ORIGINAL PAPER

FRACTURE RESISTANCE OF CUSTOM-MILLED CAD/CAM POST AND CORE USING TWO DIFFERENT MATERIALS: AN *IN VITRO* STUDY

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ABSTRACT

Introduction: Restoration of endodontically treated teeth could be challenging for dentists, as these teeth would be biomechanically compromised at multiple levels, such as tissue components and tooth structures.

Objectives: This study aimed to evaluate fracture resistance and failure modes of teeth restored with custom-milled posts and cores fabricated from polyetherketoneketone, fiber-reinforced resin materials, and prefabricated fiber posts.

Material and methods: Thirty mandibular premolars were used in the present study. After endodontic treatment, teeth were randomly assigned into three groups, i.e., MPP: restored with custom-milled posts and cores fabricated from polyetherketoneketone (PEKK); MFP: restored with custom-milled posts and cores fabricated from fiber-reinforced resin; and PFP: restored with prefabricated fiber-reinforced resin posts, then all samples were restored with metal crowns. Samples were subjected to a 45° shear force at the inner slope of buccal cusp to failure. One-way ANOVA for independent groups and χ^2 test at 0.05 statistical significance were applied.

Results: Differences between fracture resistance means of the three groups were not statistically significant ($p = 0.279 > 0.05$). The fracture resistance means for the MPP group was 423.2 ± 113.28 N; 356.90 ± 141.050 N for the MFP group; and 439.5 ± 100.616 N for the PFP group. As for failure types, no significant difference among the three groups was detected ($p = 0.366 > 0.05$). Regarding the failure modes, the reparable failure modes in each group, i.e., MPP, MFP, and PFP were 60%, 80%, and 50%, respectively.

Conclusions: Teeth restored with custom-milled posts and cores fabricated from PEKK and fiber-reinforced composite displayed an acceptable performance. Consequently, within the limitations of this study, these posts may be considered a good alternative to prefabricated fiber-reinforced posts.

Key words: shear force, fiber posts, polyetherketoneketone, custom posts, failure types.

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INTRODUCTION

Restoration of endodontically treated teeth (ETT) could be challenging for dentists, as these teeth would be biomechanically compromised at multiple levels, such as tissue components and tooth structures [1]. Several materials and clinical procedures were proposed for restoring ETT, depending on many factors, and considering the remaining dental tissues as the key factor in selecting the proper material/technique [2]. When the remaining dental tissues do not provide sufficient support for

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the restoration, posts and cores are considered a conventional technique to reinforce the tooth and improve the fracture resistance [1]. Several types of posts are found in the literature, but prefabricated fiberglass-reinforced resin posts (FRPs) are widely accepted due to their features, including their aesthetics, affordability, ease of use, excellent clinical performance, and being more compatible with natural dentine in terms of elasticity, as they have elastic modulus closer than the other materials to that of dentin [3]. However, seeking the ideal material for intra-radicular posts keeps bringing into the light new aspects to be improved. Even though prefabricated FRPs have many advantages over the other post materials, such as a lower elastic modulus (45.7 to 53.8 GPa) [4] compared with titanium posts (110 GPa) and gold posts (95 GPa) [5], this value is still three times higher than of dentin (18.6 GPa) [6]. Regarding clinical performance, adhesive failure was proved to be the most common failure type [7], and that may be attributed to anatomical variations forms of root canals as well as to improper preparation, which results in a poor fit between the post and the canal walls, and loss of retention [8, 9].

Achieving a good adaptation between the post and the canal is a challenge because of the standard diameters of prefabricated FRPs, which require excessive preparation, and could weaken root canal walls increasing the probability of fracture [10]. Fabricating anatomical posts and cores as one single piece has become possible using computer-aided design/computer-aided manufacturing CAD/CAM. Such posts have many biomechanical advantages, including reducing the likelihood of a structural failure inside post core system as they are milled of homogenous materials [11, 12]. Furthermore, they have an excellent fit on the walls of prepared canal, and require only a thin layer of luting cement, which enhances mechanical stability [13].

