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Evaluation of the Efficacy of Different Surface Treatments on the Fracture Resistance of Endocrown Fabricated Using PEEK Material (An In Vitro Study)

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ABSTRACT

Introduction: The use of endocrown for restoring badly decayed endodontically treated molars is one of the most advocated treatment options. PEEK (polyether ether ketone) has excellent mechanical and chemical properties. ***Aim of the Study:*** To assess the efficacy of different types of surface treatment of PEEK endocrowns on the fracture resistance of endodontically treated teeth. ***Methodology:*** Thirty-two CAD/CAM endocrowns were fabricated and divided into 4 groups (n=8). In the first group, the endocrowns were fabricated from lithium disilicate and treated with hydrofluoric acid. In the other three groups, the endocrowns were fabricated from PEEK, and their surfaces were treated with sulfuric acid, air abrasion, and a combination of air abrasion and laser. The endocrowns were cemented with self-adhesive resin cement. The fracture resistance was evaluated using a universal testing machine. The mode of failure was analyzed using a stereomicroscope**.** ***Result:*** There was a significant difference between different groups ($p<0.001$). The highest value was found in PEEK (A&L) (3526.27±110.18), followed by PEEK (S) (2871.53±281.74), then PEEK (A) (2847.77±28.72), while the lowest value was found in Emax (HF) (2039.05±4.99). ***Conclusions:*** PEEK endocrowns showed higher fracture resistance than E-max endocrowns. Regarding surface treatment of PEEK endocrowns, the combination of Erbium YAG laser and air abrasion improved fracture resistance compared to sulfuric acid and air abrasion alone. Both PEEK and lithium disilicate endocrowns can be used safely in terms of fracture resistance as both have values which exceed the physiologic requirements. Both lithium disilicate and air abraded PEE/K endocrowns showed mostly unfavorable modes of failure.

Keywords: Endocrown, e.max, PEEK, surface treatment.

INTRODUCTION

It is typically challenging to rebuild severely damaged coronal hard tissue and teeth that have had endodontic treatment in reconstructive dentistry. Due to their increased risk of fracture, teeth with poor structural integrity that have undergone

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endodontic treatment due to caries, trauma, or cavity preparation provide a challeng.[1] Dowel post was once thought to be the best way to place post and repair the damaged tooth structure, but today it is generally accepted that posts do not reinforce the tooth structure and may produce excessive stress that weaken the tooth.[2] Endocrown is substitute for endodontic therapy for molars introduced by ***Bindl and Mörmann in 1999***.[3]

To ensure the effectiveness of the restoration, this ceramic monolithic restoration needed particular requirements for cavity and tooth preparation.[4] Endocrown restoration realizes the biomechanical idea by cervical butt joint preparation and the diverging pulp chamber without reaching the root system and conserving the root dentine. The tooth's survival and prognosis are improved by the surviving dental structure.[5] The introduction of CAD/CAM and milling machine technology in dentistry, aided in the creation and use of dental ceramics. A CAD/CAM system completely controls industrial ceramic production, resulting in high density and minimal porosity, a consistent microstructure, and reduced residual stress in restoration. Such an enhancement has a significant influence on clinical outcome prediction and satisfaction. The development of CAD/CAM technology allowed clinicians to perform high-quality aesthetic restoration chairside. Additionally, different aesthetic restoration materials are presently being used using CAD/CAM systems.[6] Recently released CAD/CAM blocks and discs are based on the combination of ceramics and polymer networks. The microstructure investigations showed that this hybrid material was made of a network of linked ceramic and polymer molecules.[7]

Endocrown restoration is limited to silica-based ceramic materials that can be etched using acid etch to provide a strong bond to the prepared tooth when applying adhesive cements. Results from lithium disilicate are promising due to its high mechanical and aesthetic properties.[8,9]

One of the most widely used high-performance engineering polymers nowadays is polyetheretherketone (PEEK). In 1978, English scientists developed a semi-crystalline linear polycyclic aromatic thermoplastic polymer. Its tensile strength is around 80 MPa, and has a density of 1300 kg/m3.[10] The use of PEEK **(BioHPP)** might be a practical alternative for the restoration of endodontically treated teeth using endocrowns because of its outstanding mechanical and physical qualities as well as its good adhesion properties to tooth structures when bonded with resin cements.[11] Null hypotheses were that there would be no difference in the fracture resistances of PEEK endocrowns treated with different surface treatment methods and also no difference between PEEK endocrown and lithium disilicate endocrown restorations in terms of fracture resistance.

