

Fracture Resistance Of Molars Restored With Endocrowns Made Of Lithium Disilicate Glass-Ceramic And Polyetheretheretone PEEK: An In-Vitro Study

Research Article

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Abstract

Objective: The aim of this study was to evaluate the fracture resistance and failure modes of endodontically treated molars restored with endocrowns made of polyetheretherketone (PEEK) and lithium disilicate glass-ceramic (LDS).

Methods: Thirty-six extracted mandibular molars were randomly divided into three groups (n=12). Teeth in group1 (intact) were left without any treatment. Remaining teeth were sectioned parallel and 2mm above CEJ, undergone to standardized preparation and endodontic treatment, then composite was applied on pulp chamber floor to ensure a depth of 3mm for all cavities. Endocrown restorations made of LDS were used for group2 (e-max), while PEEK veneered with 1mm layer of composite was used to fabricate endocrowns for group3 (PEEK).

Following adhesive cementation, a compressive axial load was applied until failure using a universal testing machine. Fracture loads and Failure modes were recorded. Statistically analysis was performed using one-way analysis of variance.

Results: Mean fracture loads of all groups were higher than normal occlusal forces. Mean fracture strength of group (e-max) was (4842 N) and showed significantly higher value than that of other two groups ($p < 0.05$), whilst mean fracture loads of groups (intact) and (PEEK) did not show statistically differences (2708 and 2559 N respectively). All specimens of group (PEEK) exhibited repairable fractures. In contrast, all samples of group (e-max) exhibited irreparable fractures, while failure modes of group (intact) ranged between repairable and irreparable.

Conclusion: Endocrowns made of PEEK can be used to restore endodontically treated molars as they provide a conservative treatment modality with the ability to modify and repair if necessary.

Keywords: Endocrown; Fracture Resistance; Lithium Disilicate Glass-Ceramic; Peek.

Introduction

Despite all developments in dentistry and its materials, restoring of endodontically treated teeth with excessive coronal destruction is still a challenge for clinicians[1]. Many methods have been introduced to restore damaged teeth including direct restorations, indirect ones such as inlays, onlays, and full coverage crowns supported by cast metal posts and cores, fiber posts with composite resin cores or other techniques[2-5].

The amount of coronal structure remains, as well as, the type of tooth whether it is incisor, canine, premolar, or molar affect choosing the appropriate method to restore these dilapidated teeth[6]. Using any type of intraradicular posts to support a crown

requires much more removal of sound radicular dentine, therefore, the tooth will be weaker[7] and the probability of causing a root perforation and thinning of the root canal walls due to over preparation might increase[8].

Nowadays, the development of adhesive dentistry has reduced the need of posts and cores to restore endodontically treated posterior teeth with extensive coronal tissue loss[9]. Pissis introduced the “mono-block porcelain technic” which is a full ceramic restoration depends on micromechanical retention by adhesive cementation and macromechanical retention by pulp chamber walls[10].

In 1999 Bindl and Mormann[11] proposed the term “Endocrown” to describe such restoration that assembles the intraradic-

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ular post, the core and the crown in one component and can be bonded to a depulped posterior tooth.

According to literature, endocrown has exhibited excellent results regarding the clinical performance[12], in addition it presents excellent mechanical and aesthetic properties[5,9,13,14]. Moreover, endocrown does not require additional removal of intact radicular dentine, this specific property is important when the tooth has short, thin, curved roots[4]. As well as it can be placed in cases in which there is no sufficient interocclusal space to restore with crown supported by post and core[9,15]. Compared with conventional crowns with a cast post and core or a fiber post and resin core, many studies have found endocrowns were more resistant to fracture[4,15,16].

Acid-etchable ceramics have been considered the material of choice for the fabrication of endocrown because they provide aesthetics, adequate mechanical properties to withstand occlusal forces and adequate bond strength to tooth structure[17,18]. Recently, a high-performance polymer, polyetheretherketone (PEEK) has been introduced in dentistry.

PEEK is a semi-crystalline linear polycyclic aromatic, characterizes by excellent physical, mechanical and chemical properties. It has a low elasticity modulus (3-4 GPa) close to that of human bone, enamel and dentine[19-22]. PEEK is biocompatible, non-allergic and has low plaque affinity[21].

