Comparison of Fracture Resistance between Different Treatment Modalities of Mutilated Endodontically Treated Teeth Using Polyether Ether Ketone

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ABSTRACT

Aim: To compare fracture resistance of multiple treatment modalities intended for mutilated teeth using polyether ether ketone (PEEK) and zirconia materials.

Materials and methods: The study was divided into four groups according to treatment modality adopted (n = 14): fiber post (F), Nayyar core (N), endocrown (E), and Richmond crown (R). Each group was further subdivided into two groups (n = 7) according to the type of material used: zirconia (Z) and PEEK (P). Using computer-aided design/computer-aided manufacturing, restorations were constructed from both materials following tested treatment options and manufacturer direction. Finished restorations were then tried, seated, and cemented to their corresponding acrylic teeth. All specimens were tested for fracture resistance in universal testing machine with cross head speed of 0.5 mm/min speed until failure, which was confirmed by a sudden drop in the measurements of the testing machine. Results were recorded, tabulated, and statistically analyzed. Shapiro-Wilk normality tests were considered to evaluate the normality of the data distributions. One-way analysis of variance (ANOVA) followed by Tukey’s post hoc analysis was conducted to analyze the fracture resistance significant differences.

Results: Descriptive statistics of the restoration material revealed statistically a higher mean value for PEEK material (3609 ± 188.1) than zirconia (2404 ± 425.6). One-way ANOVA revealed statistically significant differences between zirconia group (p = 0.0001). Regarding zirconia group statistical significance was detected between fiber post vs endocrown (p = 0.0299), fiber post vs Richmond crown (p < 0.0001), and Nayyar core vs Richmond crown (p = 0.0004). However, there was no statistically significant difference between PEEK group (P = 0.1614).

Conclusion: Polyether ether ketone could present a viable treatment option in endodontically treated teeth.

Clinical significance: Using one-piece Richmond crowns constructed of PEEK could present a viable treatment option against conventional treatment options of root canal treatment (RCT) single-rooted teeth.

Keywords: Endodontically treated teeth, Fracture resistance, Polyether ether ketone, Zirconia.

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INTRODUCTION

Endodontic therapy topic has been criticized for weakening teeth, especially the root part, which makes teeth more prone to fracture.1 Endodontically treated teeth (ETT) are traditionally and currently restored by the conventional metal post, fiber post, or endocrown. In the past, they were restored by porcelain fused to metal Richmond crown. However, evidence has shown that fiber post, resin core, and resin filling are better alternatives than the metal post and core due to former’s higher fraction resistance and capacity to allow repairs.2 Owing to excessive loss of tooth structure, ETTs are usually weaker than sound teeth; thus, the need for a material that can withstand forces and ensure restoration longevity is the demand. Zirconia is among the dental ceramics used in contemporary restorative dentistry due to its excellent mechanical properties. Nevertheless, compared with fiber and dentin posts, zirconia displayed the least fracture resistance and most catastrophic fractures.3 Polyether ether ketone (PEEK) is a thermoplastic material that emerged in the late 1990 replacing metal components. Polyether ether ketone might represent a viable biomaterial; it is not only able to replace conventional polymers, but also metals, alloys, and ceramics in the field of dentistry.4 Polyether ether ketone is a high-temperature semi-crystalline thermoplastic polymer related to a gross up of polyaryletherketone that consists of an aromatic backbone molecular chain, which is interconnected with ketone and ether functional groups.

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biocompatibility, and closeness to zirconia properties opens a debate to whether it could be used as a coverage following the root canal treatment (RCT). Studies support the use of PEEK as researchers have found that it expressed the most favorable stress distribution compared with other treatments and especially around abutments. Also, the clinical use of PEEK varies from an alternative to polymethylmethacrylate (PMMA), computer-aided design/computer-aided manufacturing (CAD-CAM) restorations, dental implants, and metal braces and hooks.

Zoidis et al. created a modified PEEK material, known as bio-high performance polymer, that is a biocompatible, nonallergic, and rigid material that can form an alternative for the fabrication of distal extension removable dental prosthesis frameworks. Thus, the advantages offered by using PEEK in dental restorations are numerous.

The aim of this study is to compare fracture resistance of multiple treatment modalities of ETT PEEK and zirconia materials. More specifically, we intend to evaluate and compare fracture resistance of PEEK and zirconia crowns placed over endodontically treated resin models. In addition, we will evaluate and compare fracture resistance between different treatment modalities: fiber post, endocrown, Nayyar core, and Richmond crown.

**Materials and Methods**

**Study Design**

This study was conducted as an experimental, randomized, and comparative study.

