ORIGINAL RESEARCH

Impact of Mechanical Load of Three Post and Core Systems: CAD/CAM-fabricated Glassfiber, Prefabricated Glassfiber Customized with Composite Resin, and Cast Metal Posts and Cores

Iris NB Seckler[1], Carlos E da Silveira Bueno[2], Augusto S Kato[3], Sérgio L Pinheiro[4], Débora AN Leite Lima[5], Danielle FS de Souza[6], Rina A Pelegrine[7]

ABSTRACT

Aim and objective: This study assessed the fracture resistance and failure mode frequencies in three post and core systems: CAD/CAM-fabricated glassfiber post and core, glassfiber post and core customized with composite resin, and cast metal post and core.

Materials and methods: After endodontic obturation and the post space preparation, 30 extracted mandibular premolars were distributed into three groups ($n = 10$): Group GFP: glassfiber post and core customized with composite resin, Group CPC: cast metal, and Group CAD/CAM: CAD/CAM-fabricated glassfiber post and core. All the specimens were luted with RelyX U200 cement, submitted to thermomechanical cycling, and then submitted to a compression test, applied at a 45° angle relative to the long axis of the tooth, until fracture. The fracture resistance data were submitted to ANOVA complemented by the Tukey test and the failure mode data by Fisher's exact test with the Freeman–Halton extension ($\alpha = 5\%$).

Results: There was no significant difference between the fracture resistance values found for groups CPC and CAD/CAM ($p > 0.05$), and these values were significantly higher than those found for Group GFP ($p < 0.05$). In respect to failure mode frequencies, Group CAD/CAM had equal frequencies of adhesive and cohesive failures, Group GFP had exclusively cohesive failures in the composite core buildup, and Group CPC had 80% of cohesive failures in dentin vs 20% of adhesive failures ($p < 0.001$).

Conclusion: The fracture resistance of CAD/CAM-fabricated glassfiber posts and cores was comparable to that of cast posts and cores, and they were not associated with irreparable root fractures. Therefore, CAD/CAM-fabricated glassfiber posts and cores can be considered an effective method for restoring endodontically treated teeth.

Clinical significance: CAD/CAM system proved to be a viable alternative to cast posts and cores, since they were less associated with irreparable root fractures.

Keywords: CAD/CAM, Digital impression scanning, Glass fiber, Post and core technique.

Conservative Dentistry and Endodontic Journal (2020): 10.5005/jp-journals-10048-0064

INTRODUCTION

One of the factors determining the success of endodontic treatment is adequate coronal restoration, considering its importance in restoring masticatory function and preventing recontamination of the root canals.[1–3] Posts are indicated for rehabilitating endodontically treated teeth when there is insufficient residual crown structure,[2,4] and cast metal posts and cores (CPCs) are traditionally used for this purpose. Although CPCs provide a reliable record of intraradicular anatomy, resulting in adequate adaptation,[4,5] their high modulus of elasticity can predispose teeth to root fractures.[4,6] In addition, CPCs are subject to corrosion and may be associated with an unfavorable aestheticoutcome.[6]

The current literature has shown that endodontically treated teeth restored with prefabricated glassfiber posts (GFPs) have longer longevity, owing to the proximity of their modulus of elasticity to that of dentin. This property ensures a more homogeneous distribution of masticatory loads and a relative dissipation of masticatory stress along the root, thus reducing the risk of fracture.[5,7–13] Post customization provides adequate adaptation of the prefabricated GFP to the post space prepared for it and thus enables a thin layer of cement to be obtained after

[1,2,7]Faculdade São Leopoldo Mandic, Instituto de Pesquisas São Leopoldo Mandic, Endodontia, Campinas, São Paulo, Brazil

[3]Department of Restorative Dentistry, Endodontics and Dental Materials, Bauru Dental School, University of São Paulo, Bauru, São Paulo, Brazil

[4]Department of Endodontics, School of Dentistry, Pontifical Catholic University of Campinas (PUC-Campinas), Campinas, São Paulo, Brazil

[5,6]Department of Restorative Dentistry, Piracicaba Dental School, University of Campinas, São Paulo, Brazil

Corresponding Author: Rina A Pelegrine, Faculdade São Leopoldo Mandic, Instituto de Pesquisas São Leopoldo Mandic, Endodontia, Campinas, São Paulo, Brazil, Phone: +55 19 3272-5219, e-mail: rinapelegrine@terra.com.br

How to cite this article: Seckler INB, da Silveira Bueno CE, Kato AS, *et al*. Impact of Mechanical Load of Three Post and Core Systems: CAD/CAM-fabricated Glassfiber, Prefabricated Glassfiber Customized with Composite Resin, and Cast Metal Posts and Cores. Cons Dent Endod J 2020;5(2):36–41.

