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FRACTURE RESISTANCE OF ENDODONTICALLY TREATED PREMOLARS RESTORED WITH LITHIUM DISILICATE CROWNS RETAINED WITH FIBER POSTS COMPARED TO LITHIUM DISILICATE AND PEEK ENDOCROWNS (AN IN VITRO STUDY)

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ABSTRACT

Statement of Problem: With the development of adhesive systems, endocrowns have been used as an alternative to the conventional post-core and crown systems. PEEK as a restorative material for endocrowns is yet to be proven as an adequate material for restoration of endodontically treated premolars.

Purpose: The purpose of this study was to measure the fracture resistance of endodontically treated maxillary premolar teeth restored with lithium disilicate crowns retained with fiber posts and cores compared to lithium disilicate and PEEK endocrowns.

Material and Methods: Thirty-three extracted maxillary premolars were randomly assigned to 3 groups (n=11). Root canal treatment was performed on them. Teeth were mounted in epoxy resin blocks, 2 mm below the cemento enamel junction then randomly assigned to groups; Group A: Premolars with 2 mm ferrule restored with glass fiber post, core build up and full coverage lithium disilicate (IPS e.max CAD, Ivoclar-Vivadent) crowns. Group B: Premolars with 2 mm butt margin restored with lithium disilicate (IPS e.max CAD, Ivoclar-Vivadent) endocrowns. Group C: Premolars with 2mm butt margin restored with PEEK (Bre.CAM BioHPP, Bredent Medical) endocrown restorations. All teeth were scanned using CEREC primescan and designed on CEREC software. All designed restorations were milled using the inLab MCX5. PEEK endocrowns were designed and milled with cutback then veneered with composite according to the manufacturer's instructions. Restorations were surface treated then cemented using dual cured resin cement. Samples were subject to fracture resistance testing under compressible load parallel to the long axis of the tooth. Universal testing machine with a mounted rounded tip rod was used to apply vertical force while touching both cusp inclines with a load cell of 5 KN and moved at a crosshead speed of 0.5 mm/min. Data was collected and statistically analyzed. Mode of failure was examined and evaluated.

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Results: Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). One-way ANOVA test was used to compare between the three groups. The significance level was set at $P \leq 0.05$. Group A had mean value of 1690 ± 389 N, Group B was 1636 ± 432 N and Group C was 1582 ± 352 N. There was no statistically significant difference between mean fracture resistance values in the three groups (P-value = 0.845, Effect size = 0.012).

Conclusions: Within the limitations of this study, all fracture resistance values were higher than the maximum masticatory force recorded for the premolar region. Endocrowns had fracture resistance similar to those of traditional post, core and crown restorations. PEEK endocrowns were found to have similar fracture resistance to lithium disilicate endocrowns and so are considered a good option for endocrowns.

INTRODUCTION

Teeth represent an important part of the oral cavity, and natural teeth are very difficult to mimic or replace due to their complex structure and composition. Whether due to trauma, fracture, inflammation or infection, root canal treatment may be necessary to try to preserve the natural tooth instead of extracting it as long as it is restorable.

After performing proper root canal treatment of teeth, it is necessary to restore them and protect them as soon as possible. It was thought that the main reason for the weakness of teeth is due to dehydration or loss of vitality only but the primary reason for the decreased stiffness and fracture resistance is attributed to the decrease in remaining tooth structure due to caries, trauma, and extensive cavity preparation. [1,2]

Microleakage is another factor necessitating the quick restoration of the coronal part of teeth following endodontic treatment to prevent oral bacteria from seeping back into the canals and causing a periapical infection or necessitating retreatment of the teeth.

The traditional approach for restoring an endodontically treated tooth is to build up the tooth structure with a core material, commonly composite is used, with or without a post, to retain the core material. Then a full-coverage crown is constructed to encircle the whole tooth and protect it with a sufficient ferrule available. [3,4] Drilling inside the canal leads to a decrease in the remaining amount of dentin, further weakening the tooth. Moreover, it may lead to complications like perforations or root fractures with less experienced dentists. [5]

Endodontically treated teeth were being restored using metal cast or prefabricated metal posts, which resulted in a heterogenous final composition composed of the tooth dentin, the metal post, cement, core build-up material, and the final crown. This heterogenicity caused the stresses to be concentrated in unfavorable areas in the root which causes unpredictable tooth fractures whether favorable or unfavorable. [6]

The conventional metal post and core followed by a full crown has been the restoration technique for endodontically treated teeth with severe coronal loss. Restoration of endodontically treated teeth became more streamlined, biocompatible, and cost-effective with the use of glass fiber posts combined with the dentin bonding technique. Initially, the post was supposed to serve as reinforcement for the tooth's remaining structure. Other authors have found mixed outcomes with significant root fracture rates, implying that removing too much dental tissue to put a post weakens the root even more. [7]

Metal-free posts gained popularity to replace metal posts to have a better bond to the tooth dentin walls. Fiber posts are treated to attempt an adhesive bond to the tooth's dentin in the canal. Although this may have a better bond strength than metal posts, adhesive failures were also observed between the dentin surface and the fiber post. [8]

Inlays and onlays of different thicknesses and materials have been proposed to be used for restoring endodontically treated teeth. [9] According to Mondelli et al's study which was performed specifically on maxillary premolars to evaluate the strength of the teeth with different amounts of preparation and restoration; the teeth with the least amount of preparation were the teeth that had the highest fracture resistance and survival rate. [10]

With the introduction of adhesive dentistry, endocrowns became a viable option to bond to the remaining tooth structure without the need for drilling into canals. The endocrown can be used to treat teeth with significant coronal loss. Bindl and Mörmann used the term "endocrown" in 1999 to refer to a ceramic crown that extends into the pulp chamber or root canal orifices of an endodontically treated tooth to acquire retention. [11] This design prevents further loss of tooth structure and avoids post-space preparation complications.

