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# Effect of different materials with different intrapulpal extensions on fracture resistance of endocrown restored molars (In-vitro study)

***Mohamed Aly El-Agwany[1], Amina Mohamed Hamdy[2], Maged Mohamed Zohdy[2], Aliaa Mahrous[1], Ahmed Tawfik[3], Soha Osama Nabih[2]***

**Aim:** This study investigated the fracture resistance of different intrapulpal extensions of endocrowns made of lithium disilicate (L) and polyetheretherketone (P).
**Materials and methods:** sixty extracted human mandibular first and second molars were split equally into three groups based on the depth of the intrapulpal cavities (0 mm, 2 mm, and 4 mm), and then each group was further separated into two subgroups according to the material of the endocrown (L and P). Fracture resistence was assessed by a computer-controlled testing machine, and then data were collected and analyzed using a two-way ANOVA followed by Tukey's post hoc test.
**Results**: For endocrowns fabricated from polyetheretherketone, the fracture resistance values ranged from (2302±101.97 to 3363.22±382.32), which was significantly higher than that of lithium disilicate (1747.16±154.38 to 2756.73±126). The lowest values of fracture resistance for L and P restorations were 1747.16+154 and 2302.92+101, respectively, at 0 mm. depth designs, whereas the values increased to reach their maximum values of 2765.73+126 and 3363.22+382, respectively, at 4 mm depth designs.
**Conclusion:** The fracture resistance of restorations made of P polyetheretherketone is higher than that of restorations made of lithium disilicate. Increasing intrapulpal cavity depths increases the fracture resistance of endocrowned restoration.

**Keywords:** Lithium disilicate, PEEK, Designs.

1. Fixed Prosthodontics Department, Fayoum University, Fayoum, Egypt.
2. Fixed Prosthodontics Department, Ain Shams University, Cairo, Egypt.
3. Future Advanced Metrology Hub, University of Huddersfield, Huddersfield, United Kingdom.

Corresponding author: Mohamed Aly El-Agwany, email: mam42@fayoum.edu.eg

## Introduction

Endocrown is a type of adhesive monolithic restoration for root-canal-treated abutments that provides improved mechanical status, optimum seal, and proper retention from the pulpal space and remaining dental tissues. [1]Endocrown provides many advantages in comparison to conventional crowns, like the feasibility of fabrication and application, reduced clinical chair time, and superior esthetic outcome. [2]

As a "mono-block restoration made of porcelain, endocrown was first introduced as a new concept for restoring root-canal-treated abutment and described as posterior adhesive intra-coronal porcelain crown restoring endo-treated abutment. [3,4]

There is no exact agreement on the design of the endocrown. Extension of endocrown 2 mm inside pulpal space was the design of choice by several authors. This design was found to provide optimum resistance and retention. [5, 6] Many authors zoomed in on the value of preparation design for the fracture resistance of endocrown. [7,8,9]

Endocrown was suggested to be fabricated from different restorative materials that possess adhesive capacity, like glass-containing etchable ceramics (lithium disilicate-based, Leucite, or Feldspathic), composite resin, zirconia-glass ceramics, zirconia, hybrid resin nanoceramics, or high-strength polymers for adhesive bonding to tooth structure. Since lithium disilicate glass ceramics have outstanding adhesion to tooth structures, maximum esthetics, and superior strength, they are among the most effective restorative materials for the fabrication of various dental restorations.[10]

Lithium disilicate glass ceramics consist of a glassy matrix with a crystalline phase (around 70 vol%) integrated into it. Lithium meta-silicate crystals of LiSiO3 (40 vol%) in the form of platelets form during the partial crystallization process (also known as the "blue" state) and become immersed in a glassy phase. Because of its 130–30 MPa flexural strength, milling the blocks is simple. Following that, the milled restorations are tempered at 850 °C to create lithium disilicate crystals, or Li2O2Si2. As a result, the final shade and flexural strength of the milling restoration are 360 + 60 MPa.

Synthetic polymers with appropriate biomechanical and inert chemical properties are called polyetheretherketones, or PEEKs. According to reports, PEEK's semi-crystalline thermoplastic entity, which is poly-aromatic and has excellent mechanical qualities, makes it a good choice for biomedical applications. It was recommended to employ PEEK material for the creation of endocrowns due to its higher biocompatibility and mechanical qualities. Owing to its opaque white hue, veneering is necessary to enhance the aesthetics. [11]

Fracture resistance is an important factor in the durability and success of indirect restorations. It can be defined as the critical stress intensity factor at which the pre-existing crack will propagate and lead to catastrophic failure under tension. [12]

The selection of a restorative material is a critical point in the success rate of the restoration. The first criteria is to have sufficient fracture resistance to support masticatory forces and protect the remaining dental structure. The fracture load of the final restoration is the result of the combined effects of bonding between the underlying tooth, the ceramic restoration, and the cementing agent. [13]

The aim of the current study was to evaluate the fracture resistance of different intrapulpal extensions fabricated from different materials.The null hypothesis stated that altering cavity depths or fabrication materials has no effect on the fracture resistance of endocrown.