Source of support: Nil

Conflict of interest: None

---

luting. It also provides more favorable post retention conditions than those obtained when no customization is performed.[10] However, even customized prefabricated GFPs cannot provide the same cervical adaptation as that provided by CPCs, which is why maintaining a minimum residual crown structure is indicated to ensure greater balance between the forces acting on the restored tooth ("ferrule effect").[14,15]

By combining the cervical adaptation benefits of CPCs with the modulus of elasticity benefits of prefabricated GFPs, CAD/CAM-fabricated glassfiber posts and cores (CAD/CAM) represent a new perspective in restoring the function and aesthetics of endodontically treated teeth. However, the literature supporting the use of CAD/CAM systems to fabricate glassfiber posts and cores to provide the support required for the restoration of endodontically treated teeth has yet to be consolidated.[9,10,13]

Clinically, there are several situations in which, although posts and cores are recommended, there is no residual crown structure around them. In these cases, the cores are the main conductive of mechanical forces to the root, being able to influence the stress distribution and consequently lead to different failure modes (e.g., cohesive failure in the post and core, adhesive failure, or root fracture). Therefore, assessing the mechanical behavior of different materials used to compose post and core systems and its implications on the root remnant becomes important for the clinical decision.

The aim of this study was to conduct an *in vitro* assessment of the fracture resistance values and failure mode frequencies of the following three post and core systems: CAD/CAM, GFPs customized with composite resin and a composite core buildup, and CPCs. The null hypotheses tested were that there would be no difference between the evaluated systems (1) regarding their fracture resistance values and (2) regarding the failure mode frequencies associated with their use.

Materials and Methods

Sample Size Calculation

The number of 10 specimens per group was calculated using the ANOVA test, with a standard deviation of the error of 19, a test power of 0.80, and an alpha value of 0.05. The BioStat 5.3 program (Instituto Mamirauá, Belém, PA, Brazil) was used to perform the calculation.

Specimen Preparation

The specimens used were teeth indicated for extraction for several reasons and were expressly donated by patients. After extraction, the teeth were kept in a 0.1% thymol solution (Siafarma, Campinas, SP, Brazil) for a maximum period of 3 months. Thirty permanent first mandibular premolars were selected and radiographed in the buccolingual and mesiodistal directions.

The inclusion criteria were fully formed roots with a single straight[16] and oval-shaped canal (buccolingual diameter twice as large as the mesiodistal diameter in the first two-thirds of the canal, confirmed by digital radiography) and initial diameter of the foramen corresponding to a #15 K-type file (Dentsply Sirona Endodontics, Ballaigues, Switzerland). Teeth with cracks, fractures, calcifications, or pathological root resorption (internal, external, or apical), visible under a dental operating microscope at 8× magnification, were excluded from the study, as were teeth that had undergone previous endodontic treatment.

Remnants of periodontal ligament or calculus attached to the root surfaces were removed with ultrasonic inserts. The coronal portion of each tooth was sectioned with a low-speed diamond disk (Isomet 100; Buehler, Lake Bluff, IL, USA), and the root was abraded in the cervicoapical direction until obtaining a standard length of 15 mm, measured with a digital caliper (Mitutoyo, Suzano, SP, Brazil). A #15 K-type file was then inserted into the canal until its tip was seen at the apical foramen, and the working length for instrumentation was set at 1 mm short of the foramen.

Before initiating the chemical–mechanical preparation, the roots were coated with a hydrophilic polymethylsiloxane vinyl impression material (Express XT; 3M ESPE, Neuss, Germany) and embedded in acrylic resin blocks to simulate the conditions of the alveolus and periodontal ligament.[14] The blocks were immersed in water for 5 minutes after the initial polymerization phase to prevent overheating from the exothermic reaction of the acrylic resin.

