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Fracture Resistance and Failure Mode of Custom-made Post-and-cores of Polyetheretherketone and Nano-ceramic Composite

KN Teixeira • TM Duque • HP Maia • TMSV Gonçalves

Clinical Relevance

Custom-made post-and-cores of polyetheretherketone (PEEK) and nano-ceramic composite showed good fracture resistance and failure mode. Clinicians should be aware that these materials might be an efficient alternative for post-and-cores, because they promote esthetics while reducing the risk of root fractures.

SUMMARY

Purpose: The purpose of this study was to evaluate the fracture resistance and failure mode of custom-made post-and-cores manufactured with different esthetic materials.

Methods and Materials: A total of 48 mandibular premolar extracted teeth were selected, endodontically treated, and prepared to receive the posts. Specimens were randomly divided into four groups (n=12/group): group 1, polyetheretherketone (PEEK, Degos; G1); group 2, nano-ceramic composite (Lava Ultimate, 3M ESPE; G2); group 3, cast metal post (NiCr alloy, control; G3); group 4, fiberglass post (Whitepost, FGM, control; G4) customized with a nano-hybrid resin composite (Z250, 3M ESPE). Experimental post-and-cores (G1 and G2) were manufactured with a computer-aided design/computer-aided manufacturing system. All posts were cemented with self-adhesive resin cement (Rely X U200, 3M ESPE), and specimens were stored in distilled water at 37°C for 60 days. A universal testing machine was used to measure the fracture resistance (0.5 mm/min at an angle of 45° to the long axis of the tooth). Fractures were classified as repairable or catastrophic. One-way analysis of variance with Tukey post hoc and χ^2 tests for independence and Bonferroni adjustments were applied (α=0.05).

Results: The fracture resistance values (mean ± SD, in newtons) were 379.4 ± 119.8 (G1), 506.4 ± 138 (G2), 939.6 ± 146.5 (G3), and 449.6 ± 66.5 (G4). Only G3 exhibited a significant difference (*p*<0.05). The χ^2 test showed an

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association between failure mode and post-and-core material [$\chi^2(3) = 23.65; p<0.001$]. After Bonferroni adjustment, only G3 presented a higher than expected incidence of catastrophic failures ($p<0.001$). In the remaining groups, most failures were repairable and related to debonding.

Conclusions: Customized post-and-cores of PEEK and nano-ceramic composites exhibited good mechanical performance. Their fracture resistance was comparable to that observed for fiberglass customized posts, yet lower than that for cast metal posts. For PEEK post-and-cores, in particular, additional studies are needed to improve adhesiveness and reduce the risk of debonding.

INTRODUCTION

Fractures can develop as a result of endodontic treatment.[1,2] In theory, medicaments and irrigants used during root canal treatment can lead to dehydration of the tooth hard tissue, thereby weakening both the compressive and tensile strengths of dentin structure.[2,3] On the other hand, several studies[4-7] have demonstrated that the moisture of dentin remains stable, and these findings do not support such theory. The amount of remnant hard tissue present also appears to be a crucial factor for the long-term performance of the root-filled teeth.[7,8] In particular, a "ferrule effect" has been observed when at least 1.5 mm of tissue remains, and this is associated with increasing the longevity of post-endodontic restorations.[9,10]

In cases where excessive loss of dental structure has occurred and a ferrule effect is not predicted, a post-and-core system can provide structural retention of filler materials and distribution of occlusal stress along the remaining tooth structure.[9,10] In the past, only rigid posts were available, and most of them were metallic.[11] Although this kind of metal post-and-core is still popular, if the root is overloaded, a catastrophic failure may occur. The latter may involve a vertical or deep root fracture with this kind of post.[11] Failure appears to be related to the modulus of elasticity of the metal used, which is higher than that of the supporting dentin.[12] According to Newman and others,[13] the load to failure of a stainless steel post-and-core is significantly stronger than the load to failure of composite post-and-cores. Alternatively, the failure mode and deflection of a fiber-reinforced composite post-and-core appear to indicate that the remaining tooth structure is protected from fracture.