In a study, Lin et al. investigated the failure risks of an endodontically treated premolar with substantially damaged coronal hard tissue that was restored with either a CAD/CAM ceramic endocrown or a traditional crown configuration. While the endocrown and classical crown restorations had comparable overall failure rates, fatigue fracture testing demonstrated that the endocrown restoration had better fracture resistance than the traditional crown configuration. The endocrown can be regarded as a conservative, attractive, and clinically feasible restorative option for endodontically treated maxillary premolars. [12]

In general, several factors can affect fracture resistance of restored teeth. Those factors include remaining tooth structure, [1] choice of material, [13] and preparation design. [14] Many other factors affect the success and prognosis of endodontically restored teeth and recent materials developed are targeted towards approaching the physical properties of the natural teeth to allow for a more favorable stress distribution mimicking the lost natural tooth structure properties. [15]

A big advantage of adhesive dentistry is that the restoration does not rely on physical retention but rather adhesion to the enamel and dentin. The retentive elements are not required anymore as long as there is enough surface area for bonding. [16] With this approach, the placement of posts became less common. Minimal invasive preparations with maximum tooth structure conservation became the gold standard for restoring endodontically treated teeth. This made endocrown preparations more attractive for restoring teeth.

According to papers published by Pissis and Bindl for the endocrown preparation design, the preparation consists of a circumferential 1-1.2 mm wide butt margin and a central retention cavity that extends into the pulp chamber. The endocrown is fabricated as a single monoblock structure that has the core and crown as one structure. The endocrown does not take any support or retention from the root canal system, but is rather bonded to the tooth structure. [11,17]

According to Pissis, the suggested dimensions for an endocrown preparation for a premolar are a 3mm diameter cylindrical pivot and a 5mm depth extension into the pulp chamber for a maxillary first premolar. For molars, he suggested 5mm cylindrical diameter and 5mm depth. [17] The dimensions utilized in a study on premolars were comparable, with the central retention cavity's depth being 5mm from the cavosurface boundary and rounded internal line angles, but the exact dimensions for the central retention cavity were not clearly established. [18,19]

An ideal material would be that with a modulus of elasticity exactly the same as that of natural teeth.

Several materials have been proposed to mimic natural teeth dentin and enamel. Materials proposed for this type of restoration include lithium disilicate, hybrid ceramics, resin materials, and others.

This study explores the possibility of using PEEK as an alternative material to restore endodontically treated premolars due to its modulus of elasticity which is closer to that of the tooth structure. There is a gap of knowledge in the use of this material with this sort of restoration. A comparison was made between PEEK and lithium disilicate due to the latter being a commonly used material in single-tooth restorations besides its optimum bonding properties.

Two null hypotheses were suggested for the study, endocrowns constructed with PEEK will have more fracture resistance than lithium disilicate crowns retained with fiber posts and the second, that endocrown restorations with PEEK material will show more fracture resistance than endocrowns made of lithium disilicate material.

Aim of the Study

The aim of this study was to measure the fracture resistance of endodontically treated teeth restored with lithium disilicate crowns retained with fiber posts compared to lithium disilicate and PEEK endocrowns.

Two null hypotheses were suggested for the study, endocrowns constructed with PEEK will have more fracture resistance than lithium disilicate crowns retained with fiber posts and the second, that endocrown restorations with PEEK material will show more fracture resistance than endocrowns made of lithium disilicate material.

MATERIALS AND METHODS

Teeth selection

Thirty-three freshly extracted caries free maxillary premolars with comparable configuration were collected. The teeth were inspected under 3.5x magnification. The anatomic crowns were selected to be within average dimensions of 9 mm ± 1 mm at the bucco-lingual dimension and 7 mm ± 0.5 mm at the mesio-distal dimension. [20]

Teeth disinfection and storage

The selected teeth were disinfected by immersion in 5 % sodium hypochlorite solution (JK Sodium Hypochlorite solution 5%, Mansourah, Egypt) for 15 minutes at room temperature then cleaned with an ultrasonic scaler (UDS-N2 LED Ultrasonic Scaler, Guilin Woodpecker Medical Instrument Co Ltd, Guangxi, PRC) at a low power and under copious water coolant to avoid formation of any micro-cracks. The teeth were kept hydrated at room temperature in saline solution prior to the study.

Preparation of the teeth

Allocation of the samples

In a random manner the samples were divided into three main groups. According to the type of restoration and material, groups are as follows;

Group A: Lithium disilicate crowns retained with fiber posts and composite core build up;

Group B: Lithium disilicate endo-crowns with butt joint margin;

Group C: PEEK endo-crowns with butt joint margin.

Endodontic treatment: Teeth were endodontically treated and prepared to receive their respective restorations according to their assigned group. The access cavities of the teeth were performed with a high-speed hand piece (Pana Air, NSK LTD, Tokyo, Japan) under copious water coolant using a size 1 round bur (BR-46, Mani INC., Tochigi, Japan) followed by an ENDO-Z bur (Dentsply Sirona Maillefer, Switzerland) for access refinement and to prevent floor gouging during access The working length of each tooth was determined by using K-file size 10 (Mani INC., Tochigi, Japan). Root canals were then treated using a Ni-Ti rotary file system (Protaper, Dentsply, Maillefer, Switzerland) with EDTA lubricant (MD-Chelcream, Meta Biomed, Korea) until file size 25 taper 6% with working length 1 mm short of the anatomical apical foramen. Copious irrigation using 5.25% sodium hypochlorite was used in between files. After a final copious irrigation, the root canals were dried with paper points (Absorbent Paper Points, Meta Biomed, Korea) and master cone fitting was done using matching gutta percha points (Gutta Percha Points, Meta Biomed, Korea) to the full working length. A resin-based sealer (ADSEAL, Meta Biomed, Korea) was used to coat the gutta-percha points and placed in root canal to the working length. Canals were laterally condensed to fill in the anatomical shape of the cleaned and shaped canal coronally. Excess gutta-percha coronal to the orifice was removed using a heated instrument (cherry red) and the coronal part was compacted with a plugger (Hu-Friedy Mfg. Co., LLC., Illinois, USA) vertically.