## Materials and Methods

**Sample size calculation**:

A power analysis was designed to have adequate power to apply a statistical test of the null hypothesis, indicating that there was no difference in the fracture resistance of different tested materials and preparation designs. By adopting alpha (α) and beta (β) levels of (0.05), (i.e., power=95%), and an effect size (f) of (0.736) calculated based on the results of a previous study[1]; the minimal required sample size (n) was found to be (48) samples. The sample size was increased to (60) samples to account for possible procedural errors during testing. Sample size calculation was performed using G*Power version 3.1.9.7 [14]

**Teeth selection and preparation**

The intact and crack-free surfaces of sixty freshly extracted human mandibular first and second molars were assessed to be free of caries and then preserved in regular saline after external debris was eliminated using an ultrasonic scaler. The typical mean mesio-distal dimension was 10.5 mm ± 0.5 mm and the bucco-lingual dimension was 9 mm ± 0.5 mm, measured at the cemento-enamel junction level using a digital caliper. No endodontic treatment was performed on any of the sample teeth.

In order to avoid selection bias, a simple random procedure was followed. Each tooth was given a number from (1) to (60) and was randomly allocated to each of the tested groups following randomly generated sequences created using https://www.random.org

Based on the depth of the intrapulpal cavities (0 mm, 2 mm, and 4 mm), the samples were split into three groups (n = 20), and then each group was further separated into two subgroups, L and P.

Using a diamond rotary wheel instrument (Intensiv wheel 817, Swiss) installed on a high-speed headpiece, the coronal section was reduced by 2 mm from the cemento-enamel junction. The margins were niched using butt joint preparation.

**Endocrown preparation with different cavity depths:**

Using a periodontal probe, a 2 mm circumferential occlusal band thickness was checked (Fig. 1). The handpiece was mounted using a paralleling mechanism to standardize the occlusal divergence and butt reduction between samples.

Using flowable composite, the cavity depth of each sample was modified (Fig. 2) in accordance with their respective groups as follows: group (0 mm depth), the pulpal cavity was completely destroyed to the level of the occlusal borders; group (2 mm depth) Group (4 mm depth): 4 mm pulpal cavity depth from the occlusal edges and 2 mm pulpal cavity depth from the occlusal margins were left.

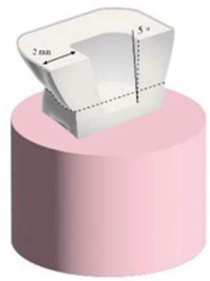

Figure 1: Schematic diagram showing 5 degrees axial wall divergence and 2mm thickness sidewalk

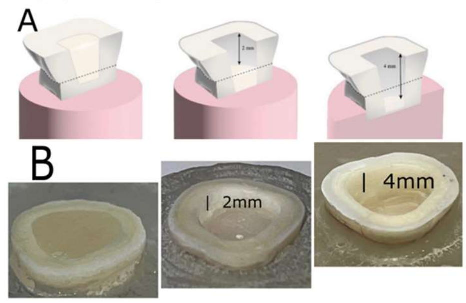


Figure 2: A) Schematic diagram showing different intra-pulpal depths (0,2 and 4), B) Prepared samples with different intra-pulpal depths (0,2 and 4).

**Restoration design and fabrication**

All samples were optically scanned using an extra oral scanner (DS Mizar optical scanner), and STL format was generated so that CAD system software could be used to make virtual dies. A restoration of 2 mm thickness with anatomical occlusal aspect was created

(Fig. 3) for subgroup L. It was subsequently milled using a 5-axis machine (SHERA Eco-Mill 5x; Bimedis, China) and crystallized using a P310 program. The restorations for subgroup (P) were made as a bi-layered structure with an indirect composite veneer measuring one millimeter in thickness and a PEEK core measuring one millimeter (Fig. 4). Using the CAD-ON technique, both components were connected using dual-cure composite resin. The surface was first prepared with light polymerized adhesive and conditioned with 110 µm aluminum oxide grit at a pressure of 3 bars, 45 degrees of application, and a distance of 3 cm.

