UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
FACULDADE DE ODONTOLOGIA
PROGRAMA DE PÓS-GRADUAÇÃO EM ODONTOLOGIA
MESTRADO EM ODONTOLOGIA ÁREA DE CONCENTRAÇÃO CLÍNICA ODONTOLÓGICA - MATERIAIS DENTÁRIOS

AVALIAÇÃO *IN VITRO* DE RETENTORES INTRARRADICULARES PRÉ-FABRICADOS, ANATÔMICOS E FRESADOS.

MARIA EDUARDA RODRIGUES GAMA
ORIENTADOR: PROF. DR. FABRÍCIO MEZZOMO COLLARES

Porto Alegre

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LINHA DE PESQUISA: BIOMATERIAIS E TÉCNICAS TERAPÊUTICAS EM ODONTOLOGIA

AVALIAÇÃO *IN VITRO* DE RETENTORES INTRARRADICULARES PRÉ-FABRICADOS, ANATÔMICOS E FRESADOS.

Dissertação apresentada ao Programa de Pós-Graduação em Odontologia da Universidade Federal do Rio Grande do Sul, como requisito final para a obtenção do título de Mestre em Odontologia, área de concentração Clínica Odontológica, ênfase em Materiais Dentários.

MARIA EDUARDA RODRIGUES GAMA
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2020

“É preciso estudar muito
para saber um pouco.”

Montesquieu

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RESUMO

GAMA, M.E.R. **Avaliação *In Vitro* de Retentores Intrarradiculares Pré-Fabricados, Anatômicos e Fresados. 2020.** Dissertação – Faculdade de Odontologia da Universidade Federal do Rio Grande do Sul, Porto Alegre, 2020.

O objetivo do presente estudo foi avaliar a cimentação de pinos de fibra fresados a partir do bloco de fibra de vidro CAD-CAM em uma situação de canal amplo e compará-los com pinos de fibra pré-fabricados e anatomizados. Caninos humanos foram tratados endodonticamente, desobturados 7 dias após, um cenário de canal amplo foi confeccionado e os respectivos pinos foram cimentados com cimento auto-adesivo (U200). Foram realizados os ensaio de resistência ao deslocamento por push-out imediato (n=12) e resistência à fratura (n=10). Imagens de microtomografia computadorizada de raio-x (n=5) foram realizadas para avaliação descritiva da linha de cimentação e presença de bolhas utilizando o software 3D Slicer 4.10.2. O teste Kruskal-Wallis foi utilizado para análise dos dados de resistência ao deslocamento por push-out, seguido de Método de Dunn, e ANOVA de uma via para resistência à fratura, utilizando Tukey como post-hoc. O nível de significância estabelecido foi de 5%. O grupo anatomizado (G_{REL}) apresentou valores mais altos (4.80±2.15 MPa) para o push-out, não havendo diferença estatística para o fresado (G_{MILLED}) (4.22±2.58 MPa), enquanto que o grupo de pinos pré-fabricados (G_{PF}) (2.71±1.81 MPa) apresentou os valores mais baixos ($p<0.05$). Falha adesiva entre cimento e dentina foi a mais presente em todos os grupos. Para o ensaio de resistência à fratura, G_{REL} (738.13±151.19 N) apresentou a maior média, seguido de G_{PF} (610.58±99.21 N), e ambos apresentaram diferença estatística comparados a G_{MILLED} (544.83±135.80 N), ($p<0.05$). G_{MILLED} apresentou maior número de falhas somente em munhão (7) comparado a G_{PF} (6) e G_{REL} (6). Apesar de se observado bolhas em todas as imagens de µCT analisadas, G_{PF} apresentou uma quantidade considerável na região cervical, onde a linha de cimentação era mais espessa. Pino de fibra de vidro fresado pode ser uma alternativa segura para a reabilitação de canais ampliados, apresentando modos de falha e retenção similar aos pinos anatomizados com resina composta.

Palavras-chave: Cimentos resinosos; Pinos Dentários; Técnica para Retentor Intrarradicular.

ABSTRACT

GAMA, M.E.R. **Prefabricated, relined and milled intraradicular glass fiber posts: An *in vitro* retention and load to fracture evaluation. 2020.** Dissertation – Faculdade de Odontologia da Universidade Federal do Rio Grande do Sul, Porto Alegre, 2020. Portuguese.

The present study aimed to evaluate push-out bond strength and load to fracture of milled fiberglass post, relined fiberglass post, and pre-fabricated fiberglass post in a flared root canal scenario. 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 pre-fabricated post; G_{REL} received relined glass fiber post; and G_{MILLED} received CAD/CAM milled glass fiber post. Cementation was performed with self-adhesive resin cement. The samples were submitted to x-ray micro-computed tomography (µCT) analysis (n=3) for the analysis of gaps and voids and to the load to fracture for the mechanical behavior (n=10). The roots were sectioned and submitted to the push-out bond strength test (n=12). All µCT images presented voids and gaps. G_{PF} showed a high amount of voids along with a thicker cement layer. On the load to fracture test, G_{REL} presented statistically significant higher values than G_{MILLED}. G_{PF} values had no statistically significant difference when compared to the two other groups. G_{MILLED} exhibited more core section failures when compared to G_{PF} and G_{REL}. On the push-out bond strength, G_{PF} presented statistically significant lower values when compared to G_{REL} and G_{MILLED}. The most common failure pattern was found to be between dentin and cement on all groups. CAD/CAM glass fiber posts may be a reliable alternative to the rehabilitation of flared root canals, presenting fractures modes and retention similar to customized fiber posts.

Keywords: Resin Cement; Dental pins; Post and core technique.