Teeth mounting: Teeth were mounted in epoxy resin blocks, 2 mm below the cemento enamel junction to simulate the level of bone, along the long axis of the tooth.

Preparation of the samples

Teeth in Group A received posts and cores, and were prepared for full coverage restorations. Teeth in Group B and C were prepared to receive endocrowns by creating a 2 mm butt margin above the CEJ (Figure 1).

Post and core supported lithium disilicate crown group (Group A)

After sectioning the coronal portion of the teeth, the gutta-percha was removed from the palatal canal using a pilot reamer of the post system (Nordin Dental, Montreux, Switzerland) to 4 mm form the apex according to the working length determined before. A post space was prepared with the corresponding drill (size 2) included in the post system. The canals were etched with 37% phosphoric acid (Meta Etchant, Meta Biomed, Korea) for 15 seconds. The canals were thoroughly rinsed with water then dried with compressed air and paper points.

A light cure adhesive agent (All Bond Universal Adhesive, BISCO Dental Products, Illinois, U.S.A.) was applied inside the root canal using a micro brush (MA-102 Microbrush, Elephant, Hong Kong, China). The adhesive was rubbed onto the canal walls for 10 seconds and the excess solvent was removed with gentle oil free compressed air for 3 seconds and light cured for 20 seconds according to manufacturer instructions.

Using a micro brush, silane coupling agent was applied on the post surface for 60 seconds and then gently air dried for 5 seconds. The post was rechecked for complete seating then luted with dual cure resin which was auto mixed and applied along the post surface and inside the post space in the canal. The post was inserted and positioned in place with firm finger pressure, then the excess resin cement was removed with a micro brush, followed by light curing for 20 seconds from occlusal surface following the manufacturer's instructions.

The tooth chamber and butt margin were etched, rinsed then dried with compressed air. A light cure bonding agent was applied using a micro brush. The bonding agent was rubbed for 10 seconds and the excess solvent was removed and light cured for 20 seconds according to manufacturer instructions. A core build up was made by injecting dual cure core build up material (Build-It FR, Wallingford, Connecticut, USA) which was injected in one increment around the post. It was light cured for 40 seconds for each surface as per manufacturer instructions.

All teeth were prepared by the same operator under the same settings with 3.5x loups magnification[21]. Teeth were prepared using a standard grit tapered with round end diamond stone with a tip diameter of 0.18 mm (TR-13 (ISO

198/018), Mani, INC, Tochigi, Japan) and finished with the same size diamond having fine grit (TR-13F (ISO 198/017), Mani, INC, Tochigi, Japan). Teeth were prepared with 2 mm circumferential ferrule and with 10 degrees convergence. All axial walls had circumferential deep chamfer margin 1mm wide with rounded line angles. Preparations were checked for undercuts and analyzed on the CEREC software using the prep check feature. The teeth with build-up were made ready to receive e.max crowns.

Endocrown groups (Lithium disilicate and PEEK) (Group B and Group C)

After coronal sectioning to prepare a circular butt margin 2 mm above the cemento-enamel margin as previously described, gutta percha was removed until canal orifice openings at the level of the pulp chamber floor. No drilling was done inside the canals. A thin layer of flowable composite material was bonded to seal the canal orifices.

Endocrown preparation was made with an extension into the pulp chamber of 4 mm with a tolerance of 0.5 mm measured from the butt joint margin to the floor of the chamber. This was measured using a graduated periodontal probe (Hu-Friedy Mfg. Co., LLC., Illinois, USA) and was confirmed later in the study during the designing phase (Figure 1).

The pulp chamber was prepared to eliminate undercuts with a 10-degree coronal divergence following the circumferential shape of the chamber walls with all internal line angles rounded and smoothened. All internal line angles were round and smooth according to the endocrown preparation design suggested by previous authors [22].

Construction of Cerec CAD/CAM endocrowns and crowns

A CAD/CAM system (Primescan, CEREC and MCX5, Dentsply Sirona, Bensheim, Germany) was used for the fabrication of all samples in this study.

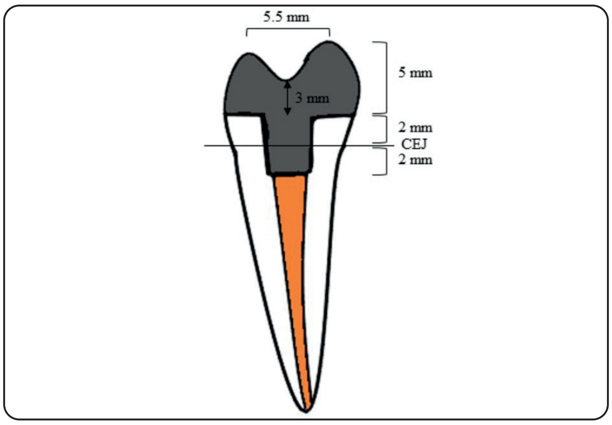

Fig. (1) Measurements of endocrown preparation and restoration design

Scanning and designing

To obtain a three-dimensional image for each of the prepared teeth to be used for the design software, a 3D intraoral scanner (CEREC Primescan) was used to scan the prepared samples. The scans were then used for the subsequent design of the restorations on the CEREC CAD software Version 5.1 then milled using a 5-axis milling machine of the same company (inLab MCX5, Dentsply Sirona, Bensheim, Germany).

Although milling of the e.max crowns and endocrowns was possible using the CEREC Primemill, a chairside milling solution that can produce single-unit restorations, including crowns, inlays, onlays and veneers; the milling of the PEEK blank is not possible using the same machine. PEEK blanks need a 5-axis blank accepting machine. So, for standardization of the milling procedure the inLab MCX5 was used to mill all restorations of all groups.