METHODS

Thirty-two mandibular first molar teeth utilized in the study were collected from the MIU bank (IRB approval no. 00010118). All extracted teeth were subjected to a standardized endodontic treatment protocol. The resin blocks were created using acrylic resin blocks with an inside 2.5 cm diameter cylindrical rounded cavity.

The tooth was placed inside the resin. The long access of the teeth was positioned parallel to the long axis of the mold to a depth of 2mm apical to the CEJ. The coronal part of the teeth was subjected to decapitation using coarse diamond discs and copious water irrigation, forming butt joint design using a milling machine to a level 2mm above the CEJ. (**Figure 1)**

A special customized bur was fabricated to prepare the pulpal part of the endocrown preparation. **(Figure 2)**

A conical-shaped stainless-steel bur was adjusted by removing its pointed tip, creating a final dimension of 7mm diameter, 3mm in length, and a taper of 6 degrees**.** A digital software was used to check the previously mentioned dimensions by uploading the tool picture.

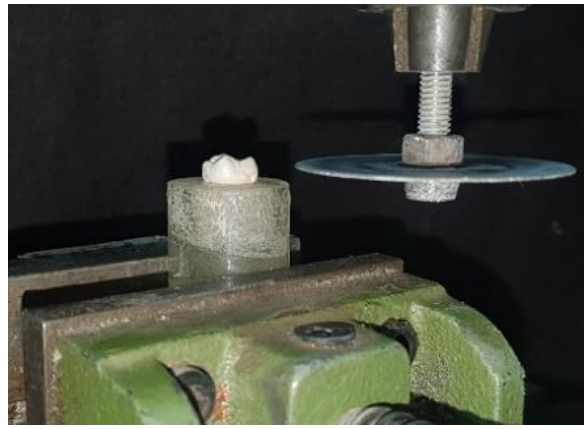

Figure (1): Decapitation of molar.

Figure (2): Customized stone by removing the pointed tip.

The pulp chamber was prepared with a divergent 7-degrees axial wall and 3mm depth inside the pulpal part of the tooth, with the customized bur reaching standardization of all the samples. A thin layer of flowable composite was used to seal canal orifices to enhance bonding of endocrowns.[1] The endocrowns were constructed using a CAD/CAM system with a lab milling machine for the milling procedure. All samples were randomly divided into four equal groups according to surface treatment protocols (n=8). The first group (Lithium disilicate): Surfaces were treated with hydrofluoric acid etching following the manufacturer's instructions. The second group (PEEK) surfaces were treated with sulfuric acid (N=8). The third group (PEEK): Surfaces were treated with air abrasion (N=8). The fourth group (PEEK) Surfaces were treated with a combination of laser and air abrasion (N=8). A CAD/CAM system Cerec AC with omnicam and MCXL in a lab milling machine was used for fabrication of all full contoured endocrown restorations. Endocrown design was done by Cerec AC system, Premium software. (**Figure 3)**

While the inherent grey color of the material may pose an esthetic concern, the application of the BioHPP translucent in the posterior molar region warrants less concern in terms of esthetic.

Cementation

The cementation procedure for all the endocrowns was carried out by using self-adhesive resin cement (Rely-x unicem 3M ESPE Nuess, Germany) following the manufacturer's instructions. A customized loading device with a 6 N applied load was used to standardize the load application during cementation.

