed. For data analysis, ANOVA and Tukey's *post hoc* tests were used, as well as Pearson's chi-square test. A significance of $P < 0.05$ was considered in all statistical analyses. **Results:** When comparing the bond strength of root regions, significant differences were obtained in groups pretreated with phosphoric acid ($P = 0.018$) and acidulated phosphate fluoride for 2 and 6 minutes ($P = 0.001$ and $P = 0.000$, respectively). Furthermore, significant differences were obtained between posts treated only with silane and those that received phosphoric acid pretreatment ($P = 0.006$) and acidulated phosphate fluoride for 6 minutes ($P = 0.001$). Significant association of mixed failure mode was observed with hydrogen peroxide ($P = 0.014$) and phosphoric acid ($P = 0.006$) pretreatments. Cohesive failure was significantly associated with acidulated phosphate fluoride pretreatment for 2 minutes ($P = 0.032$) and with posts that did not receive treatment prior to silanization ($P = 0.000$). **Conclusion:** Posts treated only with silane and pretreated with hydrogen peroxide and acidulated phosphate fluoride for 2 minutes presented significantly higher bond strength with respect to those pretreated with phosphoric acid and acidulated phosphate fluoride for 6 minutes. However, acidulated phosphate fluoride for 2 minutes and silane were associated with a better bonding type.

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Introduction

Endodontically treated teeth may require extensive coronal reconstruction. Depending on the severity of the coronal tissue loss, an intracanal post will be required for core retention and final restoration.[1-4] In this regard, metal alloy posts have been reported to cause lower retention, increased risk of root fractures, and esthetic compromise, as well as being prone to corrosion.[5-7]

In the last 25 years, the use of glass fiber-reinforced posts has been developed as an alternative to metal alloy posts. Different researchers have suggested that this type of post presents very favorable mechanical behavior for a tooth, as it presents an elastic modulus (16–40 GPa) similar to dentine (18.6 GPa), allowing a uniform distribution of masticatory forces on the root structure.[1,5] Additionally, it presents higher resistance to fatigue and greater flexibility, reducing the risk of root fractures and mechanical collapses that force tooth extraction.[3,5,8] Also, glass fiber-reinforced posts can transmit light and improve the optical appearance of the stump and the translucent or opaque crown base, resulting in more esthetic and natural restorations.[1,3,5] Moreover, they are corrosion-free, which prevents the irritation of periapical tissues and tooth discoloration.[3,5,9] However, adhesion to root dentin offers less favorable conditions compared with coronal dentin, being considered as a weak point in restorative treatment.[10] There are several factors that may affect the retention of glass fiber-reinforced posts in root canals, such as the preparation and conditioning of post space, postcementation, type of endodontic cement, adhesive system to be used, method of application of luting agent, and post pretreatment.[1,11,12]

Treatments for glass fiber posts can be divided into three categories: first, treatments with sandblasting and etching with hydrogen peroxide, phosphoric acid, or hydrofluoric acid that result in surface irregularities and exposure of glass fiber[13,14]; second, treatments with chemical bonding between the cementing material and the glass fiber post (coating and priming solutions)[15,16]; and third, the combination of micromechanical and chemical components using the two methods mentioned above.[15,17,18]

The application of hydrogen peroxide and phosphoric acid to the glass fiber post is effective, since both dissolve the epoxy resin and expose fibers, leaving an optimal surface for silanization.[14,15,18] Majeti *et al.* concluded that the surface treatment of post with 37% phosphoric acid for 15 seconds generates greater bond strength, significantly improving the post bonding to the root dentin.[2] Mosharraf *et al.* concluded that hydrogen peroxide with silane for 60 seconds generates higher bond strength, especially in the cervical region, and the lowest values were reported in the untreated group and the apical region.[18] On the other hand, acidulated phosphate fluoride (APF) has shown a gradual and significant increase of bond strength in surface treatments of feldspathic and leucite-rich porcelains.[19] To date (September 2021), there is still no evidence of studies that have applied APF as a surface treatment protocol on glass fiber posts. Instead, silanization is the most commonly used chemical pretreatment when placing a glass fiber post, since coupling agents such as silane are bifunctional molecules in which one end is able to react with the inorganic glass fiber and the other with the organic resin of the luting agent, thus favoring good adhesion.[20,21]

Therefore, this study aims to assess bond strength and failure mode of glass fiber posts that received different surface treatments prior to silanization. This study considered the Checklist for Reporting *In-vitro* Studies (CRIS) guidelines.[22]

Materials and Methods

Type of study and delimitation

This cross-sectional, analytical, and experimental *in vitro* study was carried out at the Dental Materials Laboratory of Dentistry program at the Universidad Estadual de Ponta Grossa, Paraná-Brazil and Universidad Peruana Cayetano Heredia, Lima-Peru, between January and May 2017.

Variables

The variables analyzed were: bond strength, failure mode, and the type of pretreatment on glass fiber post surface.

Sample size calculation and selection

The calculated sample size per group was 10 teeth ($n = 10$), giving a total of 50 human premolars distributed in five groups. The calculation was made from a previous pilot study, in which a mean comparison formula was applied considering an $\alpha = 0.05$ and a statistical power (1−β) = 0.8, with variances $S_1^2 = 42.34$ and $S_2^2 = 38.19$, and a mean difference equals to 8 Mpa. The distribution of sampling units was randomly assigned to the groups by a blinded laboratory assistant. Subsequently, the statistical analysis of results was also processed by another blinded researcher.