Recently, fiber-reinforced resin blocks have been presented for use along with the CAD/CAM technique as an alternative to porcelain [14]: Trilor®, a fiber-reinforced resin block, consisted of an epoxy resin as a matrix phase (25%) and reinforced with multidirectional fiberglass (75%). This material has a tensile strength of 540 MPa and elastic modulus of 26 GPa [15], combining porcelain's high mechanical properties and color stability with resin's high elasticity, which hypothetically, makes it an ideal material in fabricating customized posts and cores [13].

Recently used polymers in dentistry is polyarylethetketones (PAEKs) family, which includes many members, such as polyetheretherketone (PEEK), polyetherketone (PEK), and polyetherketoneketone (PEKK). Out of other PAEKs family members, PEKK showed superiority in respect of chemical and physical properties [16]. In a report released by Cendres + Métaux Company, PEKK was cited as having an 80% more compressive strength than unreinforced PEEK. Another study conducted by the same company stated that PEKK displayed a compressive strength of 246 MPa and elastic modulus of 5.1 GPa, which are lower than those of porcelain [17, 18]. This material could be an excellent choice for fabricating custom-milled post and core due to its' unique physical properties, such as low elastic modulus and variety of fabrication methods, including milling and pressing [18].

Recent studies [15, 17-19] have focused on the mechanical properties of these milled posts in addition to their surface treatment to optimize bonding with resin cement. Moreover, one previous study has tested fracture resistance and failure modes of the system (crown/tooth/one-piece milled post and core) in a manner closer to clinical reality [20]. Therefore, the present study may be considered the first in vitro study to test fracture resistance of the crown/tooth/one-piece milled post and core fabricated from the previously mentioned materials.

OBJECTIVES

The aim of the present study was to evaluate the fracture resistance of ETT restored with custom-milled CAD/CAM posts and cores fabricated from two different materials compared with ETT restored with prefabricated fiberglass-reinforced resin posts.

The null hypothesis was that there are no differences in fracture resistance between ETT restored with milled posts and cores made of PEKK, and fiber-reinforced resin and EET, restored with prefabricated fiberglass-reinforced resin posts.

MATERIAL AND METHODS

TEETH SELECTION AND PREPARATION

This *in vitro* study was conducted after obtaining the approval of the Research Ethics Board of Tishreen University (Approval No. 2164). According to data from a previous study [15], a power analysis was performed to determine the number of specimens that would be required in each test group. G-Power software was used to calculate sample size, with a confidence interval of 95% and statistical significance of 0.05. The total sample size was 27, and one additional sample was added to each group.

Thirty single-rooted mandibular premolars free of cracks and extracted for orthodontic reasons were included in this study after ensuring by an X-ray the presence of only a single canal. Teeth were arranged over an intra-oral sensor (SOREDEX, DIGORA Toto, Finland), and radiographs of teeth were taken placed in mesiodistal (MD) direction using paralleling technique. Teeth were placed directly on the sensor in a MD view as stabilization was not needed. X-ray cone was directed perpendicularly on the table where the sensor was placed flat [21].

These teeth were then cleaned with an ultrasonic scaler (Piezo Scaler Tigon+, W&H, Austria), and were preserved in 0.5% chloramine solution (Chloramine T, Honeywell Riedel de-Haen, Seelze, Germany) for less than 2 months. A digital caliper (IOS, USA) was used to measure the buccolingual and mesiodistal dimensions at CEJ of all teeth, which were on average 6.3 ± 0.3 mm and 4.5 ± 0.3 mm, respectively.