Cement space was set at 80 microns for crowns and 60 microns for endocrown restorations. This is attributed to the longer preparation walls of the crowns and for smoother insertion with minimal interference; unlike endocrowns which have divergent walls and shorter preparations in comparison.

Standardization of design

One of the limitations of this study is that teeth selected were maxillary premolars, so maxillary first and second premolars were collected. In this regard, designing identical teeth morphology for all samples was not possible due to the inherent difference in teeth shape and morphology between those two teeth.

To overcome this inevitable difference in shape, certain design parameters were used to make the produced restorations as close and similar to each other as possible. For that purpose, each group was standardized accordingly. A base scan was needed to be used as a base design for the restorations. This base scan would be used for the biocopy design feature in the design software. This reference scan was obtained from the first crown manufactured using the teeth library in the CEREC software for the post, core and crown group of the study. This particular tooth with the crown was rescanned as a preoperative scan and saved in the library for use with the rest of the restorations of the other groups. The CEREC software would use this scan as a reference in designing the restorations of all the other prepared samples.

Due to the previously discussed limitation of using first and second maxillary premolars, further steps were needed to ensure similar sized restorations.

For the post, core and crown group (Group A), this was achieved by standardizing the intercuspal distance for all restorations at 5.5 mm with a minimal amount of tolerance of +/- 0.5 mm in the measurements between the designed crown restorations. For further standardization, the distance between the fossa to prepared tooth structure was also standardized at 1.5 mm +/- 0.3 mm with minimal amount of tolerance between the designed crown restorations. Finally for this group, the distance between the cusp tip and the margin was kept similar at 7 mm +/- 0.5 mm and the distance from the marginal ridge to the finish line was kept similar at 5 mm +/- 0.5 mm.

For the lithium disilicate endocrown group (Group B), similar measures were taken, in which the intercuspal distance was kept similar at 5.5 mm with a minimal range of tolerance at 0.5 mm and the distance from the cusp tip to the butt joint margin was also kept similar at 5 mm with a minimal range of tolerance of 0.5 mm. Finally, the distance from the marginal ridge to the butt margin was maintained at 3 mm with 0.3 mm tolerance.

For the PEEK restored endocrown group (Group C), there was a limitation for the previously explained method to be used directly on the design software. This is because PEEK restorations will need to be milled with a cutback from the final desired design to provide the required space and thickness for the subsequent placement of the veneering composite as per the manufacturer's instructions. To accomplish this while still maintaining a relatively standardized design between the group samples and also between the group samples and the other samples of the other two groups, a standardization method specific for the PEEK group was devised.

The method of standardization used was to design a full contour endocrown for the teeth in the PEEK groups using the software. Using the previously mentioned standardization methods of intercuspal distance and cusp to butt margin distance, all measurements were kept similar and within minimal tolerances for the designed endocrowns. This design was then used to 3D print an acrylic endocrown copy of the desired final outer contour of the final restoration. This was done for each sample.

A clear index was made using clear polyvinyl siloxane material (Visio.sil ILT, Bredent medical GmbH & Co.KG Senden, Germany). This index material was injected around the tooth with the 3D printed acrylic endocrown on top of it. An index of the final desired shape and outcome was obtained using this index.

On the software, for each tooth design, a sufficient amount of cutback was done to accommodate the space for veneering composite placement after PEEK core milling. Using this finalized design, the PEEK endocrown cores were milled using the inLab MCX5 machine. Once the cores were obtained and treated according to the manufacturer instructions for composite bonding, the unique index for each tooth was placed on top of the PEEK core and tooth assembly then composite was injected in the remaining space, producing a veneered PEEK endocrown restoration with the desired initial standardized design that was printed on the 3D printer for each tooth.

Milling

For milling the restorations, the desired material as well as the size were selected and confirmed on the software. IPS e.max CAD LT A2 C14 block was inserted in the spindle of the milling chamber of the inLab MCX5 milling machine and fastened with the set screw.

With diamond burs functioning simultaneously in the shaping process and profuse water cooling sprayed from different directions, the milling process was fully automated with no interference. After completion of the milling process, the restorations were separated manually from the block holder with a diamond cutting instrument (6942.11.200 HP Coarse Dispersed Edge Double Sided Diamond Disc, Brasseler, Georgia, USA). Then excess sprue removal was carried out using green heatless stone wheel (8003.170HP Green wheel contouring stone, Brasseler, Georgia, USA). All endocrowns and crowns were checked over their corresponding teeth for seating before further procedures.

Crystallization and glaze firing for lithium disilicate crowns (Group A) and endocrowns (Group B)

The Programat CS3 furnace (Ivoclar Vivadent, Schaan, Liechtenstein) was used for crystallization and glaze firing of the restorations. The e.max CAD ceramic crowns were in their pre-crystallized form after milling in which they were in their "blue" state. Their crystallization process gives the glass ceramic restoration its final strength and desired esthetic properties.

E.max crowns and endocrowns received a glaze layer (IPS E.Max CAD Crystal Glaze Paste, Ivoclar Vivadent, Schaan, Liechtenstein) before being placed in the furnace for the crystallization process. The IPS e.max CAD restorations were supported by an object fix material (IPS Object Fix, Ivoclar Vivadent, Schaan, Liechtenstein) and fired on their firing tray according to the manufacturer's instructions. Restorations were fired to their maximum functional and esthetic properties. The appropriate present program was chosen on the firing furnace. The starting temperature was at 403 °C and increased at a rate of 90 °C/min until it reached 890 °C and was held for 2 minutes; after that, the temperature was increased at a rate of 30 °C/min until it reached 840 °C and was held for 7 minutes.

After firing, e.max restorations were removed from the furnace and were left to cool down to room temperature at a place protected from draft.

Composite layering of PEEK endocrowns

After milling of PEEK core substructure according to the predefined design that was done on the software, they were removed from the blank using a diamond bur on a low-speed handpiece. Core substructures were then prepared for bonding with the veneering composite. This process was done by preparing the surface through several procedures to achieve a strong bond between the composite and PEEK.