SUMÁRIO

2. ANTECEDENTES E JUSTIFICATIVA

Ao sofrer uma perda de estrutura coronária extensa, um dente passa a exigir a utilização de pinos intrarradiculares para retenção da subsequente restauração (MARCHIONATTI; WANDSCHER; RIPPE; KAIZER *et al.*, 2017; MAROULAKOS; HE; NAGY, 2018).

Pinos metálicos são tradicionalmente usados para possibilitar a reabilitação de dentes com perda de estrutura severa. Os pinos metálicos apresentam uma taxa de sobrevivência média de aproximadamente 7,3 anos (BALKENHOL; WOSTMANN; REIN; FERGER, 2007), e ligas com alto teor de ouro apresentam uma taxa de sobrevivência mais alta quando comparadas às ligas de metais semipreciosos (BALKENHOL; WOSTMANN; REIN; FERGER, 2007). Porém, por possuírem um módulo de elasticidade muito superior ao da dentina, a maioria das falhas podem gerar cenários catastróficos, como fraturas verticais e oblíquas em terço médio, dificilmente passíveis de manutenção do dente (LAMICHHANE; XU; ZHANG, 2014; MACCARI; COSME; OSHIMA; BURNETT *et al.*, 2007; SCHMITTER; HAMADI; RAMMELSBERG, 2011; SOARES; VALDIVIA; DA SILVA; SANTANA *et al.*, 2012; ZHOU; WANG, 2013).

Pinos convencionais estão sendo substituídos cada vez mais pelo uso de pinos pré-fabricados de fibra de vidro (DIKBAS; TANALP, 2013; LAMICHHANE; XU; ZHANG, 2014), possibilitado pelos avanços da odontologia adesiva (SOARES, C. J.; VALDIVIA, A. D.; DA SILVA, G. R.; SANTANA, F. R. *et al.*, 2012), trazendo algumas vantagens como a possibilidade de restaurações mais estéticas para dentes anteriores (DIKBAS; TANALP, 2013; LAMICHHANE; XU; ZHANG, 2014) e menor número de consultas clínicas. É importante ressaltar que a taxa de falha a longo prazo de pinos de fibra de vidro apresenta uma variação entre 7 a 11% em um período de 7 a 11 anos de acompanhamento (FERRARI; CAGIDIACO; GORACCI; VICHI *et al.*, 2007), e uma das mais frequentes causas é a falha de adesão na interface cimento-pino e cimento-dentina (DIKBAS; TANALP, 2013; MARCHIONATTI; WANDSCHER; RIPPE; KAIZER *et al.*, 2017). Nos resultados encontrados sobre resistência a fratura, pinos metálicos apresentam resultados mais altos em comparação aos pinos de fibra de vidro (MACCARI; COSME; OSHIMA; BURNETT *et al.*, 2007), porém este benefício é contraposto pelo padrão de fratura destas amostras, apresentando um maior número de cenários catastróficos. As falhas do sistema de fibra de vidro geram cenários mais favoráveis, comparados aos pinos metálicos (MACCARI; COSME; OSHIMA; BURNETT *et al.*, 2007; MARCHIONATTI; WANDSCHER; RIPPE; KAIZER *et al.*, 2017) possibilitando uma reintervenção no dente para manutenção em boca (MACCARI; COSME; OSHIMA; BURNETT *et al.*, 2007).

Para a instalação de pinos de fibra de vidro algumas características são importantes para o sucesso clínico do tratamento (MARCHIONATTI; WANDSCHER; RIPPE; KAIZER *et al.*, 2017; SKUPIEN; SARKIS-ONOFRE; CENCI; MORAES *et al.*, 2015). A presença de férula é um fator crucial para a reabilitação de um dente com pino pré-fabricado (MARCHIONATTI; WANDSCHER; RIPPE; KAIZER *et al.*, 2017; PANG; FENG; ZHU; LIU *et al.*, 2019; ZHOU; WANG, 2013). Consiste de um colar de dentina circunferencial de 1,5 a 2 mm de altura atuando positivamente sobre o prognóstico da restauração (JULOSKI; RADOVIC; GORACCI; VULICEVIC *et al.*, 2012).

Outro fator a ser observado é o material utilizado na realização do tratamento endodôntico (ALTMANN; LEITUNE; COLLARES, 2015; SERAFINO; GALLINA; CUMBO; FERRARI, 2004). A obturação endodôntica do dente a ser reabilitado realizada com cimentos à base de eugenol pode levar a reduzida polimerização do cimento resinoso. Isso acontece em decorrência de moléculas de eugenol que ficam aprisionadas dentro da matriz de cimento endodôntico formada, e quando em contato com o cimento resinoso podem impedir o processo de polimerização devido à reação com radicais livres (ALTMANN; LEITUNE; COLLARES, 2015). Além disso, a cimentação com cimentos resinosos somente em dentina radicular apresenta uma adesão menor em comparação à adesão em dentina coronária (MAROULAKOS; HE; NAGY, 2018). Após a desobturação do canal, forma-se uma *smear layer* com componentes do cimento endodôntico e gutta-percha, que não é removida totalmente quando realizado o ataque ácido do conduto, desta maneira, não permitindo a desmineralização ideal da dentina peritubular radicular (ALTMANN; LEITUNE; COLLARES, 2015; MAROULAKOS; HE; NAGY, 2018; SERAFINO; GALLINA; CUMBO; FERRARI, 2004). A adesão em dentina é alcançada através de microrretenções obtidas a partir da desmineralização parcial do conteúdo mineral da dentina e, consequentemente, exposição da rede de colágeno, para então monômeros penetrarem e realizar a formação da camada híbrida ao serem polimerizados (NAKABAYASHI; NAKAMURA; YASUDA, 1991). As diferenças de número e diâmetro tubular da dentina cervical para apical pode resultar em uma menor adesão, uma vez que o diâmetro gradualmente diminui, levando a uma menor infiltração dos monômeros (MAROULAKOS; HE; NAGY, 2018). A umidade demasiada do canal radicular e a dificuldade de penetração da luz também são desafios para a retenção do pino (MAROULAKOS; HE; NAGY, 2018).

