Fracture Resistance of Different Post-core Systems Restoring Mandibular Premolars

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Abstract:

Objective: This in vitro study aimed to compare the fracture resistance between Milled Custom-made PEEK post and core, Pressed custom-made PEEK post and core and Customized fiber post and composite core. **Materials and Methods:** A total of 21 human mandibular premolar teeth with similar root form and root canal shape averaging cervico-occlusal length of the crown about 8+/-0.5 mm and 14.5+/-0.5 mm for root length were collected for this study, endodontic treatment was performed for all teeth followed by coronal decapitation 2mm above CEJ and post space preparation, After the preparation of each root, the corresponding teeth were allocated randomly to three groups (n=7/ group) according to the type of material and fabrication technique used to generate the post-and-core: GM, milled PEEK post and core; GP, pressed PEEK post and core; GC, customized fiber post and composite core. **Results:** There was a significant difference between different groups ($p<0.001$). PEEK milled group showed the highest mean fracture resistance value (1055.25±119.31 N) followed by PEEK pressed group (963.39±117.28 N) while customized fiber post group (625.85±69.69 N) showed the lowest mean value. **Conclusion:** On the basis of the results and conditions of this study, the following conclusions can be drawn: 1- PEEK post and core made by two fabrication techniques have surpassed the fracture resistance values of customized fiber post. 2- With the widespread of in-office CAD/CAM systems, milled PEEK may represent viable alternative for dental post materials according to the tested parameters.

Introduction

When taking into account the restoration of devitalized teeth, dental materials have to be able to restore this structure loss, in order to guarantee mechanical and functional properties, esthetics and preservation of coronal seal.[1]

A post-and-core might be essential to promote retention and resistance form for the tooth-restoration unit, when a full crown is the line of treatment needed to restore an endodontically treated tooth.[2]

The material of post-and-core should have mechanical and physical properties close to those of dentin so as to better tolerate the occlusal loads, preventing tooth fracture or de-bonding of the post.[2,3]

Referencing to previous studies, using post material with a lower elastic modulus, fiber glass for example, resulted in more favourable stress distribution. However, as fiber glass posts are supplied as ready-made products, they have limited conformity to the figures of the root canal. In addition, although fiber glass posts have reduced moduli of elasticity (from45.7 to 53.8GPa) than those of different metal alloy posts (110.0GPa for titanium and 95.0GPa for gold), these are still nearly three times the elastic modulus of dentin (18.6GPa).[4]

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Recently, a new biocompatible high performance polymers, PolyEtherEtherKetones (PEEKs), were introduced as new dental materials. Because of their acceptable fracture resistance, better shock-absorbing ability and stress distribution, high performance polymers are considered as alternative novel materials for metal and glass ceramics[5,6].

PEEK Young's modulus and tensile properties are similar to human bone[7], enamel and dentin. The material is available as either pellet or granulate for the pressing technology or as blanks for milling using the Computer Aided Design/Computer Aided Manufacturing technology (CAD/CAM).[8]

For the aforementioned characteristics of PEEK, this study was conducted to evaluate PEEK as a custom post material and study the effect of processing technique on fracture resistance of the produced restoration and compare it to the contemporary customized fiber post. The null hypothesis was that No significant differences in fracture resistance in the three different systems.

Materials and Methods:

Materials used:

In this in-vitro study custom-made and customized post and core were made by 3 fabrication techniques and two different materials; PEEK blank for milling (BioHPP, Bredent, Germany), PEEK granules for pressing (BioHPP granulat, Bredent, Germany); chemical composition of PEEK used (Polyetheretherketone (PEEK) 80%, Ceramic fillers (0.3-0.5μm) 20%, Pigments (Ti, Ni, Sb) O2 ≤ 1%), fiber post (relyx fiber post, 3M ESPE, Germany) which chemically composes of (highly radiopaque glass fibers embedded into a composite resin matrix) customized with micro-hybrid composite (Amaris, VOCO, Germany) chemically composes of (Inorganic fillers 80%, Methacrylate matrix (Bis-GMA, UDMA, TEGDMA) 20%) and a composite core which composes of (Bis-GMA, 2-Hydroxy-ethylmethacrylate, Triethyleneglycol-dimethacrylate, Benzoil peroxide, Photoinitiators).