The average length of the teeth from the occlusal surface to the root apex was 16.5 ± 1 mm after cutting the crowns 2 mm above the CEJ with a water-cooled, low-speed saw (IsoMet, Buehler, Lake Bluff, IL, USA). All teeth with a variation greater than 1 mm in all dimensions were excluded. Root canals were prepared using M3-L platinum files (M3-L platinum, UDG, China) to reach a M3PG4 as a final file (25/06), with 5 ml of 5.25% sodium hypochlorite irrigation. Root canals were then dried with paper points (META BIOMED, Korea), and obturated with gutta-percha (META BIOMED, Korea) and an eugenol-free sealer (Adseal, META BIOMED, South Korea) using lateral condensation technique. The samples were stored for 48 hours to allow complete setting of the sealer. After that, roots were embedded in self-curing acrylic molds (BMS 017, BMS Dental, Italy). The acrylic was 2 mm below the CEJ and placed perpendicular to the long axis of the root using a dental surveyor (Marathon-103 Surveyor, Saeyang, China) to simulate the alveolar bone around the natural tooth. The remaining coronal structure was prepared with a medium-coarse round-end taper diamond bur (200378AA/850-018-10ML, Coltene Whaledent, Switzerland) under water-cooling to obtain a 2 mm ferrule high and a 0.8 mm chamfer at the CEJ. The preparation was finalized with a soft round-end taper diamond bur (200378AA/850-018-10ML, Coltene Whaledent, Switzerland). Burs were replaced after five uses. The width of finishing line was checked using a periodontal probe (Dental Probe UNC 15, AISI 420, Germany), and any sample with less than 1 mm wall thickness was replaced. Post space was prepared up to 11 mm using Peeso Reamers (LG Dent, China) size RA1 and RA2, and then the final drill, a 2%-tapered, customized for prefabricated fiber posts (CO DR2 12GR, Bioloren, Italy), was used to standardize the post space preparation procedures. Afterward, the samples were randomly assigned into three groups, including milled PEKK posts (MPP), milled fiber posts (MFP), and prefabricated fiber posts (PFP) as follows:

1. MPP group: Teeth in this group were restored using one-piece milled post and core fabricated from PEKK (Pekkton®, Cendres + Métaux, Milano, Italy).
2. MFP group: Teeth in this group were restored using one-piece milled fiber-reinforced posts and cores (Trilor® Bioloren, Saronno, Italy).
3. PFP group: Teeth were restored with prefabricated FRC posts (AVANT CONIC translucent Fiberglass Post, Bioloren, Italy) and composite core buildups (Spectrum, Dentsply Sirona, Germany).

FABRICATION OF POSTS AND CORES OF THE MPP AND MFP GROUPS

A two-stage putty-wash technique was implemented to take the impressions of the root canals using Zetaplus system, putty and light body (Zhermack Oranwash, Italy), and then, the impressions were sent to the technician.

At the laboratory, the impressions were sprayed with scan spray (Scan Spray Pro, Beige, Germany) and scanned with a lab scanner (ScanBox, Smart Optic, Germany). Digital data were collected and transmitted to a special software (Exocad Dental CAD, Exocad GmbH, Darmstadt, Germany). One-piece milled posts and cores were designed in these two groups according to the following specifications:

- Height of the buccal cusp for the core from the occlusal area to the chamfer was 6 mm.
- Height of the lingual cusp for the core from the occlusal area to the chamfer was 5 mm.
- The dimensions of the post were 80 μm smaller to compensate for the space needed for luting cement and the thickness of spraying powder (Figure 1).

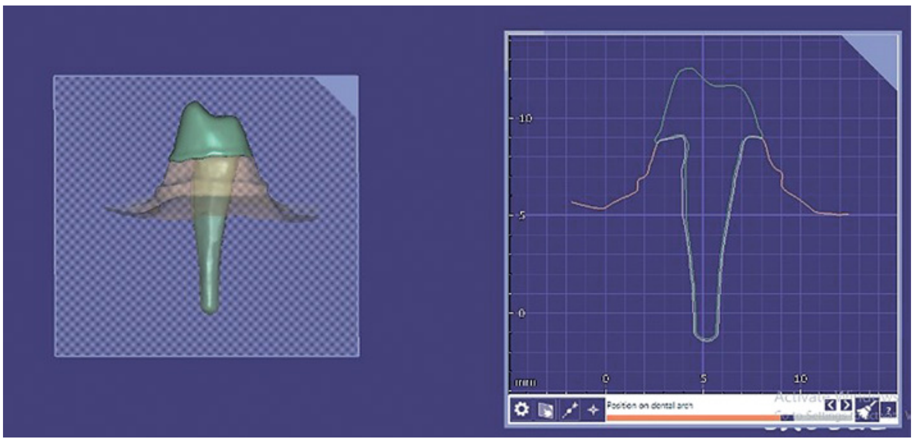

FIGURE 1. Designing the posts and cores of the MPP and MFP groups using CAD/CAM Exocad software

The posts and cores in these two groups were milled with D15 mill (D15, Yanadent, Turkey), and were then sanded with 110 µm aluminum oxide particles (Shera Aluminum Oxide, Germany) under 2-3 bar pressure.