The sample selection criteria were given below.

Inclusion criteria

- Permanent lower premolars with single root canal and crown-to-root length of 22 ± 2 mm
- Premolars free of caries, cracks, fractures, calcifications, and root resorption
- Right and left lower premolars
- Premolars with fully formed apex and without previous endodontic treatment or posts
- Premolars extracted in the last 3 months prior to the study.

Exclusion criteria

- Premolars with dilaceration.

Preparation of teeth

Soft-tissue debris or bacterial plaque was removed from the extracted teeth using an ultrasonic dental scaler (DTE D5 LED, Woodpecker, Guilin, Guangxi, China). The teeth were then subjected to radiographic examination and stored in 0.9% sodium hypochlorite solution. Subsequently, crowns were cut at the cemento-enamel junction to obtain roots with a standardized length of 14 mm.

Endodontic preparation

The root canal working length was 1 mm from apical foramen.[2,23,24] All teeth received endodontic treatment using a no. 40 reciprocating file (Reciproc, VDW, Munich, Germany) inside the root canal with an electric motor (VDW GmbH, Munich, Germany) set for reciprocating motion according to the manufacturer's instructions. During preparation, the canals were irrigated with 5 mL of 5.25% NaOCl and 17% ethylenediaminetetraacetic acid (EDTA) (Canalarge, Ammdent, Chandigarh, India) repeating the process each time the instrument was removed. The obturation was performed with the vertical condensation method, using a single R40 gutta-percha cone (VDW GmbH, Munich, Germany) and Adeseal epoxy resin sealer (Meta Biomed Co Ltd, Chungbuk, Korea). Radiographs were taken to confirm proper obturation of the root canal. The canal access was obturated with a temporary restorative material. The specimens were stored at 37°C and 100% of relative humidity during 72 hours for complete setting of the resin sealer [Figure 1].

Preparation of space for post placement

After 72 hours, gutta-percha was removed from the cervical and middle third of each root with the Gates Glidden bur no. 3 (Maillefer Dentsply, Ballaigues, Switzerland) so that only 4 mm of gutta-percha was preserved in the apex to maintain the apical seal. All post spaces were prepared to a depth of 9 mm from the sectioned surfaces using drills provided by the post manufacturer.[24] To standardize the final shape of the post spacing, drill no. 1 was used. Finally, the post spaces were irrigated with 10 mL of 5.25% NaOCl and distilled water, drying the canals with paper points [Figure 2].

Distribution of experimental groups, pretreatment, and cementation of glass fiber posts

In each sample, a White Post DC #1 glass fiber post (FGM, Joinville, Brazil) with 1.6 mm cervical diameter, 0.85 mm apical diameter, and 20 mm length was tested in the post spaces. Then, all posts were cut to 10 mm starting from the tip with a fine-grained fissure diamond bur (KG Sorensen, Sao Paulo, SP, Brazil) mounted on an NSK dental handpiece (Pana Max, Sao Paulo, Brazil) with constant irrigation. The 50 glass

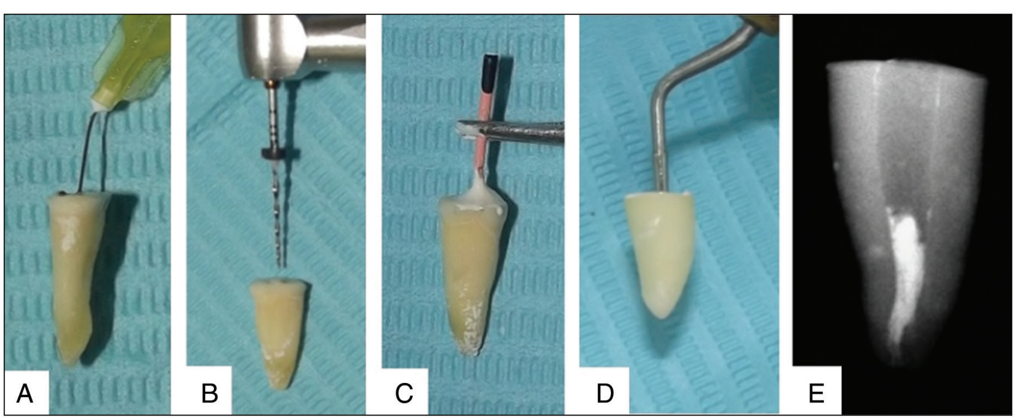


Figure 1: (A) Irrigation with 5.25% NaOCl and 17% ethylenediaminetetraacetic acid (EDTA), (B) instrumentation with rotary system, (C) obturation with single cone and resin-based cement, (D) vertical compaction technique, (E) radiographic evaluation

fiber posts were randomly divided into five groups of 10 each, according to the surface treatment used. The preparation of glass fiber posts and conformation of groups were as follows:

- Group 1: Hydrogen peroxide (H_2O_2) + silane. Glass fiber posts were cleaned with alcohol for 60 seconds and then etched with 24% H_2O_2 for 60 seconds, washed, and dried, and finally silane coupling agent (BISCO Inc., Schaumburg, IL, USA) was applied for 60 seconds.
- Group 2: Phosphoric acid (H_3PO_4) + silane. Glass fiber posts were cleaned with alcohol for 60 seconds and then etched with 37% H_3PO_4 (FGM, Condac, Brasil) for 15 seconds, washed, and dried, and finally silane coupling agent was applied for 60 seconds.
- Group 3: APF 2 minutes + silane. Glass fiber posts were cleaned with alcohol for 60 seconds and then etched with 1.23% APF (Proquident, Dentafluor, Colombia) for 2 minutes, washed, and dried, and finally silane coupling agent was applied for 60 seconds.
- Group 4: APF 6 minutes + silane. Glass fiber posts were cleaned with alcohol for 60 seconds and then etched with 1.23% APF for 6 minutes, washed, and dried, and finally silane coupling agent was applied for 60 seconds.
- Group 5: Silane (control). Glass fiber posts were cleaned with alcohol for 60 seconds and then silane coupling agent was applied for 60 seconds.

The posts were cemented into the root canals with RelyX U200 self-adhesive resin cement (3M ESPE, St. Paul, MN, USA) using an LED light-curing unit (Optilight LD Max, São Paulo, Brazil) for 40 seconds per tooth surface. After complete polymerization, the radiographic evaluation of the cementation was performed on all posts. Finally, all the samples were stored for 24 hours at 37°C in distilled water [Figure 3].

Preparation of root cuts

After storing each sample in distilled water for 24 hours, they were placed on an acrylic block and taken to a precision cutting machine with a water-cooled diamond disk (Isomet 1000; Buehler, Lake Buff, USA). The samples were serially sectioned perpendicular to the longitudinal axis of post, obtaining two discs of 1 mm (±0.5 mm) of thickness for each cervical, middle, and apical root region, giving a total of 60 discs for each treatment group [Figure 4 and Table 1].

Push out technique

Using a marker pen, each disc was marked on its apical side. The thickness of all discs was measured using a digital caliper. Diameter measurements were performed on the coronal and apical sides of the posts using microphotographs taken with a stereo microscope (Olympus, model BX 51, Tokyo, Japan) at 40× magnification, in order to calculate the adhesive area for each disc obtained. The measurements were obtained through Software Image J version 1.48r (National Institutes of Health, Bethesda, Maryland, USA) and were performed by the principal investigator, previously calibrated with an intraclass intraexaminer correlation coefficient of 0.95 (confidence interval [CI] = 0.92–0.97) and interexaminer of 0.91 (CI = 0.86–0.96), both being very good values [Figure 5].

After confirming the thickness of discs, each one was taken to an Instron testing machine (Autograph AG 15, Shimadzu, Kyoto, Japan) with its cervical side facing the metal base and the dentin–cement–post section area coinciding with the 2.5 mm diameter of the base hole. The posts were pushed out with cylindrical tips of different diameters (0.7 mm, 0.9 mm, and 1.0 mm) chosen according to the dentin–cement–post section area size.

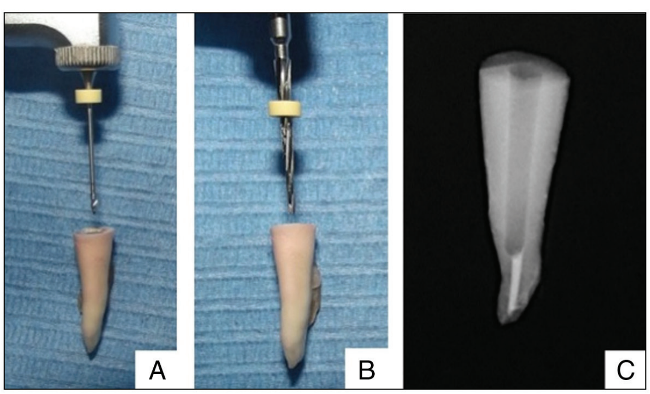


Figure 2: (A) The removal of gutta-percha with Gates Glidden bur no. 3, (B) shaping bur no. 1, (C) radiographic evaluation of post spacing

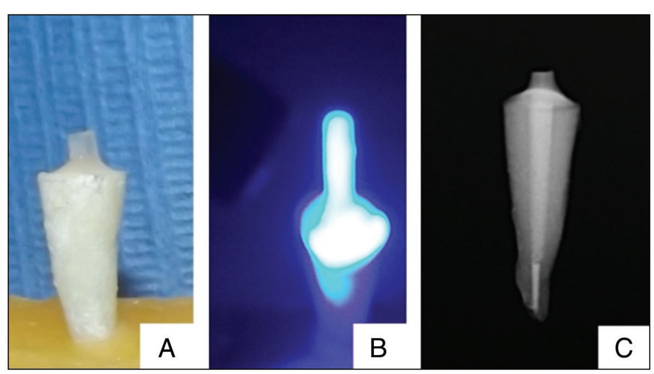


Figure 3: (A) The cementation of glass fiber post, (B) light curing of the post, (C) radiographic evaluation after cementation

The tip of the plunger was positioned so that it could touch only the post, avoiding any contact with cement and dentin. The *push out* technique was performed

Figure 4: Cervical, middle, and apical root discs

on a universal testing machine at 0.5 mm/minute. The bond strength value was determined by dividing the applied load (N) by the bonding area (N/mm^2 = MPa [megapascals]).