Modified PEEK containing 20% ceramic fillers known as BioHPP® (Bredent GmbH Senden, Germany). It distinguished by excellent stability, great optimal polishable properties, and aesthetic white shade of BioHPP® helps to produce high-quality prosthetic restorations[23]. Literature has documented multiple uses of PEEK in dentistry. PEEK intraosseous implants and implant abutments showed very promising results[19,22-25]. PEEK proved eligibility to be a substitute for metal framework in full crowns[26], fixed[19,22,25,27] and removable [28,29] partial dentures. Unfortunately, due to PEEK's grayish-brown color, it is not suitable for monolithic restorations of anterior teeth[30], thus, more aesthetic material such as composite should be used for coating to get an aesthetic result.

Numerous studies have been conducted to examine the bond strength of the adhesives/composite resin to PEEK after using different surface conditioning methods[30-33], they could reach bond strength up to 21.4 MPa. Regarding the literature, a large number of in-vivo[9,11,12,14,34,35] and in-vitro studies[12,36-41] evaluated the clinical performance and mechanical behavior of endocrown using approximately all types of dental ceramics and composites. However, only one case report[42] and two in-vitro studies[43,44] experimented modern polyetheretherketone as a material for endocrown restoration.

Therefore, the purpose of this in-vitro study was to compare the fracture resistance and failure modes of endodontically treated molars restored with endocrown made of PEEK and lithium disilicate glass-ceramic (LDS).

The null hypothesis of this study was that the use of different restoration materials would not affect fracture resistance and failure mode of endodontically treated molars.

Materials And Methods

Thirty-six sound extracted mandibular third molars with nearly similar size (mesio-distal: 9.12 ± 0.43 mm; bucco-lingual: 8.7 ± 0.44 mm), free of carious lesions, with complete root morphology, were collected for this study. Specimens were randomly divided into three groups (n=12) according to materials used.

Teeth in group 1 (intact) were left without any treatment and they were considered as the control negative group. Samples in group 2 (e-max) were restored with endocrown made of lithium disilicate glass ceramic, and teeth in group 3 were restored with endocrown made of a core of polyetheretherketone (PEEK) covered with composite resin.

Using metallic molds each tooth was embedded vertically in auto-polymerizing acrylic resin, 2 mm below cemento-enamel junction (CEJ). In the endocrown groups, reducing occlusal surface to form a flat butt-joint parallel and 2 mm above cemento-enamel junction was performed using cylindrical diamond bur 2mm in diameter.

Butt joint was smoothen using diamond wheel bur. Endodontic access cavities were prepared, then; a standardized endodontic treatment was performed for all specimens. Eugenol free temporary filler (MD-Temp, Meta Biomed, Korea) was applied to ensure setting of canal's filler.

One week later, residual gutta-percha and sealer were removed using a round carbide bur. To seal canals' orifices and uniform the depth of intra-coronal cavity (3mm from the surface of the butt-joint), composite resin restorations (Tetric N-Ceram, Ivoclar, Vivadent, Schaan, Liechtenstein) were applied using incremental technique, and each layer was light-cured for 40 seconds. A pencil and pre-cut plastic sheet were used to colour dentine outer borders of the cavity to ensure all cavities would measure 4mm bucco-lingually and 5mm mesio-distally after preparation. Standardized pulpal walls preparation was performed with occlusal convergence of 60-100° angled using a flat-end tapered diamond bur holding parallel to the long axis of the tooth and following the pulp chamber's colored border. Internal line angles were rounded, and using graded periodontal probe, all measurements were verified.

Putty-wash technique impressions were performed using condensation silicon (Zetaplus and Oranwash L, Zhermack, Rovigo, Italy). Master casts were scanned with a CAD-CAM scanner (AcuBlu, UP3D, Shenzhen, China) and data were transferred to CAD software (exocad, Dental DB, 2018), which was used to make similar full anatomy design of first mandibular molar for all restorations on the virtual models (Figure 1, A). 5mm was the height of designed endocrown measured from the butt-joint to the tips of buccal cusps. Machinable wax was used to fabricate all restorations using a 5-axis milling machine (DWX-52D, DGSHAPE, Roland DG, Hamamatsu, Japan).

For group 2 (e-max), wax sprues were attached to wax endocrowns before investing in investment material, then, IPS e-max Press (Ivoclar, Vivadent, Schaan, Liechtenstein) was used to fabricate ceramic endocrowns according to manufacturer recommendations. Finally, restorations were separated and glazed using IPS Ivocolor (Ivoclar, Vivadent, Schaan, Liechtenstein). For group 3

(PEEK), each wax pattern was set on its corresponding cast, then, a vacuum device and acetate plate were used to make a mold of endocrowns. Virtual models of CAD software were used again to fabricate another design for endocrown's PEEK cores (Figure 1, B). Using shrinkage technique, the new design was 1 mm smaller than the former in all its dimensions. After that, PEEK cores (DD peek MED, Dental Direkt materials, GmbH, Germany) were milled using the 5-axis milling machine.