The curing process was carried out in a light polymerization unit in accordance with the manufacturer's instructions. (Fig 5)

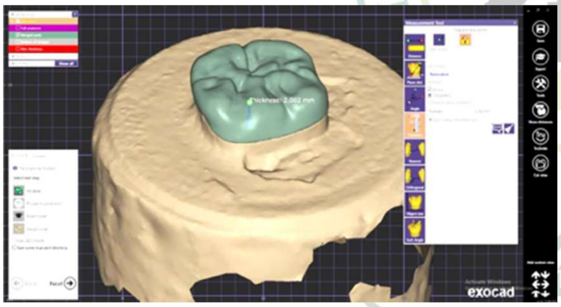


Figure 3: Original anatomical design for fabrication of subgroup (L) restorations.

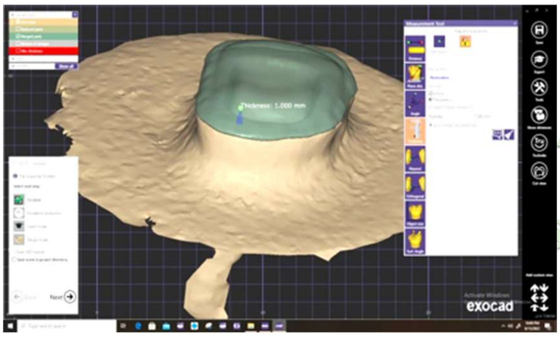


Figure 4: 1mm cutback for PEEK core fabrication

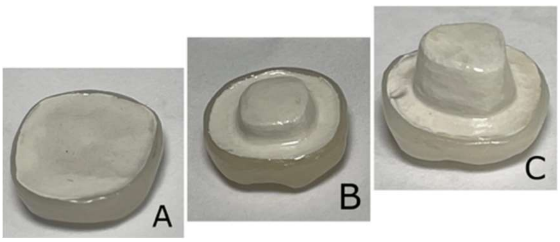


Figure 5: Cemented composite veneer over PEEK core A) 0mm depth B) 2mm depth C) 4mm depth

**Restorations, cementation, and aging:**

All samples were subjected to a dental explorer margin inspection before being cemented using 37% phosphoric acid and etched on the enamel margin for 20 seconds. The samples were then cleaned with water spray and dried using compressed air.

Use 9.5% hydrofluoric acid for 20 seconds for subgroup L, then rinse well for a further 60 seconds and allow to dry. After adding the silane coupling agent, it was given 60 seconds to react. Sandblasting with 110 µm aluminum oxide grit at 3 bars of pressure, 45° application angle, and 3 cm distance is used for subgroup (P).

Dual-polymerized self-adhesive resin cement (Breeze) was the cement of choice, and its application was after conditioning with universal MDP-containing adhesive (ALL-Bond Universal), which was light-polymerized for 20 seconds. Cementation was carried out in the central fossae of the restorations' occlusal surface under continuous loading using a loading mechanism and 1 kg of pressure.For five hours, all samples underwent hydrothermal aging in an autoclave set at 134 °C and 2 MPa.

**Samples Fracture analysis:**

All specimens were individually mounted on a computer-controlled testing machine (Model 2710-113) with a load cell of 1 kN. Data were recorded using computer software (Instron® Bluehill Lite Software). The load at failure was manifested by an audible crack and confirmed by a sharp drop in the load detection curve recorded using computer software (Bluehill Lite Software, Instron® Instruments).

**Statistical Analysis:**

The mean and standard deviation figures were used to present numerical data. They underwent the Shapiro-Wilk test to determine their normalcy. The data showed a parametric distribution and were analyzed using a two-way ANOVA followed by Tukey’s post hoc test. Using the pooled error term from the main ANOVA model, Bonferroni correction was used to compare the main and simple effects. The significance level was set at $p < 0.05$ within all tests. Statistical analysis was performed with R statistical analysis software version 4.1.3 for Windows.

**Ethical approval and consent to participate**

The Research Ethics Committee, Faculty of Dentistry, Ain Shams University, approved all experimental methods, and the study was performed in accordance with its regulations, licensing requirements, and relevant guidelines. Because this study did not contain any intervention with human participants or animals and only utilized archival teeth whose owners cannot be identified, it was exempt from ethical assessment. The approval of the ethics committee is Fdasu-RecD031819. The need for informed consent was waived by the ethical committee of Ain Shams University.

## Results

Intergroup comparisons, mean and standard deviation (SD) values of fracture resistance (N) for different materials and preparation designs were presented in (table 1) and (figures 6& 7).

