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Camila Ferreira Silva

Estudo sobre raízes alargadas restauradas com pinos de fibra de vidro reembasados com diferentes resinas compostas – Resistência adesiva, caracterização e revisão sistemática com metanálise.

Tese apresentada à Faculdade de Odontologia da Universidade Federal de Uberlândia, como requisito parcial para obtenção do Título de Doutor em Odontologia na Área de Concentração de Clínica Odontológica Integrada.

Uberlândia, Dezembro de 2020

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DEDICATÓRIA

A Deus, Aos meus pais e ao meu marido

Agradeço a Deus pela minha vida, pelo amparo e por colocar pessoas tão incríveis em meu caminho que me incentivam e apoiam.

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"Dai-me Senhor, a perseverança das ondas do mar, que fazem de cada recuo, um ponto de partida para um novo avançar."

Cecília Meireles

SUMÁRIO

RESUMO

Estudo sobre raízes alargadas restauradas com pinos de fibra de vidro reembasados com diferentes resinas compostas – Resistência adesiva, caracterização e revisão sistemática com metanálise – Camila Ferreira Silva – Tese de Doutorado – Programa de Pós-graduação em Odontologia – Faculdade de Odontologia – Universidade Federal de Uberlândia

RESUMO

A reabilitação de dentes tratados endodonticamente frequentemente requer o uso de retentores intraradiculares para viabilizar a reconstituição coronária, promovendo retenção à restauração. Muitas vezes esses pinos não se ajustam corretamente em raízes com canais amplos ou alargados, necessitando de alguns procedimentos de customização. Este estudo tem como objetivo geral avaliar diferentes resinas compostas no processo de customização e cimentação de retentores de fibra de vidro, através de testes de resistência adesiva, caracterização dos materiais em associação ao retentor e revisão sistemática; **objetivo específico 1:** comparar a resistência adesiva e padrão de falha no terço cervical de pinos de fibra de vidro customizados com resina composta regular, resina bulk fill flow.; **objetivo específico 2:** avaliar a resistência de união de pinos de fibra de vidro cimentado com resina bulk-fill flow em dentes tratados endodonticamente e depois comparar os resultados com os de pinos de fibra de vidro cimentados com cimento resinoso convencional dual; **objetivo específico 3:** avaliar o grau de conversão, dureza e resistência de união por meio dos ensaios de micro push-out e pull-out de diferentes resinas compostas quando associadas a pinos de fibra de vidro em raízes com diâmetro aumentado; **objetivo específico 4:** determinar qual técnica de customização apresenta maior resistência à fratura e um padrão de falha mais favorável quando associada a pinos de fibra de vidro para reabilitar dentes com canais alargados ou amplos. Esse estudo é baseado em testes laboratoriais e por isso possui algumas limitações, entretanto pode-se concluir que o reembasamento de pinos de fibra de vidro é importante e que resinas bulk fill podem ser utilizadas como material de reembasamento em especial as resinas de consistência regular.

ABSTRACT

Estudo sobre raízes alargadas restauradas com pinos de fibra de vidro reembasados com diferentes resinas compostas – Resistência adesiva, caracterização e revisão sistemática com metanálise – Camila Ferreira Silva – Tese de Doutorado – Programa de Pós-graduação em Odontologia – Faculdade de Odontologia – Universidade Federal de Uberlândia

ABSTRACT

Restoration of endodontically treated teeth often requires the use of intraradicular retainers to enable coronary reconstitution, promoting retention of the coronary restoration. Often these posts do not fit properly in roots with wide canals, requiring some customization procedures. This study aims to evaluate different composite resins in the customization and cementation process of fiberglass retainers, through tests of adhesive strength, characterization of materials in association with the retainer and systematic review; **specific objective 1**: to compare the adhesive strength and failure pattern in the cervical third of glass fiber posts customized with regular composite resin, bulk fill flow resin; **specific objective 2:** to evaluate the bond strength of glass fiber posts cemented with bulk-fill flow resin in endodontically treated teeth and then compare the results with those of glass fiber posts cemented with resin cement; **specific objective 3:** to evaluate the degree of conversion, hardness and bond strength by means of micro push-out and pull-out tests of different composite resins when associated with glass fiber posts in roots with increased diameter; **specific objective 4:** to determine which customization technique has greater fracture resistance and a more favorable failure pattern when associated with glass fiber posts to rehabilitate teeth with enlarged or wide canals. This study has many limitations, however it can be concluded that bulk fill resins can be used as relining material, especially resins of regular consistency and that the use of larger diameter post is essential for the rehabilitation of weakened roots.

INTRODUÇÃO E REFERENCIAL TEÓRICO

INTRODUÇÃO E REFERENCIAL TEÓRICO

Dentes tratados endodonticamente são altamente acometidos por falha biomecânica e tem sido alvo de diversos estudos (Zhi-Yue & Yu-Xing, 2003;Santos-Filho et al. 2008) que buscam compreender as diferentes propriedades mecânicas entre dentes vitais e tratados endodonticamente, e assim indicar um complexo restaurador mais próximo das propriedades mecânicas de um dente hígido. A resistência de um dente tratado endodonticamente está diretamente relacionada à quantidade e qualidade da estrutura dental remanescente sendo um fator determinante na longevidade da restauração do elemento dental (Zhi-Yue & Yu-Xing, 2003). Na realidade, o preparo do canal radicular acarreta, internamente, maior desgaste dentinário enfraquecendo ainda mais a raiz, que representa perda significativa de estrutura dental, não compensada pelo uso de pino, pois o mesmo não aumenta a resistência do conjunto dente-restauração (Trope et al., 1985).

A reabilitação protética de dentes sujeitos ao tratamento endodôntico, em situações de fragilidade, exige o uso de retentores radiculares e núcleos coronários para melhorar a retenção da coroa protética e ampliar a distribuição das tensões oclusais ao longo da estrutura dental remanescente (Santos-Filho PC, 2008).

De acordo com Clavijo et al (2009), os pinos metálicos foram usados por décadas, no entanto, esses apresentam algumas limitações. Os pinos de fibra de vidro evoluíram bastante e que perante a todos os seus benefícios como estética e módulo de elasticidade próximo ao da dentina, diminuem o risco de fraturas radiculares proporcionando assim falhas restauráveis. Os pinos de fibra são compostos pela incorporação de fibras de vidro na matriz resinosa, e são fornecidos com uma broca correspondente pelos fabricantes, para “adaptar” ao canal de acordo com o sistema de pinos, porém é muito difícil conseguir uma boa adaptação em condições clínicas em que os canais radiculares já estão enfraquecidos ou estruturalmente comprometidos por cárie, trauma, excesso de preparo ou causas iatrogênicas. Dentes com raízes alargadas e fragilizadas estão sujeitos facilmente a ocorrência de trincas, devido à grande perda de dentina intrarradicular, sobrecarregando o remanescente dentário. (Santos-Filho, 2008)

Uma vez que os pinos de fibra de vidro possuem tamanho padronizado, sua geometria muitas vezes não corresponde ao formato do canal fragilizado, resultando em uma adaptação imprecisa. Dessa forma, para que o espaço entre a dentina radicular e o pino seja selado, é necessário aumentar a espessura do cimento, podendo comprometer o prognóstico do dente restaurado. Por outro lado, resinas compostas, fibras de vidro e ionômero de vidro são materiais sugeridos para reforçar a parede de dentina radicular e melhorar a adaptação do pino, protegendo as estruturas remanescentes. A técnica de reembasamento proporciona uma redução da espessura da linha de cimentação, menor incidência de bolhas e falhas na camada de cimento influenciando na longevidade do procedimento. (Grandini, 2005)

Em um estudo laboratorial realizado com o objetivo de comparar a resistência adesiva e os tipos de fraturas que ocorrem em dentes caracterizados tratados endodonticamente restaurados com sistema de pino metálico fundido e sistemas pino de fibra de vidro. As raízes foram divididas aleatoriamente em 7 grupos e restauradas com diferentes pinos e técnicas. O grupo 1 (grupo controle), foi restaurado com núcleo metálico fundido com liga de NiCr; Grupo 2 (grupo controle): pino de fibra de vidro; Grupo 3 (alargado):núcleo metálico fundido com liga de NiCr; Grupo 4 (alargado): Pino de fibra de vidro; Grupo 5 (alargado): Pino de fibra de vidro associado a pinos acessórios de fibra de vidro; Grupo 6 (alargado): Pino anatômico de fibra de vidro (revestido com resina composta); Grupo 7 (alargado): Pino anatômico de fibra de vidro (resina composta associada com pinos de fibra de vidro acessórios). Ao final dos testes o estudo indicou que os grupos de pinos metálicos apresentaram menores valores de resistência à fratura e á prevalência de falhas catastróficas nas raízes alargadas. O estudo mostrou também que os grupos restaurados com pino de fibra de vidro associado com resina ou os grupos restaurados com pinos acessórios de fibra de vidro apresentaram resistência à fratura semelhante a dentes não fragilizados pelo alargamento do canal radicular (Silva, 2011).

Resinas compostas de preenchimento único, conhecidas como Bulk fill, têm apresentado resultados positivos quanto as configurações cavitárias, fator C (Sagsoz 2016), comparadas às resinas compostas convencionais, quando usadas em profundidades, mostraram força de união satisfatória com a estrutura remanescente (Ende 2013). A espessura do incremento tem sido testada para validar a profundidade correta para cada material tipo bulk fill, apresentando resultados estáveis para resinas do tipo fluidas comparadas as convencionais (Flury 2014), trazendo possibilidades de reabilitações, reconstruindo a perda estrutural em incrementos únicos, diminuindo a contração de polimerização e o tempo de trabalho clínico.

No estudo das estruturas dentais e materiais restauradores, os ensaios mecânicos destrutivos são importantes meios de análise do comportamento do dente em situações de aplicação de cargas pontuais e de alta intensidade (Soares et al., 2004; Soares et al., 2006). Vários estudos têm empregado estas metodologias para análise da resistência de união de dentes tratados endodonticamente (Pereira et al, 2014; Moraes et al, 2015; Dursk et al., 2016; Keul et al, 2016). O Método de Micro Push- Out permite análise dos terços cervical (base de 2,5 e ponta de 1,3), terço médio (base de 2,2 mm e ponta de 1,15) e terço apical (base de 2,0 mm e ponta de 0,97). Os diâmetros variados de pontas e bases são utilizados devido o formato cônico do pino, a fim de introduzir tensões de cisalhamento ao longo da interface de união de acordo com a conicidade (Soares et al., 2013; Pereira et al, 2014). Outro teste utilizado para avaliar a resistência de união entre pino e dentina radicular é o de pull-out, que distribui melhor as tensões, pois é capaz de medir a resistência de união entre o pino e a dentina radicular.

OBJETIVOS

2. OBJETIVOS

Objetivo Geral

Este estudo visa avaliar diferentes resinas compostas no processo de customização e cimentação de retentores de fibra de vidro, através de testes de resistência adesiva, retenção, caracterização dos materiais em associação ao retentor e revisão sistemática.

Objetivos específicos

Objetivo específico 1-

Capítulo 1 - The use of bulk-fill flow in the customization of glass fiber post

O objetivo desse estudo foi comparar a resistência adesiva e padrão de falha no terço cervical de pinos de fibra de vidro customizados com resina composta regular e resina bulk fill flow.

Objetivo específico 2

Capítulo 2 - Bond strength of glass fiber posts cemented with bulk-fill fowable composite resin

O objetivo deste estudo foi avaliar a resistência de união de pinos de fibra de vidro cimentados com resina bulk-fill flow em dentes tratados endodonticamente em comparação com pinos de fibra de vidro cimentados com cimento resinoso convencional dual.

Objetivo específico 3

Capítulo 3 – Influence of different polymeric materials for glass fiber post relining

O objetivo deste estudo foi avaliar o grau de conversão, dureza e resistência de união por meio dos ensaios de micro push-out e pull-out de diferentes resinas compostas quando associadas a pinos de fibra de vidro em raízes com diâmetro aumentado.

Objetivo específico 4

Capítulo 4 - The influence of customization of glass fiber posts on fracture strength and failure pattern: A systematic review and meta-analysis of preclinical ex-vivo studies

O objetivo deste estudo foi determinar qual técnica de customização apresenta maior resistência à fratura e um padrão de falha mais favorável quando associada a pinos de fibra de vidro para reabilitar dentes com canais alargados ou amplos.

Capítulos

3. CAPÍTULOS

3.1 Capítulo 1

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Title: The use of bulk-fill flow in the customization of glass fiber post

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Abstract

Objectives: To evaluate the influence of different composite resin in the customization of glass fiber posts on bond strength and failure mode. **Materials and Methods:** Thirty bovine roots were selected. The wall roots were reduced so that each wall had a minimum dentin thickness of 1mm. Thirty glass fiber posts (GFP) were divided into 3 groups (n=10), which received different types of customization. The first had the GFP customized by Bulk Fill flowable composite resin (BF), the second group had the GFP customized by conventional regular composite resin (CR) and the third group had no customization, all groups were cemented with Dual Resin Cements (DRC). The roots were sectioned, resulting in two 1.0-mm thick slices from cervical root regions only and push-out bond strength test was performed (EMIC – Universal testing machine). To determine failure mode, was used a stereomicroscope at 40× magnification, with a 2,5D analysis. **Statistical analysis:** Data were analyzed using 2way ANOVA (α= 0.05) and Tukey test. **Results:** BF (9.08 ± 1.9) and CR (9.17 ± 3.00) did not show a statistically significant difference (p = 0.961), regarding the bond strength test values. However, there was a statistically significant difference between DRC (5.44 ± 1.89) and the others (p <0.05). BF (66.66%) and the CR group (47.61%) presented a predominantly failure mode Type 6: mixed, between resin cement and composite. While the highest failure index of the DRC group was Type 2: adhesive between resin cement and dentin (47.61%). **Conclusion:** BF can be an alternative for customization of fiber posts, since it presented a similar behavior to the established technique with conventional composites.

Key words: Dental bonding, Glass Fiber Posts, Resins, Resin Cements, Composite resin

INTRODUCTION

The rehabilitation of endodontically treated teeth is a challenge for restorative dentistry and, therefore, several studies evaluate the presence of a high rate of biomechanical failure (1 - 4). Failures can occur due to factors such as excessive loss of tooth structure related to extensive caries, occlusal imbalance, endodontic treatment, preparation for intraradicular retainers, fractures, trauma and previous restorations (5, 6).

For a long time for the rehabilitation of endodontically treated teeth, molten metal posts were used. Among its advantages, the good adaptation to the root canal and resistance to significant fracture stand out (3, 7). However, this material has a high modulus of elasticity that increases the possibility of catastrophic fractures that often result in the need to extract the dental element (1, 3). Recently, Glass Fiber Posts (GFP) have been used in an attempt to improve the longevity of endodontically treated teeth, as they have an elasticity module similar to that of dentin, which reduces the risk of dental fractures (8) and still have better characteristics aesthetics greater practice in clinical application (9). Although the systematic review does not show a statistical difference in the risk of dental fracture between the techniques, glass fiber posts have been more indicated (10).

The use of GFP in weakened roots or with wide channels is a challenge, since the fiber post has a standardized size and, often, there is no size that allows its complete adaptation to the root canal walls, especially in the cervical third, requiring a thick layer of resin cement that increases the risk of failure (11, 12). Studies show that roots with customized GFP using composite resin have greater resistance to fracture and, when these occur, the teeth become more viable to be kept in the oral cavity (1, 3, 13). The relining provides greater interaction between the post and the root dentin and improves the performance of the resin cement, since the decrease in the thickness of the cement influences positively its adhesive strength (2).