Some additional materials have also been tested in clinical protocols to prevent catastrophic failures of endodontically treated roots.[13,14] According to Lanza and others,[15] an ideal material for a post-and-core system should be sufficiently elastic to accompany the natural flexural movements of the tooth. Post-and-core materials with biomechanical properties similar to the dentin could also be advantageous in reducing the risk of root fractures.[9,15] Examples of these materials are the high-performance polymers, such as polyetheretherketone (PEEK) and polyetherketoneketone (PEKK), and nano-ceramic composites, such as the LAVA Ultimate (3M ESPE, Neuss, Germany) with 80% of ceramic nanoparticles.[16,17] Authors emphasize that PEEK and PEKK are produced as several brands, and at this point of introduction, we are not specifying a manufacturer in particular; we are talking about the materials themselves.

A previous study revealed that PEKK (246 MPa) has a similar compression strength to dentin (297 MPa), yet a lower modulus of elasticity (5.1 GPa) compared with dentin (15 GPa).[17] In addition, these materials are easily processed by milling in a computer-aided design/computer-aided manufacturing (CAD/CAM) system, allowing the fabrication of a single-piece post-and-core.[18,19] This custom-made and industrially controlled process improves the mechanical behavior of the post-and-core system, resulting in an excellent adaptation of the post to the root canal walls.[20] It significantly reduces the thickness of the cement layer while increasing the frictional retention of the post, which improves the mechanical behavior of the post.[20]

Previous studies have shown that PEEK and PEKK are biocompatible and present good mechanical strength, shock-absorbing ability, and both chemical and thermal resistance.[18,19] However, only a few studies have evaluated PEEK and PEKK applied as post-core materials.[16,17] According to an *in silico* analysis,[16] PEKK posts showed a more favorable stress distribution compared with the conventional post-and-core materials, such as gold and fiberglass. On the other hand, a higher probability of debonding has been associated with PEKK posts because the inert surface of this material is dependent on the effectiveness of the surface treatment performed. Thus, use of such materials may potentially reduce the incidence of root fractures, However, additional experimental and clinical comparative studies are necessary to prove this theory.

Therefore, the aim of this laboratory study was to evaluate the fracture resistance and failure mode of experimental post-and-cores fabricated with PEEK and nano-ceramic composites by comparing them with conventional post-and-core materials (eg, metal and customized fiberglass). The null hypotheses tested were: 1) there is no difference between the post-and-cores (PEEK and nano-ceramic composite) in terms of fracture resistance and failure mode, and (2) there is no difference in the fracture resistance or failure mode of the post-and-core materials (eg, PEEK and nano-ceramic composite) compared with controls (eg, metal and customized fiberglass).

METHODS AND MATERIALS

Experimental Design

To test the fracture resistance and failure mode of different post-and-core materials, this laboratory experimental study was performed with a randomized and blinded design. To determine the number of specimens that would be required for each test group, a power analysis was calculated using G Power software (version 3.0.10, 2008). Considering four groups, one-way analysis of variance (ANOVA), an effect size of 0.97 and power of 95% (α=0.05), a sample of 12 specimens per group was indicated to detect significant differences. Different post-and-core materials (PEEK, nano-ceramic composite [Lava Ultimate, 3M ESPE], nickel-chromium alloy, and fiberglass customized with nano-hybrid resin composite [Z250, 3M ESPE]) were tested.

Preparation of Specimens

A total of 48 human mandibular premolar teeth with similar anatomic root canals extracted for periodontal or orthodontic reasons were selected for this study. All specimens demonstrated fully developed apices and had no cracks, caries, restorations, abrasion, erosion, or fractures. Before extraction of teeth, all patients gave consent for their teeth to be used for research purposes. The donors were fully and irreversibly made anonymous.

The bucco-lingual and mesio-distal dimensions of the teeth were measured at the highest bulge with a digital caliper (Starrett, Itú, Brazil). Teeth were carefully cleaned with periodontal curettes (Duflex, SS White, Juiz de Fora, Brazil) and stored in 0.1% thymol solution at 4°C until used. The crowns were removed at the cement-enamel junction (CEJ) with a low-speed diamond saw (Isomet-1000, Buehler, Lake Bluff, IL, USA) under water cooling to give a uniform 14-mm measurement from the apex to the CEJ. Each root was embedded in acrylic resin (Jet, Classico, Campo Limpo Paulista, Brazil), up to 2.0 mm short of the cervical portion, using a circular polyvinyl chloride cylinder (25 mm in diameter $\times$ 25 mm high). The set (tooth, matrix, and resin) remained immobile for 72 hours to ensure resin setting.

