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Influence of Different Fibreglass Post Geometries on the Stress Distribution and Pull-Out Bond Strength Before and After Mechanical Cycling

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ABSTRACT

Objective: There are no reports in the literature on whether FGP geometry influences the bond strength of the endodontically restored tooth. This study aimed to determine the stress distribution and the pull-out bond strength of different FGP geometries, before and after chewing loads simulation.

Methods: One hundred and twenty root analogues were prepared and randomly distributed in six groups according to the post geometry. Half of the specimens were aged in water at 37 °C using a mechanical fatigue machine (84 N, 2 bar, 45°, 10^6 cycles, 4 Hz); while the remaining specimens were immediately submitted to the pull-out bond strength test. The specimens were tested in a universal testing machine and the bond strength in MPa was calculated. To assess the stress concentration, the finite element method was used simulating the same post geometries that were used in the *in vitro* test.

Results: Two-way ANOVA (95%) showed no influence of post geometry on the bond strength (P=0.055) while fatigue cycling was statistical significant to reduce the bond strength values (P=0.000). The factors interaction was significant (P=0.019); however, TUKEY test (5%) showed no significant difference between post geometries after mechanical cycling. The tensile stress result showed critical areas in the post's cervical region regardless of the design.

Conclusion: The FGP geometry does not affect the root stress distribution and the long-term bond strength. However, FGP that allow a reduced cement layer thickness can improve the immediate pull-out bond strength value.

Keywords: Finite element analysis, post and core technique, resin cement, tensile strength

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HIGHLIGHTS

- The FGP geometry does not influence the bond strength after fatigue.
- Different FGP geometry does not modify the root stress concentration.
- Posts with better fit in the root canal demonstrated superior bond strength.

INTRODUCTION

The use of posts assists in the restorative options in general dental practice. The fracture strength of these teeth is compromised by modifications in the biomechanical behavior, attributed to the considerable loss of dentine structure and the type of restorative material (1-3). In many cases with the loss of coronal structure, it is necessary to use an intraradicular post to retain the restoration. The cast post-and-core has been reported as a standard procedure for decades, however, it is not always possible to use it in every treatment (4, 5). In addition, the higher the post elastic modulus, the higher is the stress concentration on the post's surface (6, 7).

As an alternative to the cast post-and-core, the use of fiberglass posts (FGP) can be indicated due to adequate mechanical properties, lower elastic modulus and greater translucency in comparison with cast post-and-core. In addition, the FGP does not oxidize (8). In addition, it is reported that FGP generates a more uniform stress distribution, reducing the risk of catastrophic failure of fracture in the root; making FGP a reasonable choice for restoration of in endodontically treated teeth (9, 10).

A clinical trial after 20 years showed that 20% of root filled teeth were lost for non-endodontic reasons (e. g., periodontal abscess, root fracture and deep caries lesion frequently involving subgingival root region) (12). According to Bitter et al. (13), the FGP placement was efficacious to reduce failures of post-endodontic restorations and approximately 7% failure rate was calculated after 3 years, regardless of the number of coronal walls (13). Regarding the post geometry, a clinical study calculated no difference in failure frequency between two post designs after 24 months, with 12.8% of failure rate caused by post fractures (14). In a 10 year evaluation, a 82.6% survival rate was calculated for prefabricated posts (15), which could be explained by the high stress concentration and fracture pattern originated in the cervical region of the root dentine (12).

The possibility of post displacement due to adhesive failures is reported as a disadvantage of FGP (10). This can occur due to different surface treatments on the root dentine surface, high cement polymerisation shrinkage and canal elastic modulus and conicity (16-18). Trying to reduce the incidence of adhesive failures, several FGP geometries were developed to increase the contact area between cement and post. However, there are no reports in the literature if the post geometry can influence on the bond strength to root dentine. It was reported that the cyclic loading has a negative effect on the bond strength. Therefore, it would be of clinical relevance to evaluate whether different FGP geometries could reduce the stress concentration and increase the bond strength under simulated chewing.

The aim of this study was to determine the stress distribution and the pull-out bond strength of different FGP geometries before and after simulated chewing loads. The null hypothesis was that there would be no calculated no difference in stress distribution or pull-out bond strength before and after chewing simulation for different FGP geometries.