The canals were instrumented with ProTaper Next rotary files (Dentsply Maillefer, Ballaigues, Switzerland) driven by the X-Smart Plus motor (Dentsply Maillefer), set to operate in continuous rotation, at 300 rpm, and with a torque of 2 N cm. The cervical, middle, and apical thirds were enlarged with the ProTaper Next X1 (17/.04), X2 (25/.06), X3 (30/.07), and X4 (40/.06) instruments, using in-and-out movements and a brushing action on the withdrawal stroke, until reaching the working length. Irrigation was performed at each instrument change by applying a 2.5% sodium hypochlorite (NaOCl) solution (Siafarma) with a syringe and NaviTip G-30 needle (Ultradent, South Jordan, UT, USA), positioned 2 mm short of the working length, for a total of 30 mL of solution per specimen. After instrumentation, the canals were irrigated with 5 mL of a 17% EDTA solution (Formula & Ação, São Paulo, SP, Brazil), activated ultrasonically with an Irrisonic E1 insert (Helse, Santa Rosa de Viterbo, SP, Brazil), positioned 2 mm short of the working length, and operated at 20% power for 1 minute, in three cycles of 20 seconds. Subsequently, the canals were irrigated again with 2.5% NaOCl and also activated ultrasonically, following the same activation protocol used for the 17% EDTA solution. The canals were dried with absorbent paper points (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA) and filled with X4 gutta-percha cones (Dentsply Tulsa Dental Specialties) and AH Plus sealer (Dentsply De Trey, Konstanz, Germany), using a McSpadden compactor (Dentsply Maillefer).

The filling material was removed using a #3 Largo burr (Dentsply Maillefer), inserted to a depth of 9.0 mm. The post spaces were irrigated with 5.0 mL of 2.5% NaOClto remove debris and filling material residues and dried with absorbent paper points (Dentsply Tulsa Dental Specialties). The teeth were then randomly distributed into three experimental groups ($n = 10$) using the program available at www.random.org.

Group GFP

Reforpost #1 GFPs (Angelus Ind. de Produtos Odontológicos, Londrina, PR, Brazil) were selected because they were compatible with the post spaces created by the #3 Largo burr. Initially, GFPs were immersed for one minute in a 70% alcohol solution (Siafarma) to remove residues and then silanized with a Ceramic Primer (3M ESPE, St. Paul, MN, USA). After 60 seconds, the posts were dried with a light air jet, and then, a universal adhesive (3M ESPE) was applied to the posts and light-cured for 40 seconds with the light-curing unit (Raddi-Cal; SDI, Bayswater, VIC, Australia) set to a power of 1200 mW/cm^2. The GFPs were covered with composite resin (Z250; 3M do Brasil, Sumaré, SP, Brazil) and placed into the intraradicular space, previously lubricated with a water-soluble gel (KY; Johnson & Johnson Medical, São Paulo, SP, Brazil). The composite resin was light-cured for 5 seconds on the buccal and lingual aspects. The resulting customized post—consisting of GFP and composite resin—was removed from the canal, and polymerization was completed for 40 seconds on each aspect. Subsequently, proper fit of the customized post to the post space was confirmed in the laboratory and radiographically. Laboratory confirmation was performed with a #5 exploratory probe (Golgran, São Caetano do Sul, SP, Brazil) and consisted of verifying the absence of gaps between the post and the residual root structure. Radiographic confirmation consisted of verifying the absence of empty spaces between the apical limit of the post and the remaining filling material. When necessary, adjustments were made with a Sof-Lex polishing disk (KG Sorensen, Barueri, SP, Brazil). The water-soluble gel was removed by irrigation with 5 mL of saline solution (Becker Produtos Fármaco Hospitalares, Embu das Artes, SP, Brazil), the canal was dried with an absorbent paper point, and the post was luted with the RelyX U200 self-adhesive resin cement (3M ESPE), according to the manufacturer's instructions. The cement was injected into the canal using a metallic tip (Accudose; Centrix, Shelton, CT, USA) coupled to a plastic syringe (Centrix), and then,the post was slowly seated by finger pressure, and excess luting cement was removed with a disposable brush. Once the post was luted, the cement was light-cured for 40 seconds on the buccal and lingual aspects. Afterward, a transparent matrix was made with a temporary light-cured restorative material (Bioplic; Biodinâmica, Ibiporã, PR, Brazil) to build up a direct composite core with standardized dimensions (height of 6 mm and width of 4 mm). The dentin portion of the specimens was then etched with a 37% phosphoric acid solution (Dentalville do Brasil, Joinville, SC, Brazil) for 15 seconds and rinsed with water for 30 seconds. Excess moisture was removed with absorbent paper, and a bonding agent (Adapter Single Bond 2; 3M ESPE) was applied and light-cured for 10 seconds, according to the manufacturer's instructions. Afterward, a small amount of composite resin Z250 (3M do Brasil) was placed inside the matrix. The matrix was then positioned on the specimen, and the composite resin was polymerized for 40 seconds on the buccal and lingual aspects.