Table 1: Intergroup comparisons, mean and standard deviation (SD) values of fracture resistance (N) for different materials and preparation designs

| Material | Fracture resistance (N) (mean±SD) | | | p-value |
|---|---|---|---|---|
| | 0 mm | 2 mm | 4 mm | |
| Emax | 1747.16±154.38$^{C}$ | 2439.39±279.61$^{B}$ | 2765.73±126.00$^{A}$ | <0.001* |
| PEEK | 2302.92±101.97$^{C}$ | 2786.38±130.97$^{B}$ | 3363.22±382.32$^{A}$ | <0.001* |
| p-value | <0.001* | 0.012* | 0.002* | |

Means with different superscript letters within the same horizontal row are significantly different *; significant ($p \leq 0.05$) ns; non-significant ($p>0.05$)

**A-Effect of material with each preparation design:**

- **0 mm:**

PEEK (2302.92±101.97) had a significantly higher value than Emax (1747.16±154.38) ($p<0.001$).

- **2 mm:**

PEEK (2786.38±130.97) had a significantly higher value than Emax (2439.39±279.61) ($p=0.012$).

- **4 mm:**

PEEK (3363.22±382.32) had a significantly higher value than Emax (2765.73±126.00) ($p=0.002$).

**B-Effect of preparation design within each material:**

- **Emax:**

There was a significant difference between different groups ($p<0.001$). The highest value was found in samples with 4 mm extension (2765.73±126.00), followed by samples with 2 mm extension (2439.39±279.61), while the lowest value was found in samples without pulpal extension (1747.16±154.38). Post hoc pairwise comparisons showed different groups to have significantly different values from each other ($p<0.001$).

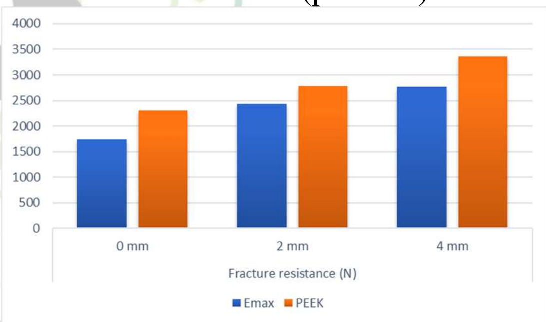


Figure (6): Bar Chart displaying the average fracture resistance (N) for various preparation designs and materials (A)

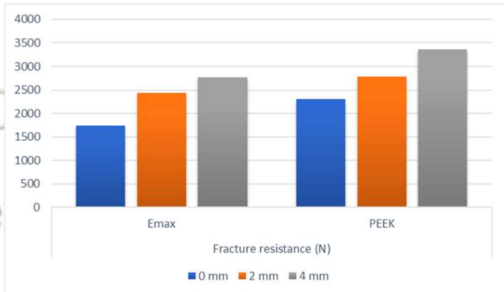


Figure (7): Bar Chart displaying the average fracture resistance (N) for various preparation designs and materials (B)

- **PEEK:**

There was a significant difference between different groups ($p<0.001$). The highest value was found in samples with 4 mm extension (3363.22±382.32), followed by samples with 2 mm extension (2786.38±130.97), while the lowest value was found in samples without extension (2302.92±101.97). Post hoc pairwise comparisons showed different groups to have significantly different values from each other ($p<0.001$).

**Discussion**

For the restoration of teeth that have had endodontic therapy and have experienced a significant loss of coronal tooth tissue, endocrowns may be an option. These days, a variety of restorative materials, including composite blocks, milled glass ceramics, pressed glass ceramics, and hybrid ceramics, are probably used in these restorations. One potential substitute for ceramics would be polyetheretherketone, or PEEK. [15,16]

The current study employed extracted human teeth to mimic the clinical setting with regard to dentin and enamel bonding. Before testing, teeth of average sizes and nearly comparable forms were chosen, allowing a maximum deviation of 10% from the established mean in order to reduce potential deviations and get closer to the intended standardization. [17]

To ensure that there was a fixed tapering of preparation among samples, a high-speed handpiece attached to a paralleling holding device was employed with a standard inlay preparation diamond kit. Because the butt margin design is regarded as the traditional method and has been utilized for nearly all in-vitro research, it was chosen.

Because butt joint designs are constructed parallel to the occlusal plane, they offer a robust surface that resists compressive pressures. [18]

Since flowable composite has a low modulus of elasticity and a coefficient of thermal expansion and contraction that is too similar to dentin's, it was chosen as the foundation for modifying cavity depths between groups (0, 2, and 4 mm).