MATERIALS AND METHODS

Finite Element Analysis (FEA)

For this study, a previously reported three-dimensional incisor model was used (19). The root canal was designed with 16 mm length with the apical 4 mm filled with gutta-percha. Six different FGP were selected, cleaned and photographed in a stereomicroscope with magnification of 7.5X. The photomicrographs were used as background to create 3D models in the modelling software (Rhinoceros 5.0, SR8, McNeel North America; Seattle, WA, USA). Each group presented a dental crown, dental root, FGP, cement and a fixation cylinder.

The root canal was standardized using a high-speed drill with water cooling and a rounded, cone-tipped, diamond bur. The apical diameter of the post space was tapered to 1.0 mm and the coronal diameter was 2.3 mm. The post lengths were 17 mm (Fig. 1).

- Nanofine Nº 2 (Apical diameter of 0.7 mm and coronal diameter of 1.5 mm);
- Ultrafine Nº 2 (Apical diameter of 0.7 mm and coronal diameter of 1.5 mm);
- Lightcore Nº 1 (Apical diameter 0.7 mm and coronal diameter 2.2 mm);
- Flat Nº 1 (apical diameter 0.9 mm and coronal diameter 1.5 mm);
- Striated conical Nº 1 (apical diameter 0.9mm and coronal diameter 1.5 mm);
- Lightball Nº 1 (Apical diameter 0.8 mm and coronal 2.2 mm).

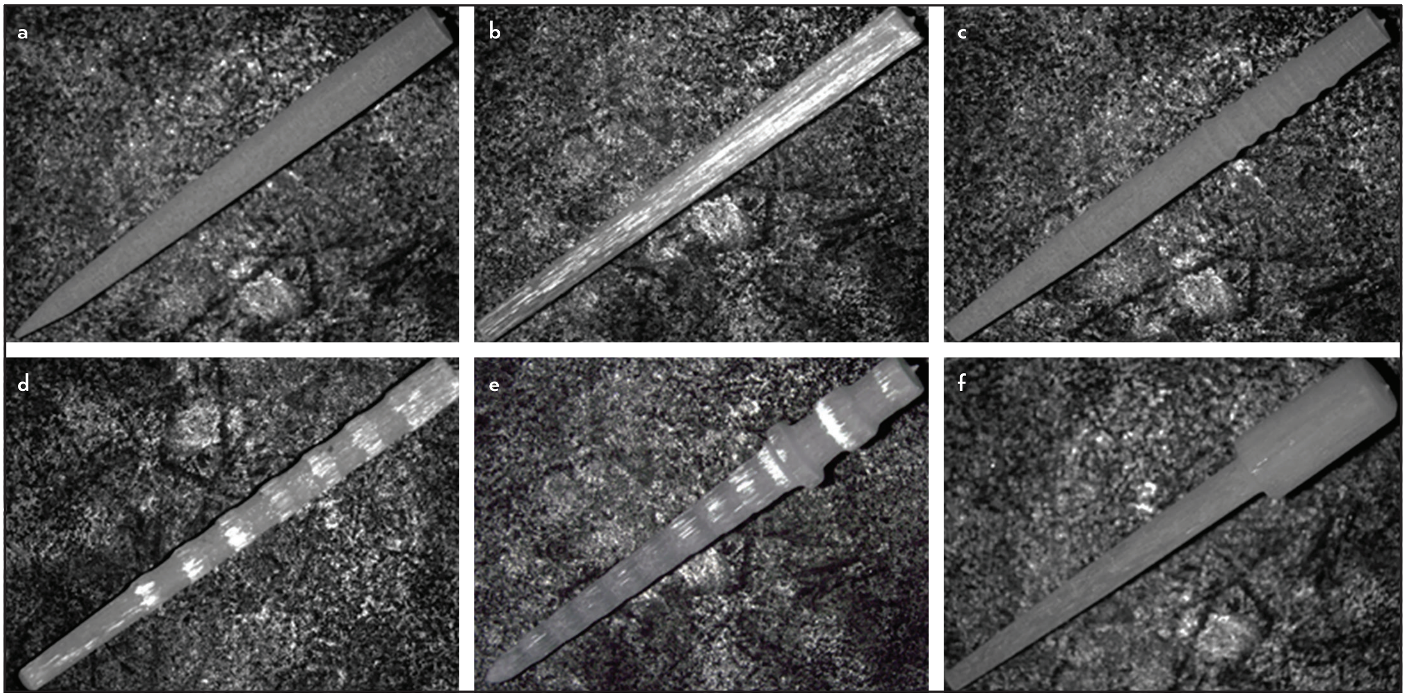

Figure 1. Different FGP geometries (7.5X magnification). (a) Nanofine design, (b) Flat design, (c) Ultrafine design, (d) Striated conical design, (e) Lightball design and (f) Lightcore

Each model was exported to the FEA software and subdivided into a specific number of nodes and tetrahedral elements. The fixed support was defined at the base of the cylinder and the load was applied at 45° with 84 N on the cingulum. The materials were considered isotropic, linear and homogeneous; except for FGP that were considered orthotropic. The structures' properties are summarised in Table 1.