ADHESION PROCEDURES IN THE MPP AND MFP GROUPS

First, the posts and cores fit was verified with a dental probe (Endodontic dental explorer EXDG16/17X, Hu-Friedy, Germany). Root canal of each sample was etched for 15 seconds with 37% phosphoric acid (Meta Etchant 37%, Meta Biomed, South Korea), then rinsed with water for 5 seconds, and dried with paper points. The posts and cores of the two groups were wiped with alcohol and left to dry [22]; then, posts of the MPP group were moisturized with a composite primer (GC, Japan) and cured using a LED curing light (Hemao Medical, China) for 40 seconds, according to the manufacturer's instructions. Whereas, the posts of the MFP group were silanized using two layers of silane coupling agent (Ultradent Products, South Jordan, UT, USA) and left for 1 minute to dry. The posts and cores were cemented in the respective canals using a self-adhesive resin cement (TheraCem, Bisco, USA), with a portion applied into the root canals and another one on the posts according to the manufacturer's instructions. Finger pressure was applied to the core, and cement residues were removed with a soft brush, and finally, light curing was carried out for 60 seconds.

POSTS AND CORES OF THE PFP GROUP

The root canal of each sample was etched for 15 seconds with 37% phosphoric acid (Meta Etchant 37%, Meta Biomed, South Korea), then rinsed with water for 5 seconds, and dried with paper points. Afterward, a bonding agent (Tetric N-Bond, Ivoclar Vivadent, Liechtenstein) was applied to coronal tissues above the finishing line, gently air blown and light cured for 20 seconds. The fiberglass posts (AVANT CONIC translucent Fiberglass Post, Bioloren, Italy) were cut to a length of 14 mm with low-speed saw (IsoMet, Buehler, Lake Bluff, IL, USA) under water-cooling, wiped with ethanol, and left to dry. Following this, fiberglass posts were cemented using self-adhesive resin cement (TheraCem, Bisco, USA) by applying a portion inside the root canals, and the other one on the posts surface, following the instructions of the manufacturer. Cement residues were removed with a soft brush, and, finally, curing was carried out for 60 seconds.

Composite cores were built up in layers (Spectrum, Dentsply Sirona, Germany), and each was cured for 30 seconds. The last layer was built using a vacuum-formed template, which was fabricated from a core of the MPP group to be used as a master core guide to standardize the size and shape of the cores. Undercuts were removed using a soft round-end taper diamond bur (200378AA/850-018-10ML, Coltene Whaledent, Switzerland).

FABRICATION OF PROSTHESES

The samples were resent to the laboratory to create metal crowns. Samples were scanned with a lab scanner (ScanBox, Smart Optic, Germany), and digital data were collected and transmitted to a special software (Exocad DentalCAD, Exocad GmbH, Darmstadt, Germany). A metal crown was designed and made from a nickel-chrome alloy (System NH, Adentatec, Germany) for each sample in the three groups, as per the following specifications:

1. Metal thickness at the finishing line was 0.8 mm.
2. Metal thickness on the occlusal surface was 1.5 mm.
3. A hemisphere-shaped hole of a 2.5 mm diameter was made on the inner slope of the supporting cusps on all crowns to correspond to the shape of the tip of the mechanical force tester.

Samples were wiped with 5.25% sodium hypochlorite, rinsed with running water, and dried with a gentle airflow. After that, each metal crown was luted to its' corresponding sample using glass ionomer cement (Vivaglass CEM PL, Ivoclar Vivadent, Liechtenstein) following the manufacturer's instructions. Residues were then removed, and the samples were preserved until mechanical testing.

Fracture resistance testing was performed using universal testing machine (Ibertest,IBMU series, Spain) at the Faculty of Mechanical Engineering at Tishreen University. The samples were installed on a special platform, and a 45° shear force was applied to the inner slope of the supporting cusp at a speed of 1 mm/m with a metal head, which tip was hemispheric with a diameter of 2.5 mm until failure. The load was measured in Newton (N), and failure types were tested radiologically and visually with 1.8x-20x dental microscope (OMS3200 dental microscope, Zumax Medical Co. Ltd., China).

Failure types were divided into two groups:

1. Reparable: This group included all the samples, in which fracture line was above the level of the simulated bone. Additionally, the post fracture, post detachment, or crown detachment were considered a reparable failure mode.
2. Irreparable: This group included all the samples, in which fracture line was below the level of the simulated bone [23].