Bulk Fill composite resins were developed to simplify the restorative process and, consequently, promise lower levels of polymerization shrinkage stress (14, 15). In addition, they have properties that allow greater light transmission (16) and can be used in a single increment of up to 5 mm, according to the manufacturer's recommendations. The volume of these composites correlates with the material's properties, such as flexural strength (17), Vickers microhardness (18) and elastic modulus (19). The higher viscosity of bulk fill flowable resins facilitate adaptation in less accessible areas (20). Bulk Fill resins are indicated for cementation, restorations in class I or II cavities, reconstitution of structural losses in single incremental layers, filling cavities with depths of approximately 5 mm and making the GFP-cementation filling core (21).

There is no consensus on customization of GFP using Bulk Fill composite resin, therefore, the objective of the present study was to evaluate the influence of different resin-based materials in the customization of GFP and to analyze the failure mode of these materials. The null hypothesis of this study was that there will be no difference between the groups.

METHODOLOGY

Root selection

Thirty bovine incisors of similar size and shape were selected, extracted from adult animals with health evaluation by the Ministry of Health and consent of the responsible veterinarian. They were stored in a buffered 0.2% aqueous solution of thymol. Then, they were cleaned with periodontal curettes (Duflex, Juiz de Fora, MG, Brazil), submitted to prophylaxis with pumice paste and water and stored in distilled water under refrigeration at 4 °C. The teeth were sectioned with diamond disc (# 7020-KG Sorensen, Cotia, SP, Brazil) under constant water jet, the crown was removed, leaving 15mm of remaining root. The selected root were randomly divided into 3 different groups (n = 10) for the micro push-out test and failure pattern analysis.

Root Preparation

To prepare the root canal, gates glidden # 2, 3 and 4 were used sequentially (Malleifer, Dentsply, Petrópolis, RJ). For irrigation, 1% sodium hypochlorite solution and saline solution were used and the final irrigation was carried out with 17% EDTA. The roots were widened with a cylindrical diamond drill (# 3215 - KG Sorensen, Cotia, SP, Brazil), so that each wall had a minimum thickness of 1 mm of dentin.

Glass Fiber Post selection

Thirty GFP (Whitepost nº 2, FGM; Joinville, SC, Brazil) were selected with a coronal third diameter of 2.0 mm, a middle third portion of with 1.8 mm and an apical third with 1.05 mm. The width of GFP was 20 mm, but only 10mm were inserted into the root.

The GFP were divided in 3 groups, which received different types of customization. The first group had the post customized with Bulk Fill Flowable composite resin (BF-Opus Bulkfill flowable, FGM, Joinville, SC, Brazil). The second group had the post customized with conventional regular composite resin (CR-Opallis, FGM, Joinville, SC, Brazil). The third group was just cemented with conventional dual resin cement (RC), without post customization as a negative group (Allcem Dual, FGM, Joinville, SC, Brazil). The group BF and CR were also cemented with conventional dual resin cement after customization (Allcem Dual, FGM, Joinville, SC, Brazil).

Surface treatment of GFP and Root Cleaning

Posts were treated with 35% hydrogen peroxide (Whiteness HP Maxx, FGM, Joinville, SC, Brazil), frictioned for 1 minute, washed with water for the same time and dried with air jets. Then, silane (Prosil, FGM Produtos Odontológicas, Joinville, SC, Brazil) was applied for 1 minute. A universal adhesive system (AMBAR Universal, FGM, Brazil) was applied after the silane time (22). The cleaning of the root canal was carried out by irrigation with distilled water and humidity control with tips of absorbent paper (Tanari, Manacapuru, AM, Brazil).

Customization of GFP

The roots were sealed with water-soluble gel, them the roots were filled with the experimental material. The GFP were inserted within the roots and them the composite material covered the post. The light cure unit (± 1200 mW/cm^2- Radii Plus, SDI, Austrália) was performed for 5 seconds only on top surface. The post customized were removed and light cured for 40 seconds on each surface (buccal, lingual, medial, distal and occlusal). The water-soluble gel was rinsed with water for 10 seconds and dried with air jet.

Root treatment

Afterwards, all the roots canal were treated with phosphoric acid 37% (Condac 37%, FGM, Brazil) for 15 seconds, cleaned with water for 30 seconds. The adhesive system (AMBAR Universal, FGM, Brazil) were rubbed on the walls and them light cured for 20 seconds. The roots were covered with impression material to avoid the light through and not influence the photoactivation.

Cementation Technique

The cement was handled according to manufacturer's instructions, inserted into the canal with a Centrix syringe with a needle tip, and also on the surface of the GFP. Five minutes were expected for the chemical cure of the cement with a constant load of 500g on the posts and light cured for 20 seconds each face of the root.

Micropush Out test

The samples were fixed to an acrylic plate (4.0 cm X 3.0 cm X 0.4 cm) with heated godiva (Godiva Exata, DFL, Jacarepaguá, RJ, Brazil) and sectioned transversely into three slices in the region cervical for each root with diamond disc (4 "x 0,12 x 0,12, Extec, Enfield, CT, USA) assembled on a precision-cutter machine (Isomet 1000, Buehler, Lake Bluff, IL, USA) cooled in water, resulting in 1.0 mm thick slices for the cervical third of the root.

For testing on the cervical third, a 2.5 mm base and a 1.3 mm tip were used. The diameters of the tips and bases were used to introduce shear stress along the bonding interface according to the conical shape. This set was assembled in a mechanical test machine (EMIC DL 2000, São José dos Pinhais, Brazil) containing a load cell of 50 KgF. The slices were positioned on the hole of the metal base and the applicator tip at the center of the post, and then were subjected to compression loading at a constant speed of 0.5 mm/min in the apex/crown direction, avoiding any mechanical obstacle due to the conical shape of the glass fiber post, until the debonding of the glass fiber post occurred.

Failure mode classification

The specimens were analyzed using the 40x magnification stereomicroscope (Mitutoyo, Tokyo, Japan), with 2.5d analysis. The failure mode were determined in a stereomicroscope magnifier (Leica) and classified into 6 different types : (1) adhesive between GFP and composite resin; (2) adhesive between resin cement and dentin; (3) adhesive between resin cement and composite; (4) cohesive failure within the post ; (5) cohesive failure within the dentin ; (6) mixed between resin cement and composite.

Statistical analysis of the data

The data were initially analyzed for detection of normal distribution and homogeneity using the Kolmogorov–Smirnov test. The values presented requirements for the use of parametric analysis, analysis of variance was performed at a 5% probability level. The Tukey test was performed to determine significant differences occurred between which groups at the level of probability ($P < 0.05$). The analyses were carried out using Sigma Plot 12 (Sys- tat Software Inc., USA).

RESULTS

Regarding the bond strength to the micro push-out, bulk fill flowable composite and nanohybrid composite did not show a statistically significant difference ($p = 0.961$). However, there was a statistically significant difference between dual resin cement group and the other two groups ($p < 0.05$) (Figure 1).

The failure mode of the bulk fill group (66.66%) and the nanohybrid composite group (47.61%) was predominantly Type 6: mixed, between resin cement and composite. While the highest failure index of the resin cement group was Type 2: adhesive between resin cement and dentin (47.61%) (Table 1).

DISCUSSION

The null hypothesis of this study was rejected, there were no significant differences between the groups of nanohybrid composite and bulk fill flowable, however, significant differences were identified when the group with no customization was compared to the groups that had a customization with both resins.

The similar results between nanohybrid composite and bulk fill flowable can be explained by the thickness cement line found in these groups. Restored roots with customized posts have greater fracture resistance (1, 13). It also improves root canal adaptation and reduces the resin cement layer (11), thus the amount of bubbles and other defects are smaller when compared to the thick cementation line. In addition, the thicker resin cement can provide bubbles that promote cracking and consequently decrease the retention of the posts (10, 11), which explains the low adhesive strength of the no customization group.

The thickness of resin cement substantially interferes in the bond strength of GFPs to root dentin, a layer of cement that is too thick or too thin significantly decrease the retention of GFPs (12). Different bonding protocols substantially influence the bond strength to root dentin (23), which justifies the best results for the groups with the lowest cementation thickness in the present study. That findings might be influenced through the use of simplified adhesive associated with dual cement that is not indicated by some studies (24).

Like shown in previous studies (11,12; 25) on the cervical third can occur some alterations and failure. On a study (25), flared root canals restored with GFP alone showed inferior adhesion at the resin–dentin interface, especially in the cervical. That's the reason that only the cervical third were analyzed.

In conventional resin composites based on bisphenol A-glycidyl methacrylate (Bis-GMA) progress has been made by adding new monomers such as urethane dimethacrylate (UDMA), ethoxylated bisphenol-A dimethacrylate, combined with higher fillers. UDMA helps to reduce the amount of contraction and stress that occurs during polymerization without degrading the mechanical properties (26). Although there have been advances in the resinous composites, the reduction of its volume related to the polymerization process can generate contraction stress, compromise mechanical and chemical stability and may decrease marginal adaptation (27).

The bulk fill composite has a high polymerization degree with curing depth of up to 8 mm (28) and low contraction stress due to its flexural properties, contraction kinetics and improved initiation systems (14, 15). The manufacturers explain that the greater depth of conversion of these composites is due to the more potent initiator system and higher translucency (16, 29), which allows collimation of the photo initiator light beam to reach the deeper layers of the resin composite. Due to its properties and lower viscosity can be indicated for cementation of glass fiber posts (30).

The treatment of the glass fiber post aims to allow chemical-mechanical bonding between the material and the surface of the post. Some studies have demonstrated that the use of hydrogen peroxide (H_2O_2) as a surface treatment of the post allows the chemical-mechanical bonding of resin composites to the post (22, 30). The use of H2O2 in high concentration on the glass fiber post showed greater exposure of the post fibers and, consequently, improved the bond strength of the resin composite to the surface of the post (31).

The difficulty of adequate adhesion to root dentin is the main cause of failure in endodontically treated teeth receiving glass fiber post restorations (GFPs) (32). GFPs are commonly cemented with dual resin cement for chemical polymerization to occur in deeper areas, where the photo initiators have reduced irradiance (33), however, polymerization in the most apical portions remains a critical factor (34). In addition, factors such as dentine morphology along the root canals may influence the bond strength (35, 36).

The no customization group had its predominantly adhesive failure pattern between resin cement and dentin. This can be explained by the greater cementation line in this group, which reduces the bond strength between GFPs and dentin (12). In addition, some studies show that the use of simplified adhesive with dual cement does not show bond strength (24), although the manufacture recommend the use and some studies shows the chemical incompatibility between the evaluated simplified adhesives and the dual-cured resin cement was not significant (37).

The groups of nanohybrid composite and bulk fill flow presented a predominantly mixed failure pattern, between resin cement and composite, which is justified due to the lower cementation line in these groups. Relining improves the adaptation (11), the frictional retention of GFPs in the root canal (38, 39) and potentiates the performance of the resin cement, since it influences the bond strength between the resin cement and composite (2, 38). The customization of GFPs reduces the tension generated by the shrinkage of the polymerization and presents greater adhesive resistance to the dentin (40). The thin cementation line reduces the defects observed in the thicker resin cement layers.

This study has some limitations that shows the lack of information and more studies. The adhesive used is not appropriated with dual cement like showed in some studies. Although the cervical third is the most unsuitable when it comes to weakened roots, it is important to carry out studies evaluating the adhesive strength of all thirds. Another limitation is the need for analysis of the entire restorative complex using fracture resistance tests, finite elements analyses and other methodologies.

Thus, bulk fill composite presents itself as an alternative in the customization of glass fiber posts, since it presented a similar behavior to the already established technique with conventional composites. The reline with bulk fill composite may facilitate the technique because it will fit better on the root, but still need further studies regarding the behavior of this material in the studied condition.

CONCLUSION

The results are preliminary and have a methodological bias, so they should not be extrapolated for clinical application. It is suggested to conclude only what the analysis allows: GFP customized with bulk-fill resins and regular composite resin have superior bond strength than conventional cementation without customization in weakened roots.

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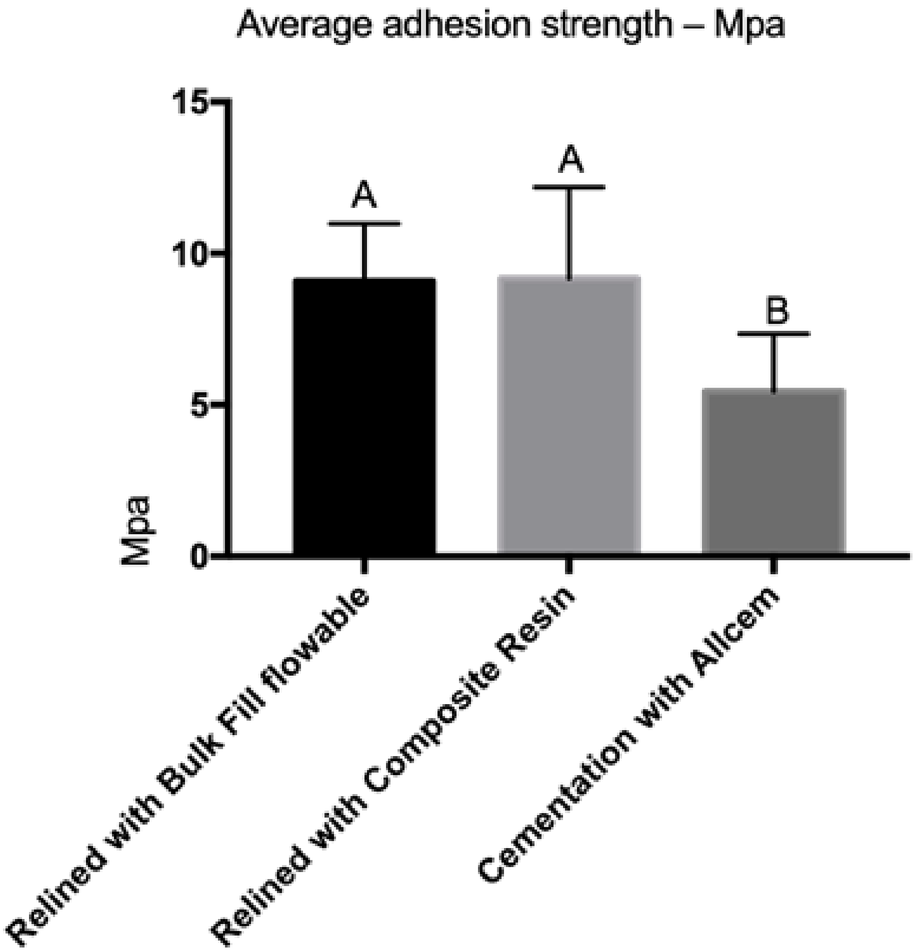
FIGURE


Average adhesion strength – Mpa
15
10
5
0
Mpa
A
A
B
Relined with Bulk Fill flowable
Relined with Composite Resin
Cementation with Allcem

TABLE

Table 1: Relining failure pattern

Relining failure pattern						
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
Bulk fill flow	0 (0%)	3 (14,28%)	3 (14,28%)	2 (9,52%)	0 (0%)	14 (66,66%)
Nanohybrid composite	0 (0%)	0 (0%)	2 (9,52%)	4 (19,04%)	0 (0%)	10 (47,61%)
Allcem	0 (0%)	10 (47,61%)	1 (4,76%)	1 (4,76%)	0 (0%)	7 (33,33%)

Push-out test failure mode distribution for each root third in the bulk-fill resin group. The failure modulus were determined in a stereomicroscope magnifier (Leica) and classified into 6 different types : (1) adhesive between GFP and composite resin; (2) adhesive between resin cement and dentin; (3) adhesive between resin cement and composite; (4) cohesive failure within the post ; (5) cohesive failure within the dentin ; (6) mixed between resin cement and composite.