Pull-out bond strength

Specimen preparation

The Ethics Committee approval was not applicable since no animal or human subjects were used in the present manuscript. An epoxy resin reinforced with glass fibre, validated as analogue to human dentine (20-22), was machined with the shape of an upper central incisor root (average total length of 27 mm, where the crown measures 11 mm and the root 16 mm) totaling 120 specimens (23). The root canal was standardised using a high speed drill with water cooling and a rounded cone tipped diamond bur.

The dentine analogues were etched with 10% hydrofluoric acid (HF) for 60 s, washed with air/water jet for 30 s, and then dried. Before cementation of the post, a thin layer of adhesive (Single Bond Universal, 3M ESPE) was applied. The dual-cure cement was manipulated in 1:1 ratio (Superpost, Superdont®, Rio de Janeiro, Brazil) and applied in the root canal. Then, the posts were inserted and kept under a 750 g weight for 5 min.

The excess resin cement was carefully removed. The post and cement was light-cured (Radii-cal LED curing light, SDI Limited, Bayswater, Australia; for 20 s at 1200 mW/cm^2 on each restoration surface. For each specimen, a composite resin crown was manufactured. The specimen were then stored for 24 h in an incubator at 37 °C in 100% relative humidity.

Mechanical cycling

Half of the specimen were aged in water at 37 °C (with 84 N, 2 bar, 45°, 106 cycles, 4 Hz) using a mechanical fatigue machine (Model ER-11000, ERIOS; São Paulo, SP, Brazil) with spherical base metal tips (Ø=1.6 mm).

Pull-out bond strength test

All specimens were subjected to the pull-out test (Fig. 2) in a universal testing machine (EMIC; São José dos Pinhais, PR, Brazil) with the aid of a universal joint metal device. A tensile force was applied with the aid of a 50 KgF load cell at a speed of 1 mm/min until the post debonded (17).

TABLE 1. The mechanical properties used in this study

Material	Elastic modulus (GPa)	Poisson ratio
Enamel	80	0.30
Dentine	18.6	0.31
Periodontal ligament	68.9×10^{-3}	0.45
Cortical bone	13	0.26
Medular bone	1.30	0.30
Gutta-percha	0.14×10^{-2}	0.45
Resin cement	7	0.30
Composite resin	10	0.30
Post	44	0.30

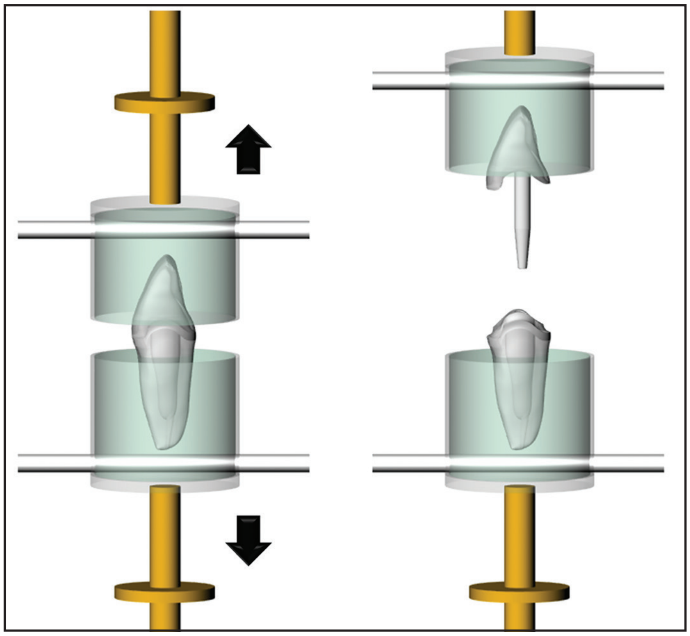

Figure 2. Schematic illustration of the pull-out bond strength setup

The tensile force required for post dislodgement was recorded in Newtons (N). The bond strengths in MPa were calculated using the following equation: bond strength (MPa)=tensile force (N)/bonding surface area (mm^2).