A escolha do cimento pode afetar a retenção do pino, cimentos auto-adesivos apresentam uma menor sensibilidade técnica ao serem comparados com cimentos resinosos convencionais (MARCOS; KINDER; ALFREDO; QUARANTA *et al.*, 2016; SARKIS-ONOFRE; SKUPIEN; CENCI; MORAES *et al.*, 2014), e a sua manipulação e inserção é um fator condicionante para diminuir a presença de bolhas (MARCHIONATTI; WANDSCHER; RIPPE; KAIZER *et al.*, 2017; SKUPIEN; SARKIS-ONOFRE; CENCI; MORAES *et al.*, 2015).

Uma boa adaptação do pino ao conduto preparado é importante para que se obtenha uma fina camada de cimento entre o pino e a dentina (MARCOS; KINDER; ALFREDO; QUARANTA *et al.*, 2016; MAROULAKOS; HE; NAGY, 2018; SCHETINI, 2014). Os sistemas de pinos de fibra de vidro acompanham uma broca com um formato similar ao do pino para uma boa adaptação, porém, alguns condutos apresentam formatos singulares ou muito ampliados, causando uma variação da espessura de cimento (TANG; WU; SMALES, 2010). Condutos alargados podem ser ocasionados por reabsorção interna, procedimentos para remoção de instrumentos fraturados ou demasiado preparo físico do canal durante tratamento endodôntico, resultando em paredes finas de dentina radicular (TANG; WU; SMALES, 2010). Ao cimentar um pino pré-fabricado em um canal alargado, uma camada espessa de cimento será formada, o aumento desta camada está diretamente relacionado à contração de polimerização, gerando uma tensão de contração (MAY; KELLY, 2013). Outro fator que influencia esta tensão é a configuração da cavidade. O conduto possui um fator C de aproximadamente 200, favorecendo que a tensão de contração de polimerização seja dissipada na interface, formando gaps ou bolhas, levando a uma maior degradação e falha (MAY; KELLY, 2013).

O uso de núcleos metálicos em canais alargados possibilitaria uma adaptação por ser personalizado, e, consequentemente, uma menor linha de cimentação. Porém, por possuírem um módulo de elasticidade muito superior ao da dentina (ONA; WAKABAYASHI; YAMAZAKI; TAKAICHI *et al.*, 2013), quando sujeitos aos estresses das forças oclusais, produzem tensões nas paredes dentinárias finas, aumentando as chances de uma fratura radicular irreparável (PANG; FENG; ZHU; LIU *et al.*, 2019). Nos casos de canais ampliados pelo preparo endodôntico, técnicas de anatomização com resina composta podem ser utilizadas para adequar o diâmetro do pino no canal, possibilitando que uma fina camada de cimento seja formada (ROCHA; GONCALVES; VASCONCELOS; MATOS MAIA FILHO *et al.*, 2017; SCHETINI, 2014). Estudos mostram que pinos customizados com resina composta, cimentados com uma camada fina e uniforme de cimento, devido à sua adaptação adequada em toda extensão do conduto, apresentam maior retenção em comparação com pinos sem customização (ROCHA; GONCALVES; VASCONCELOS; MATOS MAIA FILHO *et al.*, 2017; SCHETINI, 2014). Um conjunto de fatores pode ter influência sobre este resultado, como uma maior fricção entre o pino e a parede do canal, uma menor contração de polimerização, consequentemente uma menor tensão de contração gerada nas paredes, o que poderia favorecer a formação de falhas (ROCHA; GONCALVES; VASCONCELOS; MATOS MAIA FILHO *et al.*, 2017; SCHETINI, 2014). Além disso, o módulo de elasticidade da fibra de vidro (20 GPa) e da resina composta (15 GPa) é muito similar ao da dentina (18.6 GPa) (LAMICHHANE; XU; ZHANG, 2014). Isso possibilita que os materiais acompanhem naturalmente os movimentos flexurais, possuindo comportamento biomecânico similar ao dente (BARJAU-ESCRIBANO; SANCHO-BRU; FORNER-NAVARRO; RODRIGUEZ-CERVANTES *et al.*, 2006), reduzindo a concentração de estresse na raiz, e apresentando falhas mais favoráveis e passíveis de reabilitação comparado aos pinos metálicos (200 GPa) em ensaios de resistência à fratura (BARJAU-ESCRIBANO; SANCHO-BRU; FORNER-NAVARRO; RODRIGUEZ-CERVANTES *et al.*, 2006; LAMICHHANE; XU; ZHANG, 2014; MACCARI; COSME; OSHIMA; BURNETT *et al.*, 2007; MAROULAKOS; NAGY; KONTOGIORGOS, 2015; ZHOU; WANG, 2013)

Porém, ao adaptarmos um pino com resina composta aumentamos o número de interfaces da restauração, maior sensibilidade técnica existente, aumentando as chances de degradação e falhas (MAROULAKOS; HE; NAGY, 2018). Além disso, a maioria das reabilitações com pinos de fibra de vidro requer a construção de um munhão em resina composta. Contudo, a adesão entre a resina e a fibra de vidro não apresenta resistência suficiente para um bom desempenho clínico a longo prazo, isso pode ser devido ao grande número de ligações cruzadas da matriz epoxy do pino, que dificulta a formação de uma forte adesão química com a resina composta do munhão (NOVAIS; SIMAMOTOS JUNIOR; RONTANI; CORRER-SOBRINHO *et al.*, 2012).