STATISTICAL ANALYSES

Statistical analyses were performed using SPSS software version 20 (IBM, Armonk, New York, USA) at 0.05 statistical significance. Kolmogorov-Smirnov test was applied to test the load values distribution for normal distribution. One-way analysis of variance test ANOVA was used for independent groups to study the mean differences in fracture resistance among the three groups, while χ^2 test was applied to study the statistical significance of recurrence of failure modes in the study's groups.

RESULTS

Kolmogorov-Smirnov test revealed that data had a normal distribution ($p = 0.200$). Fracture resistance means for the MPP, MFP, and PFP groups were 423.20 N, 356.9 N, and 439.50 N, respectively (Table 1).

One-way ANOVA test showed no statistically significant differences among the means of fracture resistance in the MPP, MFP, and PFP groups ($p = 0.279$).

Sixty percent of failure modes in the MPP group were reparable (5 cases of post detachment and one case of crown detachment; Figure 2) The reparable failure modes occurred in 80% of the cases in the MFP group, and most of the failure modes in this group involved post fracture at the cervical area without tooth fracture (Figure 3). In the last group (PFP), fifty percent of failure types were irreparable (Figure 4). χ^2 results showed no statistically significant differences in failure types among the three groups ($p = 0.366$).

TABLE 1. Means and standard deviations (N) of fracture resistance in the three groups

Group	N	Mean	Std. deviation	Minimum	Maximum
MPP	10	423.20	113.289	201	570
MFP	10	356.9	141.05	115	558
PFP	10	439.50	100.61	286	556

TABLE 2. Distribution of failure modes in the three groups

Group	Failure modes		Total
	Reparable	Irreparable	
MPP	6	4	10
MFP	8	2	10
PFP	5	5	10
Total	19	11	30

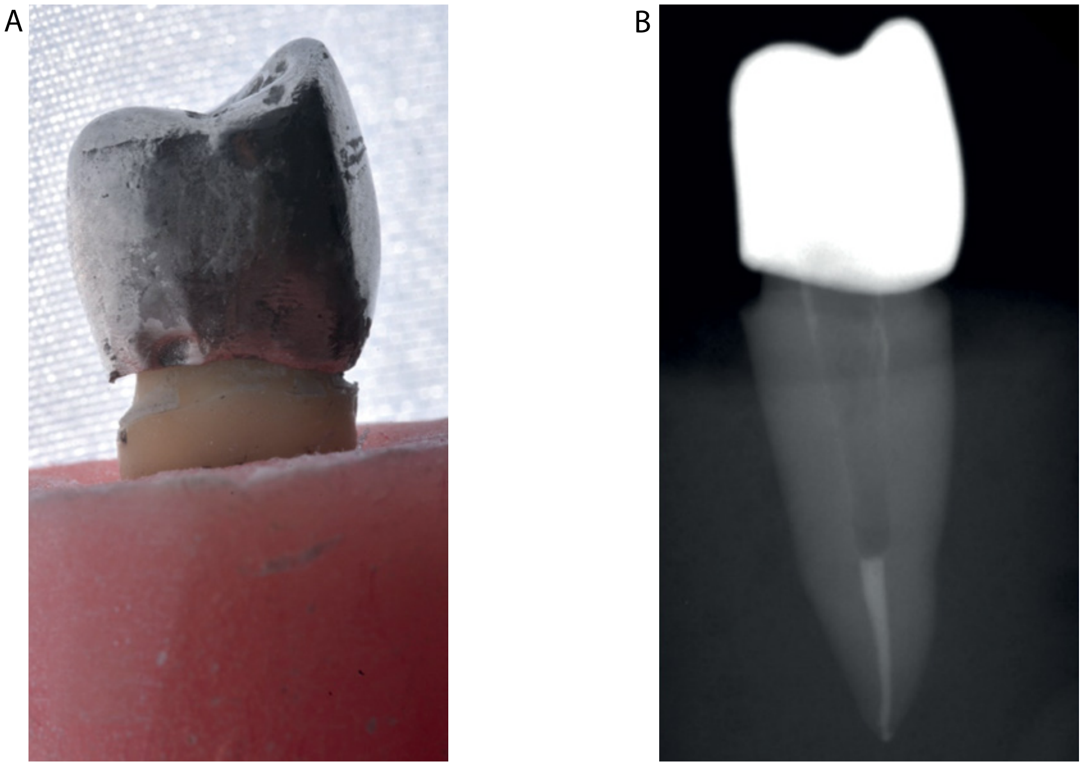

FIGURE 2. The most frequent failure modes in the group (MPP) (post detachment). **A**) Optical image; **B**) radiographic view