Endodontic treatment was then performed on all 48 teeth. Root canals were prepared by a single operator using a Wave one file (Dentsply Maillefer, Ballaigues, Switzerland) 1 mm short of the apex. Next, they were irrigated copiously with 1% sodium hypochlorite solution (Asfer Industrial Química, São Caetano do Sul, Brazil) throughout chemomechanical preparation and dried with absorbent paper points (Dentsply Maillefer). The root canals were filled with gutta-percha and AH Plus sealer (Dentsply Maillefer) using the cold lateral compaction technique. They were then immersed in distilled water and incubated at 37°C ± 1°C for 36 hours, corresponding to three times the endodontic sealer setting time, as recommended by the manufacturer.

The post-and-core space was prepared using #2 and #3 drills (Largo, Dentsply Maillefer) to remove 10 mm of gutta-percha from each root canal.[21,22] This procedure was performed without irrigation because the heat produced by the drill improved gutta-percha removal.[22] Any residual gutta-percha on the walls of the post space was detected with radiographic imaging. To standardize the post space, a fiberglass system drill (Whitepost DC, FGM, Joinville, Brazil) (corresponding to 0.5 post) was used to finish the root canal preparation (10 mm in length).

After each root was prepared, the corresponding teeth were randomly assigned to four groups (n=12/group) according to the material used to manufacture the post-and-core (Figure 1): group 1, PEEK (DEGOS, Germany; G1); group 2, nano-ceramic composite (Lava Ultimate, 3M ESPE; G2); group 3, cast metal post (nickel–chromium (NiCr) alloy (Talmax, Brazil) (control 1; G3); group 4, fiberglass (Whitepost, FGM) customized with a nano-hybrid resin composite (Z250, 3M ESPE, St. Paul, MN, USA) (control 2; G4).

In groups 1-3, a standard resin pattern for the post-and-cores was established with prefabricated resin pins (Pin Jet, Angelus, Brazil) and an acrylic resin (Pattern Resin LS, GC, Japan). Briefly, a distance of 10 mm was marked from the resin pin to the tip to guarantee that it would be completely inserted into the prepared root canal. After, the root canal space was then isolated with water-soluble gel

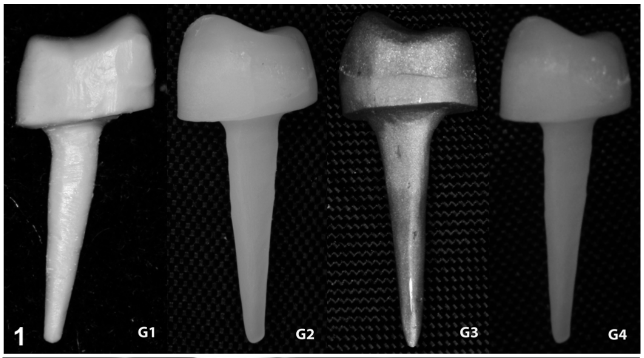

Figure 1. *Representative customized post-and-core from each group. G1, specimen (PEEK post-and-core); G2, specimen (nano-ceramic composite [Lava Ultimate] post-and core); G3, specimen (metal cast post-and core); G4, specimen (fiberglass customized with nano-hybrid resin composite post-and core).*

Figure 2. *Loading tip position on the post-and-cores and for the load test setup.*

(KY, Johnson & Johnson, Brazil), a resin pin covered with the acrylic resin was inserted into the canal space once more to capture the internal anatomy of the root canal. The pin remained in the canal space until the complete polymerization of the acrylic resin was achieved.

To standardize the size and shape of the core, a master post-and-core pattern was produced (4×4 mm^2), with acrylic resin (Pattern Resin LS, GC) in a standard root. This master pattern was positioned into the root and then the core was molded with silicone elastomeric impression material (Empress XT, 3M ESPE) To fabricate the cores for the remaining posts, a silicone mold was filled with acrylic resin (Pattern Resin LS, GC) and then positioned over each root containing an acrylic resin pin. The resin pin was responsible for obtaining an impression of the internal anatomy of each root canal. This procedure was intended to standardize the production of post-and-cores for all groups. The corresponding acrylic resin post-and-cores produced for each root were maintained in water at room temperature for 24 hours to allow the release of monomers.