Preparation of Specimens

To determine the number of specimens required for this study, a power analysis was calculated, a power analysis was designed to have adequate power to apply a 2-sided statistical test of the research hypothesis that there is no difference between the fracture resistance of posts made with different materials. According to the results of Maroulakos et al.[9] sample size was found to be total of 21 human mandibular premolars.

A total of 21 human mandibular premolar teeth with similar root form and root canal shape averaging cervico-occlusal length of the crown about 8+/-0.5 mm and 14.5+/-0.5 mm for root length were collected for this study. All specimens revealed fully developed apices and had no caries, cracks, restorations, erosion, abrasion, or fractures. Teeth were extracted for orthodontic or periodontal reasons, before teeth extraction all patients approved and gave consent for the teeth to be used for this study. The donors were made anonymous.

Teeth were carefully cleaned and stored in distilled water at room temperature until used. The crowns were decapitated 2mm above the level of the cement-enamel junction (CEJ) with a low-speed disc (Dental Fix, Canada).

Each root was embedded in acrylic resin (Acrostone, cold cure resin, Egypt), up to 2.0 mm short of the CEJ, using a circular polyvinyl chloride cylinder (25 mm in diameter 20 mm high). The set (tooth, matrix, and resin) remained stable for 72 hours to ensure setting of the resin.

Endodontic treatment was then done on all 21 teeth. Root canals were prepared by one operator.

Preparation of the post space was done using size #2 and #3 pesso reamer (Largo, Dentsply Maillefer) to remove 8 mm of gutta-percha from each root canal. This process was implemented without irrigation because the heat generated by the drill enhanced gutta-percha removal. Any residual gutta-percha on the post space walls was discovered with radiographic imaging. In order to standardize the post space, the corresponding blue drill (relyx fiber post, 3M ESPE, Germany) was utilized to finish and enlarge the preparation of the root canal (8 mm in length)(0.9 mm width apically) and the canal was enlarged leaving 2mm thickness dentin wall circumferentially, parallelometer dental surveyor (Nouvag AF30, Dentatek-Moers Gmbh, Germany) was used to standardize the long axis of drilling for all specimens.

After the preparation of each root, the corresponding teeth were allocated randomly to three groups (n=7/group) according to the type of material and fabrication technique used to generate the post-and-core: group 1; PEEK (BioHPP, Bredent, Germany; GM), group 2; PEEK (BioHPP granulat, Bredent, Germany; GP), group 3; fiberglass (relyx fiber post, 3M ESPE, Germany) customized with micro-hybrid resin composite (Amaris, VOCO, Germany) (control 1; GC).

For (GM) and (GP)

The post space of all samples of both groups was scanned with intraoral scanner (CEREC Omnicam, CEREC premium SW4.4, Dentsply Sirona). The produced scans were exported to inlab software (Inlab SW 15.1, Dentsply Sirona) using Sirona connect application.

Post and core were designed on each scan by one operator (Inlab SW 15.1, Dentsply Sirona), a cement space of 85 µm was selected and the margins of the core were designed 1 mm away from the enamel margin of the tooth and the core was 4 mm in height. (Figure1).

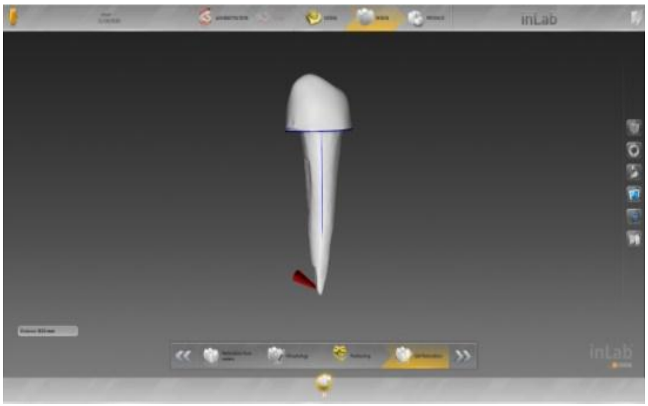

Figure (1):Designing the restoration

For GM group; the designs produced were milled into PEEK final restorations (BioHPP blank Brecam BioHPP Blank 98.5x12 Dentin, Bredent, Germany) using Inlab MCX5 milling machine (Sirona, Germany).

Fine cross-toothed carbide mills were used for cutting sprues and fine adjustments. The final restorations were then checked on their corresponding teeth.