Group CPC

CPCs were made using the direct impression technique with red, self-curing acrylic resin (Duralay; Reliance, Alsip, IL, USA). Initially, the canal walls were lubricated with the water-soluble gel, using a microbrush applicator (KG Sorensen, Barueri, SP, Brazil). Then, the acrylic resin was manipulated, using the powder/liquid ratio recommended by the manufacturer and placed into the intraradicular space using a Pinjet-type post as the carrier (Angelus Ind. de Produtos Odontológicos). After polymerization, the material was removed from the canal and reinserted; any required adjustments to the post model thus formed were made with a Sof-Lex polishing disk (KG Sorensen). Afterward, the core of the model was fabricated using the same procedure and standardized matrix used for Group GFP. The complete acrylic resin model was then sent to a prosthodontic laboratory, and casting was carried out using a copper and aluminum alloy (4.5% aluminum, 77% copper, 5.6% nickel, 12.8% zinc; Goldent, Cotia, SP, Brazil). Laboratory and radiographic confirmation of the proper fit of the CPC and the cleaning and luting procedures were the same as those performed in Group GFP.

Group CAD/CAM

The direct impression of the post space and the core model fabrication procedure with self-curing acrylic resin were performed in the same way as for Group CPC. Then, the complete acrylic resin model was opacified with a mixture of 0.1 gm of zirconia powder to two drops of isopropyl alcohol and scanned in the Ceramill Map 400 scanner (Amann Girrbach, Koblach, Austria). The digital data were collected and exported to the Exocad Dental CADprogram (Amann Girrbach), after which a digital design of the post and core was obtained. A FiberCAD Post and Core fiberglass disk, model FCA (Angelus Ind. de Produtos Odontológicos), was positioned and fixed onto the Ceramill Motion II milling machine (Amann Girrbach) and machined under constant irrigation and at constant speed. When necessary, the machined piece was manually refined to remove minor interferences.

Proper fit of the post and core was confirmed in the laboratory and radiographically, followed by cleaning, silanization, and luting procedures, as previously described. All the specimens were stored in distilled water at 37° for 24 hours for the luting agent to set completely.

Figure 1 shows representative images of the three post and core systems.

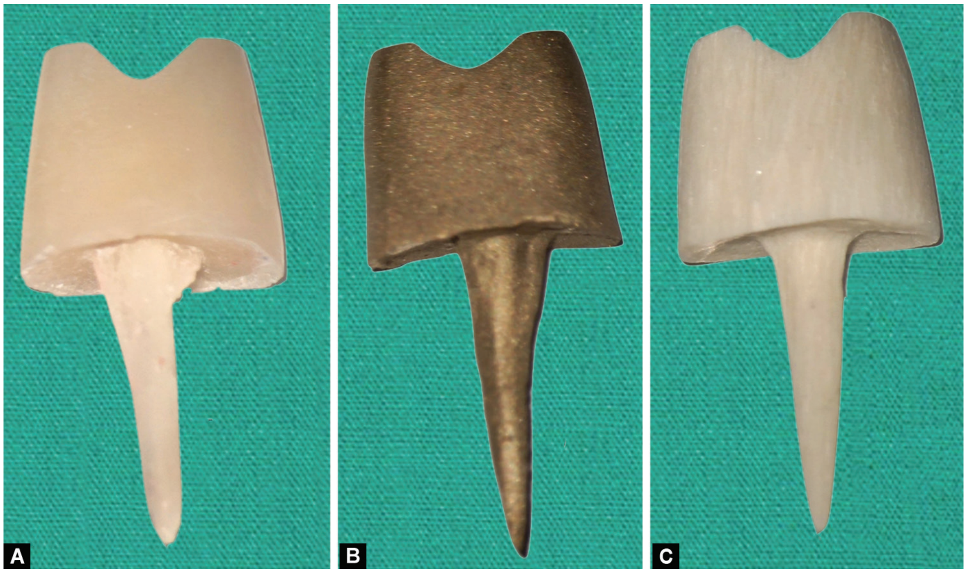

Fig. 1A to C: Representative images of the three post and core systems: (A) Prefabricated glassfiber post customized with composite resin and a composite core buildup; (B) Cast metal post and core; (C) CAD/CAM-fabricated glassfiber post and core