A melting cast technique and NiCr alloy (Talmax) were used to transform the resin pattern into the specimens of group 3. For the specimens of groups 1 and 2, the post-and-core resin pattern was digitally scanned (Identica Hybrid, MEDIT, Korea) and modeled with a CAD/CAM system (Dental CAD v 2.2, Exocad, Germany). Milling of the PEEK (Degos) and nano-ceramic composite (Lava Ultimate) blocks was performed by using a CAM system (S1 CAD/CAM Milling 5-Axis, VHF, Germany).

In group 4, the 0.5 post of the fiberglass system (Whitepost DC, FGM) was tested in the root to verify its capacity to achieve an internal adaptation. Briefly, the root canal space was first lubricated with a hydrosoluble gel (KY Lubricating Gel, Johnson and Johnson) and then coated with a nano-hybrid resin composite (Z250, 3M ESPE). The post was subsequently inserted into the canal, according to Gomes and others.[23] After excess resin was removed, the set was light cured for 40 seconds at 800 mW/cm^2 with a LED light-curing unit (Valo Cordless; Ultradent Products, South Jordan, UT, USA). Following polymerization, the post was removed from the canal, thereby producing a customized fiberglass post. The core was also standardized by applying the same method described above to produce a silicon elastomeric impression mold. After the composite resin filling the mold was light cured, a standardized core shape was obtained. The goal of this procedure was to produce similar cores for all groups, thereby reducing interference during the mechanical tests.[24]

Each finished post-and-core received a surface treatment as recommended by the manufacturer's instructions. Briefly, the post-and-cores of groups 1 and 4 were sandblasted with aluminum oxide (Al_2O_3) (for five seconds at a 30-mm distance) and washed in an ultrasonic machine. A bonding agent (Rely X ceramic primer, 3M ESPE) was subsequently applied. The group 2 post surfaces were etched with 37% phosphoric acid, washed, and then cleaned with pure water (20 seconds). In group 4, the post surfaces were cleaned with 70% alcohol, followed by application of a bonding agent (Visio.link, Bredent, Germany). Excess of adhesive on each post was removed with air jets (10 seconds). All of the bonding agents were light cured for 40 seconds at 800 mW/cm^2 with a LED light-curing unit (Valo Cordless, Ultradent).

Before post-and-core cementation, the smear layer of each prepared root canal space was removed with 3 mL 17% ethylenediaminetetraacetic acid (EDTA) solution for three minutes. After the space was flushed with 5 mL saline solution, the canals were dried with absorbent paper points (Dentsply Maillefer). A bonding agent (Adper Scotchbond Multipurpose Plus, 3M ESPE) was then applied before a self-adhesive dual-polymerized cement (RelyX U200, 3M ESPE) was applied into the root canal. The post-and-core was subsequently inserted. To standardize the force applied during cementation, a special device of the universal testing machine (4444, Instron Corporation, Norwood, MA, USA) was set to apply a constant load of 50 N for six minutes. After the excess cement was removed, an LED light-curing unit (Valo Cordless, Ultradent) (800 mW/cm^2) was applied, according to manufacturer's instructions. The specimens were stored in distilled water at 37°C for 60 days (aging simulation).

Fracture Resistance and Fracture Mode Analyses

The universal testing machine (4444, Instron Corporation) was used to evaluate fracture resistance. An increasing oblique compressive load (45°) was applied directly on the buccal edge of the core using a knife-shaped device with a round tip (2 mm diameter). The load was applied at a crosshead speed of 0.5 mm/min until fracture. The maximum failure load was recorded in newtons.

Fracture analysis was visually performed under a magnifying glass (Kozo Optical and Electronical Instruments Co Ltd, Nanjing, China) providing 3.5× magnification. For the cases involving catastrophic failure, the root fragment was removed from the acrylic resin with a Kelly hemostatic forceps to better observe the fracture present. A fracture was then classified as repairable when the fracture line was above the simulated bone level or catastrophic when a vertical root fracture was observed or if the fracture line was below the simulated bone level.

Statistical Analysis

After testing for normal distribution using the Shapiro-Wilk test, load to failure between groups was compared with one-way ANOVA. Furthermore, Tukey's honestly significant difference (HSD) post hoc test was performed for multiple comparisons. Failure mode was also analyzed with the χ^2 test and Bonferroni adjustments. The α level was set at 0.05 for all statistical testing.