For GP group; the designs were milled using Inlab MCX5 milling machine (Sirona, Germany) into wax patterns (CopraWax, WhitePeaks dental solutions, Germany).

The wax patterns were invested using special phosphate-bound investment material: powder (Gilvest HS, SRL Dental GmbH, Germany) and liquid (Gilvest liquid G high expanding, SRL Dental GmbH, Germany). The pressing procedure was completed fully automatically within 35 minutes after wax elimination, the restorations were then devested. A short water bath was used to guarantee freedom from dust and make the devesting process easier. The fine investment material residues were removed using a fine blasting device (Easyblast, BEGO, Germany), fine cross-toothed carbide mills were used for cutting sprues and fine adjustments. The final restorations were then checked on their corresponding teeth. (Figure 2)

Figure (2): Post and cores after finishing

GC group

For the third group GC; seven relyx fiber post 1.9mm at the coronal end and 0.9 mm diameter apically (relyx fiber post, 3M ESPE, Germany) were used, the post surfaces were properly cleaned by immersion in 70% alcohol for one minute and then dried using sterile gauze and silanized.

The customization was done with the direct use of micro-hybrid resin composite (Amaris, VOCO, Germany). The resin was layered on the post surface and the post/composite assembly was then inserted into the root canal formerly coated with a water-soluble gel (KY Gel, Johnson & Johnson, S˜ao Jos´e dos Campos, SP, Brazil), light-activation for 5 seconds was carried on, and was then lift from root canal and light-activated for additional 40 seconds. The posts were cleaned and silanized again. The insertion and removal axis was outlined with a marker pen on the post and the tooth.

After completing the customization process, the fiber post head was removed 4 mm above the coronal end of the specimen to allow core fabrication. For standard composite core production, a mould was constructed using transparent silicon bite registration material (CharmFlex® Bite registration impression material, Dentkist, Korea), the mould was made over one of the milled PEEK cores; a Universal Tofflemire Matrix Retainer (Premium instruments) and its band were placed over the prepared specimen encircling the coronal part of the prepared tooth and core then the bite registration material was injected using a small intraoral tip around the core till the border of the band, the material was left to complete its setting , after complete setting the mould was finished with diamond coated blue coated stone (Kerr, United states) to remove irregularities from the outer surfaces.

The tofflemire band and holder were placed to encircle the teeth of GC group, and the mould was then filled with core build up material (Dentocore, Itena, France) and placed over the trimmed fiber post into the confinement of the band, followed by light curing of the core for 40 seconds following the manufacturer instructions (SmartLite Focus, Dentsply, Sirona, Germany) with energy dose of 800mW/cm^2.

The mould was then removed and the core was checked for any defects to be corrected by flowable composite (Amaris flow, VOCO), finishing was then carried out using yellow coaded diamond stones (Kerr, United states).

Prior to cementation, the root canals were flushed with 2mL of distilled water to remove the residues of water soluble gel. The canals were dried using triple syringe with oil free air, to ensure complete drying absorbent paper cones (DentsplyMaillefer) were used.

In GM and GP groups, cementation regulations for Biohpp were followed according to the manufacturer instructions; sandblasting was done first, the posts were blasted with 110 µm aluminium oxide and 2-3 bar pressure. The blasting distance was 3 cm.

posts were coated with a visiolink primer layer (visiolink, bredent, Germany) then left for evaporation of the solvent and light cured for 90 seconds .

Self-adhesive resin cement G-CEM dual cure capsules (GC America) were used according to manufacturer's directions and injected into the root canal. Afterwards, posts were inserted into root canals and seated first by finger pressure then a seating device with 250 gm weight was used to standardize the seating pressure, soft curing was done for 5 seconds to allow proper excess cement removal and this was followed by complete curing for further 40 seconds in the cervical portion of the root, with a light cure (3M ESPE, Sumar´e, S˜ao Paulo, Brazil) and an energy dose of 800mW/cm2.