Capítulos

3.2 Capítulo 2

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Bond strength of glass fiber posts cemented with bulk-fill flowable composite resin

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ABSTRACT

This study evaluated the adhesive bond strength of glass fiber posts cemented with bulk-fill flowable resin in endodontically treated teeth, and the results were compared with those of glass fiber posts cemented with resin cement. Forty bovine incisor roots were selected and randomly divided into 2 groups (n=20). The external surfaces of the roots were coated with a molding material. The canals were prepared, and then the fiber posts (Whitepost nº 2, FGM) were cemented with either resin cement (Allcem, FGM) (n=20) or bulk-fill flowable resin (Opus Bulk Fill, FGM) (n=20). Ten roots (n=10) of each material were subjected to push-out and pull-out tests (EMIC DL 2000, Brazil) under compressive and tensile loading, respectively; a 50 N load cell and a constant crosshead speed of 0.5 mm/min was used for both tests. The testing data were analyzed using multifactorial analyses of variance two-way ANOVA and the Tukey test ($\alpha=0.05$). Two skilled operators determined the failure modes of the samples using a stereomicroscope at 40× magnification with a 2.5D analysis. For push-out bond strength, there were no statistically significant differences between the root thirds in the bulk-fill flowable resin group and those in the resin cement group ($p=0.536$). However, there were statistically significant differences ($p<0.001$) among the root thirds within the same group. For pull-out bond strength, there were no statistically significant differences between the groups ($p = 0.739$). Therefore, the bulk-fill flowable resin exhibited similar results to those of the resin cement from the same manufacturer in terms of the cementation of glass fiber posts, which suggests that bulk-fill flowable resin is a suitable alternative material for cementation.

Key words: glass fiber post, bulk-fill resin, push-out, pull-out, bond strength

INTRODUCTION

Endodontically treated teeth have a high incidence of biomechanical failure, which has been the target of several studies (1-3) that seek to understand different mechanical properties of endodontically treated teeth and relate the resistance to failure with the quality of the remaining dental structure and the kind of material used to build up the cavity.

Studies have shown that glass fiber posts (GFPs) provide support, reduce root fracture risks, and enhance retention, thereby providing enhanced stress dissipation (4, 5). However, an adhesive layer is needed to improve the mechanical behavior of glass fiber posts within dentin (6, 7).

Adhesive cementation protocols have shown that deeper portions in the adhesive layer cannot be penetrated by light, which can negatively influence the bond strength to the root dentin. Nevertheless, the optical properties of glass fiber posts can improve the degree of conversion in the root up to a depth of 8 mm (8). Moreover, the literature has recommended and demonstrated the use of resin cement with an adhesive system as an option for cementation (6,7).

In 2012, Giovannetti et al. performed some cementation protocols with a flowable composite originally proposed for bulk filling posterior restorations (13). Their study showed that bulk-fill flowable composites produced better results regarding cavity configurations (C-factors) to build up class I or II cavities (9) than conventional composite resins; in deep cavities, bulk-fill flowable composites exhibited satisfactory bond strength with the remaining structure (10).

The thickness of the incremental layer was tested to validate the correct curing depths of different bulk-fill composite resins. As a flowable resin, bulk-fill composite resins exhibit stable results (11), which enables rehabilitation possibilities, rebuilds structural loss in single incremental layers, allows cavities with depths of approximately 6 mm to be filled (10, 11), and facilitates core build up and glass fiber post cementation (12).

The fillers present within bulk-fill resins are composed of small particles that allow transillumination through the material, which activates the initiator system that absorbs the light and converts monomers into polymers (12). Bulk-fill flowable resin may provide low stress behavior to glass fiber post cementation (13).

The aim of this study was to evaluate the adhesive bond strength of glass fiber posts cemented with bulk-fill flowable resin in endodontically treated teeth and then compare the results with those of glass fiber posts cemented with resin cement. In the view of this aim, the null hypotheses were that the bulk-fill flowable resin exhibits the same behavior as resin cement in push-out bond strength and pull-out bond strength.

MATERIALS AND METHODS

1- Specimen preparation

Forty roots of bovine incisors from older animals with similar size and shape were selected from extracted teeth under sanitary evaluation by the Ministry of Health and consent of the responsible veterinarian. The teeth were stored in a buffered aqueous solution of 0.2% thymol. The teeth were cleaned with periodontal curettes (Duflex, Juiz de Fora, MG, Brazil) and submitted to prophylaxis with pumice paste and water, and then the teeth were stored in distilled water and refrigerated at 4°C. The teeth were sectioned with a diamond disc (# 7020 - KG Sorensen, Cotia, SP, Brazil) under a constant water flow; the root section were 15 mm. The selected teeth were randomly divided into two different groups: one group (n = 20) for micro push-out testing and failure mode analysis and another group (n=20) for pull-out testing.

The root canal preparation procedure comprised the sequential use of #2, #3 and #4 Gates Glidden drills (Malleifer, Dentsply, Petrópolis, RJ, Brazil). The #2 Gates Glidden drill was used across the entire root canal, the #3 Gates Glidden drill was used to reach the apical third without crossing it, and the #4 Gates Glidden drill was used only in the extension where the relief was taken. An irrigation solution of 1% sodium hypochlorite and saline solution was used between each gate with final irrigation performed with 17% EDTA. The root canal was filled with gutta-percha cones (Dentsply, Petrópolis, RJ, Brazil) and calcium hydroxide-based shutter cement (Sealer 26, Dentsply, Petrópolis, RJ, Brazil) using the lateral condensation technique. After obturation of the root canal, the relief of the canal was performed with Paiva pluggers in an extension of 10 mm, leaving 5 mm of remaining obturation material. Wide #5 Gates Glidden drills were used (Dentsply, Petrópolis, RJ, Brazil) to prepare the canal for receiving the posts at the corresponding relief extension. Forty (n=40) glass fiber posts were selected (Whitepost nº 2, FGM; Joinville; SC; Brazil) with a coronary diameter of 2.0 mm, a middle diameter of 1.8 mm and an apical diameter of 1.05 mm, and these posts received surface treatment prior to cementation. The post surface was treated with 35% hydrogen peroxide (Whiteness HP Maxx; FGM, Joinville; SC; Brazil) under friction for 1 minute, washed for the same period of time and then dried with air jets (14). Then, the posts were treated with silane agent (Prosil, FGM Produtos Odontológicos, Joinville, SC, Brazil) for one minute. Root canal cleaning was performed by irrigation with distilled water and moisture control with absorbent paper tips (Tanari, Manacapuru, AM, Brazil).

The roots were covered with a molding material (Perfil, Coltene, Rio de Janeiro, RJ, Brazil) to prevent environmental light from influencing the light curing process. In the resin cement (RC) group (n = 20), a resin cement (Allcem Dual, FGM, Joinville, SC, Brazil) was used. This resin cement required previous treatments, such as 37% phosphoric acid (Condac 37%, FGM, Joinville, SC, Brazil) for 15 seconds, and an adhesive system (AMBAR Universal, FGM, Joinville, SC, Brazil), which was light-cured on the dentin for 20 seconds with an LED unit (Radii-Cal, SDI, Australia) that had a light intensity of 800 mW/cm². A pretreated glass fiber post was inserted at same time as the resin cement, the excess resin cement was removed, and then the cement was chemically cured for 5 minutes under the application of a constant 500 g load on the glass fiber posts and light-cured for 20 seconds on each surface (occlusal, buccal, lingual, medial, and distal).

In the bulk-fill group (BF) (Opus Bulk Fill, FGM, Joinville, SC, Brazil) (n = 20), 37% phosphoric acid (Condac 37%, FGM) was applied for 15 seconds followed by the application of the adhesive system (AMBAR Universal, FGM) within the dentin root, which was light-cured for 20 seconds. Then, the bulk-fill flowable resin was applied within the root at the same time as the pretreated glass fiber post, the excess resin was removed and light-cured for 20 seconds on each surface (occlusal, buccal, lingual, medial, and distal).

2- Push-out mechanical testing

Ten samples from each group (n = 10) were stored for 7 days in distilled water at 37°C prior to push-out mechanical testing. Each sample was fixed to an acrylic plate

(4.0 cm × 3.0 cm × 0.4 cm) attached with heated Godiva (Godiva Exata, DFL, Jacarepaguá, RJ, Brasil) and sectioned in six slices in the region of the cemented glass fiber post with a double-face diamond disc (4”x 0.12 x 0.12, Extec, Enfield, CT, USA), which was attached to a precision cutter machine (Isomet 1000, Buehler, Lake Bluff, IL, USA) and cooled by water. The sectioning process produced two 1 mm thick slices for each third (cervical, middle and apical thirds) of the root.

To perform the push-out mechanical tests, three different tip sizes (1.3, 1.15 and 0.97 mm) associated with three bases (2.5, 2.2 and 2.0 mm) were used. For testing on the cervical third, a 2.5 mm base and a 1.3 mm tip were used. For testing on the middle third, a 2.2 mm base and a 1.15 mm tip were used. For testing on the apical third, a 2.0 mm base and a 0.97 mm tip were used. The varied diameters of the tips and bases were used to introduce shear stress along the bonding interface according to the conical shape.

The push-out mechanical tests were performed with a universal mechanical testing machine (EMIC DL 2000, São José dos Pinhais, Brazil) containing a 50 N load cell. The slices were positioned at the center of the post coinciding with the whole of the metal base and the applicator tip, and then the slices were subjected to a compressive load with a constant crosshead speed of 0.5 mm/min in the apex/crown direction, avoiding any mechanical obstruction due to the conical shape of the fiber post, until displacement of the glass fiber post occurred. The maximum load at failure was recorded in Newtons (N) and converted to megapascals (MPa) by dividing the applied load by the bonded area (A), which was calculated with the following formula: $A = \pi(r1 + R2)\sqrt{r1} - R2)2 + h2$, where π is a constant with a value of approximately 3.14; r and R are the smallest and the largest radii of the cross-sectioned tapered post, respectively; and h is the thickness of the section.

3- Failure mode classification

Two skilled operators determined the failure modes with a stereomicroscope at 40× magnification (Mitutoyo, Tokyo, Japan) with a 2.5D analysis. The fractured specimens were analyzed with a stereoscope (Leica) to determine where the failure occurred. In this study, failures were classified into 5 different types: [(1) adhesive failure between the post and resin cement; (2) adhesive failure between the resin cement and root dentin; (3) cohesive failure within the fiber post; (4) cohesive failure within the dentin; and (5) mixed failure with the resin cement partially covering the post surface].

4- Pull-out mechanical testing

Ten samples from each group (n = 10) were prepared and stored for 7 days in distilled water at 37°C prior to pull-out mechanical testing. A 10 mm portion of each fiber post was kept outside the larger diameter, and instead of pushing the post, it was fixed in a device and pulled until the post of the root canal was pulled out. To perform the pull-out mechanical tests, a predefined base was used in the Biomaterials, Biomechanics and Molecular Biology Research Center (CPBio - UFU) to introduce uniform tensile stresses along the interface. A composite resin support was adapted at the end of the glass fiber post, which served as a socket for the device to perform the test. This configuration was assembled in a mechanical test machine (EMIC DL 2000, São José dos Pinhais, Brazil) containing a 50 N load cell and loaded at a constant crosshead speed of 0.5 mm/min. The adhesive strength (in MPa) was calculated in the push-out tests.

STATISTICAL ANALYSIS OF THE DATA

The data were initially analyzed for detection of normal distribution and homogeneity using the Kolmogorov–Smirnov test. The values that allowed the use of parametric analysis were analyzed using multifactorial analyses of variance two-way ANOVA at a significance level of 5%. The Tukey test (α=0.05) was used to determine significant differences between the groups. The analyses were carried out using Sigma Plot 12 (Systat Software Inc., USA).

RESULTS

For the micro push-out bond strength, the bulk-fill flowable and resin cement groups did not show a statistically significant difference between the material groups ($p=0.536$). However, there was a statistically significant difference ($p<0.001$) between root regions, wherein the values in the cervical third were significantly higher than those in the middle and apical regions (Table 1). The bulk-fill group failure mode was primarily Type 5 failure in the apical third, which was mixed failure with the resin cement partially covering the post surface, followed by Type 2 failure in the cervical region, which was adhesive failure between the resin cement and root dentin (Table 2). The most frequent failure mode in the resin cement group was adhesive failure between the resin cement and root dentin in the middle third, followed by similar failures in the apical and cervical thirds (Table 3). For micro pull-out bond strength, the difference in the mean values of the two groups was insufficient to reject the possibility that the difference was due to random sampling variability, and there was not a statistically significant difference between the groups ($p = 0.739$) (Table 4).

DISCUSSION

Although bulk-fill composite resin had not previously been indicated for use in the cementation of glass fiber posts, one study showed presented protocols for testing bulk-fill flowable resin for this purpose (13). With this approach, the null hypotheses were accepted because the bulk-fill flowable resin exhibited similar bond strength results as the resin cement in push-out and pull-out tests. No differences in bond strength were identified between the resin cement and bulk-fill composite resin; however, note that bulk-fill composite resin still cannot be classified as a cement, even when used for this purpose. The mechanical testing results showed similar behavior in both materials, wherein the primary differences in the root regions of both groups were found in the middle third and the apical third.

In the rehabilitation of endodontically treated teeth with GFPs, cementing agents increase the contact between the dental structure and the restorative material, and the thickness showed significant influences on the bond strength. If the layer was excessively thick or thin, retention of the GFP significantly decreased (6,7). The results shown in this research might be explained by the excellent contact between the glass fiber post and root canal walls.

A number of authors performed mechanical property tests of endodontically treated teeth and found that flowable composite resin exhibited a low elastic modulus, low stress behavior polymerization and good marginal integrity without compromising the depth of cure (13,15), which is indicated by the luting process of glass fiber posts with flowable resin. Furthermore, the light transmission could be affected by the material composition. (16).

Bulk-fill flow resins have a high degree of polymerization because their translucency allows deeper penetration of the polymerization light and because of the addition of new photoinitiators, such as benzoyl germanium derivatives, which significantly increase the reactivity of the monomers and the depth of cure (17). With these factors, the cementation of GFPs with bulk-fill flow can be performed in deep cavities once the material is manufactured to work in situations to further facilitate the light curing process.

Differences in the degree of conversion between resin-based luting agents might also have a role in their mechanical strength. A recent study showed that the dual-cured resin cement had significantly higher flexural properties than light-cured resin cement, which is explained by the higher filler loading of the catalyst paste compared to the base paste; however, the additional curing certainly contributed to the improved strength by increasing the conversion and polymer crosslinking (18). These results can also be observed in the micro push-out bond strength test, wherein a small difference with no significant relevance exists in the middle and apical thirds.

The protocol for aging or storing the samples was related to a protocol reported by Sarkis-Onofre (2014), wherein samples were stored in distilled water for 7 days at 37°C prior to testing. This storage time showed that the bond strength did not seem to be influenced by the aging protocol (20).

The results can be explained because etch-and-rinse adhesives require an accurate technique to control the dentin moisture and proper infiltration of the adhesive solution into the root canal, which is a procedure that might be considered critical and might affect post retention. The etch-and-rinse approach has also been reported to leave a nonencapsulated collagen zone beneath the hybrid layer, which could interfere with the longevity of the bonds (22).

The difference between the results of the three root regions might suggest that the light curing process influenced the bulk-fill group in the middle and apical thirds and illustrate the compensation by the chemical polymerization in the same thirds in the resin cement group. When comparing each third, it can be seen that the cervical third exhibited a better bond strength than the other thirds because of the greater light exposure. However, the middle third exhibited a slight difference in the bond strength between the groups because the irradiance could not efficiently reach the middle and apical thirds due the depth. The bond strength in the apical third of the resin cement group was twice as high as that of the bulk-fill group, which shows the importance of independent polymerization from the light curing unit (12).

In general, there was a higher incidence of adhesive failure between the resin cement and root dentin and mixed failures than other failure modes. Within the bulk-fill group, the most prevalent category was "mixed failure with resin cement partially covering the post surface" in the apical third, whereas in the cement resin group, the most frequent failure mode was "adhesive failure between the resin cement and root dentin" in the middle third. Regardless of the group, there was a higher incidence of adhesive failure between the resin cement and root dentin and mixed failures than the other failure modes, suggesting that dentin might have influenced adhesion. The 2.5D analysis allowed a detailed identification of failures and described the spot visualized on the dentin-adhesive interface (21).