RESULTS

Results for the fracture resistance test are shown in Table 1. A significant difference was observed among the materials tested in regard to fracture resistance. The cast metal post group (G3) exhibited significantly higher values of fracture resistance compared with the other groups (G1, G2, and G4; $p<0.0001$). The PEEK (G1) and nano-ceramic composite (Lava Ultimate, 3M ESPE) (G2) groups did not differ from each other or from G4, in terms of fracture resistance.

Figure 1 illustrates finished posts of each group and an example of the customized PEEK post-and-core, cemented to the root, before and after fracture resistance analysis. Figure 2 illustrates the percentage of repairable and catastrophic failures observed in each group. Most failures observed were noncatastrophic with repairable failures, and they affected 62.5% of all of the specimens examined.

The $\chi2$ test identified an association between failure mode and post-and-core material [$\chi2(3) = 23.65$; $p<0.001$]. After Bonferroni adjustment, only G3 presented a higher than expected incidence of catastrophic failures ($p<0.001$). In the remaining groups, the differences were not significant ($p>0.05$).

In particular, all repairable failures observed at G1 were related to the post-core debonding, whereas in groups 2 and 4, these failures were more often linked to core chipping or fracture. The unique repairable failure observed in G3 was found to be related to post debonding.

Table 1: *Mean Values ± SD for Fracture Resistance (N) According to Each Group*

Groups	Post-and-core Composition	n	Mean ± SD[a]	95% CI for Mean	
				Lower Bound	Upper Bound
G1	PEEK (Degos)	12	379.4 ± 119.8 A	303.3	455.5
G2	Nano-ceramic composite (Lava Ultimate)	12	506.4 ± 138 A	418.7	594.1
G3	NiCr cast (Talmax)	12	939.6 ± 146.5 B	846.5	1032.7
G4	Fiberglass customized nano-hybrid resin composite (Z250)	12	449.6 ± 66.5 A	407.4	491.9

[a] *Means followed by different letters show significant difference (one-way ANOVA and Tukey HSD)*

DISCUSSION

To avoid catastrophic failures, several materials have been tested as post-and-core systems, especially those presenting biomechanical properties similar to that of the dentin. Moreover, the use of CAD/CAM techniques provides an industrially controlled milling process with standard and homogeneous material blocks. As a result, the biomechanical behavior of such materials is improved. Although previous studies[20,25-27] evaluated CAD/CAM post-and-core systems, to the best of the authors' knowledge, none of them analyzed the use of PEEK as a CAD/CAM post-and-core material.

Data support the acceptance of the first null hypothesis because similar mechanical behavior was observed when comparing fracture resistance and failure mode of the two experimental materials, namely PEEK and nano-ceramic composite (Lava Ultimate; groups 1 and 2). Literature regarding the mechanical behavior of PEEK post-and-cores milled in a CAD/CAM system is scarce, making it difficult to compare results. However, a previous *in silico* study[16] revealed that, in comparison to dentin, PEEK had similar flexural strength (PEEK, 200 MPa; dentin, 212.9 MPa) but lower elastic modulus (PEEK, 5.1 GPa; dentin, 18.6 GPa). As a consequence, PEEK induces lower stress in the post-and-core components, mainly because of the flexibility of this material.[16] In contrast, when the PEEK post is overloaded, stress is concentrated on the adjacent cement and core.[16] This may explain the higher incidence of post-cement debonding we observed in group 1. Beyond that, in most debonding cases, the remaining cement was left inside the root canal. It is known that PEEK has an inert surface, making the bonding procedure a challenging step.[19] In the present study, all of the PEEK posts were conditioned as recommended by the manufacturer. However, it appears that the surface treatment applied was not sufficient to prevent failures at the adhesive interface between PEEK and the resin cement. Moreover, fracture resistance of the PEEK group was comparable to that of G2 and G4. Thus, further studies are necessary to evaluate the long-term clinical performance of such posts and to improve the bonding between posts and adhesive cements.

Fracture resistance observed in the nano-ceramic composite group (506.4±138 N) was lower than previously documented in the literature.[20] According to Falcão Spina and others,[20] a fracture resistance of 621.3 ± 100.3 N was detected when nano-ceramic composite post-and-cores were analyzed. These contradictory results might be attributed to differences in methodology, but a similar mechanical behavior was evident in both studies. It is known that the elastic modulus of nano-ceramic composite (13 GPa) is similar to that of dentin (18 GPa).[28] The high number of nanoparticles (80%) and the homogeneity of the CAD/CAM blocks would also provide a better biomechanical force distribution in function. It might explain the high values of fracture resistance presented in G2 and the higher incidence of root fracture compared with G1 (PEEK) and G4 (fiberglass customized with a nano-hybrid resin composite).