Statistical analyses

The bond strength data was tested for normal distribution using Shapiro-Wilk test. After the normal distribution confirmation, two-way ANOVA and Tukey test were used for both variable tested (Evaluation factors). The tests were performed with a p value set at 5% (13). For the FEA, the results were qualitatively discretized, observing the red fringes location and affected structures. The MPa scale was organized in order to allow a visual comparison between the group's results.

RESULTS

For the FEA, the tensile stress result shows critical areas in the post's cervical region regardless the design (Figs. 3 and 4). However, the post's geometry with smooth surface showed less stress concentration in the post itself with reduced stress peak magnitude (Fig. 4). For the cement layer, the stress concentration was inversely proportional with the stress in the posts. And smooth designs showed the highest stress peaks (Fig. 4). The difference between the groups is less than 2 MPa, and the effect of this small difference of stress was verified within the in vitro test results, observing if it will be able to reduce or not the bond strength values.

For the pull-out bond strength test, two-way ANOVA showed that post geometry had no influence on the bond strength (F=2.68; P=0.055). While, fatigue cycling was able to reduce the bond strength values (F=26.05; P=0.000). The interaction between the factors (F=2.84; P=0.019) affected the pull-out bond strength between the groups (Table 2).

The most promising post design is the Striated conical with 5.64 MPa without fatigue; however, it is statistically similar to the Lightball (4.94 MPa), Nanofine (4.32 MPa), Smooth (4.01

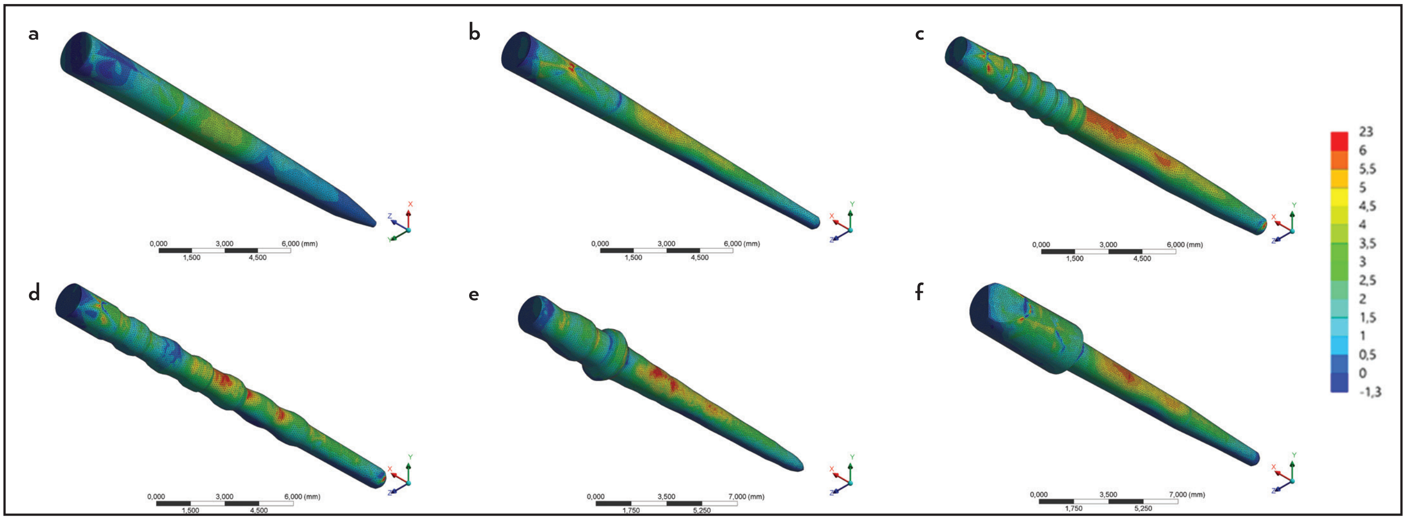

Figure 3. Tensile stress concentration in the post structure. (a) Nanofine design, (b) Flat design, (c) Ultrafine design, (d) Striated conical design, (e) Lightball design and (f) Lightcore