The post was pushed into the larger portion of the root cut to avoid limiting its displacement due to canal narrowing. It was also ensured that the contact between the plunger tip and post section occurred in the most extended area possible, in order to avoid notching effects on the surface that could interfere with results [Figure 6].

Failure mode analysis

Failure modes were assessed using a stereo microscope at 40× magnification. After the evaluation of bond strength, the failure mode was determined by the extrusion of the post section from the root canal. Each test group was analyzed by a previously calibrated evaluator with Cohen's kappa index intraexaminer 0.91 (CI = 0.88–0.94) and interexaminer 0.88 (CI = 0.83–0.92), both being very good values. The failure modes were classified as: adhesive (total dislocation of post and resin cement), mixed (post dislocation with resin cement remnants), and cohesive (failure associated to a single body, i.e., dentin, post, or cement without post dislocation)[2,25] [Figure 7].

Statistical analysis

Data were entered into a Microsoft Excel 2016 spreadsheet and subsequently imported for statistical analysis by the SPSS program (Statistical Package for the Social Sciences Inc., IBM, NY, USA) version 24.0. For descriptive analysis of bond strength, measures

Table 1: Comparison of bond strength (Mpa) between glass fiber posts with different pretreatments according to root region

Surface treatment	Root region	Discs	Mean	SD	SE	95% CI	*P*
24% H_2O_2	Cervical	20	10.99	5.62	1.26	8.36–13.62	0.058
	Middle	20	14.94	7.39	1.65	11.49–18.40	
	Apical	20	22.50	24.44	5.46	11.06–33.49	
37% H_3PO_4	Cervical	20	7.97	5.55	1.24	5.37–10.57	0.018*
	Middle	20	11.81	7.62	1.70	8.24–15.38	
	Apical	20	16.13	11.91	2.66	10.55–21.70	
1.23% APF (2 minutes)	Cervical	20	9.73	4.66	1.04	7.55–11.91	0.001*
	Middle	20	15.18	7.80	1.74	11.53–18.83	
	Apical	20	17.43	6.47	1.45	14.39–20.46	
1.23% APF (6 minutes)	Cervical	20	8.60	7.64	1.71	5.02–12.18	0.000*
	Middle	20	6.21	4.75	1.06	3.99–8.44	
	Apical	20	16.50	8.85	1.98	12.35–20.64	
Control (silane only)	Cervical	20	17.15	7.22	1.61	13.77–20.53	0.108
	Middle	20	15.93	6.91	1.55	12.69–19.56	
	Apical	20	32.73	46.64	10.43	10.90–54.55	

APF = acidulated phosphate fluoride, H_2O_2 = hydrogen peroxide, H_3PO_4 = phosphoric acid, SD = standard deviation, SE = standard error of mean, 95% CI = 95% confidence interval

*ANOVA test, $P < 0.05$ (significant differences)

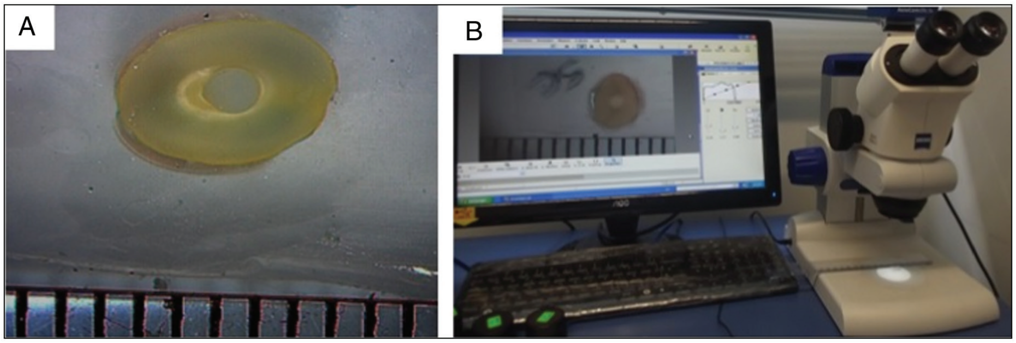


Figure 5: (A) The photograph of cervical and apical diameter on the post, (B) the use of stereo microscope at 40× magnification

