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CAD/CAM Milled Glass Fiber Posts: Adaptation and Mechanical Behavior in Flared Root Canals

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Clinical Relevance

CAD/CAM milled glass fiber posts may be an alternative for the production of custom-made, well-adapted glass fiber posts for flared root canals. Adequate adaptation leads to a homogeneous post-cement-dentin interface that is mechanically stable for reliable rehabilitation.

SUMMARY

This study aimed to evaluate the cementation and mechanical behavior of flared root canals restored with CAD/CAM milled glass fiber post-and-core systems. Sixty-six endodontically treated human canines with a flared root canal were divided into three different groups according to the type of post: G_{PF} received prefabricated posts; G_{REL} received relined glass fiber posts, and G_{MILLED} received CAD/CAM milled glass fiber posts. Cementation was performed with self-adhesive resin cement. The samples were submitted to x-ray microcomputed tomography analysis for the analysis of voids and gaps. The roots were sectioned and submitted to the push-out bond strength test. The load-to-fracture was evaluated in post-and-core systems. G_{MILLED} presented lower void and lower gap volumes when compared to G_{PF} and G_{REL}. On the load-to-fracture test, G_{REL} presented statistically significant higher values than G_{MILLED}. G_{PF} values had no statistically

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significant difference from the two other groups. On the push-out bond strength test, G_{PF} presented statistically significant lower values when compared to G_{REL} and G_{MILLED}. The most common failure pattern was between dentin and cement in all groups. CAD/CAM milled glass fiber post-and-core systems presented an enhanced adaptation of glass fiber posts to flared root canal systems. Their results were comparable to relined posts in bond strength, while load-to-fracture-results for G_{MILLED} were lower than those for G_{PF}.

INTRODUCTION

The rehabilitation of endodontically treated teeth requires an intraradicular post cementation in cases where considerable coronal destruction is found.[1,2] Different materials are used to produce the posts,[2] and glass fiber-based posts have been widely used in clinical practice. The esthetic properties and mechanical behavior of these materials closely resemble those of dental hard tissues, contributing to their high acceptance and success for prosthodontic treatments.[3-6] The failure rate for such treatments ranges from 7% to 11% after up to 10 years.[3,4,7] Most of the failures are related to root fracture and loss of post retention.[2,7,8]

The clinical success of fiber posts depends on dental geometry, the position of the tooth in the arch, adaptation, cementation technique, residual coronal structure, and ferrule presence; an effective bonding is related to successful restorative treatments.[9-11] When glass fiber posts are used in these conditions,lower stress in the post-cement interface and a lower elastic modulus reduces the fracture risk.[12-13] The success of this technique may be impaired by the presence of flared root canals, where extensive loss of tissue is found[14-16] and the adaptation of posts is challenging.

In these cases, prefabricated glass fiber posts cannot match the canals' size and shape, and for this reason, a considerable amount of cement is needed for cementation.[16-17] A thick cement layer may be related to less retention due to impaired polymerization over the root canal,[18,19] reduced mechanical strength in the cement layer,[16,20-23] and increased formation of voids and gaps.[24] Custom-made posts may be produced by relining with composite resins to increase adaptation and reduce the cement layer's thickness.[17,25,26] In these cases, different interfaces are created, as several materials are used.[27,28] The manual adaptation may be time consuming and technique sensitive for clinicians, impairing its applicability and the long-term success of this procedure.

The computer-aided design/computer-aided manufacture (CAD/CAM) process may be applied to the production of individually, anatomically fitted, and monolithic glass fiber posts.[29,30] The possibility of scanning root canals or models allows the design of customized structures that match the shape and the size of the root canal system and may be installed with a thin layer of cement with better adaptation.[31,32] CAD/CAM milled glass fiber blocks are used to produce a monolithic post-and-core that avoids the use of different materials and the presence of multiple interfaces on the cemented structure.[29,33] As CAD/CAM manufacturing becomes more accessible and is increasingly used in dental applications, it is important to understand the ability of these methods to design and build posts for flared root canals. While several advantages have been observed for this manufacturing technique, few studies have attempted to understand monolithic glass fiber post-and-core behavior.[17,29,31] The effect of these posts on roots with extensive loss of tissue diameter should be investigated for the application of these structures in the clinical scenario. This study aims to evaluate the cementation and mechanical behavior of flared root canals restored with CAD/CAM milled glass fiber post-and-core systems.

METHODS AND MATERIALS

Tooth Selection

Sixty-six extracted, single-rooted permanent upper and lower human canines were used. Inclusion criteria were the absence of calcifications, cavities, cracks, and previous endodontic treatment. Teeth were measured and included when the distance between the cementoenamel junction and the apex was at least 15 mm. All teeth were stored in distilled water at 4°C for no more than six months.