Thermomechanical Cycling

After the storage period, the specimens were subjected to cycling in a thermomechanical wear apparatus (ER-37000; Erios Equipamentos Técnicos e Científicos, São Paulo, SP, Brazil) to simulate masticatory forces equivalent to a one-year functioning period.[17] This consisted of immersing the specimens in water at temperatures ranging from 5 to 55°C, for a total of 10,000 cycles at 5-seconds intervals, and of applying a 30-N load parallel to the long axis of the tooth, for a total of 300,000 cycles.

Compression Test

Each specimen was mounted in a universal testing machine (DL 2000; EMIC Equipment and Test Systems, São José dos Pinhais, PR, Brazil), and a 2.5-mm-diameter stainless steel sphere was positioned 2 mm from the tip of the buccal cusp of the core, toward the central fossa. A constant load was applied at a speed of 0.5 mm/minute and an angle of 45° to the long axis of the tooth, until fracture. The force required for the fracture to occur was recorded (in N).

Failure Mode

The failure mode was determined using a dental operating microscope (DF Vasconcelos, Valença, RJ, Brazil) under 12.5× magnification. All the specimens were evaluated and classified as (1) adhesive failure in the tooth/post and core interface, (2) cohesive failure in the post and core, not involving the dental structure, and (3) cohesive failure in the dentin. In cohesive failure in the dentin, favorable failure was defined as fracture above the CEJ, or 1 mm or less apical to the CEJ; unfavorable failures were defined as fractures more than 1 mm apical to the CEJ.

Statistical Analysis

The fracture resistance data were submitted to analysis of variance (ANOVA), complemented by the Tukey test, and the failure mode data were submitted to Fisher's exact test with the Freeman–Halton extension. All the analyses were performed using BioStat 5.3 software (Instituto Mamirauá, Tefé, Amazonas, Brazil). The level of significance used was 5%.

RESULTS

Fracture Resistance

Arithmetic means and standard deviations of fracture strength values are summarized in Table 1. There was no significant difference between groups CPC (213.58 N) and CAD/CAM (184.80 N) (p >0.05). Group GFP had significantly lower values than those of the other groups.

Table 1: Minimum, maximum, mean, and standard deviation (SD) values of fracture resistance (in N) observed in the study groups

	CPC	*GFP*	*CAD/CAM*
N	10	10	10
Minimum	44.64	34.90	100.73
Maximum	347.69	128.03	348.33
Mean (SD)	213.58 (93.58)^{A}	78.93 (31.33)^{B}	184.80 (84.79)^{A}

CPC, cast metal post and core; GFP, prefabricated glassfiber post customized with composite resin and a composite core buildup; CAD/CAM, glassfiber post and core fabricated using a computer-aided design and computer-aided manufacturing system. Different letters indicate a statistically significant difference

Table 2: Relative frequencies of the failure modes observed according to type of post and core used

Failure mode	*CPC*	*GFP*	*CAD/CAM*
Adhesive	20%	–	50%
Cohesive in the core	–	100%	50%
Cohesive in dentin	80%	–	–

CPC, cast metal post and core; GFP, prefabricated glassfiber post customized with composite resin and a composite core buildup; CAD/CAM, glassfiber post and core fabricated using a computer-aided design and computer-aided manufacturing system

Failure Mode

The failure mode frequencies observed in each experimental group are shown in Table 2. Statistically significant differences were found among the three groups ($p < 0.001$). Cohesive failures in dentin predominated in Group CPC, and all of them were considered unfavorable failures (Fig. 2A). Adhesive failures also occurred in this group, but less frequently. Exclusively cohesive failures in the composite core buildup were observed in Group GFP (Fig. 2B), and equal frequencies of cohesive failures in the