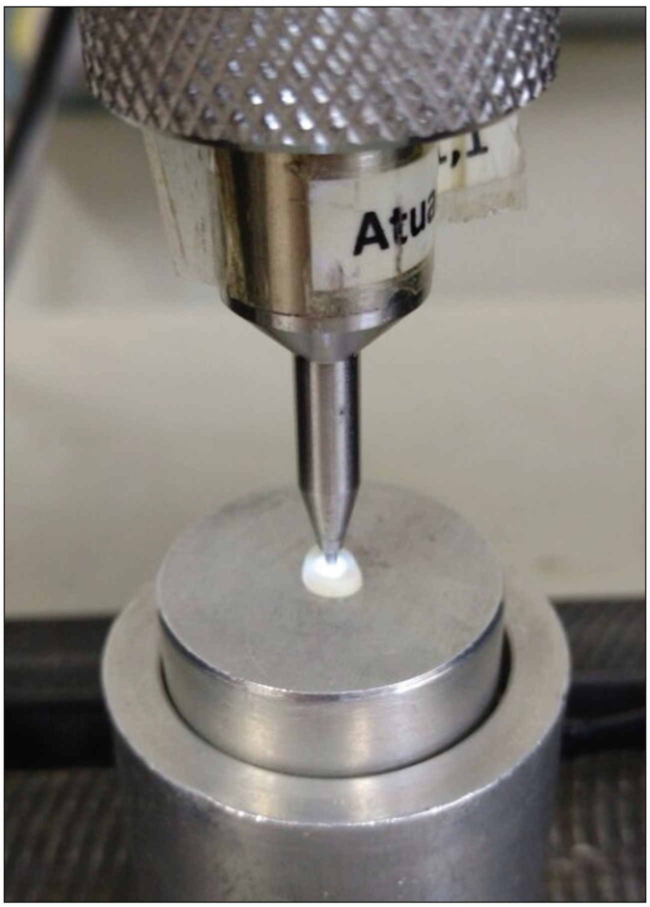


Figure 6: Universal testing machine for *push out* technique

of central tendency and dispersion such as mean and standard deviation were used. For inferential analysis, Shapiro-Wilk test was used to evaluate if the data had a normal distribution, and Levene test was used to evaluate homogeneity of variances. For comparison, we decided to use the intersubject ANOVA parametric test and Tukey's *post hoc* test. In addition, Pearson's chi-square test with Yates's correction was applied to associate the failure mode variable with the type of surface treatment on posts. Differences were considered statistically significant for $P < 0.05$.

Bioethical considerations

This research respected the bioethical principles for medical research involving human subjects of the Declaration of Helsinki related to confidentiality, freedom, respect, and nonmaleficence. This research was approved by Ethics and Research Committee of the Faculty of Stomatology at the Universidad Peruana Cayetano Heredia with letter no. 454-24-16 and registration code 100199. The teeth obtained in the present study were donated by patients, after informed consent.

Results

All glass fiber posts pretreated with 24% hydrogen peroxide (22.50 Mpa, CI = 11.06–33.49), 37% phosphoric acid (16.13 Mpa, CI = 10.55–21.70), 1.23% APF for 2 minutes (17.43 Mpa, CI = 14.39–20.46), 1.23% APF for 6 minutes (16.50 Mpa, CI = 12.35–20.64), and only silane (32.73 Mpa, CI = 10.90–54.55) presented higher bond strength in the apical region. In addition, significant differences were observed according to the root region in the groups pretreated with phosphoric acid ($P = 0.018$) and with APF for 2 minutes ($P = 0.001$) and 6 minutes ($P = 0.000$) [Table 1].

When performing complementary comparisons of the bond strength, significant differences were observed in the posts pretreated with 37% phosphoric acid between the cervical and apical root region ($P = 0.013$). On the other hand, in posts treated with 1.23% APF for 2 minutes, it was noticed that cervical region presented significant differences compared with the middle region ($P = 0.026$) and the apical region ($P = 0.001$). However, when the same pretreatment was applied for 6 minutes, it was noticed that the apical region presented significant differences with the cervical region ($P = 0.003$) and the middle region ($P = 0.000$) [Table 2].

When comparing the bond strength of glass fiber posts with different pretreatments, significant differences were observed between posts that did not receive silane pretreatment (control) and those that received pretreatment with 37% phosphoric acid (P = 0.006) and 1.23% APF for 6 minutes (P = 0.001) [Table 3].

The most prevalent failure mode was cohesive (46%) and the least prevalent was adhesive (13%). When analyzing the correspondence of the failure mode with the treatments prior to silanization, a significant association of mixed failure with 24% hydrogen peroxide pretreatment (P = 0.014) and 37% phosphoric acid (P = 0.006) was observed. A significant association of cohesive failure was also observed with pretreatment of 1.23% acidified fluoride phosphate for 2 minutes (P = 0.032) and with the posts that did not receive treatment prior to silanization (control) (P = 0.000) [Table 4 and Graph 1].

Discussion

The present study aims to compare *in vitro* the bond strength of glass fiber posts in root canal using H_2O_2 at 24%, H_3PO_4 at 37%, APF at 1.23% for 2 minutes and for 6 minutes, and only silane (control group) as surface treatments prior to silanization. Results showed that the surface treatment with only silane presented the best bond strength values. In addition, the best bond strength in all experimental groups was in the apical root region. On the other hand, a significant association of the mixed failure mode could be observed with hydrogen peroxide pretreatment at 24% and with phosphoric acid at 37%. The cohesive failure mode was also significantly associated with the 1.23% APF pretreatment for 2 minutes and with those posts that did not receive treatment prior to silanization.