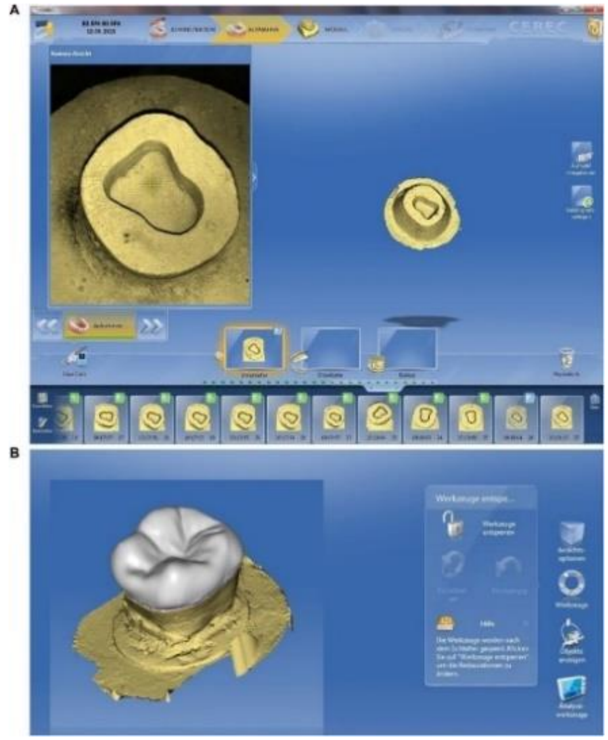

Figure (3): A: Scanned endocrown preparation. **B:** Edit final restoration.

Fracture resistance testing

All samples were mounted vertically on the lower fixed compartment of the universal testing machine (Model 3345; Instron Industrial Products, Norwood, MA, USA). The fracture test was done by comprehensive mode of load. A spherical tip of 6mm in diameter that simulates the opposing cusp was attached to the upper movable compartment of the testing machine. A load was applied (0.5 mm/ min) along their long axis and perpendicular to the occlusal surface of the endocrown restoration until a fracture occurred. Mode of failure was evaluated by using a stereomicroscope, the samples were classified according to the type of failure, either favorable (restoration fracture) or unfavorable (tooth fracture).[2]

Statistical analysis

Quantitative data was presented as mean, median, standard deviation (SD), range (Minimum – Maximum) and 95% confidence interval for the mean (95% CI) values. The data was explored for normality by checking the data distribution, using Kolmogorov-Smirnov and Shapiro-Wilk tests. For parametric data, one-way Analysis of Variance (ANOVA) was used to compare the four groups. Bonferroni's post-hoc test was used for pair-wise comparisons when the ANOVA test was significant. For non-parametric data; Kruskal-Wallis test was used to compare the four groups. Dunn's test was used for pair-wise comparisons when the Kruskal-Wallis test was significant. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM® SPSS® Statistics Version 20 for Windows.

RESULTS

There was a significant difference between different groups (p<0.001). The highest value was found in PEEK (A&L) (3526.27±110.18), followed by PEEK (S) (2871.53±281.74), then PEEK (A) (2847.77±28.72), while the lowest value was found in Emax (HF) (2039.05±4.99). Post hoc pairwise comparisons showed PEEK (A&L) to have a significantly higher values than other groups (p<0.001). In addition, they showed Emax (HF) to have a significantly lower value than other groups (p<0.001). Descriptive statistics of fracture resistance (N) for different groups were presented in **Table (1)**, mean ± standard deviation (SD) of fracture resistance (N) for different groups were presented in **Table (2).**

Table (1): Descriptive statistics of fracture resistance (N).

Group	Mean	95% CI		SD	Median	Range
		Lower	Upper			
Emax (HF)	2039.05	2034.16	2043.94	4.99	2039.20	3.50
PEEK (S)	2871.53	2595.43	3147.63	281.74	2871.53	385.79
PEEK (A)	2847.77	2819.62	2875.91	28.72	2847.77	39.33
PEEK (A&L)	3526.27	3418.29	3634.25	110.18	3526.27	150.88

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Table (2): Mean ± standard deviation (SD) of fracture resistance (N) for different groups.