**Study Setting**

Model preparation and lab work were done at Beirut Arab University Stimulation Lab. The fracture resistance testing was done in the Dental Biomaterial Lab of Saint Joseph University in Beirut, Lebanon.

**Study Sample**

It consisted of 56 readymade transparent resin maxillary first molar teeth that were used as full crowns and root presented with only access opening done. The teeth were divided into four main groups according to the treatment modality done (fiber post, Nayyar core, endocrown, Richmond crown). The main groups were further divided into two groups according to the material used (Zirconia or PEEK).

**Specimen Grouping**

Each treatment modality (fiber post, Nayyar core, endocrown, Richmond crown) consisted of 14 specimens. From each 14 specimens, 7 were done using PEEK and the other 7 using Zirconia.

**Teeth Preparation**

In the field of dental research, in vitro studies often faced the problem of homogeneity in methodology. To achieve a standardized tooth preparation, a surveyor with a suspending arm was used to control the handpiece orientation during the preparation. The table of the surveyor was adapted to secure the mold with resin tooth in a way that the long axis of the tooth was parallel to the bur. Thus, ensuring same angle of convergence and same amount of tooth reduction.

Using round-end-taper diamond bur fixed in a parallelogram, axial walls of teeth were prepared in the following manner:

For groups fiber post, endocrown, and Nayyar core, two walls were removed from each molar 2 mm above cementoenamel junction (CEJ) to justify intraradicular rehabilitation (Fig. 1). On the other hand, for group Richmond crown, using a diamond disk bur and straight handpiece adapted to the surveyor, occlusal reduction took place in which all four walls were removed 2 mm above the CEJ (Fig. 2).

**Core Construction**

**Group Fiber Post** (Fig. 3)

Preparation of the post space and post cementation was done prior to the core construction. After post space preparation using gates glidden, peeso reamers and manufacturer supplied drill, fiber post size 2 was selected. Specimens were cleaned with alcohol, etched (super etch) and bonded (3M single bond 2) then fiber post was cemented using resin cement (SetPP). Using a special gun, transparent core-former was filled with bulk fill composite from sonic fill and inverted onto the root face and light cured.

**Group Nayyar Core**

Two mm of gutta-percha was removed from each canal orifice, etching and bonding then took place in the same manner as group
F. Flowable composite was used to close all canal orifice openings and the transparent core former was used for core buildup (as in group F). Using depth guided tip limiting bur, a 0.4 mm finish line was prepared 1.5 mm away from root surface for group fiber post and Nayyar core. However, for group endocrown, the 0.4 mm finish line was prepared on the remaining two walls making sure no undercuts were present in the inner walls of the teeth.

Digital Scanning of the Specimens and Specimen Construction
Each specimen was individually placed in extraoral scanner and scanned for core restoration fabrication.

Zirconia Subgroups
All zirconia core restorations were dry milled using the CAD/CAM milling machine rainbow (Mill-Zr from Dentium). The specimens were then sintered following manufacturer directions (Wieland sintering furnace).

PEEK Subgroups
All PEEK core restorations were dry milled using PMMA burs as recommended from manufacturer, in CAD/CAM milling machine Zfx (Zimmer Biomet; Fig. 4).

Specimen Try in and Cementation
Specimens were consecutively trial fitted, cleaned with alcohol, and air particle abraded using 50-micron alumina particles and placed for 1 minute in an ultrasonic bath. Proper cementation procedure was applied by resin cement usage (SetPP).

Fracture Resistance Test
All specimens were loaded in universal testing machine with tapered rounded blunt ended cross-head 3 mm diameter and 0.5 mm/min speed until failure, which was confirmed by a sudden drop in the measurements of the testing machine. The force was applied on the central fossa that is parallel to the long axis of the tooth.

Statistical Analysis
Results were recorded, tabulated, and statistically analyzed. Numerical data were explored for normality using Shapiro-Wilk normality test. The results were represented as mean, standard deviation (SD), and standard error of the mean. One-way analysis of variance (ANOVA) with Tukey’s test for post hoc analysis was used to analyze fracture resistance differences among the different treatment modalities used within each of the zirconia and the PEEK groups. Unpaired t-test was also conducted to compare the fracture resistance means of the zirconia and the PEEK groups. Statistical significance was indicated by a p value of less than 0.05.