In the present study, all glass fiber posts were silanized, since different authors have reported that applying silane to glass fiber posts improves adhesion to cement and dentin by selectively exposing the glass fibers, unlike other treatments that can cause fractures or cracks, affecting the mechanical stability of the stump.[10,20,21,26] In addition, the application of silane is simple, being a widely accepted pretreatment procedure among researchers.[1,27]

It was decided to perform a treatment prior to silane application since Belwalkar *et al.* concluded that only silanization as surface treatment of the post prior to cementation does not improve its bond strength.[26] Other authors reinforce the above, as they have reported that the combination of chemical surface pretreatments followed by silanization significantly improves bond strength at the cement–dentin interface.[25,28] Furthermore, Sarkis-Onofre *et al.* in a systematic review with meta-analysis reported that the use of silane and cementation with self-adhesive systems proved to be more effective, as they have higher bond strength values.[17] In another systematic review by Mishra *et al.*, it was reported that the application of different surface treatments such as acid etching and

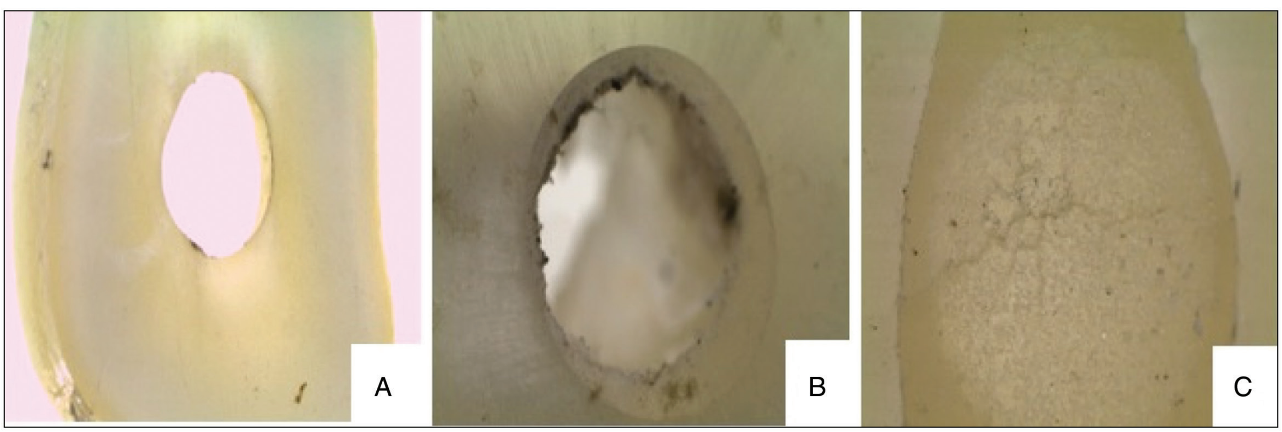


Figure 7: (A) Adhesive failure, (B) mixed failure, (C) cohesive failure

Table 2: Comparison between the bond strength of root regions according to the surface treatment group with significant difference

Root region	37% H_3PO_4		1.23% APF (2 minutes)		1.23% APF (6 minutes)	
	Middle	Apical	Middle	Apical	Middle	Apical
Cervical	P = 0.356	P = 0.013*	P = 0.026*	P = 0.001*	P = 0.557	P = 0.003*
Middle		P = 0.273		P = 0.516		P = 0.000*

APF = acidulated phosphate fluoride, H_3PO_4 = phosphoric acid

*Tukey's *post hoc*, P < 0.05 (significant differences)

Table 3: Comparison between the bond strength of different treatments prior to silanization

Surface pretreatments		*P*	*P*
24% H_2O_2	37% H_3PO_4	0.001*	0.595
	1.23% APF (2 minutes)		0.955
	1.23% APF (6 minutes)		0.277
	Silane (control)		0.263
37% H_3PO_4	1.23% APF (2 minutes)		0.946
	1.23% APF (6 minutes)		0.984
	Silane (control)		0.006**
1.23% APF (2 minutes)	1.23% APF (6 minutes)		0.706
	Silane (control)		0.054
1.23% APF (6 minutes)	Silane (control)		0.001**

APF = acidulated phosphate fluoride, H_2O_2 = hydrogen peroxide, H_3PO_4 = phosphoric acid

*ANOVA test, $P < 0.05$ (significant differences)

**Tukey's test, $P < 0.05$ (significant differences)

Table 4: Association between failure mode and different presilanization treatments

Failure mode	Surface pretreatment					Total	*P*
	24% H_2O_2	37% H_3PO_4	1.23% APF (2 minutes)	1.23% APF (6 minutes)	Control (silane)		
Adhesive	11 (18.33)	11 (18.33)	2 (3.33)	8 (13.33)	7 (11.67)	39 (13.00)	0.000*
Mixed	33 (55.00)[a],*	34 (56.67)[b],*	23 (38.33)	22 (36.67)	11 (18.33)	123 (41.00)	
Cohesive	16 (26.67)	15 (25.00)	35 (58.33)[c],*	30 (50.00)	42 (70.00)[d],*	138 (46.00)	
Total	60 (100.00)	60 (100.00)	60 (100.00)	60 (100.00)	60 (100.00)	300 (100.00)	

APF = acidulated phosphate fluoride, H_2O_2 = hydrogen peroxide, H_3PO_4 = phosphoric acid

Correspondence analysis: [a]$P = 0.014$, [b]$P = 0.006$, [c]$P = 0.032$, [d]$P = 0.000$