A Odontologia digital está trazendo eficiência principalmente na área da prótese dentária e reabilitação oral com o surgimento de máquinas fresadoras e scanners acurados (TSINTSADZE; JULOSKI; CARRABBA; GORACCI *et al.*, 2018). Os blocos de fibra de vidro fresados com tecnologia computer-aided design/computer-assisted manufacture (CAD-CAM) têm como benefícios proporcionar uma melhor adaptação ao canal radicular, principalmente em casos de canais com formato irregular ou canais alargados (EID; KOKEN; BABA; OUNSI *et al.*, 2019; PANG; FENG; ZHU; LIU *et al.*, 2019) sem a necessidade de anatomizar com resina composta um pino pré-fabricado e dispensando a realização de munhão. Além disso, a correta dimensão do pino personalizado proporciona uma maior superfície de contato com o canal radicular e uma espessura de cimento fina, evitando falhas de cimentação e gaps (EID; KOKEN; BABA; OUNSI *et al.*, 2019).

Tendo em vista que a digitalização da Odontologia está se fazendo mais presente nos tratamentos atualmente, e pouca literatura a respeito está disponível, se faz necessário mais estudos sobre a avaliação de pinos fresados com tecnologia CAD-CAM para assegurar a longevidade e sucesso clínico das reabilitações.

3. OBJETIVOS

O objetivo do presente estudo foi avaliar a resistência de união e resistência à fratura de pinos de fibra fresados a partir de bloco de fibra de vidro CAD-CAM em uma situação de canal amplo e compará-los com pinos de fibra pré-fabricados e pinos de fibra pré-fabricados anatomizados.

4. ARTIGO

A presente dissertação de mestrado apresenta-se na forma de um manuscrito escrito nas normas do periódico *Journal of Prosthodontic Research*, para o qual será submetido.

Original research article

Milled intraradicular glass fiber posts: An *in vitro* analysis of bond strength and load to fracture evaluation.

Running title: Milled intraradicular glass fiber posts.

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Key words: Dental Prothesis; Computer-Aided Design; Resin Cements; Dental pins; Post and core technique;

Abstract

Purpose: The present study aimed to evaluate push-out bond strength and load to fracture of milled fiberglass post, relined fiberglass post, and pre-fabricated fiberglass post in a flared root canal scenario.

Methods: 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 pre-fabricated post; G_{REL} received relined glass fiber post; and G_{MILLED} received CAD/CAM milled glass fiber post. Cementation was performed with self-adhesive resin cement. The samples were submitted to x-ray micro-computed tomography (µCT) analysis (n=3) for the analysis of gaps and voids and to the load to fracture for the mechanical behavior (n=10). The roots were sectioned and submitted to the push-out bond strength test (n=12).

Results: All µCT images presented voids and gaps. GPF showed a high amount of voids along with a thicker cement layer. On the load to fracture test, G_{REL} presented statistically significant higher values than G_{MILLED}. G_{PF} values had no statistically significant difference when compared to the two other groups. G_{MILLED} exhibited more core section failures when compared to G_{PF} and G_{REL}. On the push-out bond strength, G_{PF} presented statistically significant lower values when compared to G_{REL} and G_{MILLED}. The most common failure pattern was found to be between dentin and cement on all groups. Conclusion: CAD/CAM glass fiber posts may be a reliable alternative to the rehabilitation of flared root canals, presenting fractures modes and retention similar to customized fiber posts.

Keywords: Resin Cement; Dental pins; Post and core technique.

1. Introduction

The rehabilitation of endodontically treated teeth may need an intraradicular post cementation in cases where considerable coronal destruction is found [1,2]. Different materials are used to produce the posts [2], and the glass fiber ones have been widely used in clinical practice. The aesthetic properties and mechanical behavior os these materials closely resemble the dental hard tissues contributing to its high acceptance and success on prosthodontic treatments [3,4]. The failure rate for these treatments ranges between 7% and 11% [3–5], and most of the failures are related to the root fracture and the loss of post retention [2,5,6].

The clinical success of fiber posts depends on dental geometry and position of the tooth in the arch, adaptation, cementation technique, amount of residual coronal structure, and ferrule presence [7]. Fiber posts are successfully used when a 2mm dentin collar is available [8,9]. In these cases, the stress distribution of masticatory forces is dissipated due to the similar elastic module found on glass fiber posts when compared to dentin [10]. The success of this technique may be impaired by the presence of flared root canals, where the extensive loss of tissue is found [11–13].

The pre-fabricated glass fiber posts in these cases could not match the size and shape of these canals, and for this reason, a considerable amount of cement is needed for cementation [13,14]. A thicker cement layer enables an increased polymerization shrinkage and the formation of voids and gaps on these layers, weakening the post-cement-dentin structure [13,15,16]. Custom-build posts may be produced by relining with composite resins to increase the adaptation and reduce the thickness of the cement layer [14,17,18]. In these cases, different interfaces were created as several materials were used [19,20]. 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 and anatomically fitted glass-fiber posts [21,22]. 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 that may be installed with a thin layer of cement with better adaptation [23,24]. The development of glass-fiber blocks for milling manufacturing results in a one-body post-and-core, avoiding the use of different materials and the presence of multiple interfaces on the cemented structure [21,25]. While several advantages were observed for this manufacturing technique, few studies attempt to understand the behavior of one-body post-and-core glass fiber posts [14,21,23]. The effect of these posts on roots with extensive loss of tissue diameter should be addressed for the possible application of these structures on 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.

2. Materials and Methods

2.1 Teeth selection

Sixty-six extracted single-rooted permanent 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 cement enamel junction to the apex was at least 15mm. All teeth were stored at 4°C for no more than six months. This study was approved by the research ethics committee (no. 3.617.474).