This study showed some limitations, such as the protocol for adhesion and the type of bulk-fill resin tested, and suggests future studies that could be performed with different adhesives, bulk-fill flowable resins, conventional composites, cure depths, material translucency and cavity configurations.

CONCLUSIONS

Bulk-fill flow composite resin exhibited similar results to those of resin cement from the same manufacturer in terms of the cementation of glass fiber posts, which suggests that bulk-fill flowable resin is a suitable alternative material for cementation.

LIST OF ABBREVIATIONS

Note that n=number, 2.5D = 2.5-dimensional, °C = Celsius, mm = millimeter, mm/min = millimeter/minute, GFP = glass fiber post, RC = resin cement, BF= bulk fill, and N = Newtons.

DECLARATIONS

Availability of data and material

All data generated or analyzed during this study are included in this manuscript.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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Authors' contributions

VMM, CFS and LMA designed this study. LMA prepared and tested the samples. MSP analyzed and interpreted the data. MSM reviewed the manuscript. PSFSF was a mentor and corresponding author. VMM was the primary author of the manuscript. All authors read and approved the final manuscript.

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TABLES

Table 1: Mean push-out bond strength - MPa [standard deviation]

	Bulk-fill flow	Allcem
Cervical third	5.50 [3.15] Aa	5.27 [2.36] Aa
Middle third	1.86 [1.53] Ab	2.73 [2.22] Ab
Apical third	1.35 [2.18] Ab	2.87 [1.73] Ab

Bond strength of glass fiber posts cemented with bulk-fill flowable resin and resin cement determined by push-out tests. The mean values followed by the same uppercase letter in each row and the same lowercase letter in each column are not significantly different according to the results of two-way ANOVA ($p < 0.05$). The Tukey test was necessary to determine significant differences between groups.

Table 2: Push-out test failure mode distribution for each root third in the bulk-fill resin group (n=20)

	Type 1	Type 2	Type 3	Type 4	Type 5
Cervical	2 (10%)	11 (55%)	1 (5%)	0 (0%)	6 (30%)
Middle	5 (25%)	5 (25%)	2 (10%)	0 (0%)	8 (40%)
Apical	2 (10%)	2 (10%)	0 (0%)	0 (0%)	16 (80%)

Table 3: Push-out test failure mode distribution for each root third in the resin cement group (n=20)

	Type 1	Type 2	Type 3	Type 4	Type 5
Cervical	3 (15%)	10 (50%)	3 (15%)	0 (0%)	4 (20%)
Middle	1 (5%)	13 (65%)	1 (5%)	0 (0%)	5 (25%)
Apical	0 (0%)	11 (55%)	0 (0%)	0 (0%)	9 (45%)

The failure modes of glass fiber post cemented with bulk-fill flowable resin and resin cement were classified into 5 different types: (1) adhesive failure between the post and resin cement; (2) adhesive failure between the resin cement and root dentin; (3) cohesive failure within the fiber post; (4) cohesive failure within the dentin; and (5) mixed failure with the resin cement partially covering the post surface.

Table 4: Mean pull-out bond strength - MPa [standard deviation]

Bulk-fill flow	Allcem
1.305 [0.615] A	1.230 [0.335] A

Bond strength of glass fiber posts cemented with bulk-fill flowable resin and resin cement determined by pull-out tests. The means are not significantly different according to the results of the t-test ($p < 0.05$).

Capítulos

3.3 Capítulo 3

Artigo a ser enviado para publicação no periódico The journal of adhesive dentistry

Title: Influence of different polymeric materials for glass fiber post relining

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Title: Influence of different resin composite materials for glass fiber post relining

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Disclosure statement

ABSTRACT

Purpose: Evaluate the degree of conversion, hardness, and bond strengh through the micro push-out and pull-out tests of different composite resins associated with glass fiber post (GFP) in roots with weakened walls. **Materials and Methods:** Five resin composite were tested to customize GFP in weakened roots and 1 group that did not receive any customization. Two flowable bulk-fill composites: Filtek Bulk Fill Flowable - BFF; Opus Bulk Fill Flowable APS – OBF; two regular viscosity bulk-fill composites: Filtek One Bulk

Fill – BFP; Opus Bulk Fill APS - OBP, one regular resin composite: Filtek z350 - RC were tested in this study, as a material to customize the GFP. All the groups were tested on the methodologies: Degree of conversion (DC) was calculated using FTIR (n=5); Knoop hardness (KNH), using Knoop indentation on each surfaces (n=5); Adhesive strength were tested using the push out bond strength (n=10) and the pull out bond strength (n=10); The push out samples were analyzed using the ×40 magnification stereomicroscope (Mitutoyo, Tokyo, Japan), with 2.5D analysis and the failure mode were determined. **Results:** The BFF and BFP groups exhibited a higher monomer conversion than the other groups. The BFP and RC groups presented superior hardness and statistically significant results when compared to the other groups. In the cervical third, the group with relined conventional composite resin presented better bond strength than the other groups, followed by bulk-fill resins with regular consistency. **Conclusion:** This study has limitations, but it's possible to conclude that the customization is important and bulk-fill resins can be used as a customized material.

INTRODUCTION

The rehabilitation of endodontically treated teeth and their longevity are a challenge for researchers and practitioners[5]. The resistance of an endodontically treated tooth is directly related to the amount and quality of the remaining dental structure. It is a determining factor in the longevity of the restoration[30,39]. Intraradicular retainers are necessary to strongly retain the restorative material in the coronary portion[40].

Glass fiber posts (GFP) have been the best option for the rehabilitation of endodontically treated teeth, as they have an elasticity modulus similar to that of dentin, leading to a more homogeneous distribution of occlusal forces[33]. GFP are retained in the root canal through adhesion with resin cement. A satisfactory adhesion is important for the longevity of the restoration because a debonding post might stimulate tooth fracture [21].

Glass fiber posts are prefabricated retainers, with standard sizes and shapes. The dental surgeon must choose the most suitable post for each situation[8]. Size 3 is the widest option, and it is often incompatible with the diameter of canals that have destroyed roots, weakened and thin walls. Thus, it requires a greater amount of cement and, consequently, has impaired the adhesion process[4].

Customizing the main retainer may improve the adhesion and stability of the retainer whitin the roots with a diameter larger than prefabricated posts[11]. The components for customization are accessory posts[35], composite resins [34], glass fiber post[14], and glass ionomer cement[24]. Another strategy is root reinforcement, in which the root can be restored with composite resin to reduce the cementation line.

Bulk-fill composite resins were developed to simplify the restorative process[26,32]. Since they undergo less polymerization shrinkage, they can be used in increments of up to 5 mm[9]. The main advantage of this technique is its easy adaptation in hard-to-access areas[37].

Customizing GFP increases the bond strenght and fracture strenght of the restorative complex[35]. The use of conventional regular composite resins is a widespread technique of great clinical relevance[34]. With the evolution of new resin based materials such as bulk-fill resins, it is necessary to evaluate the behavior of these materials in association with GFP. Therefore, the objective of this study was to evaluate the degree of conversion, hardness, and bond strengh through the micro push-out and pull-out tests of different composite resins associated with GFP in roots with weakened walls. The null hypothesis of this study is that the customizing material will not influence on the adhesion.

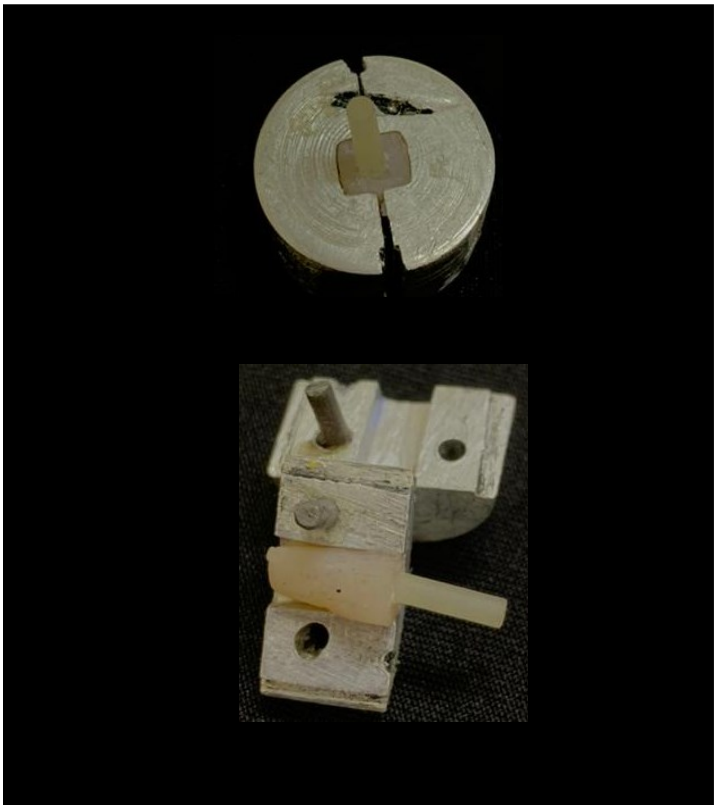
MATERIAL AND METHODS

Study design

Five resin composite were tested to customize GFP in weakened roots and 1 group that did not receive any customization (control group). Two flowable bulk-fill composites: Filtek Bulk Fill Flowable - BFF (3M-ESPE, St Paul, USA); Opus Bulk Fill Flowable APS – OBF (FGM, Joinville SC, Brazil); two regular viscosity bulk-fill composites: Filtek One Bulk Fill – BFP (3M-ESPE(, St Paul, USA); Opus Bulk Fill APS - OBP (FGM, Joinville, SC, Brazil), one regular resin composite: Filtek z350 - RC (3M-ESPE, St Paul, USA) were tested in this study, as a material to customize the GFP (GFP- Whitepost nº 3, FGM; Joinville, SC, Brazil). The GFP used had coronal third diameter of 2.0 mm, a middle third portion of with 1.8 mm, and an apical third with 1.05 mm. All the groups were tested on the methodologies: Degree of conversion (DC) was calculated using FTIR; Knoop hardness (KNH), using Knoop indentation on one surface; Adhesive strength were tested using the push out bond strength and the pull out bond strength; The push out samples were analyzed using the ×40 magnification stereomicroscope (Mitutoyo, Tokyo, Japan), with 2.5D analysis and the failure mode were determined.

Sample preparation for DC and KNH

The samples of each group (n=5) were prepared using alluminum matrix that simulates a root with an internal aperture of 5 mm diameter and depth of 10 mm (Figure 1) in a light controled room. To minimize the presence of bubbles and obtain a smooth surface, the mould was placed on a glass plate and a polyester strip was positioned between the glass plate and the mould. The mould were sealed with water-soluble gel and then filled with the composite experimental material. The GFPs were inserted within the mould and them the composite material covered the post. All materials were light cured using a continuous mode (±1,200 mW/cm^2–Radii Plus, SDI, Austrália), performed for 5 seconds only on cervical surface inside de matrix. The post customized were removed and light cured for 40 seconds on each surface.



Degree of conversion (DC)

The degree of conversion of the experimental materials were assessed after 24 hours. They were stored in a dry containers at an oven with 37 ºC and protected from the light. The DC were assessed using Fourier transform infrared (FTIR) spectroscopy (Vertex 70, Bruker Optik GmbH, Ettlingen, Germany) with attenuated total reflectance sampling, midinfrared (MIR) and deuterated triglycine sulfate detector elements (Bruker Optics). The spectra were obtained between internal standard aromatic C=C bonds stretching vibrations (1638 cm^{-1}), and aliphatic C=C bonds stretching vibrations (1608 cm^{-1}) at a 4 cm-1 resolution and 32 scans were averaged. All analyses were performed under controlled temperature (23±1ºC) and humidity (60±5%) conditions. DC was calculated from the equivalent aliphatic and aromatic ratios of cured (C) and uncured (U) materials [2,12,22,31].

$$DC(\%) = \left(1 - \frac{Cured\ (\text{area under 1638} = \text{area under 1608})}{Uncured(\ \text{area under 1638} = \text{area under 1608})}\right) x100$$

Knoop hardness (KNH)

After measuring degree of conversion, the samples from each group were used for analysis of KNH. Prior to testing, the surfaces were polished with metallographic diamond pastes (6, 3, 1 and 0.25 µm; Arotec, São Paulo, SP, Brazil). The Knoop indentation values were determined with a microhardness tester (FM700; FutureTech Corp., Kawasaki, Japan) by applying a load of 500 g for 15 s. Five indentations were made on the middle of each surface with interval of 1 mm between them to obtain an average value.

Root Selection

One hundred and twenty bovine incisors of similar size and shape were selected and extracted from adult animals with health evaluation by the Ministry of Health and consent of the responsible veterinarian. They were stored in a buffered 0.2% aqueous solution of thymol. Then, they were cleaned with periodontal curettes (Duflex, Juiz de Fora, MG, Brazil), submitted to prophylaxis with pumice paste and water, and stored in distilled water under refrigeration at 4°C. The teeth were sectioned with diamond disc (7020-KG Sorensen, Cotia, SP, Brazil) under constant water jet, the crown was removed, leaving 15 mm of remaining root. The selected root was randomly divided into six different groups (n = 20).

Root Preparation

To prepare the root canal, gates glidden 2, 3, and 4 were used sequentially (Malleifer, Dentsply, Petrópolis, RJ). For irrigation, 1% sodium hypochlorite solution and saline solution were used and the final irrigation was performed with 17% EDTA. The roots were weakened with a cylindrical diamond drill (3215–KG Sorensen; Cotia, SP, Brazil) so that each wall had about thickness of 1 mm of dentin mensured with a digital caliper.

Surface Treatment of Glass Fiber Post and Root Cleaning

Posts were treated with 35% hydrogen peroxide (Whiteness HP Maxx; FGM, Joinville, SC, Brazil), frictioned for 1 minute, washed with water for the same time, and dried with air jets. Then, silane (Prosil; FGM Produtos Odontológicas, Joinville, SC, Brazil) was applied for 1 minute. A conventional adhesive system (AMBAR; FGM, Brazil) was applied after the silane time[27]. The cleaning of the root canal was performed by irrigation with distilled water and humidity control with tips of absorbent paper (Tanari; Manacapuru, AM, Brazil).

Customization of Glass Fiber Post

The roots (n=20) were sealed with water-soluble gel and then the roots were filled with the experimental material. The GFP were inserted within the roots and them the different composite materials of each group covered the post. The light cure unit (±1,200 mW/cm2–Radii Plus, SDI, Austrália) was performed for 5 seconds only on cervical. The post customized were removed and light cured for 40 seconds on each surface (buccal, lingual, medial, distal, and occlusal). The water-soluble gel was rinsed with water for 10 seconds and dried with air jet.

Cementation Technique

The cement used were dual self-adhesive resin cement RelyX U200 (3M-ESPE, St Paul, USA). The cement was handled according to manufacturer's instructions, inserted into the canal with a Centrix syringe with a needle tip, and also on the surface of the GFP[42]. Total 5 minutes were expected for the chemical cure of the cement with a constant load of 500g on the posts and light cured for 20 seconds on each face of the root.

Micro Push-Out Test

The samples (n=10) were prepared and stored for 24 hours in distilled water at 37 °C prior to push-out mechanical testing. It were fixed to an acrylic plate (4.0 × 3.0 × 0.4 cm) with heated Godiva (Godiva Exata, DFL, Jacarepaguá, RJ, Brazil) and sectioned transversely, with diamond disc (4 × 0.12 × 0.12, Extec, Enfield, Connecticut, United States) assembled on a precision-cutter machine (Isomet 1000, Buehler, Lake Bluff, Illinois, United States) cooled in water. The sectioning process produced two 1 mm thick slices for each third (cervical, middle and apical thirds) of the root.