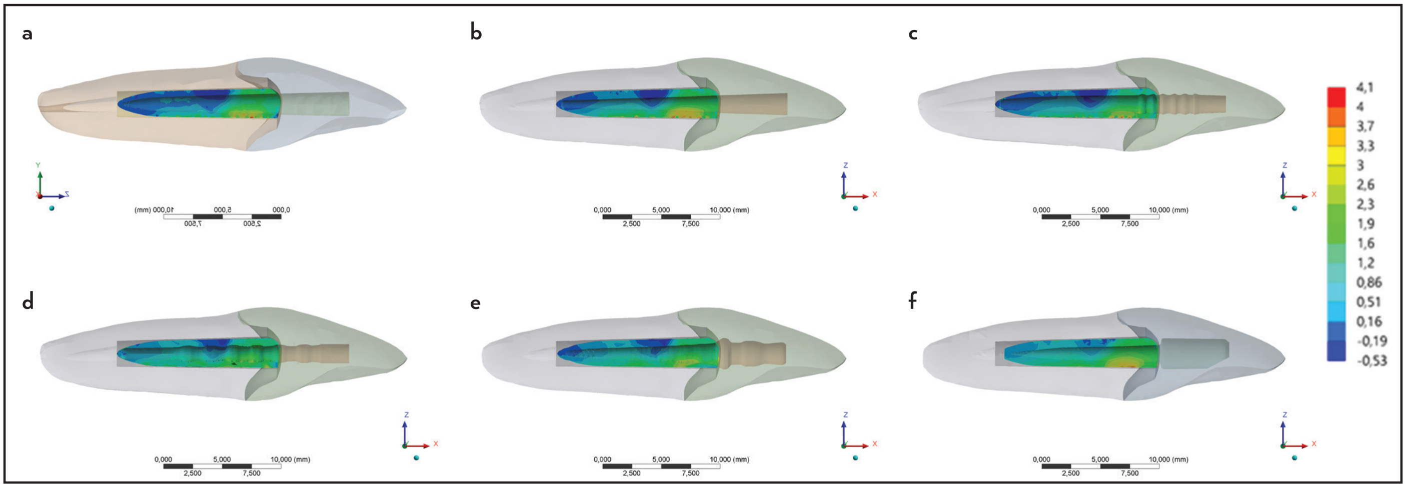

Figure 4. Tensile stress concentration in the cement layer. (a) Nanofine design, (b) Flat design, (c) Ultrafine design, (d) Striated conical design, (e) Lightball design and (f) Lightcore

TABLE 2. Average bond strength (MPa) with various post geometries, before and after mechanical cycling

Post design	Mechanical cycling	MPa	Tukey (95%)*		
Striated conical	Not	5.64±1.24	A		
Lightball	Not	4.94±0.98	A	B	
Nanofine	Not	4.32±1.32	A	B	C
Flat	Not	4.01±1.09	A	B	C
Lightcore	Not	3.70±0.85	A	B	C
Lightball	Yes	2.99±1.36		B	C
Flat	Yes	2.99±1.17		B	C
Ultrafine	Yes	2.88±0.76		B	C
Striated conical	Yes	2.68±0.54		B	C
Nanofine	Yes	2.53±0.67			C
Lightcore	Yes	2.50±0.79			C
Ultrafine	Not	2.42±1.01			C

*Tukey test. Means that do not share a letter are significantly different

MPa) and Lightcore (3.70 MPa) designs without fatigue. The only post design with significant low bond strength value without fatigue was the Ultrafine (2.42 MPa). After fatigue testing, no significant difference was observed between the post designs. For all specimens, the failure was adhesive between resin cement and root canal walls.

DISCUSSION

In the present study, it was observed that posts that allow a reduced cement layer (striated conical, lightball and nanofine) presented an improved immediate bond strength mean value; however, there was no statistical difference between the groups after the chewing simulation. Based on this result, the null hypothesis has been partially rejected. This finding corroborates with previous studies (24, 25) that the closer the geometric design of the post is to the anatomy of the root canal, the smaller the cement layer, the better the post-and-core performance. A thinner cement layer can reduce the polymerisation shrinkage stress, improving the post bond strength with the root canal and its long-term behaviour (18).

In a short overview of the results section, the stress concentration was different between the post designs and can justify the immediate bond strength difference between the groups.

However, after chewing simulation there was no difference between the posts.

In another study, the authors concluded that a better fit between post and root canal, the greater the additional pressure during cementation procedure, leading to a better frictional contact between the cement/post and the dentine/post interfaces (26, 27). Based on this concept, it is possible to understand why the groups with the highest bond strength are also the groups with the largest diameter. However, this beneficial effect seems to be associated only with the initial bond strength, since after the mechanical fatigue, all groups showed statistically similar values.