2.2 Root canal preparation

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

2.3 Post preparation

Before the post-cementation procedure, gutta-percha removal was performed with Largo drills (Dentsply, Mailleifer) and 4mm of filling material remained on the apical third. The root canals were expanded with Largo drills (Dentsply, Mailleifer) #2 and #3, washed with 5ml of distilled water, and dried with paper points (Dentsply, Brazil). The prepared teeth were divided into three groups according to the different glass fiber posts used for reconstruction: pre-fabricated glass fiber post (G_{PF}); composite resin relined glass fiber post (G_{REL}), and CAD/CAM milled glass fiber post (G_{MILL}).

For the G_{PF} group, posts (Exacto #3, Angelus Indústria de Produtos Odontológicos S/A, Londrina, PR, Brazil) were cleaned with 70% ethyl alcohol and air-dried for 30s. Silane was actively applied for 60s and air-dried for 30s. A self-etching resin cement (U200, 3M ESPE, São Paulo, Brazil) was mixed and dispensed into the post space with a syringe (Centrix, DFL Indústria e Comércio

S.A., Rio de Janeiro, RJ, Brasil) and an endodontic tip as described previously [11, 13]. The post was inserted and polymerized 40 seconds in the buccal and palatine faces with a calibrated LED light-curing 1500 mW/cm^2 (SDI Indústria e Comércio Ltda., São Paulo, SP, Brazil).

For the G_{REL} group, an adhesive resin (Scotchbond, 3M ESPE, São Paulo, Brazil) layer was applied around the post and light-cured for 1 minute. For the relining, a Composite resin (Filtek, Z350 3M ESPE, São Paulo, Brazil) was used directly around the post, inserted into the root canal, and light-cured for 5s. 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 washed with 70% ethyl alcohol [12] and air-dried and cemented as to the G_{PF}.

For $G_{MILLED,}$ the post space was filled with acrylic resin (Duralay, Reliance Dental Mfg. Co., Alsip, USA) for root canal modeling. The acrylic resin posts were scanned with a digital scanner (Shining3D DS-EX - Shining 3D Tech Co., Ltd. Hangzhou, China) and computer-aided designed (CAD) posts were obtained with the root dimensions. Glass fiber (FiberCad, Angelus Indústria de Produtos Odontológicos S/A, Londrina, PR, Brazil) discs were used for milling on a computer-aided machine (CAM) (DM5 - Tecnodrill Indústria de Máquinas Ltda, Novo Hamburgo, Brazil**)**. The customized milled posts were then cleaned, silanized (Angelus Indústria de Produtos Odontológicos S/A, Londrina, PR, Brazil), and cemented as described for the G_{PF} and G_{REL} groups. All specimens were water stored for seven days at 37°C. The preparation of posts for the different groups is summarized in Table 1.

2.4 X-ray micro-computed tomography analysis

After cementation, the specimens (n=5) were scanned by x-ray microcomputed tomography (InspeXio SMX-90CT Plus- SHIMADZU, Kyoto, Japan). The X-ray tube was operated at 80kv and 114 mA with a voxel size of 0.013mm. The images were reconstructed. Reconstruction was performed by inspeXio SMX-90CT software (Shimadzu Corp., Kyoto, Japan) and resulted in a stack of 541 images. The Dicom files were used to tridimensional reconstructions with 3D Slicer 4.10.2 software (slicer.org) with the following settings: segmentation editor, threshold (range from 2060.83 to 2118.48), threshold quantification, segmentation statistics. The same operator performed a descriptive analysis of voids and gap formation on the cement layer.

2.4 Push-out bond strength test

Teeth (n=12) were sectioned on a low-speed, water-cooled diamond saw. For each tooth, nine slices were made with 0,7mm ± 0,1mm diameter. Before the analysis, slices were stored in distilled water at 30ºC for 7 days. The push-out bond strength test was performed in each slice that was 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 cross-head speed of 0,5mm/min until failure. To express bond strength results in megapascals (MPa), the maximum load in newtons (N) was divided by the bonded area (mm^2). The bonded area was calculated using the following formula:

$$(\pi R + \pi r) \times \sqrt{(R-r)^2 + h^2}$$

Where R, r, and h are cervical radius, apical radius, and slice height.

Π=3,14

A single operator performed all measures. 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.

2.6 Load to Fracture

For the load to fracture analysis, the samples were submitted to a core reconstruction. For G_{PF} and G_{REL} groups the samples were etched with phosphoric acid 37% (Scotchbond etchant; 3M Dental Products) for the 30s in enamel and 15s in dentin. A commercial primer (3M ESPE) was applied in dentin, the solvent was evaporated, and an adhesive layer was applied. After light-curing, the core was built with a composite resin (BISCORE, Bisco- Schaumburg,USA) with a 5mm height. Polymerization was performed for 1 minute on each side. For $G_{MILLED,}$ the core was modeled with acrylic resin (Reliance Dental Manufacturing LLC; Alsip- USA) during the post preparation. 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 one-body system post-and-core structure was obtained.

The restored root canals were embedded in acrylic resin, with a ferrule of 2mm. The 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 in the palatal surface at a 45° angle in a fatigue testing machine (Servopulser- Shimadzu Servohydraulic Fatigue Testing System; Kyoto- Japan) with a crosshead speed of 1mm/min until fracture. Mode of fracture was recorded and classified as repairable in the tooth where debonding, core fractures or oblique fractures in cervical third was identified, or non-repairable in the tooth where vertical fractures or oblique fractures in middle and apical third was observed [13].

2.7 Statistical Analysis

A descriptive analysis was performed for µCT images. The normality of the data was assessed by Shapiro-Wilk test. For the push-out test, normality was not verified, and thus a repeated-measures ANOVA was employed with Dunn's *posthoc.* On load to fracture, a normal distribution was obtained, and data were analyzed by with one-way ANOVA, and Tukey. The significance level was set at 5%.