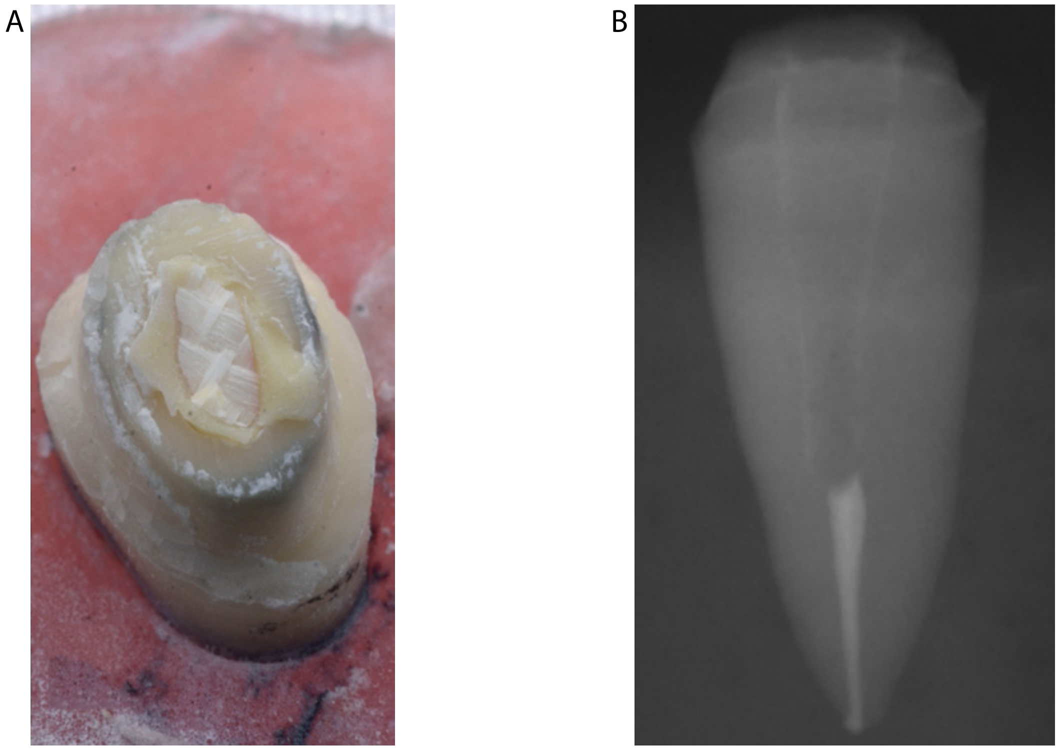

FIGURE 3. The most frequent failure modes in the group (MFP) (post fracture at the cervical area). **A**) Optical image; **B**) radiographic view