Root Canal Preparation

The selected teeth were decoronated 2 mm above the cementoenamel junction using a double-sided diamond disc (KG Sorensen Ltda, Cotia, SP, Brazil) with low speed and under water cooling. All root canals were instrumented with reciprocating files (V-file TDK Blister, Eurodonto, Curitiba, PR, Brazil), under NaOCl 2.5% irrigation. The root canals were then filled with 1 ml of EDTA (Odahcam, Dentsply, São Paulo, SP, Brazil) for 3 minutes. Root canal obturation was performed using a lateral condensation technique with gutta-percha (Dentsply) and a resin-based endodontic sealer (AH Plus, Dentsply, Konstanz, Germany). All specimens were stored for seven days in distilled water at 37°C before further preparation.

Post Preparation

Before the post-cementation procedure, gutta-percha removal was performed with a stainless steel bur (Exacto #3, Angelus Indústria de Produtos Odontológicos S/A, Londrina, PR, Brazil), and 4 mm of filling material remained in the apical third. The root canals were enlarged with a sequence of Largo burs, washed with 5 ml of distilled water, and dried with paper points (Dentsply, São Paulo, SP, Brazil). The enlargement was performed to guarantee that dentin walls presented a 1 mm thickness to simulate flared root canals, to standardize the samples, and to minimize the anatomical differences between teeth. The prepared teeth were divided into three groups according to the different glass fiber posts used for reconstruction: prefabricated glass fiber post (G_{PF}), composite resin relined glass fiber post (G_{REL}) and CAD/CAM milled glass fiber post (G_{MILLED}). The preparation of posts for the different groups is summarized in Table 1. All specimens were water stored for 24 hours at 37°C.

For the G_{PF} group, posts (Exacto #3, Angelus) were cleaned with 70% ethanol. Silane (Angelus) was actively applied for 60 seconds and air-dried for 30 seconds. A self-etching resin cement (U200, 3M Oral Care, São Paulo, SP, Brazil) was mixed and dispensed into the post space with a syringe (Centrix, DFL Indústria e Comércio S.A., Rio de Janeiro, RJ, Brazil) and an endodontic tip. The post was inserted and polymerized for 40 seconds from the buccal and palatine faces with 1500 mW/cm^2 from a calibrated LED light-curing unit (Radii-cal, SDI Indústria e Comércio Ltda., São Paulo, SP, Brazil).

For the G_{REL} group, an adhesive resin (Adper Scotchbond Multi-Purpose, 3M Oral Care) layer was applied around the post and light-cured for 1 minute. For the relining, a composite resin (Filtek Z350, 3M Oral Care) was used directly around the post, inserted into the root canal, and light-cured for 5 seconds. The post was removed and light-cured for 60 seconds. After the relining, the post space was cleaned with distilled water and dried with paper cones. The post was

Table 1: *Description of Different Groups and the Cementation Protocol*

Groups	Cementation Protocol
G_{PF}	• Ethanol cleaning • Air drying • Silane application for 60 s • Air drying 30 s • Cement insertion with a syringe • Post insertion • Polymerization for 40 s
G_{REL}	• Ethanol cleaning • Air drying • Silane application for 60 s • Air drying 30 sec • Adhesive application • Adhesive polymerization for 60 s • Application of composite resin around post for post relining • Post modeling into the flared root canal • Composite resin polymerization for 60 s • Cement insertion with a syringe • Post insertion • Polymerization for 40 s
G_{MILLED}	• Ethanol cleaning • Air drying • Silane application for 60 s • Air drying 30 s • Cement insertion with a syringe • Post insertion • Polymerization for 40 s

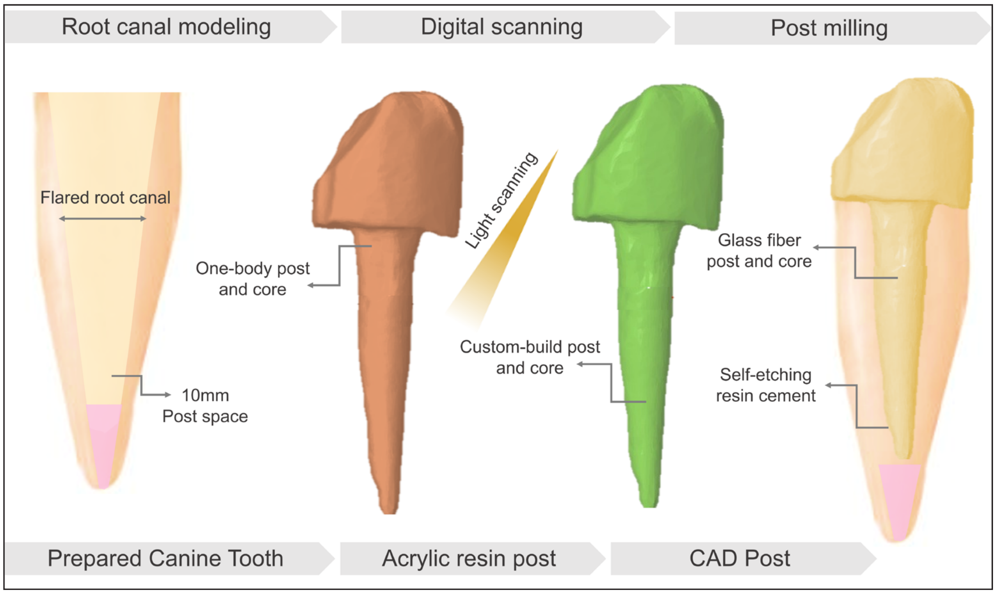

Figure 1. *Representative schematics of CAD/CAM milled glass fiber post production. After tooth preparation, the acrylic resin was used for canal root modeling. The modeled post was scanned for designing a custom-build CAD post that was milled and cemented on the flared root canal.*

washed with 70% ethanol, air dried, and cemented, as described in Table 1.