Fracture resistance (N) (mean±SD)				f-value	p-value
Emax (HF)	**PEEK (S)**	**PEEK (A)**	**PEEK (A&L)**		
2039.05±4.99 C	2871.53±281.74 B	2847.77±28.72 B	3526.27±110.18 A	**64.21**	**<0.001***

**: significant at p ≤ 0.05.*
Means with different superscript letters within the same horizontal row are significantly different.

A bar chart showing average fracture resistance (N) for different groups was presented in (**Figure 4)**.

There was no significant difference between different groups (p=0.630). The majority of the samples in Emax (HF) and PEEK (A) had an unfavorable mode of failure, while for other groups, half of the samples had favorable **(Figure 5)** and the other half had an unfavorable mode of failure **(Figure 6)**.

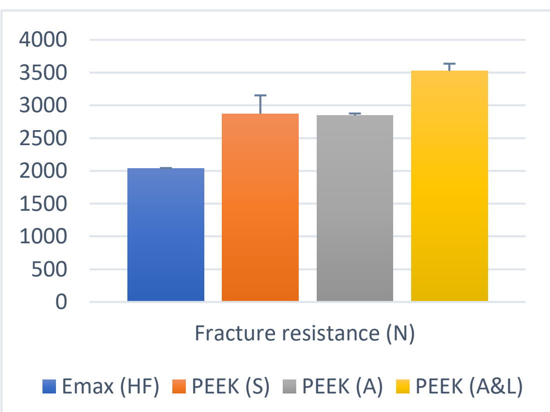

Figure (4): Bar chart showing average fracture resistance (N) for different groups.

Figure (5): Restoration fracture**.**

Figure (6): Tooth fracture.

DISCUSSION

Endocrown is considered an alternative treatment to the traditional approach of post and core, and crown for the management of endodontically treated teeth. It utilizes its retention macro-mechanically from the pulp chamber space and micro mechanically from the adhesive cement, thus allowing for minimal preparation of tooth structure. Excluding the steps of post-placement preparation not only allowed for more conservation of the tooth structure but also decreased the chance of operational errors during drilling. Fabrication of a one-piece adhesive monoblock restoration preserved maximum tooth structure and provided more surfaces for adhesion. Unlike post and core endocrown, it did not require a ferrule effect, which made it a favorable treatment especially for subgingival compromised teeth.[3,4]

E-max was chosen since it is the material that is most commonly used to fabricate endocrown. Monolithic lithium disilicate glass based endocrowns provide a restoration which is not only aesthetically pleasing but also durable and long lasting.[5] While Emax has been widely adopted as the material of choice for the fabrication of endocrowns owing to its good strength, bonding, and excellent esthetics, other materials such as Polyetheretherketone (PEEK) have been suggested as a promising alternative to Emax, especially in molar teeth. Up to this point, the fracture resistance of PEEK endocrowns as well as the effect of different surface treatments on its fracture resistance have not been subjected to adequate study.

PEEK shows favorable mechanical and physical properties such as heat resistance, solvent resistance, high hardness, low water absorption, excellent electrical insulation, good wear resistance, and high fatigue resistance, as well as being biologically compatible, lack of toxicity, and absence of a clinically significant inflammatory reaction, its use has been advocated in varies industries including dentistry.[6] PEEK`s matrix allows union of carbon and glass fibers for the development of thermoplastic fiber composites, and the increment of carbon fibers safely increases the hardness and fracture resistance.[7] Furthermore PEEK is semi-crystalline polymer, containing polyamide molecules with an inherent grey color which may pose an esthetic concern, however, the application of the material in the posterior molar region warrants less concern in terms of esthetic.[8]