Outer surfaces of PEEK cores were sand-blasted using 50 µm Aluminum Oxide (AL₂O₃) particles, at a pressure of 2.5 bar, for 10 seconds. After cleaning by distilled water, a layer of adhesive agent (visio-link, Bredent, Senden, Germany) was applied on the outer surfaces using a micro-brush and light-cured for 90 sec according to manufacturer recommendations.

PEEK cores were set on their corresponding casts and using incremental technique, cores were covered with condensing 1mm thickness micro-hybrid composite resin (Tetric N-Ceram, Ivoclar, Vivadent, Schaan, Liechtenstein) with the help of previously made acetate molds. Excessive composite was removed and endocrowns were finished and polished.

To improve composite's mechanical properties, PEEK endocrowns were additionally photo-polymerized using laboratory LED light-curing unit with temperature of 60°C for 10 minutes. Before cementation, all restorations were fitted on their corresponding teeth.

The intaglio surfaces of e-max endocrowns were etched using hydrofluoric acid gel (9% porcelain etch, Ultra Dent, South Jordan, UT, USA) for 60 seconds, then, they were rinsed off with water spray for 20 seconds and air-dried until chalky appearance became obvious. A thin layer of silane coupling agent (Universal Silane, Ultra Dent Products, UT, USA) was applied using microbrush and left for 60 seconds to evaporate.

For PEEK endocrowns, sandblasting and adhesive agent were used to treat intaglio surfaces the same technique aforementioned. Recipient teeth were etched using selective etching technique by applying 37% phosphoric acid (Eco-Etch, Etching Gel, Ivoclar, Vivadent, Schaan, Liechtenstein) for 30 seconds on the enamel tissue and for 15 seconds on the dentine tissue, rinsed off with water spray for 20 seconds and gently air-dried to avoid the collapse of dentine's collagen.

The bonding agent (Tetric N-Bond Universal, Ivoclar, Vivadent, Schaan, Liechtenstein) was applied on the prepared teeth, left for 20 seconds, air-blown and light-cured for 10 seconds. Both types of

restorations were luted using a dual-cure resin cement (Variolink N, Base and Catalyst, Ivoclar, Vivadent, Schaan, Liechtenstein). Same amount of base and catalyst were mixed carefully and applied onto the intaglio surfaces of endocrowns. All restorations were seated accurately with light finger pressure on the corresponding prepared teeth, followed by brief light-curing for 3-5 seconds to remove the excess of luting cement, then each surface was photo-polymerized for 40 seconds.

After that, samples were kept in distilled water at room temperature for 72 hours. Universal testing machine (Testometric, Rochdale, England) with a 5.5-mm diameter stainless steel semi-ball, at a cross-head speed of 0.5 mm/min, was used to perform the fracture test. Samples were vertically loaded on the center of the occlusal surface (axial loading). The maximum force of fracture was recorded in newton (N), then, all specimens were visually examined and the failure modes were classified according to following table (Table 1).

Statistical Analysis

Statistical analysis of all obtained data was performed using SPSS software (version 25). Shapiro-Wilk test was used to test the normal distribution of fracture resistance outcomes. All results were normally distributed ($p > 0.05$). One-way ANOVA was used to compare mean fracture resistance between the three groups. Variables were expressed as the mean \pm standard deviation. Games-Howell post hoc test was used to compare significant differences between groups. Fisher's exact test was used to evaluate the fracture types.

Results were considered statistically significant when p value showed less than 0.05 for all tests.

Results

Mean fracture resistance (in Newton) for group (e-max) was (4842 N), followed by (2708 N) for group (intact), while group (PEEK) had the least mean fracture resistance (2559 N). The mean fracture strength of the groups with respective standard deviations, minimum and maximum values are seen in table 2. According to results, group (e-max) showed significantly higher fracture strength than other two groups ($p < 0.05$), while no significant differences were determined between (intact) and (PEEK) groups ($p > 0.05$). The results of the groups' failure modes are shown in table 3. Regarding the mode of failure, results showed that all specimens of group (PEEK) exhibited repairable fractures (the fracture occurred in the interface between PEEK and composite in all sam-

FIGURE 1: Designing of the restorations. Designing a full anatomy of first mandibular molar for all wax endocrowns on the virtual models (A), Designing PEEK cores 1mm smaller than the full anatomy design in all dimensions (B).