The G_{MILLED} group was prepared as described in Figure 1. The post space was filled with acrylic resin (Duralay-Reliance Dental, Alsip, IL, USA) for root canal modeling. The acrylic resin posts were scanned with a digital scanner (Shining3D DS-EX, Shining 3D Tech, Hangzhou, China) and computer-aided designed (CAD) posts were obtained with the root dimensions. Glass fiber discs (Fiber Cad - Post & Core, Angelus Indústria de Produtos Odontológicos S/A, Londrina, PR, Brazil) were used for milling on an industrial computer-aided machine (CAM) (DM5 Tecnodrill Indústria de Máquinas Ltda, Novo Hamburgo, RS, Brazil). The CAD/CAM milled posts were prepared and cemented as described in Table 1.

X-ray Micro-computed Tomography

After the cementation, five specimens per group were scanned by x-ray microcomputed tomography (inspeXio SMX-90CT Plus, Shimadzu, Kyoto, Japan). The X-ray tube was operated at 80 kv and 120 mA with a voxel size of 0.013 mm. Reconstruction was performed by inspeXio SMX-90CT software (Shimadzu) and resulted in a stack of 541 images. The Dicom files were used for tridimensional reconstructions with 3D Slicer software (https://slicer.org).[34] The quantification of the volume of voids and gaps was performed in 220 two-D images that were standardized in the samples to analyze the cement layer. The quantification was performed with imaging software (ImageJ, NIH, Bethesda, MD, USA) by the segmentation of the 2D image stack with a grayscale threshold selected between 0-140. The empty spaces in the cement layer were selected with an automatic selection tool, and the area was calculated on each image. The volume of empty spaces in the cement layer was calculated based on the measured area and the thickness of each slice in the 2D stack. All analyses were performed with the same threshold.

Push-out Bond Strength

For the push-out bond strength, cemented root canals (n=12) were sectioned on a low-speed, water-cooled, double-sided diamond disc. For each tooth, nine slices were made with 0.7 mm ± 0.1 mm thickness. Before the analysis, the slices were stored in distilled water at 30°C for 24 hours. The push-out bond strength test was performed on each slice, placed with the apical side downward on a universal testing machine (EZ-SX Shimadzu, Kyoto, Japan). A compressive load was applied to the center of the slice at a crosshead speed of 0.5 mm/min until failure. The bond strength results were based on the maximum force (N) applied and the area of the section. The area was calculated using the formula:

$$\text{Area} = (\pi R + \pi r) \times L,$$

where R, r, and L are cervical radius, apical radius, and adhesive area.

The adhesive area (L) was calculated with the thickness (h) of each slice based on the following formula:

$$L = \sqrt{(R - r)^2 + h^2}.$$

A single operator performed all measurements. Failure pattern was classified as adhesive, between dentin and cement interface (Ac/d) and between cement and post interface (Ac/p) or cohesive in dentin.

Load-to-Fracture

For the load-to-fracture analysis, ten samples per group were submitted to a core reconstruction. For G_{PF} and G_{REL} groups, the coronal portion of the posts was etched with phosphoric acid 37% (Scotchbond etchant, 3M Oral Care) for 30 seconds in enamel and 15 seconds in dentin. A commercial primer (Adper Scotchbond Multi-Purpose, 3M Oral Care) was applied to the dentin. Solvent evaporation was performed, and an adhesive layer was applied. After light-curing, the core was built with a composite resin (BISCORE; Bisco Inc, Schaumburg, IL, USA) with a 5 mm height. Polymerization was performed for 60 seconds on four sites equally distributed in vestibular, bucal, distal, and mesial regions of the core. For G_{MILLED}, the core was modeled with acrylic resin (Reliance Dental Manufacturing LLC; Alsip, IL, USA) in the moment of root canal modelling. The dimensions of the core were the same used for G_{PF} and G_{REL}. The scanning and milling were performed at the same time, and thus a monolithic post-and-core structure was obtained.

The restored root canals were embedded in acrylic resin, and simulation of the periodontal ligament was performed with silicone rubber. Specimens (n=10) were then fixed in a metallic device, and a load was applied to the palatal surface at a 45° angle in a testing machine (Servopulser, Shimadzu Servohydraulic Fatigue Testing System, Kyoto, Japan) with a crosshead speed of 1 mm/min until fracture. Mode of fracture was recorded and classified as repairable in the tooth where debonding, core fractures, or oblique fractures in the cervical third were identified, or non-repairable in the tooth where vertical fractures or oblique fractures in middle and apical third were observed.