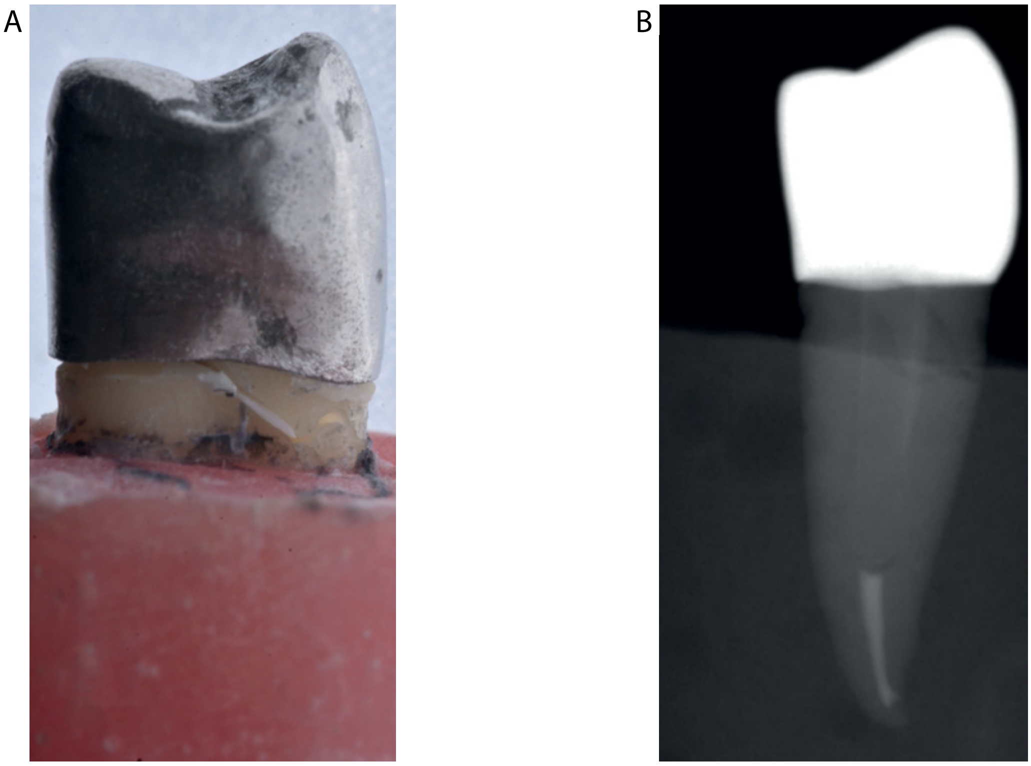

FIGURE 4. The most frequent failure modes in the group (PFP) (tooth fracture under CEJ). **A**) Optical image; **B**) radiographic view

DISCUSSION

This study aimed to evaluate the fracture resistance and failure types of teeth restored with custom-milled CAD/CAM posts made from PEKK and FRC in a simulated clinical situation. Despite their good mechanical properties, these materials have not received sufficient attention to be used as posts and cores. Additionally, a few studies in the medical literature have evaluated their use as a material for fabricating posts and cores [15, 17-20]. This study tried to simulate a clinical situation of tooth restored with posts and cores, therefore it focused on evaluating the mechanical behavior of crown/tooth/one-piece milled post and core system. Also, the esthetic aspect in the mandibular posterior region was not a major concern. That is why, metal crowns were used instead of any esthetic crowns.

The null hypothesis was accepted. There were no differences in fracture resistance between ETT restored with milled posts and cores made of PEKK and fiber-reinforced resin, and EET restored with prefabricated fiberglass-reinforced resin posts. This convergence among fracture resistance means that it might be attributed to the biomechanical behavior of post-and-core restored teeth, which could be primarily more dependent on the amount of the remaining dental tissues than on the type and hardness of the post used [24-26]. On the other hand, the biomechanical behaviors of the three posts used in this study are considered very similar, which could lead to a similar behavior under loads in a simulated clinical situation. A study by Nahar *et al.* [27] reported that stresses centered in the root dentin and the area of adhesive cement in teeth restored with PEKK posts were very similar to that in the teeth resorted with prefabricated fiberglass-reinforced resin posts, with most of these stresses centered in the area of an adhesive cement.

Additionally, Eid *et al.* [20] in a finite element analysis study found that custom-milled CAD/CAM resin posts displayed a behavior comparable to that of prefabricated fiberglass-reinforced resin posts in terms of their distribution of stresses inside the root dentin. A great concentration of stresses was found in the cervical area of the post and core along with the area of an adhesive cement.

The values of fracture resistance obtained in this study are higher than the masticatory force reported in the literature, i.e., 304.9 N in males and 284.9 N in females [28]. Therefore, under the conditions of this study, these posts may be considered clinically applicable.

As for failure modes, this study found that 60% of such modes in the MPP group were reparable (post and crown detachment), and 80% of failure modes in the MFP group were reparable (post fracture at cervical area). Regarding the control group PFP, 50% of failure types were reparable (tooth fracture above the CEJ). As for failure modes in the MPP group, the elasticity of PEKK reduces the stresses inside the post and core material, but the stresses under loads would be concentrated on luting cement. It was shown that when posts with very low elastic modulus are used, the probability of vertical root fractures is reduced, but a detachment of the post or prostheses might occur [17]. That could explain the fact that most of the failure modes of teeth restored with PEKK posts in this study were post detachment.