It is important to emphasize that the values of fracture resistance observed in both present and previous[20] studies were higher than those corresponding to a normal adult occlusal force, which varies from 190-290 N (in the anterior teeth) to 200-360 N (in the posterior region).[29] Biofeedback of the periodontal receptors also acts to inhibit excessive muscle activity, avoiding damage to the tooth.[30] It significantly reduces the chance of catastrophic failure of the post-and-core systems in a real clinical situation.

A second null hypothesis was also raised, claiming no differences in fracture resistance or failure mode between the customized post-and-core materials (G1 and G2) and controls (G3 and G4). Based on these results, this hypothesis was rejected, in part, because significantly higher values of fracture resistance and a greater incidence of catastrophic failures were observed in the cast metal post-and-core group (G3, control 1; $p<0.0001$). This result was predicted, because the modulus of elasticity of the NiCr alloy (200 GPa) is much higher than that of dentin (18 GPa) and the other post materials (PEEK, 5.1 GPa; nano-ceramic composite, 13 GPa; customized fiberglass post, 53.8 GPa).[16,20,31] Therefore, under excessive loading, the cast metal post produces a slow-growing crack that causes successive adhesive failure at the post–cement–root dentin interface.[32] It leads to the mobility of the post within the root, consequently acting like a wedge.[32] Thus, the energy accumulated in the inner post is transferred to the dentin, causing root fracture.[32] This might explain the fracture behavior observed in this group, where most failures were catastrophic (91.6%). The exclusive repairable failure, observed in G3 (cast metal post), was related to debonding, which agrees with the theory described.

When we compared the G1 (PEEK) and G2 (nano-ceramic composite) experimental groups to the second control group, G4 (fiberglass post customized with nano-hybrid resin composite), the second null hypothesis was accepted, because no differences were observed. Although one study[33] reported higher values of fracture resistance for fiberglass post-and-cores, the results of the present study are consistent with other previous studies.[20,32] There are a few possible reasons for these discrepancies. First, in the study with higher values,[33] all the fiberglass post-and-cores received a cemented ceramic crown, and this may have improved the mechanical behavior of the post-and-core system. Second, the materials of all three groups (G1, G2, and G3) present similar moduli of elasticity, which are similar to that of dentin. As a result, load distribution is improved concomitant with a reduced risk of catastrophic failures. Third, all post-and-cores of G1-G3 were customized, thereby increasing adaptation of the posts to the root walls and reducing thickness of the resin cement. This customization was achieved with CAD/CAM techniques or with a fiberglass post relining technique performed with a nano-hybrid resin composite, which captured the anatomy of the root canal. Thus, good post adaptation was found to increase frictional retention, thereby resulting in a better performance of the post-and-core systems.[34] This characteristic, in addition to the modulus of elasticity involved, may have contributed to a reduction in the incidence of nonrepairable fractures of such posts compared with the metal cast post of G3. Similar mechanical behavior has been reported in previous studies.[20,35]

Nowadays, esthetics is important to both patients and clinicians. In this sense, new esthetic materials, such as PEEK, nano-ceramic composite, and fiberglass, seem to be good options for clinical practice. In addition, the use of CAD/CAM techniques produces a well-adapted post unit, with color compatibility, good optimal properties and mechanical resistance, and lower incidence of nonrepairable root fracture. Furthermore, blocks are also available in different shades, improving the esthetic outcomes, especially important for anterior restorations.

The results of the present study appear promising, although they should be interpreted with caution due to the limitations inherent to a laboratory study. For example, a single crown was not cemented to the different post-and-core systems tested. It is known that the use of crowns may influence the bonding performance of the post-and-cores because crowns can exert an additional protective factor to avoid catastrophic failures.[20] The aim of the present study was to evaluate the mechanical behavior of four different materials for post-and-core. Use of cemented crowns could potentially represent an external influence on force distribution, thereby interfering with the results obtained. For this reason, we applied a mechanical test directly to the cemented post-and-cores in the present study. Second, only single-rooted lower premolars were used, and a load was applied at a 45° angle. These parameters were selected because they present the worst case scenario regarding fracture resistance of endodontically treated teeth, which is the most suitable method for evaluating the behavior of post-and-core.[36] In addition, to achieve maximum standardization and reduce possible interferences during the mechanical test, the coronal part (core) of all posts was assembled based on a master pattern core, as described in the methods. Therefore, core sizes and dimensions were similar in all groups, as shown in Figure 1.