Statistical Analysis

A descriptive analysis was performed for microCT images. Data were submitted to equal variance analysis, and the normality of the data was assessed by Shapiro-Wilk. The volume of voids and gaps on microCT, as well as the load-to-fracture values, were compared by one-way ANOVA and Tukey. Repeated measures were used as dependent samples. Each tooth was sliced in nine samples, and thus a dependent analysis was performed for this factor. For the push-out test, two-way repeated-measures ANOVA and Tukey were used. The significance level was set at 0.05.

RESULTS

MicroCT images (Figure 2) were analyzed, and the presence of voids and gaps was evaluated in the cement layer of all specimens tested. Reduced volume of voids and gaps was observed for G_{MILLED} when compared to G_{REL} and G_{PF} (Figure 2; $p<0.05$). The presence of voids and gaps was observed mainly in the cervical third for all groups, while for G_{PF} (Figure 2A) and G_{REL} (Figure 2B), voids were observed in the apical third. The representative slices of microCT analysis are shown in

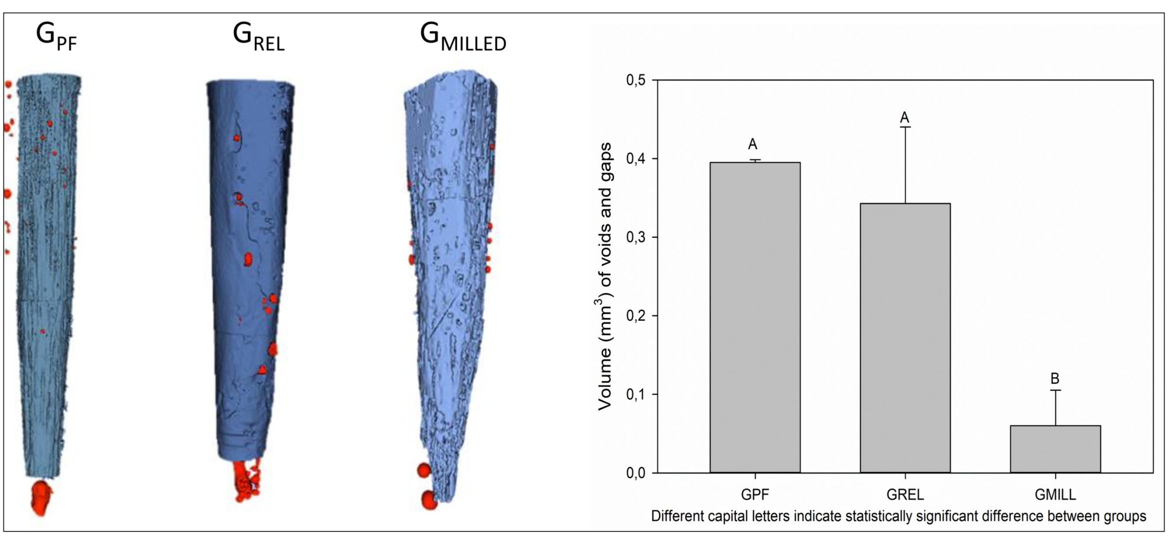

Figure 2. *Representative images of different posts used in each experimental group. The red structures surrounding the posts (blue) shows the presence of voids on the cement layer. Mean and standard deviation for void and gap volume measurements in microCT images. The voids and gaps were calculated in mm³.*

Figure 3. The cement layer thickness and the presence of voids and gaps are shown for the three groups. Fiber alignment is similar for G_{PF} (Figure 3A) and G_{REL} (Figure 3B), while a different pattern is observed for G_{MILLED} (Figure 3C).

For the push-out bond strength analysis, the obtained values ranged from 4.80 ± 2.15 MPa to 2.71 ± 1.81 MPa on G_{REL} and G_{PF}, respectively. No statistically significant difference was found between different thirds in any of the groups (p=0.103). There was a statistically significant difference between groups (p=0.023), and there was no interaction between the two factors (p=0.424). G_{MILLED} showed no statistically significant difference from G_{REL} and G_{PF} (Table 2; p>0.05). The failure modes are shown in Table 2. Adhesive failure was found on at least 58% of the samples. G_{REL} group presented a higher percentage of adhesive failure (69.66%), while G_{MILLED} presented the lowest percentage of adhesive failure (58.9%).

The load-to-fracture results are shown in Table 3. The average load-to-fracture on G_{REL} was 738.13 ± 151.19 N. G_{MILLED} values were statistically significantly lower than G_{REL} (544.83 ± 135.80 N; p<0.05). G_{PF} results were not statistically significantly different than G_{REL} and G_{MILLED} (p>0.05). The failure mode analysis showed increased core fractures (reparable) for G_{MILLED}. Non-reparable fractures were observed for G_{REL} (1) and G_{MILLED} (3).

DISCUSSION

The rehabilitation of teeth with extensive loss of hard tissues is a challenge in clinical practice,[7] and different techniques have been studied for the reinforcement of flared root canals.[26] In the present study, CAD/CAM milled glass fiber posts were used to restore flared root canals *in vitro*. A monolithic system was produced, and when compared to prefabricated and relined glass fiber posts, the tested posts presented a lower amount of voids and gaps, with comparable push-out bond strength values. The load-to-fracture was lower as compared to the other groups.