The process started with sandblasting of the PEEK surface using 110 μm aluminum oxide particles with a pressure of 2 bar with an angle of approximately 45°. The blasting distance was maintained at a distance of approximately 3 cm. This was following the manufacturer's instructions.

Following sandblasting, PEEK cores were air blasted using oil-free air then cleaned using compressed steam to remove any residues. A special adhesive material (Visio.link, Bredent medical GmbH & Co.KG Senden, Germany) was thinly applied to the surface of the core. This was done to achieve a sufficient adhesion between the veneering composite and the PEEK framework. Curing of the visio.link adhesive material was done by a bench top light polymerization device (bre.Lux PowerUnit 2, Bredent medical GmbH & Co.KG Senden, Germany) with a wavelength range of 370-400 nm for 90 seconds.

After removing the cores from the light curing unit, the conditioned area had a silk-matte finish. This shows that the layer thickness is perfect. A mix of opaquer light and catalyst (Opaquer combo. lign light and catalyst, Bredent medical GmbH & Co.KG Senden, Germany) was made and placed on the surface of the cores; this enhances the bonding to the following layers of composite to be placed. This was then light cured for 180 seconds in the bench top light curing unit.

The first layer of composite was then placed, manufactured by the same company. Opaque composite (Crea.lign opaquer 5, Bredent medical GmbH & Co.KG Senden, Germany) was placed to help in creating an even more esthetic final result, even though the PEEK substructure is white which provides good esthetics on its own. This was then cured for 360 seconds in the benchtop light curing device. Veneering composite was then placed on the PEEK core. This was done by using the clear index obtained from the design phase. This allows for the standardization of the final endocrown. Veneering (Crea.lign composite, Bredent medical GmbH & Co.KG Senden, Germany) composite was used to veneer PEEK milled cores according to the manufacturer's instructions.Veneering composite was first injected into the clear matrix mold, then firmly seated using finger pressure on the corresponding seated PEEK core and prepared tooth. This allows the veneering material to flow in the negative space created between the PEEK core and the matrix.

This assembly was then placed into the benchtop light curing unit and cured for 360 seconds to achieve the sufficient bond between the composite and PEEK core and strength of the restoration. Upon removal from the light curing device, the clear matrix is then removed from the surface of the restoration and the veneering composite was found fully bonded to the PEEK core substructure.

PEEK endocrown restorations were then finished and polished according to the manufacturer's instructions to achieve a high shine. High shine polishing is done to achieve superior esthetics, decrease plaque affinity, decrease its tendency for discoloration and increase its surface quality.

Finishing procedure was done using first the Ceragum rubber polisher (Ceragum rubber polisher, Bredent medical GmbH & Co.KG Senden, Germany) to remove the excess crea.lign composite and flash. Then an extra fine brush (Extra fine abraso-fix round brush, Bredent medical GmbH & Co.KG Senden, Germany (ref 35000752)) was used to finish the surface of the endocrown restoration. This grossly finished the restoration and removed the residual material on the restoration surface. Pre-polishing is carried out using a goat hair brush (Goat hair brush, Bredent medical GmbH & Co.KG Senden, Germany) and polishing paste (Acrypol polishing paste, Bredent medical GmbH & Co.KG Senden, Germany). The goat hair brush was dipped in the paste then was run on the surface of the endocrown until a semi-polished surface was achieved. Minimal pressure is needed to achieve sufficient polish. High-gloss polishing is carried out using a cotton buffing wheel (Cotton buff with shaft, Bredent medical GmbH & Co.KG Senden, Germany) and a high luster polishing paste sold by the same company (Abraso-Starglanz high luster polishing paste, Bredent medical GmbH & Co.KG Senden, Germany). The polishing paste was placed on the restoration then the cotton wheel was run over it with minimal pressure to buff the surface and give it the high gloss appearance.

Finalized PEEK endocrown restorations (Figure 2) were seated on the prepared specimens and marginal adaptation was confirmed. Final treatment of the fitting surface was done to prepare the restorations for bonding with the tooth structure.

Fig. (2) Final high-gloss PEEK endocrown restoration

Bonding procedures

Surface treatment of restorations

Fitting surfaces of each material were treated according to their respective manufacturer's instructions and made ready for cementation.

Lithium disilicate (e.max) restorations

Intaglio surfaces of lithium disilicate restoration were treated according to the manufacturer's instructions. 9.5% hydrofluoric acid gel was applied for 20 seconds to etch the restorations then rinsed for 60 seconds with running water and dried with moisture-free air for 30 seconds. A ceramic primer (Porcelain Primer, BISCO Dental Products, Illinois, U.S.A.) containing silane coupling agent was applied to the intaglio surface of all endocrowns using a microbrush; and allowed to dry for 60 seconds.

PEEK restorations

Peek endocrown fitting surfaces were sandblasted using 110 µm aluminum oxide particles at a pressure of 2 bar with an angle of approximately 45°. The blasting distance was maintained at approximately 3 cm. Any impurities were removed after sandblasting by steam cleaning the PEEK core before bonding.

Following sandblasting, a special adhesive material (Visio.link, Bredent medical GmbH & Co.KG Senden, Germany) was thinly applied to the surface of the fitting area of the PEEK which extended into the tooth chamber area. This was then cured using a light polymerization device (bre.Lux PowerUnit 2, Bredent medical GmbH & Co.KG Senden, Germany) with a wavelength range of 370-400 nm for 90 seconds. After light curing, the conditioned area had a semi-matt finish, indicating the perfect layer thickness of the material. This allowed for sufficient bonding to the tooth dentin surface using resin-based adhesives.

Surface treatment of prepared natural teeth

Prepared tooth surfaces were etched with 37% phosphoric acid–etching gel for 15 seconds, rinsed for 20 seconds, and dried with oil-free air for 5 seconds.