Another concern is the effect of different sizes of posts. Whereas is still controversial the suggestion that the rigidity of the post should be equal or close to that of the tooth to evenly distribute the occlusal forces along the post length (28, 29) as, information regarding the post design are scarce. However, there is no difference for the fracture load comparing 6,9 and 12 mm post holes preparation based in the clinical crown length (28). Thus, more post preparation is not needed and post lengths equal to clinical crown length can be used to obtain an adequate fracture resistance (28). The present study complements this information suggesting that the post geometry should be based on the prepared canal radius and a retentive geometry is not beneficial for the bond strength.

According to Bitter et al. (13, 29), the volume of voids does not depend on the post shape and voids are commonly at the coronal level of the post space. The present study corroborate with this study, since there is no difference between the post geometries, and the cervical region concentrated the highest stress magnitude. The presence of voids associated with the highest stress peaks indicate that the cervical region is the most critical area in the post bond strength and a proper surface treatment and cleaning protocol should be carefully performed in this region.

The fracture strength values of teeth restored with a root canal treatment can be affected according to different post and core systems. However, the use of fiber posts does not improve fracture resistance (30).

A previous study reported that the elastic behavior of the post may be interpreted as a disadvantage because the cyclic bending between the crown and core induces microcracks during cyclic loads (31). In the present study, the FGP material was the same regardless the posts geometries, what can justify the similar mechanical behavior after mechanical cycling procedure.

Failures in teeth with post-core-crown restorations are usually classified into restorable and non-restorable fractures. And, the use of FGP to restore teeth with different angulations could be a clinically challenge (32). However, in the present study, the central incisor was simulated, with 45° of applied load and there is no report of non-restorable fractures in any group. Therefore, the principal failure could be a decrease in the bond strength, which could lead in the FGP debonding. However, a systematic review comparing FGP and metal posts observed no difference in success rates, post debonding rates, or root fracture rates between both treatment modalities to restore severely damaged endodontically treated teeth (33).

In order to standardise the geometry of the specimens, with similar root canals between the groups, the present study used a dentine analogue substrate (G10). The G10 resin is a validated polymeric material able to present bond strengths with resin cement similar to humid dentine (20). According to Bitter et al. (13), all analyses demonstrated sufficient compatibility between G10 and dentine, in terms of both bonding and elastic behavior, allowing its use to support ceramic specimens in *in vitro* tests (20). This approach allowed to obtain controlled root geometries, with similar canal size, diameter and shape. Consequently the cement layer thicknesses were also similar and the polymerisation shrinkage stress factor comparable between the groups. However, as a study's limitation, the effect of irrigation procedures and a correct removal in the post-endodontic space cannot be evaluated. The literature reports that this is an important factor for the adhesion of resin cement, dentin and post and therefore, a study's limitation that should be taken into account when extrapolating the results (17, 34-37).

The FEA showed stress concentration in the cervical region for all groups, with different magnitude, however, similar stress maps. Based on this results, the possible mechanical failure could start at the cervical level, in the coronal third of the root. This stress region is in agreement with previous theoretical studies that evaluated FGP using the FEA (7, 19, 29, 33, 38).

In order to ascertain the polymerisation of the bonding system in all tested samples, the present study performed the luting procedure using a dual-cure adhesive system. The use of 1200 mW/cm^2 light source was also applied to start the photo-initiated polymerisation and the samples were stored for 24 h prior to the mechanical test to ensure the complete cure of the cement, especially in the apical third of the roots. This protocol aimed to guarantee a similar degree of conversion of the cement layer regardless the canal region and different dentine types (39). However, even with these controlled procedures, complete polymerisation cannot be verified before the mechanical test.

There are different brands of FGP available to treat restoratively compromised endodontically treated tooth, with different shapes and geometries. However, there is lack of data in the literature showing if posts manufactured with the same material can present a different mechanical behavior by modifying its geometry. The present study showed that after the mechanical cycling process, there is no significant difference between the posts bond strength. Basically, when the patients start to apply masticatory loads on the rehabilitated teeth, the FGP geometry will be irrelevant for the bond strength. However, before the mechanical cycling protocol, the posts with better fit with the root canal showed superior bond strength.

The need for long-term evaluation on post-endodontic treated teeth is essential (11). The vast majority of clinical studies on root filled teeth are based on determined follow-up periods (12).

CONCLUSION

The FGP geometry does not affect the root stress distribution and the long-term bond strength. However, FGP that allow a reduced cement layer thickness can improve the immediate pull-out bond strength value.

Disclosures

Conflict of interest: None declared.

Ethics Committee Approval: Not necessary.

Peer-review: Externally peer-reviewed.

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