3. Results

µCT images (Figure 1) were analyzed, and the presence of voids and gaps were evaluated in the cement layer of all specimens tested. G_{PF} presented a considerable amount of voids, mainly in cervical third, although they were smaller when compared to those present in G_{REL} and $G_{MILLED.}$ G_{REL} and G_{MILLED} showed similar bubble place distribution through the cement layer.

On the push-out bond strength analysis, the obtained values ranged from 4.80±2.15 MP to 2.71±1.81 MPa on G_{REL} and, respectively. G_{MILLED} presented higher push-out bond strength when compared to G_{PF} ($p < 0.05$), and no statistically significant difference was found between G_{REL} and G_{MILLED} (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 failures (58.9%).

3.2 Load to fracture

The load until the fracture results is shown in Table 3. The average load to fracture on G_{REL} was 738.13±151.19 N. G_{MILLED} values were statistically significant lower than G_{REL} (544.83±135.80 N; $p < 0.05$). Pre-fabricated posts resulted in load to fracture values and no 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).

4. Discussion

The rehabilitation of teeth with extensive loss of hard tissues is a challenge in clinical practice [5], and different techniques have been studied for the reinforcement of flared root canals [18]. In the present study, CAD/CAM milled glass fiber posts were used to restore flared root canals *in vitro*. A one-body system was produced, and when compared to pre-fabricated and relined glass fiber posts, the tested posts presented a lower amount of voids and gaps along with adequate values for push-out bond strength. Load to fracture was lower when compared to other groups, but reparable failures were more frequently observed on CAD/CAM milled glass fiber posts.

The adaptation of the glass fiber post is related to the thickness of the cement layer needed for the procedure [15,20]. The formation of voids and gaps is found due to air entrapment during the manipulation of the cement, and it is known that a thin layer of cement is related to the lower formation of voids and gaps [14,26]. When flared root canals were considered, the amount of cement used on pre-fabricated posts is obviously increased, and the match between the root canal shape and the fiber post may reduce the amount of cement and the formation of this voids and gaps [14,25]. This was observed in the descriptive analysis found in Figure 1. A thick cement layer and an increased number of voids were found on $G_{PF,}$ while lower amount of voids were observed on the custom-build posts (G_{REL} and G_{MILLED}). The apical third presented more voids than the cervical third, and this is found before [27,28]. The relationship between the presence of voids and gaps and the bond strength is studied in different posts, and conflicting results are found.

While some reports related lower bond strength to void-containing structures [28,29], other studies did not found a statistically significant difference [27,30]. Although the effect of voids and gaps is not always present, a thin and uniform layer of cement is desired for the stability of the bonding and the mechanical interlocking of the cemented post [20].

The adaptation of glass fiber posts and the quality of the cementation affect the push-out bond strength [18,30–32], and customized posts present increased values when compared to pre-fabricated ones [18]. Table 3 shows the push-out bond strength results where increased values were found for G_{REL} and $G_{MILLED.}$ This is in accordance with previous studies where the better adaptation resulted in a thinner cement layer, which is difficult to be obtained on pre-fabricated posts cemented on root canals with extensive loss of tissue. As the cement is known to present lower mechanical strength when compared to glass fiber posts, the high the amount of cement on the root canal, the lower the force needed for dislodgement on the root slices [18]. Lower gap formation corroborates with these results that may be related to lower debonding on post-and-core treatments, which is known to be the common cause of failure on these treatments [5].

The push-out bond strength may be influenced by both the amount of the cement and the quality of formed polymeric network [33]. As photocured luting agents were used in the present study, the polymerization into the root canal could be affected by the decreased light transmission trough the canal [34]. The middle and apical thirds of the root may be especially affected by the reduced light transmission [33,34] that may occur due to the presence os large opaque posts into the root canal [35] . Based on this finding, it is possible to state that an adequate polymeric network was formed. Cohesive failure was found on 38.5% of samples on the G_{MILLED} group on the cervical third. The mismatch in elastic modulus could explain this high cohesive percentage - dentin with 18 GPa, milled glass fiber post with 25 GPa, and resin cement with8 GPa. On the $G_{MILLED,}$ a thinner cement layer was formed, and thus stress absorption may be lower with higher dissipation it to the thin dentin walls [36].

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, adaptation of the post, and the stress dissipation on the post-cement-dentin interface [21,37]. The milling process is shown to result in decreased resistance for glass fiber posts alone [21]. In contrast, previous study found comparable results between cemented pre-fabricated and milled posts [22,24,25]. In the present study, static mechanical testing was performed on cemented posts with ferule simulation without aging, and the G_{MILLED} group showed the lowest load to fracture values (Table 3) without a statistically significant difference to G_{PF}. G_{REL} achieved the highest values. The direction of the fibers is a key factor for adequate stress dissipation, and milling the glass fiber blocks with the vertical fiber orientation is required to guarantee the adequate mechanical properties [21]. The analysis of failure modes shows that most of the samples presented chipping failures on the core, and the fracture occurred parallel to the fiber orientation showing that milling was performed in the right direction (Table 3). Non-reparable fractures were observed on G_{MILLED} (Table 3). Although lower values were found, the core chipping indicates easily reparable fractures. Some studies suggest that stiff materials with a high load to fracture results may result in increased catastrophic failure [38]. The possibility of repair on the fractured post and core structures is desired for tooth maintenance.