A coat of bonding agent (All Bond Universal Adhesive, BISCO Dental Products, Illinois, U.S.A.) was applied to the preparation with a micro brush. Excess solvent was dried with oil-free air for 3 seconds, then light cured for 20 seconds.

Dual cure resin cement (Biscem, BISCO Dental Products, Illinois, U.S.A.) was applied on the prepared surface of teeth. Each crown and endocrown was bonded to its corresponding tooth. The excess cement was tack cured for 2 seconds then removed using a sharp explorer. A loading device was used to apply constant load of 1.5 KGs parallel to the long axis of the tooth of each specimen. Resin cement is then light activated for 20 seconds per surface in each direction.

Fracture resistance determination

After cementation, samples were left on a benchtop for 15 minutes for the resin cement to fully set. Manufacturer recommends at least 10 minutes are required at room temperature (20°C) for full setting. Samples were then stored in saline solution for 48 hours before being subject to fracture testing.

For fracture resistance testing, a single static compressive load application was applied along the long axis of each specimen (Figure 3). Machine head was placed in contact of buccal and lingual cusps' inclines occlusally. Specimens were individually mounted on a computer controlled universal testing machine (Model 3345; Instron Industrial Products, Norwood, MA, USA) with a loadcell of 5 KN. Data was recorded using an associated computer software (Bluehill Lite Software, Instron® Instruments, Norwood, MA, USA).

Test specimens were secured to the lower fixed compartment of the testing machine by tightening screws. Fracture test was done by compressive mode of load applied occlusally using a metallic rod with round tip with 3.8 mm diameter attached to the upper movable compartment of the testing machine travelling at a cross-head speed of 0.5 mm/min [12,19,23–25].

The load at failure was manifested by an audible crack and confirmed by a sharp drop at load-deflection curve and was recorded using a computer software (Bluehill Lite Software V2.32, Instron® Instruments, Norwood, MA, USA). The load required to fracture was recorded in Newton. Data recorded was collected, tabulated and statically analyzed accordingly.

Mode of fracture observation

Mode of fracture of the tested samples was

Fig. (3) Restored tooth fixed to the mount ready for fracture testing

observed and recorded for analysis. Samples were examined visually and photographed. The specimens' fractures were considered either favorable or unfavorable.

Fractures were considered favorable if the fracture is repairable; either a tooth fracture above the cemento enamel junction or a fracture within the restoration while preserving the remaining tooth. Unfavorable fractures were those with tooth fractures below the cemento-enamel junction (CEJ) or vertical fractures that are non-repairable.

RESULTS

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). Fracture resistance data showed normal (parametric) distribution. Data were presented as mean, standard deviation and 95% Confidence Interval (95% CI) for the mean values. One-way ANOVA test was used to compare between the three groups. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

Fracture resistance results

Samples that were treated with post, core build up and e.max crowns (Group A) had a mean fracture resistance value of 1690.1 N with standard deviation of 389.8 N.

In endocrown groups, IPS e.max endocrown restored teeth had a mean value of 1636.5 N with a standard deviation of 432 N while the PEEK endocrown restored teeth had a mean value of 1582.9 N and a standard deviation of 352.3 N.

There was no statistically significant difference between mean fracture resistance values in the three groups (P-value = 0.816, Effect size = 0.013). Results and descriptive statistics are presented in (Table 1).

Mode of Fracture Results

Following fracture resistance test, mode of fracture of the samples was examined and tabulated (Table 2).

Specimens were examined, fractures were evaluated and classified into favorable or unfavorable. Fractures are considered favorable if the fracture is repairable; either a tooth fracture above the cemento enamel junction or a fracture within the restoration while preserving the remaining tooth. Unfavorable fractures are those with tooth fractures below the cemento-enamel junction (CEJ) or vertical fractures that are non-repairable.

Fracture pattern in Group A (fiber post, core and lithium disilicate crown)

Within Group A, the most common mode of fracture observed was fracture above the CEJ or restoration fracture. This was observed in more than 70% of the samples and is a favorable (repairable) mode of fracture. 5 samples had fractured core and lithium disilicate crown, 3 samples had fractured lithium disilicate crown only. The rest of the samples (3 samples) had unfavorable types of fractures in

TABLE (1) Descriptive statistics and results of one-way ANOVA test for comparison between fracture resistance values (N) in the three groups

Group	Mean	SD	95% CI		*P*-value	*Effect size (Eta Squared)*
			Lower bound	Upper bound		
Group A (IPS e.max crown) (n = 11)	1690.1	389.8	1428.2	1952	0.816	0.013
Group B (IPS e.max endocrown)(n = 11)	1636.5	432	1346.3	1926.7		
Group C (PEEK endocrown) (n = 11)	1582.9	352.3	1346.2	1819.6		

TABLE (2) Observed Fracture mode of samples

Study Group	Fracture Mode			
	Favorable (repairable)		Unfavorable (non-repairable)	
	Count	Percentage	Count	Percentage
Group A (e.max crown)	8	72.7%	3	27.3%
Group B (e.max endocrown)	3	27.3%	8	72.7%
Group C (PEEK endocrown)	11	100%	0	0%

which the core, lithium disilicate crown, and part of the tooth below the CEJ was fractured.

Fracture pattern in Group B (teeth restored with lithium disilicate endocrowns)

In this group with lithium disilicate endocrowns, more than 70% of fractures were unfavorable. 8 samples had fracture in the tooth structure as well as the lithium disilicate endocrown. The tooth structure fractured below the CEJ which as unrestorable hence the unfavorable outcome (Figure 4). In the remaining teeth (3 samples), fractures observed were within the restoration material so the outcome was favorable in which the restoration can be replaced.

Fracture pattern in Group C (teeth restored with PEEK endocrowns)

Mode of fracture of teeth restored with PEEK endocrowns were all favorable (11 samples). All fractures in this group were within the veneering composite placed on the PEEK core (Figure 5). Cores remained cemented to the tooth and no tooth structure was fractured in this group. Failures were 100% favorable and repairable.