The internal adaptation of the post influences the cement needed for the procedure.[20,28] The formation of voids and gaps is found due to air entrapment during the cement manipulation, and it is known that a thin layer of cement is related to the formation of fewer voids and gaps.[17] When flared root canals were considered, the amount of cement used on prefabricated posts was obviously increased, and the space between the root canal shape and the fiber post may reduce the amount of cement and the formation of these voids and gaps.[17,33] Although the custom-build posts (G_{REL} and G_{MILLED}) are known to use a small amount of cement, the volume of empty spaces on the cementation region was higher for G_{REL} when compared to G_{MILLED} (Figure 2; p<0.05). This finding may be attributed to the space found on the apical third, because the shape of the post in this

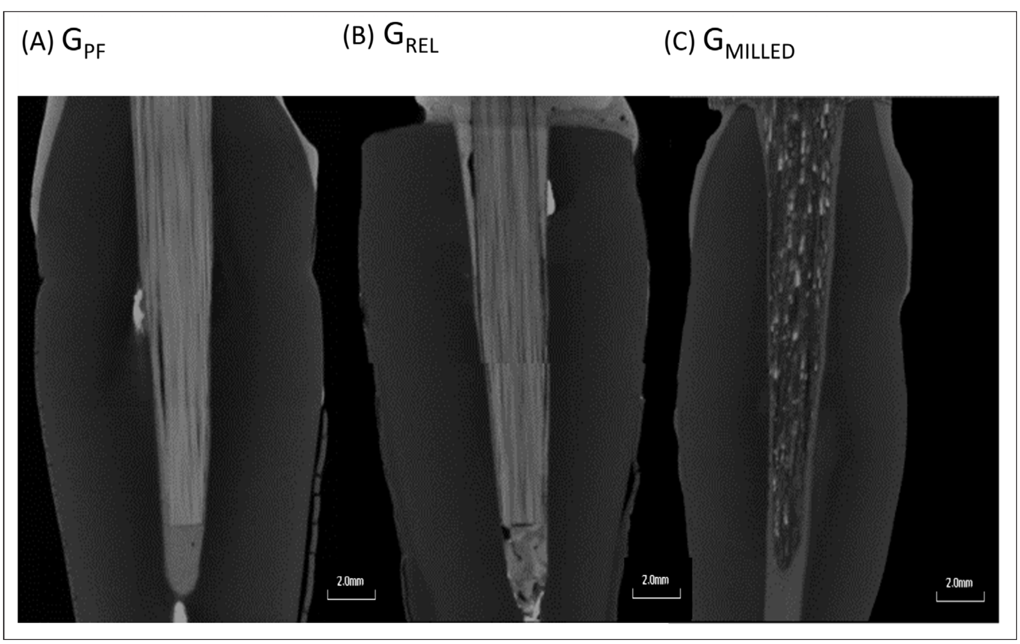

Figure 3. *Representative images of microCT analysis where the thickness of the cement and the fiber orientation is observed for different posts. The prefabricated posts (A) and relined posts (B) present similar fiber alignment, while the cement layer on these specimens is different due to the presence of composite resin used in relining and the higher number of interfaces. (C) CAD/CAM milled glass fiber posts show a different fiber alignment pattern maintaining the parallel alignment found in A and B. A homogeneous and thin cement layer is observed.*

Table 2: *Push-out Bond Strength (MPa) and the Failure Modes After Testing* [a]				
Groups	**MPa**	**Adhesive**		**Cohesive**
		Ac/d	**Ac/p**	
G_{PF}	2.71 ± 1.81A	61.53%	3.37%	28.08%
G_{REL}	4.80 ± 2.15B	69.66%	5.61%	24.71%
G_{MILLED}	4.22 ± 2.58B	58.9%%	3.44%	38.35%

[a] *Different uppercase letters indicate a statistically significant difference* ($p< 0.05$).
Failure modes: Ac/d: adhesive between dentin and resin cement interface; Ac/p: adhesive between post and resin cement interface; Cohesive = cohesive in dentin.

region is not as closely adjusted to the conical shape of the root in the G_{PF} and G_{REL} as it is for G_{MILLED} (Figure 2). The CAD/CAM milled was able to reproduce the apical portion's conicity, leading to a reduced amount of cement and a reduced volume of voids in this third (Figure 2 and Figure 3). This shows that the accuracy of the scanning and milling process was guaranteed by the chosen method. It is important to highlight that an industrial milling machine was used in the present study, and thus the results may not be directly translated for the production of posts in dental milling machines. Despite this limitation, the benefits in post adaptation may be further explored for other CAD/CAM systems such as the ones designed exclusively for dental applications. The relationship between the presence of voids and gaps and the bond strength has been studied in different posts, and conflicting results have been found. While some reports related lower bond strength to void-containing structures,[22,28] other studies did not find a statistically significant difference.[23,24] Although the effect of voids and gaps is not always present, a thin and uniform cement layer is desired for stability of bonding and the mechanical interlocking of the cemented post.[28]