To perform the micro push-out mechanical tests, three different tip sizes (1.3, 1.15 and 0.97 mm) associated with three bases (2.5, 2.2 and 2.0 mm) were used. For testing on the cervical third, a 2.5 mm base and a 1.3 mm tip were used. For testing on the middle third, a 2.2 mm base and a 1.15 mm tip were used. For testing on the apical third, a 2.0 mm base and a 0.97 mm tip were used. The varied diameters of the tips and bases were used to introduce shear load stress along the bonding interface according to the conical shape.

The push-out mechanical tests were performed with a universal mechanical testing machine (EMIC DL 2000, São José dos Pinhais, Brazil) containing a 50N load cell. The slices were positioned at the center of the base where the GFP coinciding with the whole of the metal base and the applicator tip, and then the slices were subjected to a compressive load with a constant crosshead speed of 0.5 mm/min in the apex/crown direction, avoiding any mechanical obstruction due to the conical shape of the glass fiber post, until displacement of the GFP occurred. The maximum load at failure was recorded in Newtons (N) and converted to megapascals (MPa) by dividing the applied load by the bonded area (A), which was calculated with the following formula:

$$A = \pi(r1 + R2)r1 - \sqrt{-R2)2 + h2}$$

where π is a constant with a value of approximately 3.14; r and R are the smallest and the largest radii of the cross-sectioned tapered post, respectively; and h is the thickness of the section.

Failure Mode Classification

The push- out specimens were analyzed using the ×40 magnification stereomicroscope (Mitutoyo, Tokyo, Japan), with 2.5D analysis. The failure mode were determined in a stereomicroscope magnifier (Leica) and classified into seven different types[1]: adhesive between GFP and composite resin; 2 adhesive between resin cement and dentin; 3 adhesive between resin cement and composite resin; 4 cohesive failure within the post; 5 cohesive failure within the resin;6 cohesive failure within the dentin and 7 mixed between resin cement and composite.

Pull-out mechanical testing

Ten samples from each group (n = 10) were prepared and stored for 7 days in distilled water at 37 °C prior to pull-out mechanical testing. A 10 mm portion of each glass fiber post was kept outside the larger diameter, and instead of pushing the post, it was fixed in a device and pulled until the post of the root canal was pulled out. To perform the pull-out mechanical tests, a predefined base was used in the Biomaterials, Biomechanics and Molecular Biology

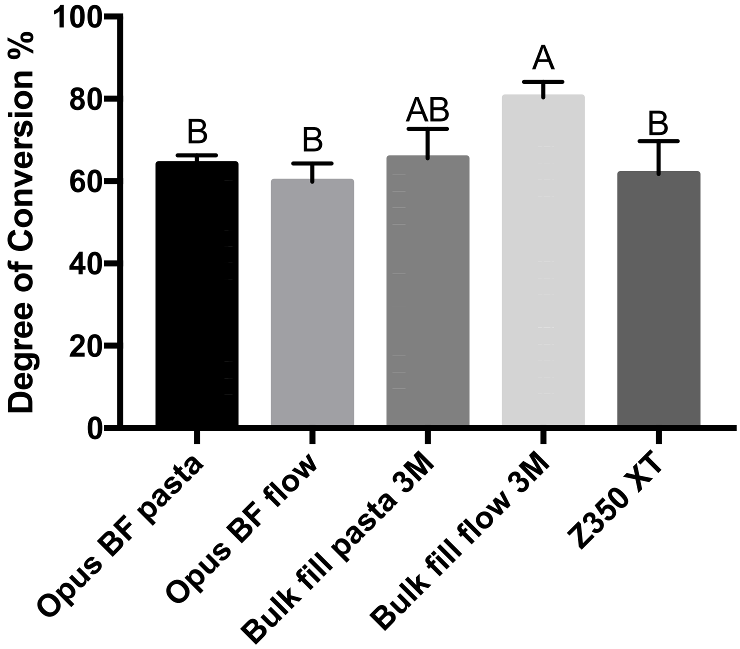
Research Center (CPBio–UFU) to introduce uniform tensile stresses along the interface. The groups was assembled in a mechanical test machine (EMIC DL 2000, São José dos Pinhais, Brazil) containing a 50 N load cell and loaded at a constant crosshead speed of 0.5 mm/min. The bond strength (in MPa) was calculated as the same in the push-out tests.

Statistical analysis

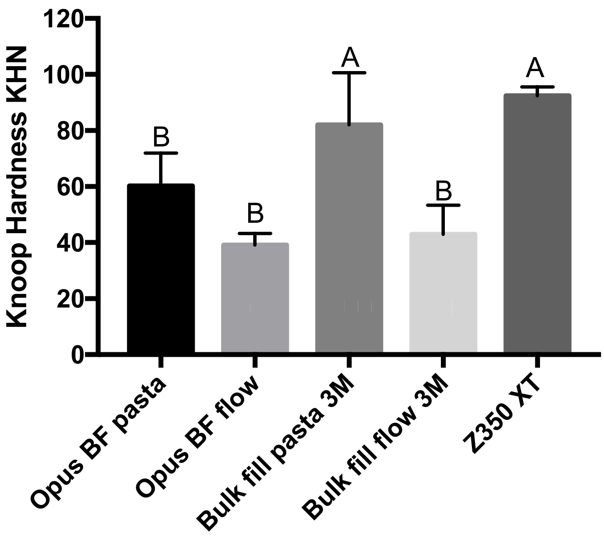
One-way ANOVA followed by Tukey's test ($P < 0.05$) with a significance level (α) of 5%. were performed to Degree of conversion, Knoop microhardness, and Pull-out bond strength. Two-way ANOVA two way of repeated measurements followed by Kruskas-Wallis test with multiple comparations were performed to Push-out bond strengh. Chi- square were applied at failure mode. For all testing, groups were combined between materials, surface and/or thickness. Statistical analysis was performed using a GraphPad Prism software.

RESULTS

One-way ANOVA showed that the degree of conversion of resins associated with GFP varied according to groups and comparisons. The BFF and BFP groups exhibited a higher monomer conversion than the other groups $p= 0.01$. The other groups showed no statistical difference $p\geq0.05$. The results are presented in Figure 2.



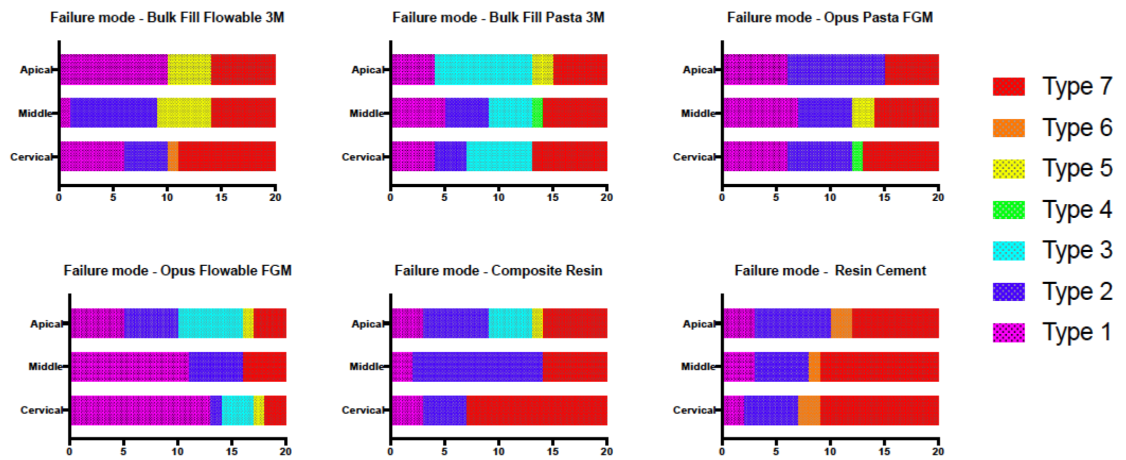
Regarding the hardness of the composites associated with GFP, the one-way ANOVA test showed that the BFP and RC groups presented superior and statistically significant results when compared to the other groups, p= 0.001. The results are presented in Figure 3.



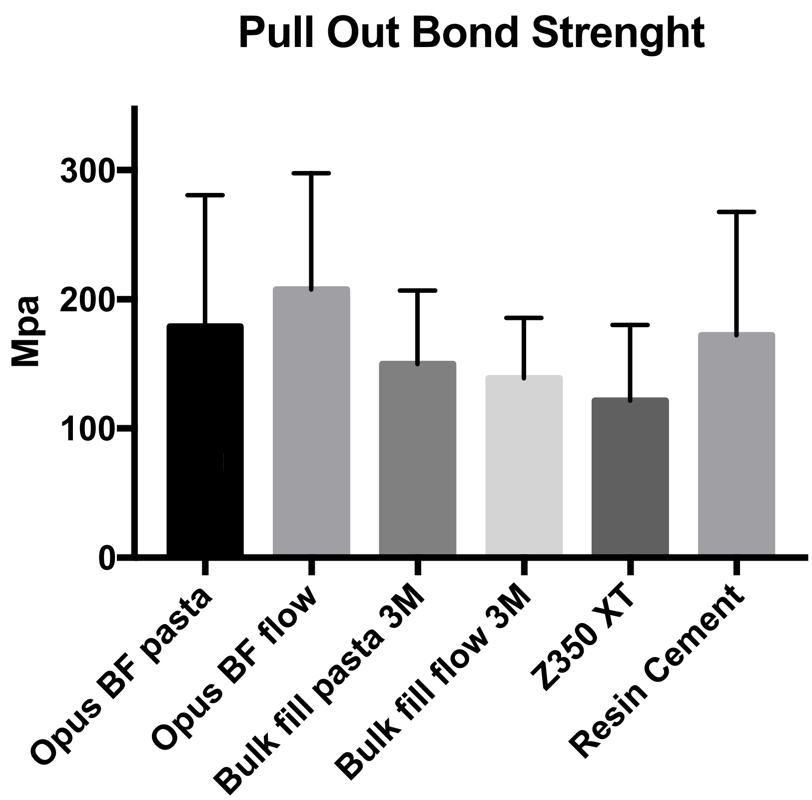
The micro push-out test showed different results according to the third, the results are presented on table 1. In the cervical third, the group with relined conventional composite resin presented better bond strength than the other groups, followed by bulk-fill resins with regular consistency p= 0.01. In the middle (p=0.0003) and apical (p=0.03) thirds, the non-relined group showed better resistance to detachment .

Thirds	BF pasta- 3M	BF flow- 3M	Opus pasta- FGM	Opus flow- FMG	CR- Filtek z350	Resin cement
Cervical	7,93(3,17)^{AB}	6,03(1,07)^{B}	8,68(2,52)^{AB}	5,41(3,44)^{B}	9,87 (1,90)^{A}	8,46(2,51)^{AB}
MeddLE	8,65(2,46)^{AB}	8,57(4,08)^{AB}	6,41(2,17)^{B}	4,90(2,40)^{B}	8,64(2,30)^{AB}	10,94(2,44)^{A}
Apical	6,26 (2,79)^{B}	7,75(2,35)^{AB}	4,55(2,08)^{AB}	5,97(4,46)^{AB}	7,59(2,18)^{AB}	10,16(2,84)^{A}

The samples submitted to the push-out test had their failure pattern assessed. The results are presented in figures 4. We noticed a tendency of cohesive and mixed failures in the cervical third and a predominance of bond failures in the middle and apical third. Only the Opus Flow group presented mostly bond failures between post s and resin in the cervical third. The resin cement group had a failure pattern in most samples, including in the cervical, middle, and predominantly mixed apical thirds.



The pull-out test, employing the one-way ANOVA test, presented no statistical difference between groups (p≥0.05), the results are present on figure 5



DISCUSSION

The null hypothesis was accepted following the results found in previous papers[34,35]: the GFP behavior associated with composite resin compared to bulk-fill resin and resin cement can be a suitable treatment with acceptable mechanical properties.

The matrix used in this study was developed in order to be able to evaluate the DC and KNH of resins associated with GFP. The specimens must be smooth and straight to be able to be measured, so the matrix was intended to simulate the internal measurements of the root canal.

The bovine teeth channels did not receive any filling material, only cleaning was performed. This was done to prevent endodontic cement, filling material and desobturation from interfering with the customization result.

GFP has pre-established and standardized sizes. A drill was developed for each post for a better adaptation of the roots[24]. Large root canals result from carious lesions, trauma to young teeth, endodontic over instrumentation, previous restorations with oversized posts, and developmental anomalies[17,18]. In some cases, not even the largest prefabricated post (number 3 DE) adapts to the root canal. That is, the internal diameter of the canal is larger than the diameter of the post, suggesting that characterization is necessary to improve the mechanical properties of the rehabilitated tooth[7]. This recommendation comes from some laboratory studies, in which researchers noticed that posts that needed a greater amount of cementation ended up moving more easily[10,12,19,23,15,34,35]. This bond failure was related to a large amount of cement placed inside the canal. Resin cement has a high polymerization shrinkage, and the use of large quantities can generate cracks and, consequently, bond failure[16]. We found similar results in our study.

The GFP treatment aims to increase the chemical-mechanical bond between the material and the surface of posts. Some studies have shown that the use of hydrogen peroxide (H2O2) as a treatment for the post surface increases the post's bond to the resin cement [27,28]. The use of H_2O_2 at high concentrations in the GFP showed greater exposure of post fibers and, consequently, improved the bond strength of the composite resin to the post surface[27]. Therefore, we incorporated this step into the preparation of the samples in our study.

Endodontically treated teeth that require posts must be cemented with double-activated resin cement, both by chemical reaction and by light[14]. Besides the double polymerization, self-adhesive cement does not require an adhesive system on the dental surface, promoting the advantage of reducing clinical steps[31]. This cement has adhesive properties similar to that of conventional cementation protocols[13]. Most previous studies have chosen conventional dual resin cement. Although studies have shown no statistical difference in the type of cement used[1,8,31], a reduced number of steps may diminish errors and improve the adhesive capacity. This may explain the positive result of non-customized posts. On the other hand, some other studies have shown that self-adhesive cement significantly improves adhesion when compared to other types of cement[11,41].

Most previous studies were carried out under conditions similar to those in this work, using bovine teeth with weakened walls and enlarged root canal. However, these studies were carried out with posts of a diameter smaller than 3, using mainly 0.5 posts[10,11,16,19,23,34,35]. We used the largest diameter post (3) in this study. Thus, even though the post had not been fully adapted to the root canal, the cementation line was smaller than the one presented in previous studies. For this reason, the customization technique did not significantly influence bond strength tests.

Another important factor to assess is the configuration of the root canal after the preparation and weakening of the roots. Since the internal configuration of the canal is conical, the cervical region shows further root weakening and post gap. For this reason, customization only made a difference in the cervical third. In the middle and apical thirds, the gap of the post was not significant, and the customization portion was very thin. Thus, failures were more likely to appear in the adhesive interfaces. This result justifies the low bond resistance results presented by the customized groups in the middle and apical thirds.

It also clarifies the results of the failure pattern. In the cervical third, the failure pattern percentage was higher in the mixed and cohesive types, showing that customization resulted in good adaptation, increasing the bond strength. In the middle and apical thirds, the predominance of bond failures reflects problems specific to the region, such as polymerization difficulties and fragile adhesive interfaces.

The pull-out test results conflicted with some studies. The pull-out test is a macro test and cannot show small differences like the push-out test. Despite the differences in results, the lack of statistical difference between the groups may be a consequence of the similar behavior of bulk-fill flow resins and resin cement, especially in hardness. In addition, it is a test that assesses frictional retention, thus, all posts were well adapted in the root canal, so there was no difference between groups.

The test that measures the degree of conversion represents the number of monomers converted into polymers during the polymerization reaction of composite resins. A composite that presents an unsatisfactory polymerization generates soluble residues that can affect the bond quality[25] (Marigo, 2015). In this study, the 3M ESPE bulk-fill resins had a higher degree of conversion. This can be explained by their own features, which, added to translucent posts, facilitate the passage of light from the photoactivator and composition.