DISCUSSION

Endodontically treated teeth with extensive loss of the coronal tooth structure used to be restored using metal or fiber posts and cores [26]. Besides the need for removal of more sound tooth structure in the root canal space to create space for the post, several risks are associated with such restorative procedure including root perforation, weakening of the remaining tooth structure and the risk of apical crack or fracture. Furthermore the benefits of a post in the root canal for the overall retention of successive reconstruction is recently being questioned [14].

In this study natural maxillary premolar teeth were used. This was in an attempt to closely mimic the natural situation intraorally. Restorations can be bonded to the dentin and enamel of the tooth structure and so the bond strength, restoration fracture resistance, tooth fracture resistance, preparation and restoration design can be evaluated. This closely approximates the clinical situation in regards to the tooth anatomy, bonding to natural tooth structures, pulp chamber contour and other factors when compared to other studies conducted on artificial teeth [27].

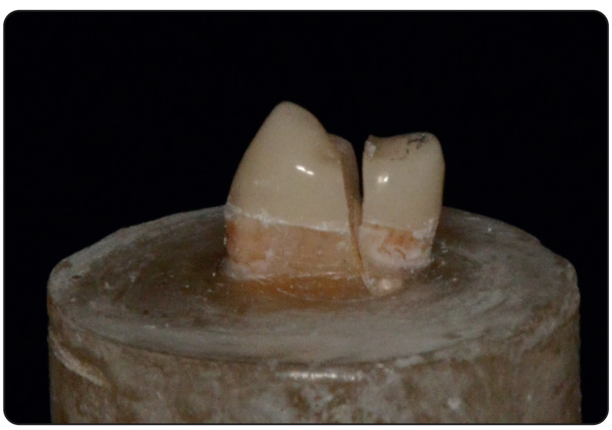

Fig. (4) Unfavorable (unrestorable) fracture in a tooth restored with an e.max endocrown

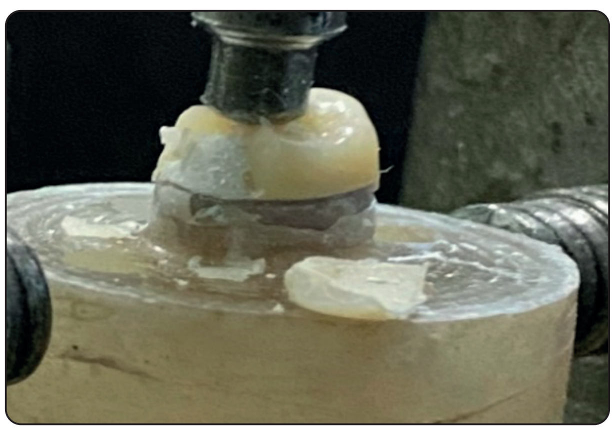

Fig. (5) PEEK endocrown restored sample after fracture resistance test with veneering composite debonding from core

Even though there are limited studies conducted on premolar teeth with endocrowns, a 10 year clinical study showed high success rate of endocrowns on premolars as well as molar teeth [28]. High fracture resistance of endocrown restored teeth can be attributed to the conservative nature of this restoration's preparation [29]. Another study found similar success rates with endocrowns for molars and premolars and suggested that premolars can be considered suitable candidates for endocrowns [30].

Teeth selected in the study had certain selection criteria to be able to standardize their size and dimensions. A caliper was used to measure the tooth and discard the teeth with extremes of dimensions. Teeth selected were all free of caries even if it may have been in the coronal section that would be cut off. This was to eradicate possible extension of caries to the remaining dentin and bonded areas. Furthermore, teeth were stored in isotonic saline solution throughout the study to protect the teeth from desiccation and simulate the intraoral cavity.

Fiber posts were used because studies found that failures that occur with them were repairable such as fractures in the cervical third of the root. Cast metal post exhibited catastrophic failures such as oblique or horizontal fractures in the middle third of the root or vertical fractures of the root. The better mode of failure with fiber posts is possibly due to the similar modulus of elasticity between the fiber post and tooth dentin which facilitates stress dissipation and due to the resin cement that filled the space between the post and the tooth dentin. This may have acted as means for stress absorption when the tooth was under occlusal forces [31].

Adhesive dentistry has reduced the use of posts in restoration of endodontically restored teeth to gain intraradicular retention for the core buildup and the final restoration. Compared to other types of indirect restorations, endocrowns are relatively easier to provisionalize and represent a cost-effective procedure, requiring less chair side time. Supragingival margins of endocrowns are easier to clean from excess cement and are easier for plaque control. Endocrown preparations also require minimal tooth reduction and eliminate the need for post space creation so preserves better the remaining sound tooth structure [32].

Several studies and clinical reports have shown favorable performance, fracture resistance and resistance to debonding of endocrowns in molar teeth [11,19,33,34]. However, most studies were limited to molars which may be due to their larger pulp chambers and larger bondable surface area. Also, most studies were concentrated on glass ceramic materials with the likes of lithium disilicate. Limited studies were found in which premolar teeth were tested and other types of materials like PEEK as an endocrown were not explored to test their success.

With regards to the materials, Lithium disilicate was used in this study, due to its popularity in use which is attributed to its high quality, high strength and natural looking restorations. When lithium disilicate is bonded to the prepared tooth, it showed high strength, which is acceptable even for posterior single tooth restorations [35].

Lithium disilicate has been favored for use in the fabrication of endocrowns in several previous studies [27,32]. This was attributed to the material's unique crystalline structure which gives it its high strength and high esthetics. Light diffusion, opalescence and translucency in lithium disilicate were designed to mimic the natural tooth structure [36].

IPS e.max CAD was selected due to its long-term clinical success, stability and decreased laboratory procedures. It also has very good bonding characteristics to the tooth structure because of being an etchable ceramic [37]. E.max press was not used for many reasons. While the material composition may be similar, it would be more difficult to standardize the final restorations using the press method. This is because more steps are involved in the manufacture of press restorations which would increase the risk of errors and affect the results. The procedure of waxing, investing, pressing, and devesting may affect the final restoration if minor errors are introduced. The streamlined and closed system of CAD/CAM provides a more reliable restoration that is easier to standardize due to less procedural steps. Furthermore, CAD/CAM is less time consuming and requires less human manipulation.