PEEK`s physical and mechanical properties make it attractive material to be introduced in the dental field. Its Flexural 140-170 MPa strength, elastic modulus is 3.6 GPa, and by incorporating carbon fibers, the elastic modulus can be improved to 18 GPa which is close to that of dentine, hardness, high fatigue resistance makes it an attractive material to be tested for endocrown fabrication. Thermoplastic high-performance polymers (HPP) are expected to withstand occlusal loads during functions and consequently have to display mechanical strength, in order to prevent cracks, fractures, plastic deformation, or even failures.[9] PEEK deformation can be classified either as temporary or permanent; plastic deformation is the permanent distortion that occurs when a material is subjected to tensile, compressive, bending, or tension stress that exceed its yield strength and cause it to elongate, bend and twist. This type of deformation involves stretching of the bonds and it is irreversible even after removal of the applied force, while temporary deformation means elastic deformation it is reversable.[10]

According to our study, all samples were standardized in all the steps starting from teeth selection to the fracture test. Mandibular first molars were chosen in this study to construct endocrowns. Using molars instead of premolar and anterior teeth because of sufficient tooth structure for bonding. The failure rate of cemented endocrown in premolars is considered higher than that in molars due to less adhesion surface, and a greater premolar crown height in ratio to its width. The mechanical properties of the endocrown cemented to molar have better performance and fewer failures than in premolars.[11]

Natural teeth are used to closely imitate the clinical situation with respect to the morphology, macro and microstructures. Moreover, natural teeth selection allowed for proper surface treatment of both enamel and dentine for bonding and a more accurate extension of the pulp chamber cavity in comparison to acrylic artificial teeth.[3,4,12]

Cavity design was standardized following the guidelines used in a previous study by *Pissis P.1995* [13] to ensure accurate and reproducible results. After tooth preparation of all the samples a layer of flowable composite was placed in the floor of the tooth to block the pulpal irregularities, ensure the absence of undercuts, and improve bonding to the restoration. A CAD/CAM system Cerec AC with omnicam and MCXL in a lab milling machine was used for the fabrication of all endocrown restorations in this study. This allowed for a reduction of human errors and helped in the standardization procedures. Standardization for all the samples was performed by the biogeneric copy mode present in the software to ensure sample with typical occlusal anatomy.[14]

Regarding surface treatment of the samples, e.max was etched with 9% hydrofluoric acid etch as recommended by the manufacturer. While in PEEK the following surface treatments were tested, sulfuric acid, air abrasion, and a combination of laser with air abrasion. A previous study by ***Chaijareenont P et al.2018***[15] investigated different concentrations of sulfuric acid on the bond between PEEK and resin composite. Six groups surface pretreatment (no pretreatment, etched with 70, 80, 85, 90, and 98% sulfuric acid for 60 s) were done on PEEK. The results showed that 90% and 98% sulfuric acid achieved higher SBS values and were the optimal concentrations to improve PEEK adhesion. Accordingly, a concentration of 98% was applied for PEEK in the current study.

Self-adhesive resin cement was used for sample cementation, having large surface area of the dentine substrate made self-adhesive resin cement the chosen material in this study. RelyX unicem was selected for bonding to dentine as it showed good results in a previous study by ***Behr et al.2009***.[16] Selective etching separately before bonding the samples was also recommended to improve the adhesion with enamel.

A strict cementation procedure has been done to eliminate any variation between samples. This study utilized an 80 µm spacer as recommended by ***Liu et al. 2011***[17] to allow for sufficient space to accommodate the cement. Cement thickness during cementation procedure may affect the test result after load application. Increase cement thickness may increase the degree of flexure of the crown and the corresponding high tensile stress produced in the core. On the other hand, having very thin layer of cement, between dentin and ceramic will be very close which is a stiffer material. A cementing device was used to cement all samples to perform standardized load and eliminate the chance of rebound that may happen during cementation and perform uniform thickness to all samples.