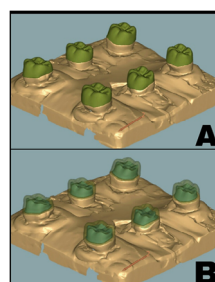


FIGURE 2: Failure modes. Repairable fracture of intact group (did not exceed CEJ) (A1), irreparable fracture of intact group (exceeded CEJ) (A2), irreparable fractures of e-max group (B1-B3), Repairable fractures of PEEK group (Limited in veneering composite) (C1, C2).

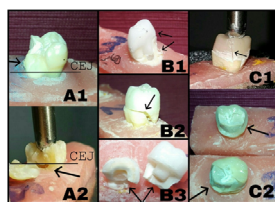


TABLE 1: Classification of failure modes.

Type	Failure mode	Description	Prognosis
I	Cohesive failure	Fracture of the restoration	Repairable
II	Fracture of the restoration/ tooth complex above the (CEJ)	Fracture of the restoration and the tooth above the CEJ	Repairable
III	Fracture of the restoration/ tooth complex below the (CEJ)	Fracture of the restoration and the tooth below the CEJ, which require tooth extraction	Irreparable

TABLE 2: Results of fracture strength

Groups	Mean fracture resistance	SD	Median	Max	Min
Intact	2708	753	2777	3682	1488
E-max	4842	1593	5331	7202	1518
PEEK	2559	461	2523	3205	1859

TABLE 3: Results of Failure modes

Groups	n	Failure mode (Repairable)	Failure mode (Irreparable)
Intact	12	5 (41.6%)	7 (58.3%)
E-max	12	0 (0%)	12(100%)
PEEK	12	12(100%)	0(0%)

ples) as seen in figure 2, C1, C2. In contrast, all samples of group (e-max) exhibited irreparable fractures (the fracture involved both restoration and tooth and extended below CEJ) as seen in figure 2, B1-B3, while failure mode of group (intact) ranged between repairable (5 samples) and irreparable (7 samples) as seen in figure 2, A1 and A2 respectively. Group (PEEK) showed significant difference compared to other two groups.

Discussion

With the development of adhesive dentistry, the need for using post and core has reduced[13]. Etchable ceramics such as those reinforced with lithium disilicate, associated with the adhesive systems and resin cements, has made it possible to restore posterior teeth, especially molars, without cores and intraradicular posts[9,45]. Furthermore, previous studies have favored the use of lithium disilicate for the fabrication of endocrowns[18,46,47].

In recent years, polyetheretherketone (PEEK) with its high physical, mechanical and chemical properties has been increasingly introduced to prosthetic dentistry[19,23]. Studies and clinical reports have demonstrated favorable performance of prosthesis

made of PEEK[26-28]. However, there is no sufficient evidence that peek covered with composite resin can be used as an alternative material of endocrown restoration.

Thus, the purpose of this study was to compare the fracture resistance and failure modes of endodontically treated molars restored with endocrown made of peek and lithium disilicate glass-ceramic (LDS). In the current study, the use of natural molars might have increased the variability of the fracture load compared with artificial teeth. However, the use of natural teeth closely approximates clinical situation regarding tooth architecture and morphology.

To decrease these variables, a strict inclusion criteria was used including bucco-lingual and mesio-distal dimensions. Furthermore, a standardized endodontic treatment, preparation and restoration design was performed for all specimens. Many studies have evaluated the effect of intra-coronal depth of teeth restored with endocrowns on fracture resistance[41,43,48]. In this context, fracture resistance of depulped molars restored with ceramic endocrowns extend 1mm, 3mm and 5mm inside the pulp chambers has been compared, authors concluded that greater extension of endocrowns inside the pulp chamber provided better mechanical

performance[41]. Another study recommended that pulp chamber extension should not be less than 3mm[17]. Numerous studies have looked for the optimum method to obtain enough bond strength between PEEK and composite[31,49,50]. In this study, the choice of PEEK surface treatment was based on recommendations of most of related articles[32].

In the current study, mean fracture loads of all groups were higher than the reported physiologic occlusal forces which vary from 200 to 900 N [51]. According to results, the mean fracture resistance and failure modes of group 1 (intact) were comparable to those of a previous study that reported a mean fracture resistance of intact teeth of (2596 ± 459) N, and 80% of fractures were irreparable[39]. Group 2 (e-max) showed the higher mean fracture resistance, which significantly different from that of two other groups.