Results
- Shapiro-Wilk test, using a right-tailed normal distribution
  The data passed the Shapiro-Wilk normality test with p values greater than 0.05 for all groups; thus, Shapiro-Wilk revealed that the data were normally distributed.
- Effect of treatment modality on fracture resistance (Fig. 5):
  - For zirconia group: One-way ANOVA revealed that there was statistical significant differences between zirconia groups (p < 0.0001). Tukey’s post hoc analysis test with each of the zirconia group detected significant difference among the different modalities (Table 1).
  - For PEEK group: One-way ANOVA revealed that there were no statistical significance differences between PEEK groups (p = 0.1614). No statistical significant difference was detected upon performing Tukey’s post hoc test (Table 2).

Fig. 4: Finished specimens classified
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Effect of the restorative material on fracture resistance (Fig. 6): Descriptive analysis of the restorative materials revealed a greater mean value for PEEK (3609 ± 188.1) than zirconia (2404 ±

Table 1: Results of Tukey's post hoc test among different treatment modalities using zirconia groups

<table>
<thead>
<tr>
<th>Tukey's multiple comparisons test</th>
<th>Mean 1</th>
<th>Mean 2</th>
<th>Mean Diff.</th>
<th>Summary</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber post vs Nayyar core</td>
<td>1598</td>
<td>1897</td>
<td>-298.7</td>
<td>NS</td>
<td>0.8137</td>
</tr>
<tr>
<td>Fiber post vs endocrown</td>
<td>1598</td>
<td>2611</td>
<td>-1013</td>
<td>*</td>
<td>0.0299</td>
</tr>
<tr>
<td>Richmond crown vs Nayyar core</td>
<td>1987</td>
<td>2611</td>
<td>-614</td>
<td>NS</td>
<td>0.1783</td>
</tr>
<tr>
<td>Richmond crown vs Nayyar endocrown</td>
<td>1897</td>
<td>2611</td>
<td>-714.3</td>
<td>NS</td>
<td>0.1783</td>
</tr>
<tr>
<td>Richmond crown vs Nayyar endocrown</td>
<td>1897</td>
<td>3511</td>
<td>1614</td>
<td>***</td>
<td>0.0004</td>
</tr>
<tr>
<td>Endocrown vs Richmond crown</td>
<td>2611</td>
<td>3511</td>
<td>-899.3</td>
<td>NS</td>
<td>0.0619</td>
</tr>
</tbody>
</table>

Table 2: Results of Tukey's post hoc test among different treatment modalities using PEEK groups

<table>
<thead>
<tr>
<th>Tukey's multiple comparisons test</th>
<th>Mean 1</th>
<th>Mean 2</th>
<th>Mean diff.</th>
<th>Summary</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber post vs Nayyar core</td>
<td>3443</td>
<td>4100</td>
<td>-657.4</td>
<td>NS</td>
<td>0.3505</td>
</tr>
<tr>
<td>Fiber post vs endocrown</td>
<td>3443</td>
<td>3220</td>
<td>223.1</td>
<td>NS</td>
<td>0.9390</td>
</tr>
<tr>
<td>Richmond crown vs Nayyar core</td>
<td>3443</td>
<td>3673</td>
<td>-230.4</td>
<td>NS</td>
<td>0.9334</td>
</tr>
<tr>
<td>Richmond crown vs Nayyar endocrown</td>
<td>4100</td>
<td>3220</td>
<td>880.6</td>
<td>NS</td>
<td>0.1350</td>
</tr>
<tr>
<td>Richmond crown vs Nayyar endocrown</td>
<td>4100</td>
<td>3673</td>
<td>427.0</td>
<td>NS</td>
<td>0.6942</td>
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<tr>
<td>Endocrown vs Richmond crown</td>
<td>3220</td>
<td>3673</td>
<td>-453.6</td>
<td>NS</td>
<td>0.6533</td>
</tr>
</tbody>
</table>

Table 3: Fracture resistance values and unpaired t-test for restorative material

<table>
<thead>
<tr>
<th>Group</th>
<th>Zirconia (n = 7/group)</th>
<th>PEEK (n = 7/group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber post</td>
<td>1598.29 ± 278.1</td>
<td>3442.71 ± 374.5</td>
</tr>
<tr>
<td>Nayyar core</td>
<td>1897.0 ± 244.4</td>
<td>4100.14 ± 245.0</td>
</tr>
<tr>
<td>Endocrown</td>
<td>2611.29 ± 187.8</td>
<td>3219.57 ± 163.0</td>
</tr>
<tr>
<td>Richmond crown</td>
<td>3510.57 ± 238.1</td>
<td>3673.14 ± 275.2</td>
</tr>
<tr>
<td>Mean</td>
<td>2404</td>
<td>3609</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>851.2</td>
<td>376.2</td>
</tr>
<tr>
<td>Std. Error of Mean</td>
<td>425.6</td>
<td>188.1</td>
</tr>
<tr>
<td>p-value</td>
<td>0.0413*</td>
<td></td>
</tr>
</tbody>
</table>

*Significant difference p-value ≤ 0.05

425.6). Unpaired t-test conducted to compare the mean between PEEK and zirconia detected a significant difference among them (p = 0.0413; Table 3).