According to the results of our study, null hypotheses were rejected because there was a significant difference in fracture resistance between the different surface treatment methods and also between the lithium disilicate endocrown and the PEEK endocrown. PEEK endocrowns showed the highest fracture resistance in comparison to E-max endocrowns.[17] The results showed that endocrown restorations fabricated from PEEK material all had higher fracture resistance in comparison to that of Emax regardless of the surface treatment used. In addition, the fracture mode of PEEK endocrowns tended to be more favorable in comparison to that of lithium disilicate under a compressive load because of its plastic deformation property.[18]

These results were similar to a previous study by ***Ghajghouj and Faruk (2019)***[19] they compared the fracture resistance of endocrowns fabricated using PEEK, lithium disilicate, and Vita Suprinity. They concluded that endocrowns restorations fabricated from PEEK material had the highest fracture resistance under compressive loading of (3026 N) while Vita Suprinity and e.max had a fracture resistance of (1784 N and 1196N, respectively). This can be explained by the inherent property of integrated crack prevention in PEEK material. PEEK is semi-crystalline polymer, containing polyamide molecules.[8] PEEK matrix allows the coalition of carbon and glass fibers for the development of thermoplastic fiber composites, and the increment of carbon fibers safely increases the hardness and fracture resistance.[7]

Within PEEK endocrown groups, the combined use of Air abrasion and Er.YAG for surface treatment prior to cementation resulted in significantly higher fracture resistance when compared to the use of Air abrasion or sulfuric acid for surface treatment. This could be explained by a combination of both the inherent physical & mechanical properties of PEEK and its similarities to human dentin in terms of its elastic modulus, together with the superior bond strength achieved by the combined surface treatment. These results were in accordance with a previous study by ***Jahandideh et al 2020***.[20] They evaluated the effect of laser irradiation alone and in combination with airborne particle abrasion and silica coating. They found that airborne particle abrasion and silica coating in combination with the Er:YAG laser created a durable bond between PEEK and resin. This may be attributed to the ability of Er:YAG lasers to produce high penetration depth in combination with air abrasion which may have increased surface energy to be more effective in creating an optimal substrate surface. Our results were in contrast to a previous study by ***Was et al S. 2020***[21] who concluded that mechanical surface treatment as air abrasion is more effective for increasing the bond strength than other chemical surface treatments.

Debonding of the restoration will lead to separation of the endocrown from the tooth structure that may indirectly affect its fracture resistance.

However, further studies are required to find the most efficient type of PEEK surface treatment and parameters of a laser for this purpose.

In terms of the failure mode, “Favorable failures” were defined as repairable failures above the level of bone simulation and included adhesive failures. On the contrary, “unfavorable failures” were defined as non-repairable, catastrophic failures below the level of bone simulation, including vertical root fractures.[4] The results showed that there was no significant difference between different groups (p=0.630). The majority of the samples in Emax (HF) and PEEK (A) had an unfavorable mode of failure, difference in fracture pattern between PEEK and E-max may be explained by the differences in the physical and mechanical properties between both materials. while for other groups, half of the samples had favorable, and the other half had unfavorable mode of failure. ***Saib et al. 1993***[22] established that an increased degree of crystallinity or higher molecular density of PEEK strongly affects fatigue striations that may have led to favorable failure. However, the mechanism of fatigue crack propagation in PEEK has not been clearly explained as of yet. Among the limitations of this study are that in vitro studies need further clinical trials, also no ageing or thermocycling was done, and there was no composite veneering for PEEK endocrowns.

CONCLUSION

Within the limitations of this study, the following conclusion can be drawn:

1. PEEK endocrowns showed higher fracture resistance than E-max endocrowns.

2. Regarding surface treatment of PEEK endocrowns, combination of Erbium YAG laser and air abrasion improved fracture resistance compared to sulfuric acid and air abrasion only.

3. Both PEEK and lithium disilicate endocrowns can be used safely in terms of fracture resistance as both have values which exceed the physiologic requirements.

4. Both lithium disilicate and air abraded PEEK endocrowns showed mostly unfavorable modes of failure.

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CONFLICTS OF INTEREST: The authors declare that they have no conflict of interest.

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