The cement layer may play an important role in push-out bond strength. Because cement is known to present lower mechanical strength than glass fiber posts, the higher the amount of cement in the root canal, the lower the force needed for dislodgement of the root slices. The lower volume of voids found for G_{MILLED} may explain these results because of the CAD-controlled cementation layer and the amount of cement used for cementation. Polymerization was performed for 60 seconds on 4 sites equally distributed in vestibular, bucal, distal and mesial regions of the core.[7] The push-out bond strength results were not affected by the tooth third in each group, showing that the cementation procedure was effective and that polymerization was achieved along the full extent of the root, excluding the possible effect of a low degree of conversion in the bond strength results.[18,35] Adhesive failures between the cement and the dentin were the most common failure mode found for all the groups, showing that dislodgement is more prone to happen in this interface and that the mechanical properties of luting agents were maintained.

The mechanical behavior of glass fiber posts may be influenced by the production method, and this is directly related to the orientation of the fibers, the adaptation of the post, and the stress dissipation on the post-cement-dentin interface.[5,29,36] The milling process is shown to result in decreased resistance for glass fiber posts alone.[29] In contrast, previous studies found comparable results for load-to-fracture when cemented prefabricated and milled posts were tested.[30,32,33,37] In the present study, static mechanical testing was

Table 3: *Load-to-fracture Results (N) and the Frequency of Reparable and Irreparable Modes of Fracture* [a]				
Groups	**Load-to-fracture**	**Reparable**		**Irreparable**
		C	**F**	**F**
G_{PF}	610.58N ± 99.21AB	6	4	0
G_{REL}	738.13N ± 151.19A	6	3	1
G_{MILLED}	544.83N ± 135.80B	7	0	3

[a] *Different uppercase letters indicate a statistically significant difference* ($p>0.05$).
Reparable failures: core (C) or cervical third (F). Irreparable failures in the middle and apical third (F).

performed on cemented posts, and the G_{MILLED} group showed the lowest load-to-fracture values (Table 3), without a statistically significant difference from G_{PF}. The fibers' direction is a key factor for adequate stress dissipation, and milling the glass fiber blocks with vertical fiber orientation is required to guarantee adequate mechanical properties.[29] The alignment of fibers during milling must be obtained by the adequate positioning of the glass fiber block, avoiding different fiber orientation in the post. The representative slices in Figure 3 show that fiber orientation was kept parallel to the root's long axis in all tested groups. The analysis of failure modes in the G_{MILLED} group shows that most of the samples showed chipping failures on the core, and that fracture occurred parallel to the fiber orientation, showing that milling was performed in the right direction (Table 3). Although lower values were found, the core chipping indicates easily reparable fractures, but nonreparable failures were also found. Some studies suggest that stiff materials with high load-to-fracture values may result in increased catastrophic failure.[6] The possibility of repair of the fractured post and core structures is desirable for tooth maintenance, and the impact of the nonreparable failures found in the CAD/CAM milled group must be further evaluated.

The CAD/CAM milling process emerges as a machinable custom-build option to increase the adaptation of glass fiber posts on flared root canal systems. The application of a laboratory CAD/CAM system may contribute to the translation of these results to clinical practice, as access to this technology may be easier for dentists. CAD/CAM is known to present a high startup cost and the need for training, potentially limiting its application in clinical practice, especially for chair-side CAD/CAM.[38,39] Laboratory systems may be more accessible, and, in the results of this initial analysis, were shown to result in well-adapted posts for flared root canals. Using the findings of the present study, it is possible to design further analysis to compare the accuracy of different CAD/CAM systems in the design and fabrication of these posts. The production of a one-body monolithic system avoids the need for in-office adaptation of post and core production and prevents the formation of a multiple-interface system in the post system. The CAD/CAM manufacturing used in this study offered adequate adaptation with reduced cement layer and a lower amount of voids and gaps, evidenced by the high bond strength obtained in the G_{MILLED} group compared to the group with prefabricated posts. This adaptation is essential, especially for flared root canal systems, and may represent an alternative for reliable rehabilitation with lower technique sensitivity.

CONCLUSIONS

CAD/CAM milled glass fiber post-and-cores presented an enhanced adaptation of glass fiber posts to flared root canal systems. Their results were comparable in bond strength but lower in load-to-fracture when compared to relined posts.

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Regulatory Statement

This study was approved by the research ethics committee from Universidade Federal do RioGrande do Sul. The approval code issued for this study is 3.617.474

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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REFERENCES

1. Ferrari M, Cagidiaco MC, Goracci C, Vichi A, Mason PN, Radovic I, & Tay F (2007) Long-term retrospective study of the clinical performance of fiber posts *American Journal of Dentistry* **20(5)** 287-291.

2. Marchionatti AME, Wandscher VF, Rippe MP, Kaizer OB, & Valandro LF (2017) Clinical performance and failure modes of pulpless teeth restored with posts: A systematic review *Brazilian Oral Research* **31(31)** e64.