Regarding the MFP group, in which most of them were fractures within the post, these could be attributed to the propensity of posts milled from fiber-reinforced resin to display a common fracture mode, which is resin matrix fracturing and fibers detaching from it. Properties of these posts primarily depend on properties of their resin matrix [29], which makes these posts fracture similar to brittle materials. Electron microscope images of fracture modes of posts milled from fiber-reinforced resin showed inter-laminar and intra-laminar fractures parallel to fibers [29]. This underscores the resin matrix of these posts is more important than the type and direction of its' fibers.

Another possible reason for the brittle behavior of these posts is that milling might have an impact on their mechanical properties [15, 30], as the milling process might generate stresses inside the cut surface of the post and core. Additionally, it is the possible breaking of fibers during milling, which might affect the interface between fibers and resin matrix, and attenuates the biomechanical properties of the milled post compared with those of the block of the milled ones [31].

Fabricating the customized posts in the MFP and MPP groups was achieved using a half-digital technique. A silicon impression was taken and scanned with a laboratory scanner [32, 33]. Direct scanning of the impression has the advantage of making the direct or indirect fabrication of the acrylic model less necessary; it also optimizes the precision of the post, and is time- and cost-efficient [34].

There are several studies compared different PEKK post surface treatments to improve adhesion to resin and, consequently, the stability inside the root canal [18, 35, 36]. Nonetheless, these studies have not developed a unified protocol to treat PEKK surface. In the present study, the surface of the PEKK posts was sanded with 110 μm aluminum oxide particles, and then a primer was applied and cured according to the manufacturer's instructions. Aluminum oxide sanding with a primer applied achieved satisfactory results in improving bonding between PEKK posts and resin cement [18].

This study tested the fracture resistance of the crown/tooth/post and core system in a manner closer to clinical reality. The presence of the ferrule effect and using crowns enhanced the fracture resistance of teeth restored with post and core [25], which might lead to some confusion in interpreting the findings of this study in comparison with previous studies. This study may be considered the first *in vitro* study to investigate fracture resistance of the crown/tooth/one-piece milled post and core system. Previous studies have focused on testing the feasibility of using two materials examined in this study in the fabrication process [15, 17, 18, 37]. Therefore, to test this system in a manner that simulates clinical reality, shear forces applied to nickel-chrome prostheses were chosen as forces to test fracture resistance. A continuous 45° shear force was applied to the inner slope of the supporting cusp to failure. Applying force at 45° subjects the post-and-core restored tooth to additional non-axial forces, which in turn, are associated with undesirable loads on teeth. This form of force further represents a worst-case scenario for fracture resistance of endodontically treated teeth, which makes this angle appropriate for evaluating the biomechanical behavior of teeth restored with fiberglass-reinforced resin posts [25]. It should be noted that the present study is not the first one to employ this method and angle in fracture resistance tests, as both have been used in several previous studies [24, 38, 39].

This study has some limitations. Here, X-ray was used to detect the roots if they have single canals instead of cone-beam computed tomography (CBCT), as mentioned in a previous study [40]. The shear force applied did not simulate (compression, tensile, shear) forces and their directions inside the oral cavity. Also, the crowns in this study were not subjected to stress and thermodynamic cycles before applying static force. Therefore, more in vitro studies should be conducted, in which crowns are subjected to stress and thermodynamic cycles, and other forces in different angles should be selected and applied.

CONCLUSIONS

Under the conditions of this study, we may conclude that there is no difference in fracture resistance and failure types between teeth restored with custom-milled CAD/CAM posts and cores fabricated from PEKK, and fiber-reinforced resin and teeth restored with prefabricated fiberglass-reinforced resin posts. The post detachment was the most recurring failure type in teeth restored with custom-milled CAD/CAM posts and cores fabricated from PEKK, while the posts and cores fracture were the most recurring in teeth restored with custom-milled CAD/CAM posts and cores fabricated from fiber-reinforced resin. The custom-milled CAD/CAM posts and cores fabricated from PEKK and fiber-reinforced resin can be considered a good alternative to prefabricated fiberglass-reinforced resin posts.

CONFLICT OF INTEREST

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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