Hardness is linked to the composite's ability to resist chewing forces[36]. The results of this confirm that bulk-fill composites with regular consistency, even when in contact with glass fiber posts, have a greater hardness than composites with a fluid consistency. Posts customized with fluid resins performed poorly in the push-out test, which can be explained by the hardness and more load particles present in regular resins.

The use of flow resins was not significantly inferior to the other resins, however, a technical difficulty was encountered during sample preparation. For its use as a customization material, a smoothness of the root wall is necessary to avoid retaining the post wrapped with resin.

This study has many limitations, but it’s possible to conclude that the customization is very important and bulk-fill resins can be used as a customized material as the conventional resin.

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Capítulos

3.4 Capítulo 4

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The influence of customization of glass fiber posts on fracture strength and failure pattern: A systematic review and meta-analysis of preclinical *ex-vivo* studies

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ABSTRACT

Objective: To perform a systematic review of the literature to assess the efficacy of different techniques of glass fiber post adaptations on the fracture strength of wide or enlarged canals and the failure pattern. **Methods:** Six databases were used as primary search sources (PubMed, Scopus, LILACS, SciELO, Science Direct, and Web of Science) and three databases (Open Grey, Open Thesis, and OATD) were used to partially capture the "grey literature". The research included laboratory studies that used human upper anterior teeth aiming to assess the fracture strength and failure pattern of different glass fiber post customizations. The search had no restriction of year, language, and publication status. The risk of bias of the studies was assessed from the criteria established in systematic reviews of laboratory studies. Standardized mean differences were calculated by comparing the mean fracture strengths of customized and non-customized posts. Pooled estimates were calculated by Glass' delta method using the random-effects model. Subtotal estimates were presented according to each type of relining procedure and an overall estimate was described considering all studies combined. **Results:** The search provided 2291 results, from which six met the eligibility criteria and were included in the qualitative assessment of the review. Only three studies presented a moderate risk of bias. The meta-analysis results showed that the use of auxiliary posts produced higher mean fracture strengths than non-customized posts (SMD = 2.21; 95%CI: 0.74; 3.68), and it was more effective than the use of composite resin to reline the posts. **Conclusion:** Based on laboratories studies customized posts presented higher mean fracture strengths and a more favorable failure pattern than non-customized posts. Future studies should follow a standardized approach to implementation and reporting of data

KEYWORDS: Flared root; Glass fiber post; Non-vital tooth.

INTRODUCTION

The endodontic therapy used in contemporary dentistry requires a satisfactory restorative solution after treating the root canal (1). From the mechanical standpoint, endodontically treated teeth present a decrease in moisture content and loss of crown and root structures (2), with a reduction of up to 19.82% in fracture strength (3-6). Wide root canals are caused by carious lesions (7), trauma in young teeth (7), endodontic over-instrumentation (7), previous restorations with posts of excessive diameter (8), and development anomalies (8). These rehabilitations often require additional retention through intraradicular retainers (8). Knowing that the diameter of prefabricated glass fiber posts are standardized and their geometry does not often correspond to the shape of the weakened canal, treating these dental elements becomes a challenge (9-11).

To resolve this clinical situation, it is suggested customizing glass fiber posts to increase the retention of the post in the canal and customize the path of the retainer during insertion, also requiring a thin cement layer (12,13). Thus, the mechanical overlap between the post and the dentinal walls increases, improving the bond strength of the cement in the canal and post stability (12,14-16). Moreover, it reduces the concentration of polymerization stress on the cement layer (14), consequently increasing bond strength (17). Composite resins (18,19), glass fiber strips (20), resin-modified glass ionomer cement (21), and auxiliary posts (22) are materials suggested to reinforce the radicular dentin wall and improve post adaptation, promoting higher bond strength, as shown in push-out tests, as well as a more repairable failure pattern (23).

Systematic reviews on radicular retainers have been published, analyzing the difference in the performance of glass fiber posts in anterior and posterior teeth (24), the effect of surface treatment of indirect retainers on the adhesion between dentin and glass fiber posts (25,26), and the influence of the material of intraradicular retainers on the maintenance of rehabilitated teeth (27). However, it is necessary to study the best way to rehabilitate teeth with enlarged and weakened roots. Therefore, this systematic review of the literature aims to determine what relining technique presents higher fracture strength and a more repairable failure pattern when associated with glass fiber posts to rehabilitate teeth with wide or enlarged canals. This review hypothesizes that a difference will exist for the techniques that performed the adaptation of retainers on fracture strength and more repairable failure patterns compared to the technique without anatomization.

METHODOLOGY

This systematic review was performed according to the list of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) recommendations (28). The systematic review protocol was registered in the OSF (Center for Open Science) database under link https://osf.io/2jks8/ .

Study design and eligibility criteria

The systematic review was designed to answer the following guiding question, created according to the PICO strategy: Do glass fiber posts relined with either composite resin or the presence of auxiliary posts (intervention) increase fracture strength (outcome 1) and present a more favorable failure pattern (outcome 2) than enlarged roots (population) when compared to posts cemented without customization (control)?

The research included laboratory studies using healthy human teeth aiming to assess the mechanical behavior of the relining materials of glass fiber posts. The search had no restriction of publication year and language.

The following were excluded: 1) Studies that only included relining materials other than composite resin and auxiliary posts; 2) Studies that did not compare with a control group; 3) Studies that did not assess fracture strength.

Sources of information and search

The bibliographic research was performed in January 2019 and updated in February 2020. The Science Direct, LILACS, PubMed (including MEDLINE), SciELO, Scopus, and Web of Science databases were used as primary search sources. The Open Grey, Open Thesis, and OATD databases were used to partially capture the "grey literature". A manual search was also performed through a systematized analysis of the references of the eligible articles. All steps were performed to minimize selection and publication biases. The MeSH (Medical Subject Headings) and DeCS (Health Sciences Descriptors) resources were used to select the search descriptors according to the specificities of each database (Table 1).

Study selection

The results obtained were exported to the EndNote Web™ software (Thomson Reuters™, Toronto, Canada), in which duplicates were removed electronically. The remaining results were exported to Microsoft Word™ 2010 (Microsoft™ Ltd, Washington, USA), in which the remaining duplicates were removed manually. Before the selection process, as a calibration exercise, three reviewers discussed the eligibility criteria and applied them to a sample of 20% of the studies retrieved to determine the inter-examiner agreement. After achieving a proper level of agreement (Kappa ≥ 0.81), two eligibility reviewers (CFS and LCC) methodically analyzed the titles of the studies, independently. The titles that did not relate to the topic of the study were eliminated in this first moment. In a second moment, the same reviewers analyzed the abstracts. Studies that did not answer the research question and did not meet the eligibility criteria were eliminated. The results in which the titles met the objectives of the study but did not have abstracts available were fully analyzed.

In a third moment, the preliminary eligible studies had their full texts obtained and evaluated to verify whether they fulfilled the eligibility criteria. For all these moments, when the reviewers (CFS and LCC) disagreed, a third one (LRP) was consulted to make a final decision. The studies rejected were registered separately, explaining the reasons for exclusion.

Data collection

Before extracting the data, aiming to ensure the consistency between the reviewers (CFS and LCC), a calibration exercise was performed, in which the information of an eligible study was extracted and discussed with a third reviewer (MNO). Thus, the studies were analyzed following the extraction of information concerning manuscript authorship, year of publication, country of origin of the study, sample number, materials and brands used for relining, comparison group, cementation agent used, mechanical tests used, ethical criteria used, endodontic filling cement, canal cleanliness, relationship of canal preparation, crown rehabilitation, ferrule, mean and standard deviation of fracture strength values, and failure pattern mode.

Risk of individual bias of the studies

The assessment of the risk of bias and methodological quality of the studies selected was adapted from Sarkis-Onofre et al., 2014 (29). Two authors (CFS and LCC) assessed each domain independently and systematically regarding their potential risk of bias, as recommended by the PRISMA (28). The reviewers solved any disagreement through discussions and when both reviewers disagreed, they consulted a third one (author MNO) for a final decision.

The following criteria were used for the assessment: Q1- Were the teeth extracted randomized when divided into the groups? Q2- Were the teeth extracted free of caries or restorations? Q3- Were the materials investigated used according to the manufacturers' instructions? Q4- Did the teeth used present similar dimensions? Q5- Was the endodontic treatment of the samples performed by one single operator? Q6- Was a sample calculation performed? Q7- Was the operator of the mechanical test blind to the type of sample tested? (Sarkis-Onofre et al., 2014)

The risk of bias was considered High when the study obtained up to 49% of "yes" answers, Moderate when the study obtained 50% to 69% of "yes" answers, and Low when the study reached more than 70% of "yes" answers.

Summary measures and syntheses of results

Standardized mean differences (SMDs) were calculated by comparing mean fracture strengths between relined (intervention) and non-relined posts (control). The SMD is an effect size estimate calculated by the difference between the means from both groups and divided by the pooled standard deviation (30). Pooled SMDs were estimated using Glass' delta method due to the heterogeneity between variances from intervention and control groups (31). Between-study heterogeneity was assessed using I^2 statistics and a random-effects model was used. Overall estimates were presented for each type of relining.

The pooled percentage of repairable and irreparable failures comparing intervention and control groups for each type of relining were also estimated. Proportion meta-analyses were adjusted to calculate pooled estimates using random-effects models. To prevent 0 or 100% estimates from dropping from the analyses, a Freeman-Tukey Double Arcsine Transformation was used to stabilize variances. All analyses were performed using the Stata software, version 16.1 (StataCorp, College Station, TX, USA).

RESULTS

Study selection

During the first phase of study selection, 2291 results were found distributed in eight electronic databases, including the grey literature. After removing the repeated/duplicate results, 1574 studies remained for the analysis of titles and abstracts. After a detailed analysis, only 50 studies were eligible for the full-text analysis. In the search update, one more potentially eligible study was retrieved. The references of the 51 potentially eligible studies were assessed carefully and no additional result was selected, totaling 51 studies for the full-text reading. After reading the full texts, 45 studies were excluded and the reason for each one is described in Appendix 1. Figure 1 reproduces the process of search, identification, inclusion, and exclusion of articles.

Characteristics of eligible studies

The studies were performed in China (32), Egypt (33), and Brazil (34-37). Four studies (32,35-37) described having respected the ethical criteria, also using a consent form for the participants of the studies. The analysis of the six studies resulted in a total sample of 170 human teeth. As for specimen preparation, one study (34) compared auxiliary posts and fiber posts customized with composite resin with teeth without relining, one study compared the influence of the number of auxiliary posts (32), and four studies (33,35-37) compared only posts relined with composite resin. The main cement used was the dual-cured conventional resin cement because it was used in four studies (32,34,36,37). Freitas 2007 (35) used the self-adhesive ionomer resin cement, and Borzangy et al., 2019 (33) used the self-adhesive resin cement.

Six studies (32-37) evaluated compressive fracture strength. Three studies (33,35,37) applied mechanical fatigue before the other tests. Five studies (33-37) analyzed the failure mode.

The thickness of 1 mm of remaining dentin was used in all studies (32-37), but Barcellos et al., 2013 (36) added an intervention and control group with a thickness of 2 mm. Tables 2 and 3 show more details on the characteristics of the eligible studies.

Risk of individual bias of the studies

Table 4 shows the information on the risk of bias and individual quality of the studies included in this systematic review. Three studies presented a moderate risk of bias, while three presented a high risk of bias. Question 1, referring to sample randomization, received a negative answer in most studies and the positive answers were only applied when the randomization method was mentioned. Question 5 only received a positive answer from Barcellos et al., 2013 (36) because only these authors mentioned this phase of producing the sample, which becomes essential for standardizing the specimens. Questions 6 and 7 received negative answers in all the studies included. The sample calculation is often not performed, so the information from previous studies is considered. It is important to blind the operator of the mechanical tests to prevent manipulated results, but the performance of this phase was not mentioned by any author.

Specific results of the eligible studies

The study by Barcellos and colleagues (36) not only assessed the influence of relining but also the influence of the amount of dentin. The group of teeth relined with 2 mm of dentin presented a higher fracture strength than the group of teeth relined with 1 mm. Bonfante et al., 2007 (34) compared auxiliary posts and posts relined with composite resin and the group of auxiliary posts presented the highest fracture strength. Ferro et al., 2016 (37) compared direct and indirect relining with composite resin along with a group of non-weakened roots. Their study showed no statistically significant difference between the groups when analyzing fracture strength. However, the rate of survival of the samples after fatigue was 100% for the group of non-weakened roots, 80% for the restorations with glass fiber posts relined with composite resin in weakened roots, and 70% for the group without customization in weakened roots. Five studies (33-37) assessed the failure pattern of the samples. In all studies, most irreparable failures were associated with the groups that did not receive any relining method.

Synthesis of results and meta-analysis

All six studies selected (31-37) were included in the meta-analysis. Some studies were included more than once, as different types of intervention and control groups were tested. The six studies resulted in 13 data points for analysis.

Figure 2 presents the meta-analysis. Studies using auxiliary posts had mean fracture strengths of 2.80 standard deviations (95%CI: 0.41; 5.18), which was higher than non-relined posts, while the mean fracture strength of fiber posts reinforced with composite resin was statistically similar to non-relined post estimates (SMD = 0.94; 95%CI: -1.21; 3.08). Out of the eight comparisons that analyzed fiber posts reinforced with composite resin, six described higher fracture strengths for the intervention group, one described no difference, and one described lower mean fracture strengths for fiber posts reinforced with composite resin compared to non-relined posts. Freitas et al. (2007), who cemented posts using resin-modified glass ionomer, found that fiber posts reinforced with composite resin had mean strength differences of 6.06 standard deviations (95%CI: -8.12; -4.00), which is lower than non-relined posts. Considering this result was different from others, a sensitivity analysis was performed excluding only this study to verify the potential impact on the estimates. Hence, the SMD subtotal for fiber posts reinforced with composite resin was 1.61 standard deviations (95%CI: 0.51; 2.71), showing the highest value for the intervention group, and the between-study heterogeneity reduced to 81.7%.

The pooled percentage of repairable and irreparable failures were also calculated (Table 7). Overall, the percentage of repairable failures for auxiliary posts was higher than the glass fiber post reinforced with composite resin, for both treatment and control groups. In turn, there were no differences between treatment and control groups when applying either auxiliary or reinforced glass fiber posts.

DISCUSSION

Glass fiber posts have standardized diameters and, to facilitate their adaptation, a drill goes along with the post so the root is prepared to adapt properly to the post (9). However, in some clinical situations that result in increased canal diameter, not even the prefabricated post (number 3 DE) adapts to the root canal, that is, the internal diameter of the canal is larger than the post diameter, suggesting that characterization should be performed to improve the mechanical properties of the tooth rehabilitated (38). In the present systematic review, the hypothesis was confirmed, observing the statistically significant difference between the fracture strength of customized glass fiber posts and the group of non-customized posts. Moreover, there was a difference between the failure pattern of customized glass fiber posts and the group of non-customized posts.

The lack of adaptation of glass fiber posts in the root canal eliminates the mechanical overlap effect, which is important to retain the restorations (38,39). The maladjustment results in a thick layer of resin cement, producing bubbles, and consequently adhesive failures that promote the detachment of retainers (40). Therefore, this adhesive failure causes the retainer to be loose within the root canal and work as a wedge, leading the root to fracture (41). These factors justify the negative result of the control group in this systematic review. In five out of the six eligible studies (33-37), the fracture strength value of the non-customized group was significantly lower than the groups subjected to some type of post customization procedure.

An adequate bond is important for the longevity of glass fiber posts. Some factors besides the thickness of the resin cement affect the quality of adhesion, starting from the filling of the root canal, without using eugenol-based cement that interferes with adhesion (42), and the cleanliness of the canal before starting the cementation process with EDTA, which is important to eliminate inorganic particles that may harm adhesion (43). The surface treatment of glass fiber posts before cementation also improved the adhesion properties of a material, facilitating chemical and micromechanical retentions between the different constituents (44). According to the protocol established by Menezes et al. (45), the application of 35% hydrogen peroxide may improve the bond strength of the composite on the post surface.