For PEEKs, bonding to PEEK is still quite challenging. [19,20] In this investigation, universal bonds with mdp functional groups were used to prime the intaglio surface of PEEK repair. This was confirmed by Chersoni S. et al. [20], who discovered that water-based SE bonds are appropriate for hydrophobic and chemically inert surface adhesion, effectively meeting PEEK's characteristics. Because the hydrophilic primer may sift through PEEK's porous surface, the shear bond strength is enhanced.

The results of all groups ranged from (1747.16+154.38) to (3363.22+382.32) which were so much higher than the normal biting force at molar region (400N - 600N). During clenching, the occlusal force has been observed to be as high as (850N - 900N) Indicating that all results were clinically accepted. [21,22]

**Effect of restorative materials on fracture resistance:**

The overall fracture resistance of the models in this study showed that although endocrowns fabricated with PEEK and lithium disilicate were very successful under normal occlusal functional loads, there were statistically significant differences between fracture resistances of subgroups P and L under high occlusal loads. For endocrowns fabricated from PEEK, the fracture resistance values ranged from (2302±101.97 to 3363.22±382.32), which was significantly higher than that of lithium disilicate (1747.16±154.38 to 2756.73±126). The increased fracture resistance readings of PEEK samples were a function of their microstructure. The PEEK matrix allows the coalition of carbon and glass fibers for the development of thermoplastic fiber composites, and the addition of carbon fibers safely increased the hardness and fracture resistance. [23]

Despite PEEK's relatively rigid molecular chain structure, the material has high ductility and can accommodate large deformations in unilateral stress during compression. In the case of stresses within the yield limit, the material is elastically deformed, and if exceeding the yield limit, the deformation is permanent. [24]

PEEK has mechanical, physical, and elastic properties similar to human bone, enamel, and dentin, providing bioactivity for PEEK as an endocrown. The findings of the current study were in agreement with those of Ouqba G. et al.[23], who found that PEEK endocrowns showed higher fracture resistance than both IPS Emax CAD and Vita Suprinity.

**Effect of cavity depths on fracture resistance:**

Finally, the outcome of this study revealed a correlation between cavity depth and the fracture resistance of restorations. This was apparent when the lowest values of fracture resistance for lithium disilicate and PEEK restorations were 1747.16+154 and 2302.92+101, respectively, at 0 mm. depth designs, whereas the values increased to reach their maximum values of 2765.73+126 and 3363.22+382, respectively, at 4 mm depth designs.

These results coincided with a finite element analysis done by Nereu R.D. et al.[25]who concluded that a greater extension of endocrowns inside the pulp chamber provided better mechanical performance. This could be explained by the fact by the fact that increasing endocrown extension inside the pulpal cavity increases the available surface area for adhesion and thus provides better transmission of masticatory forces.

But this outcome wasn't in agreement with Ouqba G. et al[23]who concluded that different cavity depths (intracoronal extensions) did not influence the fracture resistance of endocrown restorations.

There was another explanation for this result regarding restoration thickness. Tsai et al.[26]found that there was a synergistic correlation between ceramic crown thickness and fracture resistance, a result that was also concluded by Ahmed A. et al[27]and Carvalho A. et al.[28]when they tested the effect of lithium-disilicate endocrown thickness on fracture resistance and found increased fracture resistance with increased intrapulpal extension.

This explanation was also applicable to PEEK restorations, and it coincided with a study done by Evaggelia P. et al[29]who stated a fact for PEEK that with thicker dimensions of restoration, a higher elasticity is obtained, which provides sufficient stiffness and stability because of the critical property of ductility of PEEK. They compared the deformation that occurred to different thicknesses of membrane samples made of PEEK, and they found that thicker thicknesses showed elastic deformation, whereas thinner thicknesses showed plastic changes.

Thus, the null hypothesis was rejected, and there was an effect of changing cavity depths or materials of fabrication on the fracture resistance of endocrown.

**Conclusions**

Fracture resistance of restorations made of PEEK is higher than that of restorations made of lithium disilicate.

Increasing intrapulpal cavity depths increases fracture resistance of endocrown restoration.

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No funding was recieved to this study

**Data availability**
The datasets used and/or analyzed during the current study are available from the corresponding authors on reasonable request.

**Declaration**
The authors declare that they have no competing interests

**Ethical approval and concent to participate**The Research Ethics Committee, Faculty of Dentistry, Ain Shams University, approved all experimental methods, and the study was performed in accordance with its regulations, licensing requirements, and relevant guidelines. Because this study did not contain any intervention with human participants or animals and only utilized archival teeth whose owners cannot be identified, it was exempt from ethical assessment. The approval of the ethics committee is Fdasu-RecD031819. The need for informed consent was waived by the ethical committee of Ain Shams University.

**Conflicts of interest**

Conflict of interest related to this work are denied by the author

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