3. Cloet E, Debels E, & Naert I (2017) Controlled Clinical Trial on the Outcome of Glass fiber composite cores versus wrought posts and cast cores for the restoration of endodontically treated teeth: A 5-year follow-up study *International Journal of Prosthodontics* **30(1)** 71-79.

4. Bergoli CD, Brondani LP, Wandscher VF, Pereira G, Cenci MS, Pereira-Cenci T, & Valandro LF (2018) A multicenter randomized double-blind controlled clinical trial of fiber post cementation strategies *Operative Dentistry* 2018 **43(2)** 128-135.

5. Alonso de la Peña V, Darriba IL, Caserío Valea M, & Guitián Rivera F (2016) Mechanical properties related to the microstructure of seven different fiber reinforced composite posts *Journal of Advanced Prosthodontics* **8(6)** 433-438.

6. Zhou L & Wang Q (2013) Comparison of fracture resistance between cast posts and fiber posts: A meta-analysis of literature *Journal of Endodontics* **39(1)**11-15.

7. Naumann M, Koelpin M, Beuer F, & Meyer-Lueckel H (2012) 10-year survival evaluation for glass-fiber-supported postendodontic

restoration: A prospective observational clinical study *Journal of Endodontics* **38(4)** 432-435.

8. Sarkis-Onofre R, Fergusson D, Cenci MS, Moher D, & Pereira-Cenci T (2017) Performance of post-retained single crowns: A systematic review of related risk factors *Journal of Endodontics* **43(2)** 175-183.

9. Naumann M, Schmitter M, Frankenberger R, & Krastl G (2018) "Ferrule comes first. post is second!" Fake news and alternative facts? A systematic review *Journal of Endodontics* **44(2)** 212-219.

10. Batista VE de S, Bitencourt SB, Bastos NA, Pellizzer EP, Goiato MC, & Dos Santos DM (2020) Influence of the ferrule effect on the failure of fiber-reinforced composite post-and-core restorations: A systematic review and meta-analysis *Journal of Prosthetic Dentistry* **123(2)** 239-245.

11. Savychuk A, Manda M, Galanis C, Provatidis C, & Koidis P (2018) Stress generation in mandibular anterior teeth restored with different types of post-and-core at various levels of ferrule *Journal of Prosthetic Dentistry* **119(6)** 965-974.

12. Santos AFV, Meira JBC, Tanaka CB, Xavier TA, Ballester RY, Lima RG, Pfeifer CS, & Versluis A (2010) Can fiber posts increase root stresses and reduce fracture? *Journal of Dental Research* **89(6)**587-591.

13. Ona M, Wakabayashi N, Yamazaki T, Takaichi A, & Igarashi Y (2013) The influence of elastic modulus mismatch between tooth and post and core restorations on root fracture *International Endodontic Journal* **46(1)** 47-52.

14. Li Q, Xu B, Wang Y, & Cai Y (2011) Effects of auxiliary fiber posts on endodontically treated teeth with flared canals *Operative Dentistry* **36(4)** 380-389.

15. Maccari PC, Cosme DC, Oshima HM, Burnett LH, & Shinkai RS (2007) Fracture strength of endodontically treated teeth with flared root canals and restored with different post systems *Journal of Esthetic Restorative Dentistry* **19(1)** 30-36; discussion 37.

16. Kubo M, Komada W, Otake S, Inagaki T, Omori S, & Miura H (2018) The effect of glass fiber posts and ribbons on the fracture strength of teeth with flared root canals restored using composite resin post and cores *Journal of Prosthodontic Research* **62(1)** 97-103.

17. Caceres EA, Sampaio CS, Atria PJ, Moura H, Giannini M, Coelho PG, & Hirata R (2018) Void and gap evaluation using microcomputed tomography of different fiber post cementation techniques *Journal of Prosthetic Dentistry* **119(1)** 103-107.

18. Alves Morgan LFDS, Pinotti MB, Ferreira FM, Gomes GM, Silva GC, Albuquerque RDC, & Moreira AN (2018) Influence of light transmission through fiber posts: Quantitative analysis, microhardness, and on bond strength of a resin cement *Indian Journal of Dental Research* **29(1)** 74-80.

19. Bell-Rönnlöf A-ML, Jaatinen J, Lassila L, Närhi T, & Vallittu P (2019) Transmission of light through fiber-reinforced composite posts *Dental Materials Journal* **38(6)** 928-933.

20. Sahafi A, Benetti AR, Flury S, & Peutzfeldt A (2015) Retention of root canal posts: Effect of cement film thickness, luting cement, and post pretreatment *Operative Dentistry* **40(4)** E149-157.

21. Chang Y-H, Wang H-W, Lin P-H, & Lin C-L (2018) Evaluation of early resin luting cement damage induced by voids around a circular fiber post in a root canal treated premolar by integrating micro-CT, finite element analysis and fatigue testing *Dental Materials* **34(7)** 1082-1088.