In the analysis of mechanical properties of the dental structures and restorative materials, the fracture strength test has been used to determine the intensity of the compression load supported by the weakened root before fracture, simulating the closing movement performed by mandibular muscles (46). The eligible studies (32-37) used this methodology to verify the influence of the relining technique on the fracture strength of dental elements. Five studies applied a compressive load with angulation of 135° along the axis of the sample to test the failure, and only one study used angulation of 45°. Another relevant factor is the intensity of the load applied. It is known that the bite force decreases from the posterior to the anterior region (47). The maximum bite force in the region of incisors is between 93 N (48) and 200 N (47) and between 120 N (49) and 469 N in the region of canines (50). Moreover, in the presence of parafunctional habits such as bruxism, the force intensity is statistically higher than in the absence of parafunction (51).

In the present review, both studies that compared the use of auxiliary posts with the control group showed higher maximum strength than the maximum bite force (32,34). However, when analyzing the control group and the group of posts customized with composite resin, these data were divergent. Two studies (33,34) observed a higher maximum force than the maximum bite force, one study (36) showed superior data for the intervention group, and two studies (35,37) presented lower maximum strength than the maximum bite force for both groups.

After destructive mechanical tests, it is important to analyze where and how the failure occurred, verifying whether the tooth could be rehabilitated again or not when faced with the force applied. The majority of irreparable failures were verified in posts cemented without customization (33,36,37). This may have occurred because of a higher predisposition of this group to an adhesive failure before the fracture. A loose post may produce wedge movements within the root canal, causing irreparable failures (52).

The customization techniques for glass fiber posts studied were the use of auxiliary posts and relining with composite resin. These techniques were selected for being standardized procedures and the most used to reduce the thickness of resin cement. According to the meta-analysis, regardless of the technique, it is important to perform some type of customization procedure. This result was also found in other studies (22,33,53) because post customization improves its adaptation and retention in the canal.

Biological structures, as well as non-biological structures, are susceptible to failures caused by the stress concentration and consequent strain (54). The dental and restoration failure occurs mainly in presence of cycle loading, because the stress fluctuation decreases the critical failure as consequence of changes on mechanical properties of the materials, micro-crack formation and dormant cracks growth (55, 56)

It is worth noting that the samples subjected to mechanical cycling before the tests presented lower values when compared to the studies that did not apply fatigue (35,37). The mechanical cycling applied in these studies simulated aging and the masticatory action of 12 months. This parameter is relevant because it shows the resistance to fatigue of the material, simulating clinical conditions and comparing the unique application of a test. It is known that a healthy tooth subjected to mechanical cycling also presents a reduction in mechanical properties, as the enamel decreases tensile strength and dentin decreases compression strength (57).

The thickness of the dentinal cervical portion is important to increase the adhesiveness of the post to the root canal, as well as its fracture strength. As a result of excess root canal preparation, dental trauma, and need for retainers in young patients with a wide pulp, there is a reduction of fracture strength for representing clinical conditions with a reduced dentinal thickness (58-60). Hence, the failure pattern of these cases becomes less favorable, as seen in the study by Barcelos et al., 2013 (36), in which the group with 2 mm of thickness remaining presented higher fracture strength and a more predictable failure pattern than the other group in that study and the others included in the review.

Thus, it is prudent that crown and root preparations are as conservative as possible to increase the prognosis of endodontically treated teeth and the longevity of the associated restoration. According to the study performed by Fontana et al., 2019 (61), the ferrule does not interfere with the fracture strength of teeth restored with glass fiber posts, but it allows failures to be more repairable and present less catastrophic fractures.

In the present study, the groups of teeth previously anatomized with auxiliary posts presented higher strength than the groups customized with composite resin (32,34**)**. It is worth noting that only two studies included assessed this type of customization. This may have occurred due to a higher difficulty in performing the technique, as well as the higher cost. Moreover, caution is required when analyzing the data. Teeth that are endodontically treated and restored with different techniques should be assessed by fracture strength and bond strength. Studies show lower bond strength values in the rehabilitation of main posts associated with auxiliaries (62). These results may be related to the presence of bubbles within the cement layer. The retention of bubbles occurs more often between the posts, resulting in the non-uniformity of the cement layer and the unstable distribution of stresses in the walls, compromising post adhesion (63,64).

The studies (33-37) that tested the fracture strength of posts relined with composite resin presented conflicting values. Two studies (35-37) showed that not customizing with composite resin presented better results than groups that received anatomization. This may be explained by a lack of adhesion between the composite resin and the post, producing a movement within the root canal that may lead to failure. In one study (37), the fracture strength of posts relined with composite resin was 12% lower than the non-relined post, while another study (35) obtained a difference of 22% between the same groups, contradicting the research performed by Bonfante et al. 2007 (34), Barcellos er al. 2013 (36), and Borzangy et al. 2019 (33). In all these studies, the groups relined with composite resin presented higher values. This problem may be solved with a more effective surface treatment.

The relining procedure with auxiliary posts or composite resin increases significantly the cost of material and the clinical time to perform the additional anatomization steps of the main fiber post. This causes many professionals to neglect the need to characterize prefabricated posts for believing that resin cement alone is sufficient to support the compressive loads of mastication. The study performed by Dal Piva et al., 2017 (14) showed that resin cement does not have sufficient load particles to be used with great thicknesses. Thus, it is recommended to use a method of customization of glass fiber posts in cases of root enlargement.

The association of mechanical analyses and clinical behavior of intraradicular retainers becomes essential for decision-making when establishing protocols. Clinically, the failure pattern is vital to determine whether the tooth can be rehabilitated again and continue performing its function (65). Another important aspect is the analysis of the survival rate of different materials used to rehabilitate endodontically treated teeth. According to the study by Cloet et al. 2017 (66), the likelihood of success was 81.6% for non-customized glass fiber posts and 87.8% for customized posts, while the likelihood of survival was 91.4% for non-customized glass fiber posts and 92.1% for customized posts.

This study is not free of limitations and the main one is including experimental preclinical eligible studies. Therefore, further studies are required with a long-term follow-up to assess the influence of relining on the longevity of the cementation of glass fiber posts in enlarged roots.

CONCLUSION

This systematic review with meta-analysis indicates that, customized glass fiber posts presented higher fracture strength and a more favorable failure pattern. The evidence derives from laboratory studies but reinforces the importance of customizing glass fiber post in wide channels in order to avoid adhesive failures and provide greater durability to the treatment. Future studies should follow a standardized approach to implementation and reporting of data.

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FIGURES

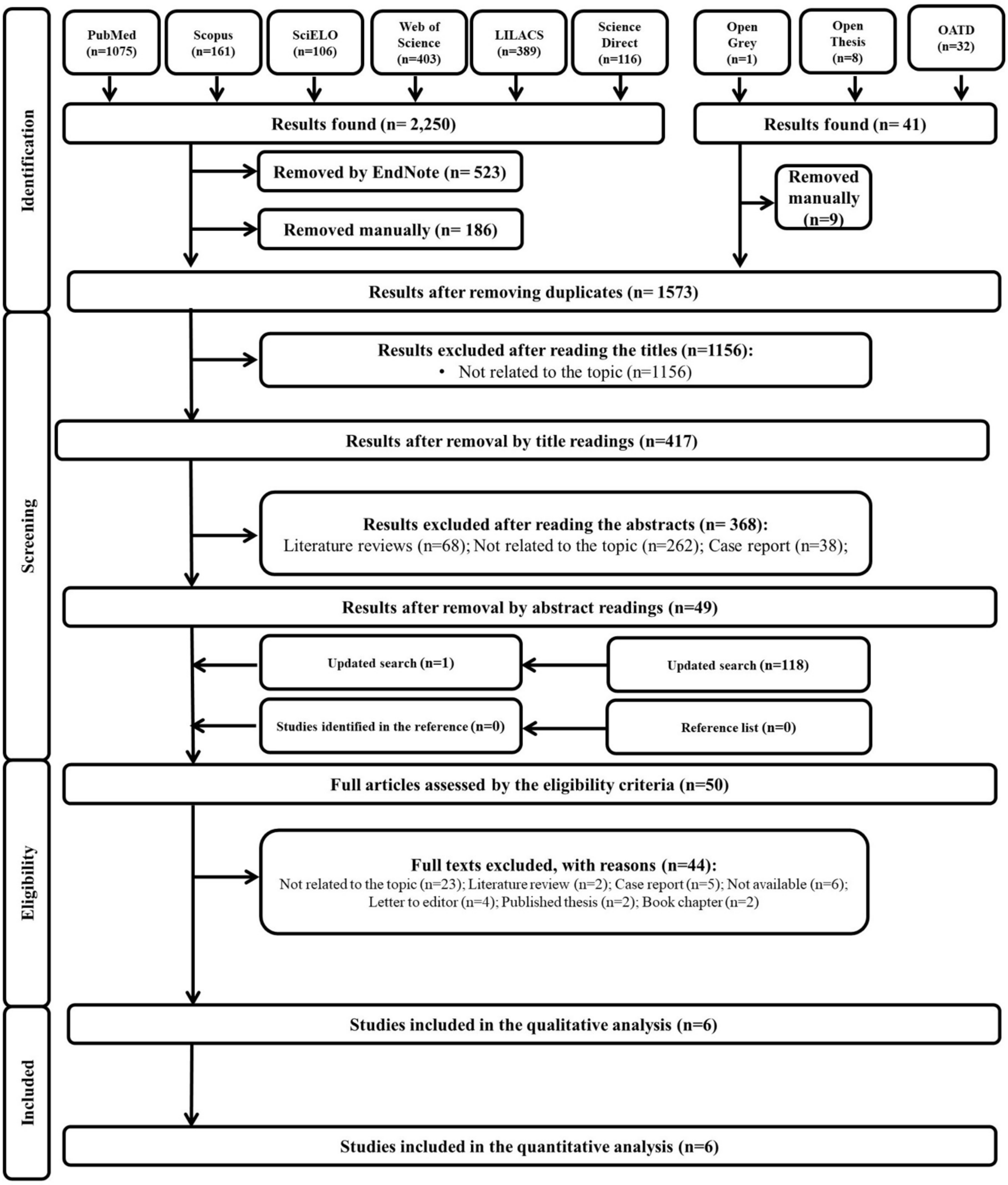

Figure 1- Flowchart of search, identification, inclusion, and exclusion processes of the studies, adapted from Preferred Reporting Items for Systematic Reviews and Meta-Analyses

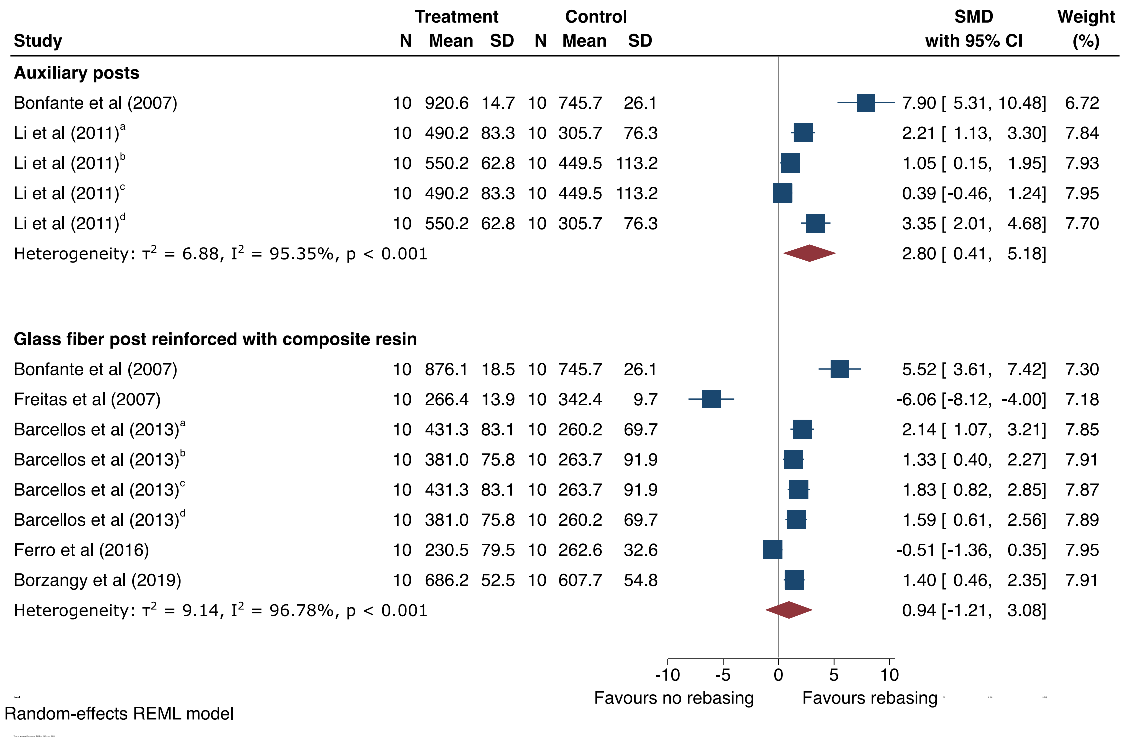

Figure 2- Standardized mean differences (SMDs) between intervention and control groups according to type of rebasing. Li et al $(2011)_a$ = GFPRAP x GFPSD (DT); Li et al $(2011)_b$ = GFPRAP x GFPSD (ML); Li et al $(2011)_c$ = GFPRAP x GFPSD (ML); Li et al $(2011)_d$ = GFPRAP x GFPSD (DT); Barcellos et al $(2013)_a$ = 2mm dentin + GFPRCR x 2mm dentin + GFPSD; Barcellos et al $(2013)_b$ = GFPRCR x GFPSD; Barcellos et al $(2013)_c$ = 2mm dentin + GFPRCR x GFPSD; Barcellos et al $(2013)_d$ = GFPRCR x 2mm dentin + GFPSD

Table 1. Strategies for database search.