The CAD/CAM milling process emerges as a machinable custom-build alternative to increase the adaptation of glass fiber posts on flared root canal systems. The one-body system created in this study presented adequate adaptation with reduced cement layer and lower presence of voids and gaps, which was evidenced by the high bond strength obtained on root slices. The mechanical behavior was acceptable leading, most commonly, to reparable failures that clinically may represent the maintenance of the tooth structure. The CAD/CAM manufacturing of this post may promote easily applicable and less technique sensitive personalized treatments for root canal systems with a wide diameter and extensive loss of tissue.

5. Conclusion

CAD/CAM glass fiber post-and-core at flared root canal presented fractures modes repair and push-out bond strength similar to relined fiber post. Therefore, it may be a reliable alternative to the rehabilitation of flared root canals.

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Table 1.

Description of groups and cementation technique

Groups	Description of groups and cementation technique
G_{PF}	Pre-fabricated glass fiber post cemented in a flared root canal Post was cleaned with alcohol, air dried, silane was applied (1min), air-dried (30s), cement insertion, polymerization
G_{REL}	Pre-fabricated glass fiber post customized with composite resin cemented in a flared root canal Post was cleaned with alcohol, air dried, silane was applied (1min), air-dried (30s), the adhesive layer was applied, polymerization of the adhesive layer (1min), composite resin around the post, water-soluble gel applied inside conduct, post inserted, polymerization (5s) post inside conduct, polymerization (1 min) post outside conduct, cement insertion, polymerization
G_{MILLED}	Milled fiberglass disc cemented in a flared root canal Post was cleaned with alcohol, air dried, silane was applied (1min), air-dried (30s), cement insertion, polymerization (1 min)

Table 2.

Means value and standard deviation of push-out bond strength in (MPa) for different Groups and percentage of failure mode for each group in push-out bond strength test.

Groups	**MPa**	**Adhesive**		**Cohesive**
		Ac/d	Ac/p	
G_{PF}	2.71 ± 1.81^{A}	61.53%	3.37%	28.08%
G_{RELI}	4.80 ± 2.15^{B}	69.66%	5.61%	24.71%
G_{MILLED}	4.22 ± 2.58^{B}	58.9%%	3.44%	38.35%

Failure modes: Ac/d: adhesive between dentin and resin cement interface; Ac/p: adhesive between post and resin cement interface; Cohesive in dentin.

Different uppercase letters indicate statistically significant difference (P<0.05).

Table 3.

Means and standard deviation of fracture strength (N) for different groups and Number of teeth with fracture of the core section (C) or root fracture (F).

Groups	**N**	**Reparable**		**Irreparable**
		C	F	F
$\mathbf{G_{PF}}$	610,58±99,21^{AB}	6	4	0
$\mathbf{G_{REL}}$	738,13±151,19^{A}	6	3	1
$\mathbf{G_{MILLED}}$	544,83±135,80^{B}	7	0	3

Different uppercase letters indicate statistically difference (P>0.05).

Figure 1.

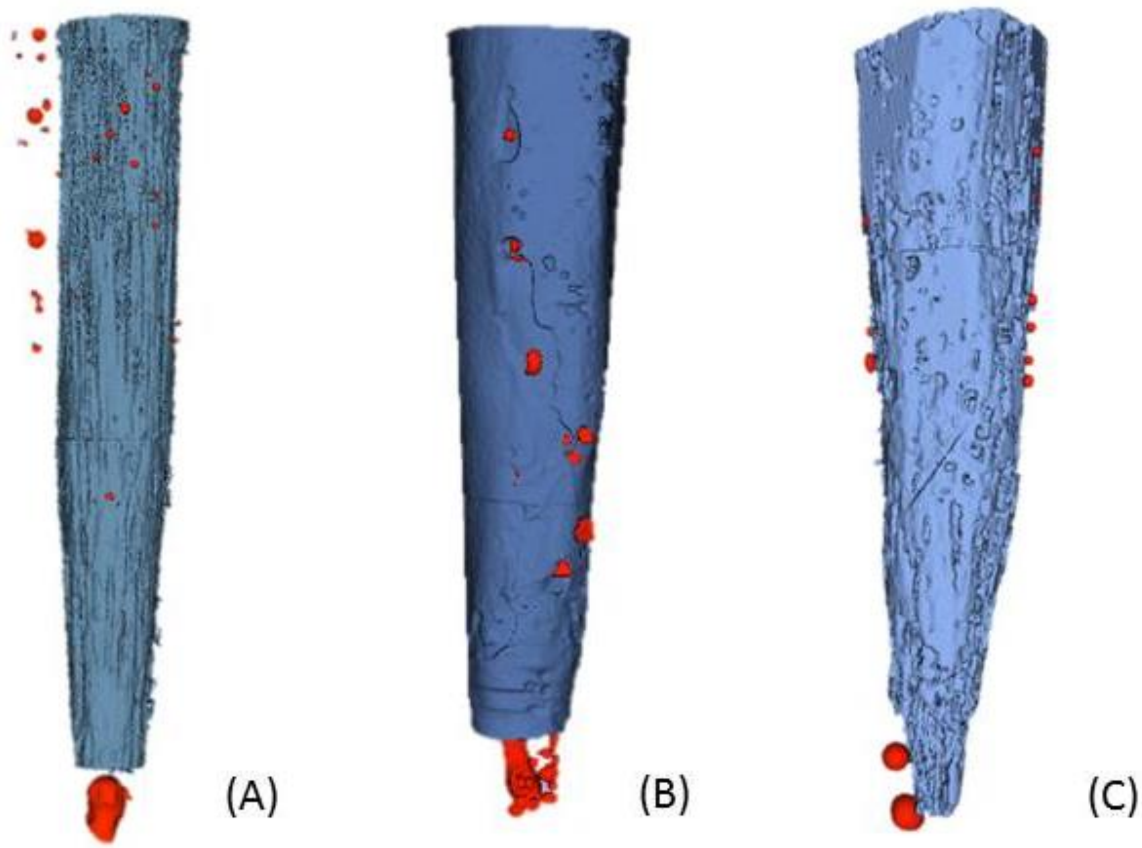
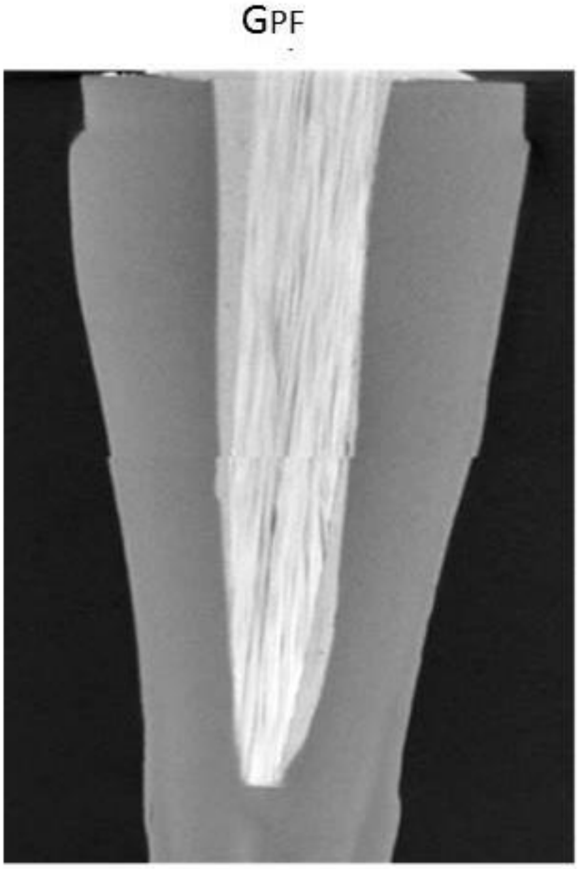