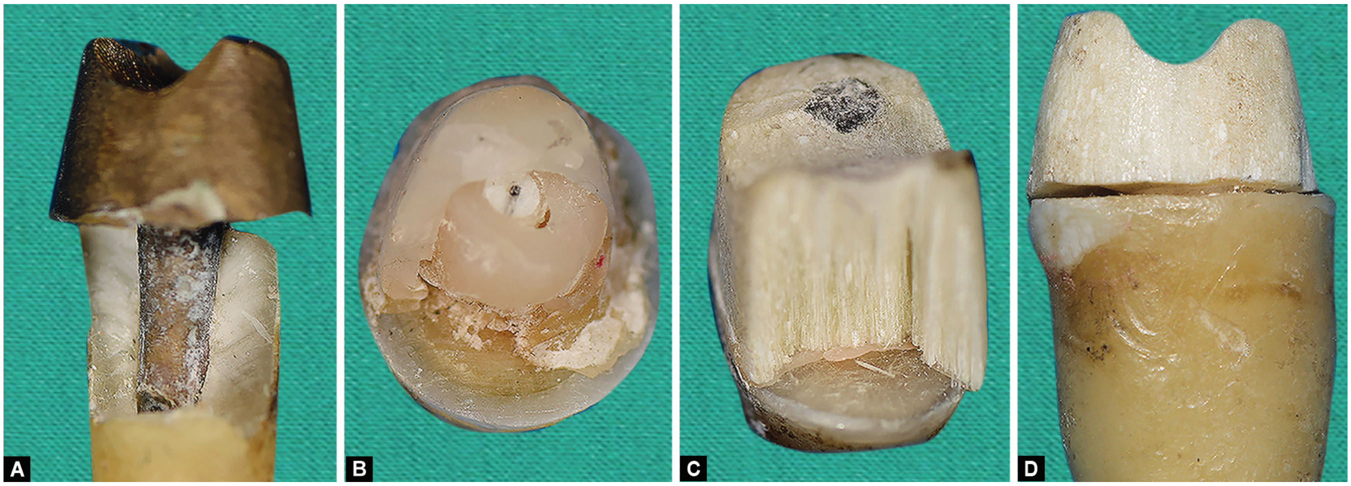

Fig. 2A to C: Representative images of the failure modes observed in the experimental groups: (A) Cohesive failure in dentin observed in Group CPC. CPC; (B and C) Cohesive failures in the core observed in groups GFP and CAD/CAM–GFPC; (D) Adhesive failure observed in Group CAD/CAM–GFPC core (Fig. 2C) and adhesive failures (Fig. 2D) were observed in Group CAD/CAM.

DISCUSSION

The tested null hypotheses were rejected, since significant differences were found between the groups regarding fracture resistance values and failure mode frequencies. Group CPC had significantly higher fracture resistance values than those of Group GFP. On the other hand, there was no significant difference between the fracture resistance values found for groups CPC and CAD/CAM, and these values were significantly higher than those found for Group GFP.

Tsintsadze et al.[9] compared the performance of CAD/CAM, prefabricated GFPs, and CPCs in oval root canals using the "push-out" test and also analyzed the thickness of the resulting cement film around the posts after cementation. The CAD/CAM achieved a retention rate comparable to that of CPCs and higher than that of prefabricated GFPs; however, a thinner cement film was observed surrounding CPCs than CAD/CAM. Pang et al.[13] evaluated weakened roots of maxillary incisors restored with metal crowns supported by CAD/CAM, prefabricated GFPs, or CPCs. The results showed that specimens in the CAD/CAM group achieved a fracture resistance value similar to that of the specimens in the CPC group; however, there was a predominance of repairable fractures in the former as opposed to a predominance of irreparable root fractures in the latter, which corroborates the results of the present study.

The RelyX U200 resin cement was used in this study in order to combine the benefits offered by self- and light-cured materials—such as prolonged working time and a high rate of conversion of the luting agent in both the presence and absence of light.[11] This cement also enables the simplifying of procedures, by eliminating the dentin etching and adhesive application steps, thus leading to fewer procedural errors.[18,19] In addition, the cement was inserted into the root canal with a syringe and metal tip to reduce the number of bubbles in the post/root canal interface. The purpose of using a resin cement in the three study groups was to avoid potential bias related to the different properties of the materials indicated for GFPs and CPCs, in agreement with the methodologies used by Bilgin et al.[6] and Habibzadeh et al.[4]

All the teeth were subjected to thermomechanical cycling to simulate the action of masticatory forces during one year of functioning,[17] as also performed by Stricker and Göhring[1] and Kul et al.[20] In contrast, Habibzadeh et al.[4] and Haralur et al.[5] did not use thermomechanical cycling, and Spina et al.[8] used only mechanical cycling.