Database	Search Strategy (Janeiro, 2019)
PubMed http://www.ncbi.nlm.nih.gov/pubmed	("Nonvital Tooth"OR "Devitalized Tooth" OR "Pulpless Tooth" OR "Pulpless Teeth" OR "Devitalized Teeth" OR "Nonvital Teeth" OR "Endodontically-Treated Teeth" OR "Endodontically-Treated Tooth" OR "Tooth Endodontically Treated" OR "Flared Root") AND ("Post and Core Technique" OR "Post-Core Technic" OR "Post and Core Technic" OR "Post Technique" OR "Post Technic" OR "Dental Dowel" OR "Fiber Post" OR "Fiber Reinforced Post" OR "Glass Fiber Post" OR "Anatomic Post" OR (Anatomized AND Post) OR (Relined AND Post))
Scopus http://www.scopus.com/	((“Tooth” OR “Teeth”) AND (“Devitalized” OR “Pulpless” OR “Flared Root”)) AND ("Post and Core Technique" OR "Post-Core Technic" OR "Post and Core Technic" OR "Post Technique" OR "Post Technic" OR "Dental Dowel" OR "Fiber Post")
	((“Tooth” OR “Teeth”) AND (“Devitalized” OR “Pulpless” OR “Flared Root”)) AND ("Fiber Reinforced Post" OR "Glass Fiber Post" OR "Anatomic Post" OR "Anatomized Post" OR "Relined Post")
LILACS http://lilacs.bvsalud.org/	(“Devitalized” OR “Pulpless”) AND ("Post-Core" OR "Post and Core”)
	tw:((“Devitalized” OR “Pulpless”) AND ("Post Technic" OR "Post Technique")) AND (instance:"regional") AND (db:("LILACS"))
	tw:((“Devitalized” OR “Pulpless”) AND ("Post Technic" OR "Dental Dowel" OR "Fiber Post")) AND (instance:"regional") AND (db:("LILACS"))
	tw:((“Devitalized” OR “Pulpless”) AND ("Fiber Reinforced Post" OR "Glass Fiber Post")) AND (instance:"regional") AND (db:("LILACS"))
	tw:((“Devitalized” OR “Pulpless”) AND ("Anatomic Post" OR "Anatomized Post" OR "Relined Post")) AND (instance:"regional") AND (db:("LILACS"))
	tw:((“nonvital tooth”) AND ("Post Technic" OR "Dental Dowel" OR "Fiber Post" OR "Post Technic" OR "Dental Dowel")) AND (instance:"regional") AND (db:("LILACS"))
	tw:((“Endodontically-Treated”) AND ("Post Technic" OR "Dental Dowel" OR "Fiber Post" OR "Post Technic" OR "Dental Dowel")) AND (instance:"regional") AND (db:("LILACS"))
SciELO http://www.scielo.org/	("Endodontically-Treated") AND ("Post Technic" OR "Dental Dowel" OR "Fiber Post" OR "Post Technic" OR "Dental Dowel")
	(“Devitalized” OR “Pulpless” OR “Flared Root”) AND ("Post and Core Technique" OR "Post-Core Technic" OR "Post and Core Technic" OR "Post Technique" OR "Post Technic" OR "Dental Dowel" OR "Fiber Post")
	(“Devitalized” OR “Pulpless” OR “Flared Root”) AND ("Fiber Reinforced Post" OR "Glass Fiber Post" OR "Anatomic Post" OR "Anatomized Post" OR "Relined Post")
Web Of Science http://apps.webofknowledge.com/	(("Nonvital Tooth" OR "Devitalized Tooth" OR "Pulpless Tooth" OR "Pulpless Teeth" OR "Devitalized Teeth" OR "Nonvital Teeth" OR "Endodontically-Treated Teeth" OR "Endodontically-Treated Tooth" OR "Tooth Endodontically Treated" OR "Flared Root") AND ("Post and Core Technique" OR "Post-Core Technic" OR "Post and Core Technic" OR "Post Technique" OR "Post Technic" OR "Dental Dowel" OR "Fiber Post" OR "Fiber Reinforced Post" OR "Glass Fiber Post" OR "Anatomic Post" OR "Anatomized Post" OR "Relined Post"))
ScienceDirect https://www.sciencedirect.com/	((“Tooth” OR “Teeth”) AND (“Devitalized” OR “Pulpless” OR “Flared Root”)) AND ("Post and Core Technique" OR "Post-Core Technic" OR "Post and Core Technic" OR "Post Technique" OR "Post Technic" OR "Dental Dowel" OR "Fiber Post")
	((“Tooth” OR “Teeth”) AND (“Devitalized” OR “Pulpless” OR “Flared Root”)) AND ("Fiber Reinforced Post" OR "Glass Fiber Post" OR "Anatomic Post" OR "Anatomized Post" OR "Relined Post")
OpenGrey http://www.opengrey.eu/	("Nonvital Tooth" OR "Devitalized Tooth" OR "Pulpless Tooth" OR "Pulpless Teeth" OR "Devitalized Teeth" OR "Nonvital Teeth" OR "Endodontically-Treated Teeth" OR "Endodontically-Treated Tooth" OR

	"Tooth Endodontically Treated" OR "Flared Root") AND ("Post and Core Technique" OR "Post-Core Technic" OR "Post and Core Technic" OR "Post Technique" OR "Post Technic" OR "Dental Dowel" OR "Fiber Post" OR "Fiber Reinforced Post" OR "Glass Fiber Post" OR "Anatomic Post" OR "Anatomized Post" OR "Relined Post")
OpenThesis http://www.openthesis.org/	("Devitalized" OR "Pulpless" OR "Flared Root") AND ("Fiber Reinforced Post" OR "Glass Fiber Post" OR "Anatomic Post" OR "Anatomized Post" OR "Relined Post")
	("Devitalized" OR "Pulpless" OR "Flared Root") AND ("Post and Core Technique" OR "Post-Core Technic" OR "Post and Core Technic" OR "Post Technique" OR "Post Technic" OR "Dental Dowel" OR "Fiber Post")
	("Endodontically-Treated") AND ("Post Technic" OR "Dental Dowel" OR "fiber post" OR "Post Technic" OR "Dental Dowel" OR "Fiber Post")
OATD http://www.oatd.org/	("Nonvital Tooth"OR "Devitalized Tooth" OR "Pulpless Tooth" OR "Pulpless Teeth" OR "Devitalized Teeth" OR "Nonvital Teeth" OR "Endodontically-Treated Teeth" OR "Endodontically-Treated Tooth" OR "Tooth Endodontically Treated" OR "Flared Root") AND ("Post and Core Technique" OR "Post-Core Technic" OR "Post and Core Technic" OR "Post Technique" OR "Post Technic" OR "Dental Dowel" OR "Fiber Post" OR "Fiber Reinforced Post" OR "Glass Fiber Post" OR "Anatomic Post" OR (Anatomized AND Post) OR (Relined AND Post))

Table 2 – Summary of the main characteristics of the eligible studies.

Author	Sample*	Intervention	Comparator	Relined agent	Cementing agent	Methods used
Bonfante et al., 2007	30 healthy maxillary canines	GFPRAP (Fibre-Kor Pentron Corporation and Reforpin) n=10; GFPRCR (Fibre-Kor Pentron Corporation) n=10.	GFPSD (Fibre-Kor Pentron Corporation) n=10;	Nanoparticulada 65%wt Filtek Flow (3M ESPE, St. Paul, Minnesota, United State)	All groups were cemented with Dual-cured resin cement (RelyX ARC 3M ESPE, St. Paul, Minnesota, United States)	- Compressive fracture strength testing 135º - Mode of failure
Freitas, 2007	20 healthy canines maxillary	GFPRCR (Reforpost; Angelus) n=10	GFPSD (Reforpost; Angelus) n=10	Microhíbrida com nanopartículas 60% wt Z250 (3M ESPE, St. Paul, Minnesota, United State)	All groups were cemented with Self adhesive ionomer resin cement (RelyX Luting 2 3M ESPE, St. Paul, Minnesota,United States)	- Mechanical cycling - Compressive fracture strength testing 135º - Mode failure
Li et al., 2011	40 healthy maxillary central incisors	GFPRAPx (Macro-Lock glass fiber post + 2 Fibercone auxiliary fiber posts (RTD Inc); GFPRAPy (Macro-Lock glass fiber post + 5 auxiliary fiber posts (RTD Inc).	GFPSD (Light glass fiber post, Bisco Inc, Schaumburg); GFPSD (Macro-Lock glass fiber post (RTD Inc); each test	-	All groups were cemented with Dual-cured resin cement (PermaCem, DMG Inc);	- Fracture failure test 45º to the long axis of the root. - Pull-out test
Barcellos et al., 2013	40 healthy canines maxillary	2mm dentin+ GFPRCR (Angelus) n=10; GFPRCR (Angelus) n=10;	2mm dentin+ GFPSD (Angelus) n=10; GFPSD (Angelus) n=10	Microhíbrida com nanopartículas 60% wt Z250 (3M ESPE, St. Paul, Minnesota, United State)	All groups were cemented with Dual-cured resin cement (RelyX ARC 3M ESPE, St. Paul, Minnesota, United States)	- Compressive fracture strength testing 135º - Mode failure

Ferro et al., 2016	20 healthy canines maxillary	GFPRCR (Reforpost Fiber Glass; Angelus) n=10	GFPSD (Reforpost Fiber Glass; Angelus) n=10	Microhíbrida com nanopartículas 60% wt Z250 (3M ESPE, St. Paul, Minnesota, United State)	All groups were cemented with Dual-cured resin cement (RelyX ARC 3M ESPE, St. Paul, Minnesota, United States)	- Dynamic Fatigue Test - Compressive fracture strength testing 135º - Failure mode
Borzangy et al., 2019	20 healthy maxillary central incisors	GFPRCR (RelyXTM, 3M ESPE, St. Paul, Minnesota, United State) n=10	GFPSD (RelyXTM, 3M ESPE, St. Paul, Minnesota, United State) n=10	Nanoparticulada 63,5% wt Tetric N-Ceram, Ivoclar Vivadent	All groups were cemented with self adhesive dual- cured resin cement (RelyX Unicem 3M ESPE, St. Paul, Minnesota, United States)	- Dynamic Fatigue Test - Compressive fracture strength testing 135º - Failure mode

*The sample value refers to the groups that were used to answer the guiding question and not the total number of each study. GFPRAP- Glass fiber post reinforced with acessory post; GFPRCR- Glass fiber post reinforced with composite resin; GFPSD- Glass fiber post smaller diameter; RTD- Recherches Techiques Dentaires; DMG- Dental Milestones Guaranteed

Table 3 – Summary of the main characteristics of the eligible studies.

Author	Root canal obturation	Root Cleaning	Canal Prepare	Coronal restoration	Ferule
Bonfante et al., 2007	-	24% EDTA for 3 minutes,rinsed with distilled water for 1 minute	2/3	Metallic Crown	Absence
Freitas, 2007	Sealer 26 (Dentsply Indústria e Comércio Ltda., Petrópolis-RJ)	24% EDTA for 3 minutes, rinsed with distilled water for 1 minute	2/3	Metallic Crown	Absence
Li et al., 2011	-	Phosphoric acid 37%, distilled water	2/3	Metallic Crown	Presence
Barcellos et al., 2013	Endofill (Dentsply Maillefer, Ballaigues, Switzerland)	2% Chlorhexedine and distilled water	2/3	Metallic Crown	Presence
Ferro et al., 2016	-	Phosphoric acid 37%, distilled water	2/3	Metallic Crown	Presence
Borzangy et al., 2019	AH-Plus sealer (Dentsply IH Ltd, United Kingdom)	Phosphoric acid 37%, distilled water	2/3	Metallic Crown	Presence

Table 4. Bias risk assessment and methodological quality according to Sarkis-Onofre et al., 2014.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	% yes/risk
Bonfante et al., 2007	--	√	√	√	--	--	--	42,85 %- High
Freitas, 2007	--	√	√	√	--	--	--	42,85 %- High
Li et al., 2011	--	√	√	√	--	--	--	42,85 %- High
Barcellos et al., 2013	--	√	√	√	√	--	--	57,14%- Moderate
Ferro et al., 2016	√	√	√	√	--	--	--	57,14%- Moderate
Borzangy et al., 2019	√	√	√	√	--	--	--	57,14%- Moderate

Q1- Was there a randomization of extracted teeth when they were divided between groups? Q2- The extracted teeth were free of caries or restorations? Q3- The researched materials were used according to the manufacturers' instructions? Q4- Did the teeth used have similar dimensions? Q5- The endodontic treatment of the samples were performed by a single operator? Q6- Was a sample calculation performed? Q7- Was the operator of the mechanical test blind to the type of sample tested? - √ - Yes; -- - No; U – Unclear; N/A – Not applicable.

Table 5 - Summary of the main results of the studies included in the quantitative analysis.

Author	Groups	n	Fracture Strenght Test	
			Mean (N)	SD
Bonfante et al., 2007	G1- GFPRAP	10	920.64	14.72
	G2- GFPRCR	10	876.12	18.46
	GC- GFPSD	10	745.69	26.15
Freitas, 2007	G1-GFPRCR	10	266.44	13.92
	GC- GFPSD	10	342.44	9.73
Li et al., 2011	G1- GFPRAPx	10	490.17	83.27
	G2- GFPRAPy	10	550.25	62.84
	GC- GFPSD (DT)	10	305.73	76.34
	GC- GFPSD (ML)	10	449.50	113.18
Barcellos et al., 2013	G1- 2mm dentin+ GFPRCR	10	431.29	83.07
	G2- GFPRCR	10	380.97	75.84
	GC- 2mm dentin+ GFPSD	10	260.23	69.74
	GC-GFPSD	10	263.69	91.87
Ferro et al., 2016	G1-GFPRCR	10	230.50	79.50
	GC- GFPSD	10	262.60	32.60
Borzangy et al., 2019	G1-GFPRCR	10	686.20	52.50
	GC- GFPSD	10	607.70	54.80

SD – Standard Deviation. GFPRAP- Glass fiber post reinforced with acessory post; GFPRCR- Glass fiber post reinforced with composite resin; GFPSD- Glass fiber post smaller diameter; GFPRAPx – Glass fiber post reinforced with 2 acessory post; GFPRAPy- 5 Glass fiber post reinforced with 5 acessory post; RTD- Recherches Techiques Dentaires; DMG- Dental Milestones Guaranteed

Table 6: Summary of the main results of the studies included in the quantitative analysis.

Author	Groups	n	Failure modes (%)	
			Repairable	Irreparable
Bonfante et al., 2007	G1- GFPRAP	10	70	30
	G2- GFPRCR	10	80	20
	GC- GFPSD	10	80	20
Freitas, 2007	G1-GFPRCR	10	70	30
	GC- GFPSD	10	70	30
Li et al., 2011	G1- GFPRAPx	10	90	10
	G2- GFPRAPy	10	100	-
	GC- GFPSD (DT)	10	100	-
	GC- GFPSD (ML)	10	100	-
Barcellos et al., 2013	G1- 2mm dentin+ GFPRCR	10	100	-
	G2- GFPRCR	10	50	40
	GC- 2mm dentin + GFPSD	10	70	30
	GC- GFPSD	10	80	20

Ferro et al., 2016	G1-GFPRCR GC- GFPSD	10 10	80 60	20 40
Borzangy et al., 2019	G1-GFPRCR GC- GFPSD	10 10	60 40	40 60

SD – Standard Deviation. GFPRAP- Glass fiber post reinforced with acessory post; GFPRCR- Glass fiber post reinforced with composite resin; GFPSD- Glass fiber post smaller diameter; GFPRAPx – Glass fiber post reinforced with 2 acessory post; GFPRAPy- 5 Glass fiber post reinforced with 5 acessory post; RTD- Recherches Techiques Dentaires; DMG- Dental Milestones Guaranteed

Table 7 – Overall estimates of percentage of repairable and irreparable failures between control and treatment groups using auxiliary posts and glass fiber post reinforced with composite resin.

	Auxiliary posts		**Glass fiber post reinforced with composite resin**	
	Treatment	**Control**	**Treatment**	**Control**
Repairable	93.0% (80.0; 100.0)	99.0% (91.0; 100.0)	78.0% (60.0; 92.0)	69.0 (58.0; 80.0)
Irrepairable	7.0% (0.0; 20.0)	1.0% (0.0; 9.0)	22.0% (8.0; 40.0)	31.0% (20.0; 42.0)

Conclusões

- Resinas bulk-fill flow podem ser utilizadas como material de reembasamento, pois apresentaram uma resistência de união parecida com as resinas convencionais.
- Resinas bulk-fill flow podem ser utilizadas como material de cimentação de pinos de fibra de vidro pois apresentaram resultados de resistência de união e retenção parecidos com o grupo cimentado com cimento resinoso convencional dual.
- O pino de fibra de vidro não altera o grau de conversão e a dureza de resinas compostas.
- A utilização de cimento resinoso auto-adesivo parece desempenhar uma resistência de união superior a pinos cimentados em raízes alargadas
- Resinas bulk-fill flow e regular das marcas 3M e FGM podem ser utilizados como material de customização.
- Pinos de fibra de vidro de maior calibre geram maior adaptação em raízes amplas.

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Anexos

5- Anexos

5.1- Normas do Periódico 1

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Divide your article into clearly defined and numbered sections. Subsections should be numbered 1.1 (then 1.1.1, 1.1.2, ...), 1.2, etc. (the abstract is not included in section numbering). Use this numbering also for internal cross-referencing: do not just refer to 'the text'. Any subsection may be given a brief heading. Each heading should appear on its own separate line.

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State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.

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