Figure 2.



Legends to figures

Title: Figure 1. Representative images of a 3-dimensional model of voids in cementation layer in each group around post.

Legend:

(A) G_{PF}
(B) G_{REL}
(C) G_{MILLED}

Title: Figure 2. Representative image of post cementation taken by x-ray microcomputed tomography.

5. CONSIDERAÇÕES FINAIS

A reabilitação de dentes tratados endodonticamente com extensa perda de estrutura coronária e canais alargados ainda é considerado um desafio para os dentistas. Elementos com canais alargados carecem de uma espessura de dentina radicular satisfatória, principalmente em terço cervical, o que torna o elemento fragilizado (KUBO; KOMADA; OTAKE; INAGAKI *et al.*, 2018; SAVYCHUK; MANDA; GALANIS; PROVATIDIS *et al.*, 2018). Além disso, a necessidade de utilizar um pino radicular que se adapte ao canal tratado está bem definida na literatura, a espessura da camada de cimento resinoso possui influência sobre a retenção do pino, podendo estar relacionada com uma maior formação de bolhas internas no cimento e/ou na interface cimento-dentina devido à contração de polimerização e tensão de contração gerada, formando pontos de vulnerabilidade (GOMES; REZENDE; GOMES; GOMES *et al.*, 2014; MAY; KELLY, 2013; SCHETINI, 2014).

Com os avanços da tecnologia, a procura por um pino intrarradicular adaptável a canais alargados ou com formatos singulares que possua um módulo de elasticidade similar ao dente, com o intuito de uma melhor distribuição de forças, e que também permita uma camada fina de cimentação sem aumentar o número de interfaces de materiais levou a fabricação de blocos de fibra de vidro para serem fresados a partir de um escaneamento da peça modelada ou do conduto (DA COSTA; FREIRE; CAREGNATTO DE MORAIS; MACHADO DE SOUZA *et al.*, 2017).

De acordo com os resultados encontrados no presente estudo, é possível concluir que o uso de pinos fresados em canais alargados possibilitou a confecção de uma linha de cimento tênue e com adesão similar ao uso de pinos pré-fabricados anatomizados. Quanto ao ensaio de resistência à fratura, os elementos cimentados com pinos fresados demonstraram valores menores comparados aos outros grupos. Na literatura não há um consenso de valor mínimo necessário para ser considerado aceitável para este teste, portanto não se pode afirmar que este resultado é considerado insatisfatório. Os pinos de fibra de vidro são caracterizados como vantajosos ao serem comparados com pinos metálicos quanto ao modo de falha quando submetidos ao teste de resistência à fratura, apresentando um maior número de falhas consideradas reparáveis. Neste estudo, os modos de falha dos pinos fresados foram similares aos observados nos outros dois grupos, apresentando resultados muito similares em números. Fraturas radiculares consideradas irreparáveis foram observadas nos grupos de pinos customizados e fresados. Porém, como vantagem dos pinos fresados, todas as fraturas em munhão ocorreram na forma de lascamento da face palatina no sentido da disposição das fibras, facilmente passiveis de reparo.

Quando este cenário de canal alargado não possui férula, seria necessário o uso de núcleos metálicos fundidos para possibilitar a confecção de uma linha fina e uniforme de cimento. Porém, a somatória da fragilidade do elemento, junto com o alto módulo de elasticidade do núcleo metálico ao sofrerem as forças da mastigação, a chance de fratura radicular aumenta. Tendo em vista que a outra opção de tratamento deste cenário é a extração do dente, é não só interessante, como necessária a realização de ensaios laboratoriais comparando o uso de núcleos metálicos fundidos e o uso de pinos de fibra de vidro fresados, com o objetivo de aumentar a longevidade desses dentes.

Os pinos fresados são uma alternativa promissora na reabilitação de dentes anteriores tratados endodonticamente com canais alargados, necessitando mais estudos para assegurar sua eficácia laboratorial e clínica.

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