Fracture resistance is partially associated with the load application method, which probably explains the differences found between the different studies. In the present study, the load was applied at an angle of 45° in relation to the long axis of the tooth until fracture,[4,5,21] considering that this is, predominantly, the angle with which the masticatory load falls on premolars.[14] Bilgin et al.[6] and Guo et al.[14] also applied loads at 45° angles, whereas Stricker and Göhring[1] did so at 60° angles, and Costa et al.,[22] at 30° angles. Full-coverage crowns were not cemented on the cores, so the load was applied directly to them in order to assess the mechanical behavior of the different materials used in this study to make the posts and cores. Post and core systems cemented into the tooth become the main body of the conductive load of the restorations to the root and minimize the influence of the crown material on the stress distribution.[13] According to Salameh et al.,[23] the different type of full-coverage crowns was not a significant factor affecting fracture resistance after the restoration of endodontically treated teeth, whereas the presence of a post was.

Although groups CPC and CAD/CAM were similar with respect to fracture resistance, their behavior was different with respect to failure mode. A substantial rate of cohesive root failures was observed in Group CPC. CPCs are rigid systems that allow stress induction on canal walls, predisposing the tooth to irreparable root fractures.[6,9,12] On the other hand, there were no cohesive dentin failures in Group CAD/CAM, confirming the potential of glass fibers to enable stress dissipation,[12] thus preventing their direct impact on dentin.

Glassfiber posts were used in both the CAD/CAM and GFP groups; however, their respective failure mode frequencies were different. Group GFP had exclusively cohesive failure in the core, probably because the core was built up with composite resin; therefore, the lower fiber support in that portion may have predisposed the core to this mode of failure when loading,[24] before any adhesive failure could occur. In contrast, Group CAD/CAM had a lower rate of cohesive failure in the core compared to Group GFP, which can be explained by the fact that CAD/CAM is fabricated by a controlled industrial milling process, which allows a highly accurate adaptation of the post to the post space, unlike prefabricated GFPs. This condition enables a higher concentration of fibers, especially in the cervical portion, where prefabricated GFPs have limitations. Thus, CAD/CAM displayed a better biomechanical behavior than GFPs, considering that a lower concentration of fibers can lead to post fragility. Furthermore, the more accurate reproduction of intraradicular anatomy provided by CAD/CAM could, in principle, enable luting with a thinner cement film and potentially generate less stress from polymerization shrinkage and more favorable retention conditions.[11,22] Notwithstanding, the post/resin cement interface is still a weak link in post retention[10] and may explain the occurrence of equal frequencies of adhesive failures and cohesive failures in the core in this group.

CONCLUSION

The fracture resistance of CAD/CAM-fabricated glassfiber posts and cores was comparable to that of cast posts and cores, and they were not associated with irreparable root fractures. Therefore, CAD/CAM-fabricated glassfiber posts and cores can be considered an effective method for restoring endodontically treated teeth.

REFERENCES

1. Stricker EJ, Göhring TN. Influence of different posts and cores on marginal adaptation, fracture resistance, and fracture mode of composite resin crowns on human mandibular premolars. An in vitro study. J Dent 2006;34(5):326–335. DOI: 10.1016/j.jdent.2005.07.007.
2. Zhou L, Wang Q. Comparison of fracture resistance between cast posts and fiber posts: a meta-analysis of literature. J Endod 2013;39(1):11–15. DOI: 10.1016/j.joen.2012.09.026.
3. Maslamani M, Khalaf M, Mitra AK. Association of quality of coronal filling with the outcome of endodontic treatment: a follow-up study. Dent J 2017;5(1):1–8. DOI: 10.3390/dj5010005.
4. Habibzadeh S, Rajati HR, Hajmiragha H, et al. Fracture resistances of zirconia, cast Ni-Cr, and fiber-glass composite posts under all-ceramic crowns in endodontically treated premolars. J Adv Prosthodont 2017;9(3):170–175. DOI: 10.4047/jap.2017.9.3.170.
5. Haralur SB, Ahmari AMM, Alqarni SA, et al. The effect of intraradicular multiple fiber and cast posts on the fracture resistance of endodontically treated teeth with wide root canals. Biomed Res Int 2018;2018:16714981-6. DOI: 10.1155/2018/1671498.