Aging and testing

All specimens were subjected to thermocycling by immersion in 2 water tanks (cold, warm) with temperatures of 5℃ and 55℃ (15 seconds cold, 15 seconds warm, 5 seconds water drip) for 5000 cycle (thermo scientific, ThermoFisher, USA), which represents approximately 6 months of clinical service. [10]

A Universal testing machine (5kN Universal Materials Testing Machine LR5KPlus) with 1mm diameter tip with blunt end was used to load the specimens along their long axis, load was applied in an ascending manner to the center of the core at a crosshead speed of 1mm/min till fracture occured, the load at which fracture occurs was recorded in Newotons (N)

Statistical analysis:

Numerical data were explored for normality by checking the data distribution, calculating the mean and median values and using Kolmogorov-Smirnov and Shapiro-Wilk tests. Data showed parametric distribution so; it was represented by mean and standard deviation (SD) values. One-way ANOVA followed by Tukey's post hoc test was used for intergroup comparison. The significance level was set at p ≤0.05 for all tests. Statistical analysis was performed with IBM (IBM Corporation, NY, USA.) SPSS (SPSS, Inc., an IBM Company) Statistics Version 26 for Windows.

Results:

1.Descriptive statistics:

Descriptive statistics for maximum load values (N) for different groups were presented in (Table 1).

2.Intergroup comparisons:

Mean and standard deviation (SD) values for maximum load values (N) for different groups were presented in (Table 2) and (Figure 3).

Table 1: Descriptive statistics for maximum load values (N) for different groups

Group	Mean	SD	Median	Min.	Max.
PEEK milled	1055.25	119.31	1034.00	939.65	1261.72
PEEK pressed	963.39	117.28	962.12	844.73	1128.67
Customized fiber post	625.85	69.69	630.50	539.23	708.88

Table 2: Mean ± standard deviation (SD) values of maximum load (N) in different groups

Maximum load (mean±SD)			p-value
PEEK milled	**PEEK pressed**	**Customized fiber post**	
1055.25 ± 119.31^{A}	963.39 ± 117.28^{A}	625.85 ± 69.69^{B}	<0.001*

; significant (p ≤ 0.05)

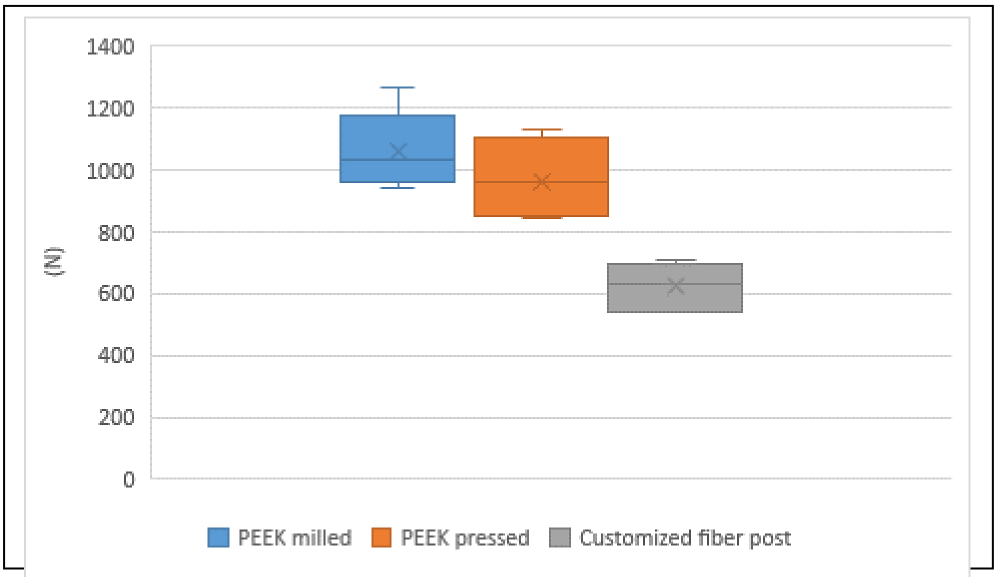

Figure (3): Bar chart showing fracture load values (N) for different groups

There was a significant difference between different groups (p<0.001). PEEK milled group showed the highest mean value (1055.25±119.31 N) followed by PEEK pressed group (963.39±117.28 N) while customized fiber post group (625.85±69.69 N) showed the lowest mean value. Pairwise comparisons showed that customized fiber post group had a significantly lower mean value than other groups (p<0.001).

Discussion:

The present study tested the performance of PEEK generated by two fabrication techniques as a possible dental post material by comparing it with the standard contemporary fiber post.