22. Silva NR da, Rodrigues M de P, Bicalho AA, Soares PBF, Price RB, & Soares CJ (2019) Effect of resin cement mixing and insertion method into the root canal on cement porosity and fiberglass post bond strength *Journal of Adhesive Dentistry* **21(1)** 37-46.

23. Bitter K, Falcon L, Prates Soares A, Sturm R, von Stein-Lausnitz M, & Sterzenbach G (2019) Effect of application mode on bond strength of adhesively luted glass-fiber bundles inside the root canal *Journal of Adhesive Dentistry* **21(6)** 517-524.

24. Uzun İ H, Malkoç MA, Keleİ A, & Öİ reten AT (2016) 3D micro-CT analysis of void formations and push-out bonding strength of resin cements used for fiber post cementation *Journal of Advanced Prosthodontics* **8(2)** 101-109.

25. Dal Piva AM de O, Tribst JPM, Borges ALS, Bottino MA, & Souza RO de A (2018) Do mechanical advantages exist in relining fiber posts with composite prior to its cementation? *Journal of Adhesive Dentistry* **20(6)** 511-518.

26. Farina AP, Chiela H, Carlini-Junior B, Mesquita MF, Miyagaki DC, Randi Ferraz CC, Vidal CMP, & Cecchin D (2016) Influence of cement type and relining procedure on push-out bond strength of fiber posts after cyclic loading *Journal of Prosthodontics* **25(1)** 54-60.

27. Watzke R, Frankenberger R, & Naumann M (2009) Probability of interface imperfections within SEM cross-sections of adhesively luted GFP *Dental Materials* **25(10)**1256-1263.

28. Gomes GM, Rezende EC, Gomes OM, Gomes JC, Loguercio AD, & Reis A (2014) Influence of the resin cement thickness on bond strength and gap formation of fiber posts bonded to root dentin *Journal of Adhesive Dentistry* **16(1)** 71-78.

29. Ruschel GH, Gomes ÉA, Silva-Sousa YT, Pinelli RGP, Sousa-Neto MD, Pereira GKR, & Spazzin AO (2018) Mechanical properties and superficial characterization of a milled CAD-CAM glass fiber post *Journal of the Mechanical Behavior of Biomedical Materials* **82** 187-192.

30. Pang J, Feng C, Zhu X, Liu B, Deng T, Gao Y, Li Y, & Ke J (2019) Fracture behaviors of maxillary central incisors with flared root canals restored with CAD/CAM integrated glass fiber post-and-core *Dental Materials Journal* **38(1)** 114-119.

31. Moustapha G, AlShwaimi E, Silwadi M, Ounsi H, Ferrari M, & Salameh Z (2019) Marginal and internal fit of CAD/CAM fiber post and core *International Journal of Computerized Dentistry* **22(1)** 45-53.

32. Falcão Spina DR, da Costa RG, Correr GM, & Rached RN (2018) Scanning of root canal impression for the fabrication of a resin CAD-CAM-customized post-and-core *Journal of Prosthetic Dentistry* **120(2)** 242-245.

33. da Costa RG, Freire A, Caregnatto de Morais EC, Machado de Souza E, Correr GM, & Rached RN (2017) Effect of CAD/CAM glass fiber post-core on cement micromorphology and fracture resistance of endodontically treated roots *American Journal of Dentistry* **30(1)** 3-8.

34. Fedorov A, Beichel R, Kalpathy-Cramer J, Finet J, Fillion-Robin J-C, Pujol S, Bauer C, Jennings D, Fennessy F, Sonka M, Buatti J, Aylward S, Miller JV, Pieper S, & Kikinis R (2012) 3D slicer

as an image computing platform for the quantitative imaging network *Magnetic Resonance Imaging* **30(9)** 1323-1341.

35. Pulido CA, de Oliveira Franco APG, Gomes GM, Bittencourt BF, Kalinowski HJ, Gomes JC, & Gomes OMM (2016) An *in situ* evaluation of the polymerization shrinkage, degree of conversion, and bond strength of resin cements used for luting fiber posts *Journal of Prosthetic Dentistry* **16(4)** 570-576.

36. Bilgin MS, Erdem A, Dilber E, & Ersoy I (2016) Comparison of fracture resistance between cast, CAD/CAM milling, and direct metal laser sintering metal post systems *Journal of Prosthodontic Research* **60(1)** 23-28.

37. Eid R, Azzam K, Skienhe H, Ounsi H, Ferrari M, & Salameh Z (2019) Influence of adaptation and adhesion on the retention of computer-aided design/computer-aided manufacturing glass fiber posts to root canal *Journal of Contemporary Dental Practice* **20(9)** 10031008.

38. Blackwell E, Nesbit M, & Petridis H (2017) Survey on the use of CAD-CAM technology by UK and Irish dental technicians *British Dental Journal* **222(9)** 689-693.

39. Kollmuss M, Kist S, Goeke JE, Hickel R, & Huth KC (2016) Comparison of chairside and laboratory CAD/CAM to conventional produced all-ceramic crowns regarding morphology, occlusion, and aesthetics *Clinical Oral Investigations* **20(4)** 791-797.