Finally, in the present laboratory study, static force was used to evaluate fracture resistance, and specimens were only stored in distilled water at 37°C for 60 days without thermocycling. Although the results might be useful in predicting clinical function, it is suggested that the effect of other factors, such as thermocycling and other dynamic fatigue tests or surrogate models, must be tested to more realistically evaluate the clinical applicability of the PEEK and nano-ceramic composite post-and-core systems. Another point of concern is related to the bonding strength of such experimental post-and-cores. Further studies should investigate the so-

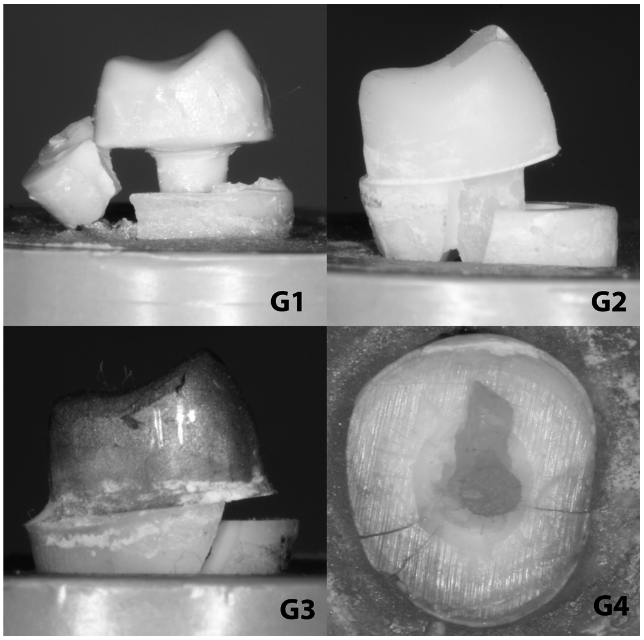

Figure 3. *Catastrophic failures observed. G1, specimen (PEEK post-and-core); G2, specimen (nano-ceramic composite [Lava Ultimate] post-and core); G3, specimen (metal cast post-and core); G4, specimen (fiberglass customized with nano-hybrid resin composite post-and core).*

called ideal bond strength, which must be strong enough to ensure the long-term clinical success of the restoration.

CONCLUSIONS

Within the limitations of this laboratory study, the following conclusions were drawn regarding the use of new materials for post-and-core systems. Customized post-and-cores manufactured with PEEK and a nano-ceramic composite exhibited good mechanical performance. Moreover, the fracture resistance of these post-and-cores was comparable to that of fiberglass posts customized with a nano-hybrid resin composite and lower than that of cast metal posts. The high incidence of debonding observed for PEEK post-and-cores requires further study, especially regarding the post surface conditioning. Due to the lower incidence of catastrophic failures and mechanical properties comparable to those of fiberglass customized posts, these esthetic materials should be considered as alternatives, especially when produced with CAD/CAM milling systems.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the Research Ethics Committee of the Federal University of Santa Catarina The approval code issued for this study is: CAAE 49116315.0.0000.0121.

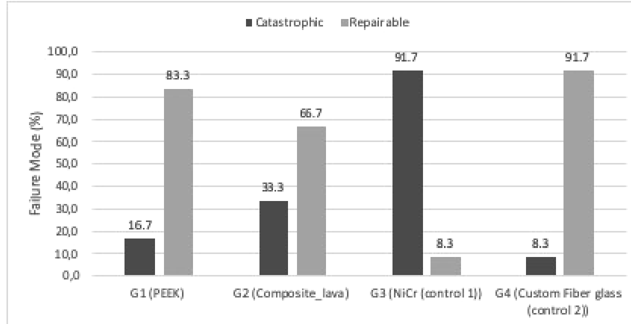

Figure 4. *Failure modes (catastrophic or repairable) observed in each post-and-core group (n=12/group).*

Conflict of Interest

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

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