In this study natural teeth were used to best simulate the actual canal space and allow endodontic treatment for the teeth, mandibular premolars were selected as they have mostly a uniform root shape for the purpose of standardization and to minimize the effect of different post geometries on the results of fracture resistance.

The current study used the Universal testing machine for fracture resistance testing, a vertical load was applied as it seems to test more the cohesive properties of the tested materials and to distribute the stress more evenly between the dental tissues and the restorative material simulating a physiological occlusion.[11] Consequently, full coverage crowns were eliminated as they are known to increase the fracture resistance of ETT with fiber posts.[12]

The data gained from this study approves the refusal of the null-hypothesis, since the fracture resistance of differently produced restorations was statistically diverse, PEEK milled group showed the highest mean value (1055.25±119.31 N) followed by PEEK pressed group (963.39±117.28 N) while customized fiber post group (625.85±69.69 N) showed the lowest mean value. Pairwise comparisons showed that customized fiber post group had a significantly lower mean value compared to the other two groups ($p<0.001$), while the comparison between PEEK groups revealed insignificant differences.

These findings were found to be in harmony with the results of the study by Stawarczyk et al.[13] who assessed the influence of different fabrication methods of three-unit reinforced PEEK FDPs on fracture resistance. PEEK milling blanks are industrially pre-pressed, the milled restorations revealed slightly higher fracture resistance values than those pressed from granular PEEK. It could therefore be concluded that the industrial pre-pressing technique for the CAD/CAM blanks improve the mechanical characteristics as the industrial manufacture under optimal circumstances display a decreased risk of porosities within the restorations.[13] On the contrary, the mechanical properties of pressed restorations are more operator-dependent; the preheating process, the vacuum pressing equipment and other elements may affect the overall quality of the produced object.[13]

The mean fracture resistance recorded in the current study of milled reinforced PEEK (1055.25±119.31N) and pressed reinforced PEEK (963.39±117.28N) showed relatively lower values compared to the manufacturer released data concerning CAD/CAM milled three-unit PEEK FDPs, veneered with resin composite which displayed a mean fracture resistance of 2,055 N. In addition, results of the previously mentioned study[13] showed mean fracture loads of milled PEEK (2,354 N) and Pressed PEEK (1,738 N). This can be explained as different types of restorations were used, as 3 units FPDs have higher fracture resistance values than custom-made post and core.

Another study by Stawarczyk et al.[14] investigated the fracture resistance of CAD/CAM milled non-veneered three-unit PEEK fixed prosthesis frameworks with a connector area of 7.36 mm^2 revealed a restoration fracture resistance of 1,383 N with a deformation at approx. 1,200 N, these values are comparable to those in the present study.

For the customized fiber post with composite core group, the mean fracture resistance value obtained from the current study (625.85±69.69 N) was higher than those obtained from a study done by Teixeira et al.[15] who evaluated the fracture resistance and failure mode of custom-made post-and-cores manufactured with different esthetic materials, the mean fracture resistance value for the customized fiber post with composite core group was (449.6±66.5 N). This may be due to different angulation of the applied load to the long axis of the tooth, as the samples were placed in the universal testing machine with the load directed 45^0 to the buccal edge of the core.

It should be affirmed that the values of fracture resistance observed in this study 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).[16]

Finally, the results of this study might be directly related to the materials/ methodology utilized and might not reflect what could happen under different circumstances. The resin cement used was left to complete its setting at room temperature (25℃), which is few degrees less than body temperature. As known with other adhesive cements, the polymerization shrinkage, degree of polymerization, timing and reaction kinetics may have been influenced by the conditions of the study.[17,18] The failure loading protocol included aging-induced degradation of the adhesive interfaces (water storage of samples and thermocycling) but it did not involve a dynamic process that could simulate the oral conditions more accurately, also crowns were not used in order to prevent external impacts over force distribution, as the scope of this study was radicular events, but clinically results are expected to be higher as crowns act as protective factors preventing catastrophic failure involving the root.

Future studies should perform the comparison between groups of teeth with variable levels of idealistic tooth structure.

Conclusion:

On the basis of the results and conditions of this study, the following conclusions can be drawn:

1. PEEK post and core made by two fabrication techniques have surpassed the fracture resistance values of customized fiber post.
2. With the widespread of in-office CAD/CAM systems, milled PEEK may represent viable alternative for dental post materials according to the tested parameters.

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