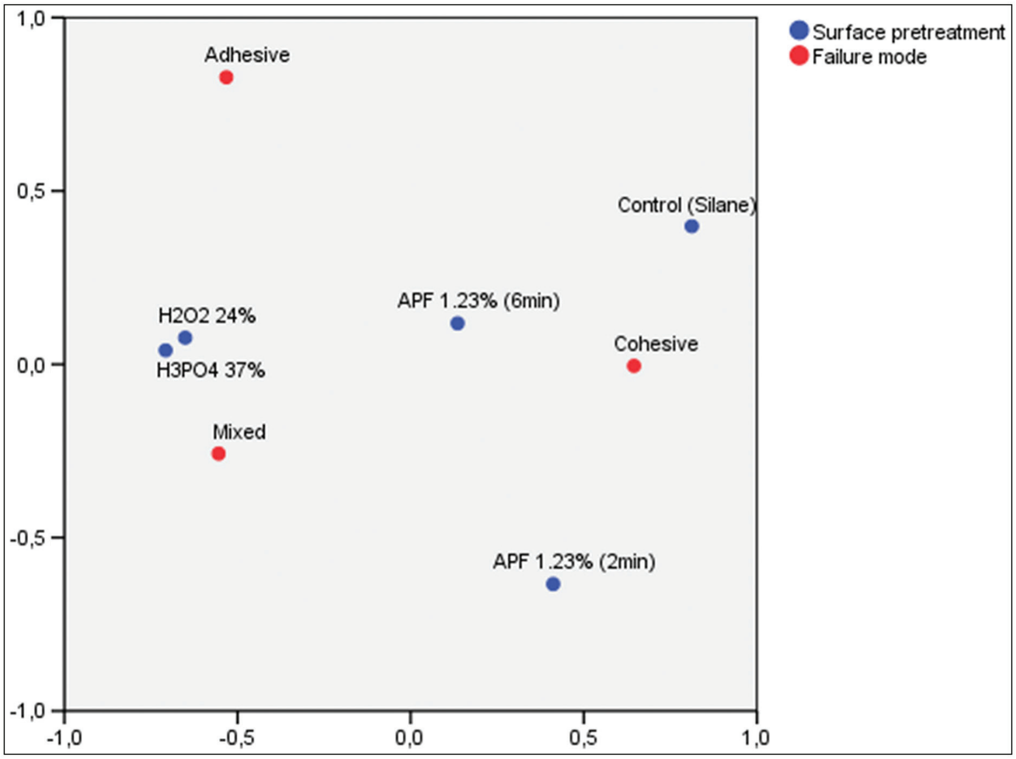
*$P < 0.05$ (significant association based on Pearson's chi-square)

hydrogen peroxide among others altered the surface topography and increased the retention of glass fiber posts.[1] However, in this report, hydrofluoric acid is not recommended for the treatment of post as it extensively damages the surface topography.

Regarding treatments of glass fiber posts prior to silanization, it has been reported that 24% hydrogen peroxide significantly improves the bond strength on dentin because of its ability to dissolve the epoxy resin matrix in the post through a substrate oxidation mechanism.[15] It has also been reported that 24% hydrogen peroxide increases the surface roughness and exposes the fibers, creating a better chemical bond between silane and post, emphasizing that the highest bond strength values were observed after the application of hydrogen peroxide for 60 seconds compared with the application for 15 and 30 seconds.[15,27] These results are corroborated in the present study since posts pretreated with 24% hydrogen peroxide for 60 seconds showed significantly higher bond strength compared to pretreatment with 37% phosphoric acid and 1.23% APF for 6 minutes. However, it was also evident that the posts pretreated with hydrogen peroxide presented an unfavorable type of bond failure, i.e., mixed type, which could perhaps shorten the longevity of cemented post. Therefore, it is recommended to carry out randomized and controlled longitudinal studies to evaluate the bond strength of posts pretreated with 24% hydrogen peroxide.

It was also decided in this study to assess the application of 37% phosphoric acid prior to glass fiber post silanization, since it was reported to increase the bond strength, especially when applied for 15 seconds.[1,28] This has been supported by some authors, since they obtained higher bond strength values when performing acid treatment of the surface compared with untreated controls.[2,15] However, in this study, when using the 37% phosphoric acid treatment, no significant improvement in bond strength was obtained compared with the other pretreatments; these differences in results are probably due to the heterogeneity of the methodology used with respect to the type of post, origin of manufacture, tooth, technique, and filling material.[1,2]

No study has been found to date (September 2021) that applies 1.23% APF as a surface treatment for glass fiber posts. However, its inclusion in the present study is justified as it is frequently used in ceramics to generate surface roughness, improving bond strength.[19] On the other hand, it has been reported that 1.23% APF in gel significantly decreases the surface microhardness of resin composites, generating higher surface roughness with the formation of porosities and rupture of the



Graph 1: Correspondence analysis between failure mode and surface treatment prior to the silanization of glass fiber post. APF = acidulated phosphate fluoride, H_2O_2 = hydrogen peroxide, H_3PO_4 = phosphoric acid

matrix–load interface.[17] This allowed to suppose that, if the application time of 1.23% APF is controlled, it could generate an optimal surface with mechanical microretention on the glass fiber posts by acting on its resinous matrix. Therefore, in the present study, this pretreatment was applied on post surfaces for 2 and 6 minutes, since it was reported that the pretreatment allows significant bonding resistance between ceramic surfaces and resin composites when applied for at least 2 minutes, without significant improvement after 6 minutes.[19,29]

Studies using self-adhesives as luting material for glass fiber posts showed similar results in all three root regions (cervical, middle, and apical).[30-33] However, this differs from the findings obtained in the present study, since a significantly higher bond strength was obtained in the apical region when the post surface was pretreated with 37% phosphoric acid and 1.23% APF, coinciding with the reports of Vildósola *et al.*[34] and Boing *et al.*[35] It is possible that the bond strength was better in the apical region because of root anatomy, since the glass fiber posts used in this study were conical in shape, making them better adapted to this region. In addition, the self-adhesive cement used (RelyX U200) showed, in other studies, better volume and fluidity at the apical region of root,[1,36] which favors good bonding.