6. Bilgin MS, Erdem A, Dilber E, et al. Comparison of fracture resistance between cast, CAD/CAM milling, and direct metal sintering metal post systems. J Prosthodont Res 2016;60(1):23–28. DOI: 10.1016/j.jpor.2015.08.001.
7. Costa RG, Morais ECC, Leão MP, et al. Three-year follow up of customized glass fiber esthetic posts. Eur J Dent 2011;5(1):107–112. DOI: 10.1055/s-0039-1698865.
8. Spina DRRF, Costa RG, Farias IC, et al. CAD/CAM post-and-core using different esthetic materials: fracture resistance and bond strengths. Am J Dent 2017;30(6):299–304.
9. Tsintsadze N, Juloski J, Carrabba M, et al. Performance of CAD/CAM fabricated fiber posts in oval-shaped root canals: an in vitro study. Am J Dent 2017;30(5):248–254.
10. Garcia PP, Costa RG, Garcia AV, et al. Effect of surface treatments on the bond strength of CAD/CAM fiberglass posts. J Clin Exp Dent 2018;10(6):591–597. DOI: 10.4317/jced.54904.
11. Andrade GS, Tribst JP, Bottino MA, et al. A study on stress distribution to cement layer and root dentin for post and cores made of CAD/CAM materials with different elasticity modulus in the absence of ferrule. J Clin Exp Dent 2019;11(1):1–8. DOI: 10.4317/jced.55295.
12. Eid R, Juloski J, Ounsi H, et al. Fracture resistance and failure pattern of endodontically treated teeth restored with computer-aided design/computer-aided manufacturing post and cores: a pilot study. J Contemp Dent Pract 2019;20(1):56–63. DOI: 10.5005/jp-journals-10024-2476.
13. Pang J, Feng C, Zhu X, et al. Fracture behaviors of maxillary central incisors with flared root canals restored with CAD/CAM integrated glass fiber post-and-core. Dent Mater J 2019;38(1):114–119. DOI: 10.4012/dmj.2017-394.
14. Guo J, Wang Z, Li X, et al. A comparison of the fracture resistances of endodontically treated mandibular premolars restored with endocrowns and glass fiber post-core retained conventional crowns. J Adv Prosthodont 2016;8(6):489–493. DOI: 10.4047/jap.2016.8.6.489.
15. Kim AR, Lim HP, Yang HS, et al. Effect of ferrule on the fracture resistance of mandibular premolars with prefabricated posts and cores. J Adv Prosthodont 2017;9(5):328–334. DOI: 10.4047/jap.2017.9.5.328.
16. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol 1971;32(2):271–275. DOI: 10.1016/0030-4220(71)90230-1.
17. Stegaroiu R, Yamada H, Kusakari H, et al. Retention and failure mode after cyclic loading in two post and core systems. J Prosthet Dent 1996;75(5):506–511. DOI: 10.1016/s0022-3913(96)90454-0.
18. Gomes GM, Gomes OM, Reis A, et al. Effect of operator experience on the outcome of fiber post cementation with different resin cements. Oper Dent 2013;38(5):555–564. DOI: 10.2341/11-494-L.
19. Sarkis-Onofre R, Skupien JA, Cenci MS, et al. The role of resin cement on bond strength of glass-fiber posts luted into root canals: a systematic review and meta-analysis of in vitro studies. Oper Dent 2014;39(1):31–44. DOI: 10.2341/13-070-LIT.
20. Kul E, Yanıkoğlu N, Yeşildal Yeter K, et al. A comparison of the fracture resistance of premolars without a ferrule with different post systems. J Prosthet Dent 2020;123(3):523.e1–523.e5. DOI: 10.1016/j.prosdent.2019.08.018.
21. Stawarczyk B, Liebermann A, Eichberger M, et al. Evaluation of mechanical and optical behavior of current esthetic dental restorative CAD/CAM composites. J Mech Behav Biomed Mater 2015;55:1–11. DOI: 10.1016/j.jmbbm.2015.10.004
22. Costa RG, Freire A, Morais ECC, et al. Effect of CAD/CAM glass fiber post-core on cement micromorphology and fracture resistance of endodontically treated roots. Am J Dent 2017;30(1):3–8.
23. Salameh Z, Sorrentino R, Ounsi HF, et al. The effect of different full-coverage crown systems on fracture resistance and failure pattern of endodontically treated maxillary incisors restored with and without glass fiber post. J Endod 2008;34(7):842–846. DOI: 10.1016/j.joen.2008.03.025.
24. Chieruzzi M, Pagano S, Pennacchi M, et al. Compressive and flexural behavior of fiber reinforced endodontic posts. J Dent 2012;40(11):968–978. DOI: 10.1016/j.jdent.2012.08.003.