Subjective analysis of the fracture behavior

Three different fracture patterns were observed concerning the compartments that failed: fracture of the restoration, fracture of the resin model, or fracture of both the restoration and resin model. In almost all of the PEEK groups, a combination fracture took place due to PEEK's resiliency and high modulus of elasticity. However, in zirconia groups, most of the fracture took place in the material that was presented by zirconia scattering as glass (Flowchart 1).

Discussion

Restoration of mutilated teeth still presents a challenge in restorative dentistry. Achieving the triad of function, longevity, and esthetics is a target pursued by all researchers. Till now, there is no unanimous agreement between clinicians on the perfect technique/material to restore mutilated teeth. The current study is another stepping stone to hopefully reach that goal.

Results of all four treatment modalities gave acceptable results that could indicate the validity of the treatments as they have been used for ages. However, when using zirconia material, there was a significant difference between the modalities used. Fiber post modality gave the lowest fracture results followed by Nayyar core.

- Effect of the restorative material on fracture resistance (Fig. 6): Descriptive analysis of the restorative materials revealed a greater mean value for PEEK (3609 ± 188.1) than zirconia (2404 ±
This could be explained by the fact that drilling into the root for post placement weakened the remaining tooth structure.

Upon comparing between different treatment modalities used, Richmond crown proved to be a good treatment option. Richmond crown, the single piece post retained crown which was considered as an outdated treatment revealed a plausible result when used with PEEK material in which one of the highest fracture resistance results were recorded. Although the concept of Richmond crown is almost not used nowadays, several studies showed superior results when Richmond crown was constructed from zirconia. CAD/CAM one-piece zirconia post and core resulted in higher fracture resistance than the prefabricated zirconia posts. Also, the fact that a single unit decreases the frequency of failure by creating a monoblock effect.

Endocrown PEEK showed a lower fracture resistance results than those of Richmond crown. During the testing step, most of the endocrown PEEK subgroup dislodged from the resin tooth directly after reaching the fracture point. The dislodgment could be related to several factors either that the fact in which endocrown does not have any root extension plays a significant role in the dislodgment point or simply because no real bonding could be achieved with the resin model teeth. Endocrowns have many disadvantages like debonding and risk of root fracture because of the difference in the modulus of elasticity between the harder ceramic and softer dentin. Also, the tests emphasized on the importance of the stresses falling on the tooth itself in which endocrowns are for minimal functional and lateral stresses. Also, the greater the extension of endocrowns inside the pulp chamber, the better mechanical performance was provided.

Polyether ether ketone material in most of the specimens did not directly break that emphasizes their resiliency characteristic. Polyether ether ketone crowns underwent bending in which the testing force was able to penetrate the crown to some point until reaching the maximum force and then it failed. This fracture pattern was evident in all PEEK specimens, bending of the crown took place on the occlusal surface where the force was centralized and then a simple crack in the middle of the tooth was present. The fracture pattern could be related to PEEK’s low modulus of elasticity (4-GPA) and the high flexural strength that allowed the absorption of stresses derived from the function.

The fact that PEEK material provided a higher fracture resistance than zirconia indicated the need for further studies. Several recommendations are suggested ranging from full crown studies which are done to detect whether the veneering material affects the fracture load. Also, it is suggested to use electron microscopy to explore changes in the surface texture of PEEK since it bends before fracture. This study opened the eyes to the use of Richmond crown in the current days. It is suggested for dentists and clinicians to investigate the use of Richmond crown fracture strength and the ability to be used again.

Conclusions
Within limitations of the present study, it could be concluded that selection of the most suitable treatment modality and preparation design for mutilated teeth should be guided by knowledge of their indications, advantages, and disadvantages, as well as the amount and quality of remaining tooth structure.

Also, PEEK material that has modulus of elasticity comparable to dentin enables the equitable distribution of forces and may offer better resistance to fracture as compared with zirconia when restoring mutilated teeth. When comparing PEEK-based restorations, all treatment modalities were capable to withstand high fracture loads; however, in zirconia-based restorations, fiber post is not recommended. The study when examined from a mechanical point of view showed that Richmond crown emerged as the recommended preparation design.
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REFERENCES