The monolithic nature and large thickness of ceramic endocrown restoration could justify the high fracture strength in the current study. Moreover, high mechanical performance of (LDS) due to presence of crystalline particles increases the fracture strength against loading[52]. These results are in accordance with previous studies that reported the superiority of reinforced glass ceramic endocrowns in terms of fracture resistance over other materials[38,39,44].

On the other hand, some studies reported that resin nano-ceramics (RNC) endocrowns showed the highest mean fracture load value over lithium disilicate ceramic, polymer infiltrated ceramics and zirconia-reinforced lithium silicate ceramics (ZLS) [53,54]. Industrial fabrication of these blocks under high temperature and high pressure has led to a high volume fraction filler and high conversion, thus significantly improving their mechanical properties[55,56].

Unfortunately, failure modes of all specimens in group (e-max) were irreparable. This result can be explained by the fact that the development of fracture in tooth extended under endocrown increased bending of the endocrown material and, thus, accelerates its fracture. Hence, this process depends on the strength of the tooth (the base of the construction)[40]. A previous study also reported that the highest rate of irreparable fractures were occurred in (LDS) group in comparison with (ZLS), and (RNC) groups under axial and lateral forces[38].

They related these outcomes to the difference in modulus of elasticity between the materials. (LDS) is more rigid than the other two materials and has a high modulus of elasticity, which concentrates strain in weak area and results in irreparable fractures [57].

Same results were found when fracture modes of (LDS) and two types of composite endocrowns were compared[39]. In the current study, group 3 (PEEK) showed relatively high mean fracture resistance which could be comparable to unrestored teeth. This result is not surprising regarding high mechanical performance, fracture resistance and stiffness of PEEK polymer. Additionally, PEEK has low elastic modulus (4 GPa) similar to human bone, enamel, and dentin, thus, it subside applied forces and distribute stresses by cushioning effect[26].

High bond strength between PEEK polymer and composite resin also play a role in enhancing fracture strength[23]. Findings of

this study are ,somewhat, in agreement with another one which reported high fracture resistance (3026 ± 270 N) of endodontic treated premolars restored with endocrown made of PEEK[43].

However, mean fracture load of PEEK group in mentioned study was significantly higher than that of e-max group. Oblique forces applied on restored premolars at 45° angle reduced the forces required to fracture e-max samples in comparison with axial forces applied on relatively larger molars in our study[38].

On the other hand, fracture modes of all PEEK specimens in our study and a recent one were repairable[44], compared to mixed fracture involving PEEK restoration and dentine in the previous study. This result can be justified by the presence of veneering composite resin in the recent two studies, which split away from underlying PEEK.

Fortunately, the mean fracture load required to separate composite layer was much higher than the reported maximum masticatory forces applied in molar region even in parafunction cases such as "bruxism", that can apply occlusal loads up to approximately 1000N[58].

Clinically, beside stress absorption advantage of endocrown made of PEEK, the veneering composite makes it possible to repair fractured segment, if necessary, directly and intra-orally instead of replacing all the restoration. Furthermore, in some cases in which it is essential to modify the restoration such as raising the vertical dimension or in the context of orthodontic treatment, veneering composite could be altered easily. Another advantage of PEEK is that it does not wear the opposing natural teeth[59]. However, PEEK can be significantly affected by aging other than (LDS) [44].

As with all in-vitro studies, this study has limitations. Although it is necessary to mimic the clinical situation in in-vitro tests, the periodontium around the roots was not simulated in the present study. During the fracture test, the movement of specimens according to the ligament simulation material could change the fracture resistance results and failure modes positively[60]. However, teeth roots were embedded into acrylic resin, 2 mm below CEJ, to simulate the alveolar bone. In addition, thermo-mechanical cycling was not applied in all of the groups. Thus, the clinical relevancy of such aging methods has to be correlated with clinical studies in the future.

Conclusion

Within the limitations of the current study, it can be concluded that minimum fracture load of endocrowns made of lithium disilicate glass ceramic or PEEK veneered with composite resin, was much higher than the maximum masticatory forces.

Although (LDS) endocrowns showed higher fracture resistance than PEEK ones, they showed more irreparable failure rates.

Based on the results of the current study and in light of the available literature, endocrowns made of PEEK can be used to restore endodontically treated molars as they provide a conservative treatment modality with the ability to modify and repair if necessary. However, further investigations are required to confirm their long-term success in different clinical situations.

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