According to results obtained in the present study, it was noticed that the mixed failure mode was significantly associated with 24% hydrogen peroxide and 37% phosphoric acid pretreatments. The first case may be due to the fact that hydrogen peroxide compromised cement polymerization as it could form free radicals and a free oxygen layer, causing a decrease in bond strength.[2,18] The second case may be due to the fact that the mixed failure mode has been related to adhesion problems at the post–cement level. In this sense, the 37% phosphoric acid applied for 15 seconds could have superficially affected the post integrity, which caused a part of it to detach during the *push out* test.[37,38] Majeti *et al.* reported that when using hydrogen peroxide for 60 seconds and phosphoric acid for 15 seconds, the adhesive failure mode between resin cement and dentin was the most prevalent, followed by cement-related cohesive failure mode.[2] This was discordant with the results obtained in the present study, since the cohesive failure mode was significantly associated with pretreatment of 1.23% APF for 2 minutes and with posts that did not receive treatment prior to silanization. In relation to the cohesive failure mode associated with fracture in post, dentin, or cement, it was significant in posts that did not receive treatment prior to silanization. This can be explained by the important role of silane as a bifunctional and chemical bonding agent for adhesion at different post–cement–dentin interfaces.[10,39] In reference to the pretreatment of posts with APF, no scientific evidence was found to explain its bonding failures, but it can be argued that the percentage used (1.23% in gel), considering its components in minimum percentages (sodium fluoride, hydrofluoric acid, and phosphoric acid) and with an exposure time of 2 minutes, was ideal to achieve good post–cement–dentin bonding, since bond strength did not present significant differences with posts treated only with silane. The latter obtained the best results, evidenced by the association obtained with the cohesive failure mode. The pretreatment of glass fiber posts with 1.23% APF for 6 minutes was not significantly associated with cohesive failure mode and also presented significantly lower bond strength than those posts treated only with silane. This could be due to the fact that such time was enough to considerably damage the surface topography of glass fiber post, as it contained more organic matrix compared with ceramic surfaces,[19,28] thus weakening the post–cement–dentin bond. It has been reported that root dentin offers less favorable conditions for the adhesion of glass fiber-reinforced posts than coronal dentin due to various factors[10] such as the application method of luting material and post pretreatment.[1,11,12] Therefore, the importance of the present study lies in demonstrating whether surface conditioning of the glass fiber posts prior to silanization significantly increases the bond strength to the root canal. From the results obtained, it was evidenced that silanization, as the only pretreatment of glass fiber post, is enough to achieve optimal results, since silane, being a bifunctional molecule, is capable of forming a chemical bond with glass fiber and with the organic resin of luting material, favoring good bonding, and also explains its significant association with cohesive failure mode, showing good physical and chemical bonding between both materials, since the *push out* test showed bond fracture.[20,21]

The results obtained should be interpreted with caution because laboratory studies have limitations because of their great procedural heterogeneity, increasing the risk of bias. For this reason, it is recognized that the findings of this *in vitro* study cannot be extrapolated to clinical field, so randomized controlled clinical trials with the same variables are recommended. Furthermore, it is advisable to conduct studies comparing surface treatments prior to silanization according to the variable "type of cementation," considering self-adhesive and conventional resin cements, as well as dual-cured or self-cured cements.

Conclusion

In summary, considering the limitations of the present *in vitro* study, posts treated only with silane and pretreated with hydrogen peroxide 24% and APF 1.23% for 2 minutes showed higher bond strength compared to those pretreated with phosphoric acid 37% and APF 1.23% for 6 minutes. However, pretreatment with APF 1.23% for 2 minutes and treatment only with silane were associated with a better bonding type.

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Conflicts of interest

There are no conflicts of interest.

Authors' contributions

They conceived the research idea (FMSR), elaborated the article (FMSR, DECA, LACG, CFCR), collected, tabulated the information (FMSR, LYT), carried out the bibliographic search (ACP, LYT), interpreted the statistical results (CFCR), helped in the development of the discussion (FMSR, DECA, ACP, CFCR), and performed the critical review of the article (FMSR, CLG, LACG, CFCR). All authors approved the final version of the article.

Ethical policy and institutional review board statement

This research respected the bioethical principles for medical research involving human subjects of the Declaration of Helsinki related to confidentiality, freedom, respect, and nonmaleficence. This research was approved by Ethics and Research Committee of the Faculty of Stomatology at the Universidad Peruana Cayetano Heredia with letter no. 454-24-16 and registration code 100199. The teeth obtained in the present study were donated by patients, after informed consent.

Patient declaration of consent

Not applicable.

Data availability statement

The data that support the study results are available from the author (Prof. Flor Magaly Santander-Rengifo, e-mail: flor.santander@upsjb.edu.pe) on request.

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