To closer approach the physical properties of the tooth, materials with modulus of elasticity close to that of the tooth structures had to be explored to test their effectiveness in repairing the lost tooth structure and to restore that structure as close to nature as possible. PEEK is more commonly used in implant restorations, and has shown great success due to its modulus of elasticity [38,39]. PEEK has resistance to hydrolysis, superior mechanical properties, and resistance to high temperatures. PEEK did not show any evidence of cytotoxicity, mutagenicity, carcinogenicity or immunogenicity [40]. It is considered to be a biologically inert material. Another advantage of PEEK use in fixed prosthesis is that it has minimal amount of wear and has very little deterioration in its properties during processing. It is also very easy to repair in case there is a need for modification or fix in comparison to ceramics [41].

CAD/CAM fabricated PEEK was used due to their higher fracture resistance. In a study by Tekin et al., the authors stated that CAD/CAM fabricated 3-unit PEEK prostheses have higher fracture resistance than pressed PEEK prostheses. They also stated that the resistance to breakage was higher than that of lithium disilicate glass ceramics [38].

Preparation design used in this study was similar to previous studies conducted comparing between endocrowns constructed on extracted premolar teeth and full coverage crowns constructed on post and core restored extracted teeth [12,42].

Preparation design of premolars was standardized to decrease differences in preparation within each group that would affect the fracture values obtained. Design was similar to a study by Lin et al., in which the authors followed a preparation design for the premolar endocrown group and the post, core and crown group. [12]

CAD/CAM was used in this study due to its reliability and ease of design and manufacturing. CEREC is a CAD/CAM system which has been one of the oldest systems. It is an integrated system from start to finish with a streamlined and seamless workflow. This helps in decreasing variables and incompatibilities that may arise with having separate intraoral scanner, CAD and milling machine manufacturers. Furthermore, CEREC software allowed standardization of the restorations through measurements that were done at the design phase, utilizing the biocopy feature, using the same tooth library throughout the study, prep check feature, and easy adjustments that would have been much more difficult if done by the traditional methods. Also, for PEEK restorations, a uniform cutback is easily designed and visualized on the software.

Using the 5-axis MCX5 milling machine also allowed for higher accuracy when milling the restorations compared to a 4-axis milling machine. This allowed the machine to mill the designed restoration with more detail following the prepared tooth walls. Furthermore, milling of PEEK blanks is not possible with the 4-axis machine, for this reason all restorations were milled on the 5-axis MCX5 machine which allowed further standardization.

For the PEEK group, the clear index helped attain a negative mold of the desired and designed final restoration dimensions. It also allowed light curing of the composite veneer on PEEK core that would have not been possible with opaque types of silicone index materials.

Sample testing was done by applying compressive load using a universal testing machine along the long axis of restorations using a load applicator in the form of stainless-steel tip which was centered in the occlusal surface between the buccal and lingual cusp at crosshead speed of 0.5mm/min until failure [12,43].

Fracture load of all samples in this study was higher than the maximum masticatory forces which can vary up to 500 N [44,45]. Those results are in accordance with studies that had similar fracture load values for endocrowns [46]. Compared with previous similar in vitro studies, results of this study showed similar fracture strength when endocrowns were compared to post and core supported conventional crowns [12,19,29,47,48].

Other studies found that endocrown construction in premolars was not as successful, this may be attributed to the amount of remaining tooth structure and the amount of surface area that was available for boding to the restorations in those studies. In one study a feldspathic ceramic block was used unlike lithium disilicate blocks that were used in this study [49,50].

Using the pulp chamber increases the surface area for bonding in endodontically treated teeth. Furthermore, the use of endocrown restorations which are directly bonded to the tooth structure allows a better biomechanical and functional union between the tooth and the restoration instead of a multiphase restoration similar to the case with post, core and crown restored teeth. This close to monoblock approach also justifies the similar fracture strength of endocrowns to post and core restorations in this study.

The first and second null hypotheses of this study are accepted. Endocrowns were found to be a viable option to restore endodontically treated teeth compared to crowns. PEEK endocrowns have comparable fracture resistance to lithium disilicate endocrowns.

Results of this study found no statistical significance between the 3 different tested groups. Fracture strength was similar between the control post, core and lithium disilicate crown group and the lithium disilicate endocrown group. This can be attributed to the preservation of the remaining tooth structure and efficient bonding between lithium disilicate and tooth structure. This coincides with a study conducted by Lin et al [12].

Results also showed no statistically significant difference between types of restoration materials tested. PEEK veneered endocrowns veneered with visio.lign composite had similar fracture strength as lithium disilicate endocrowns.

This result is different from a study conducted by Ghajghouj and Taşar-Faruk who compared IPS e.max and PEEK endocrown fracture resistance. Their results showed much higher fracture resistance in the PEEK restored endocrowns. Their study was done on mandibular premolars though, and there is no reference whether PEEK endocrowns were veneered with composite that would make it estheticaly acceptable or done on a full contour milled PEEK endocrown [15].

Ghajghouj and Taşar-Faruk have attributed the higher fracture resistance of PEEK endocrowns to their mechanical, physical, and elastic properties which are similar to human bone, enamel, and dentin, providing bioactivity for PEEK as a restoration [15].

Results of this study show the possibility of use of endocrowns as a viable option instead of conventional post, core and crown system. Endocrowns in premolar teeth show promising results when compared to full coverage restorations, while preserving natural tooth structure.

This is in accordance with a study performed by Hassouneh et al., who studied different restorative materials and compared their post-fatigue fracture resistance with post, core and crown restorations. Authors concluded that endocrowns are as effective as post,core and crowns in restoring premolar teeth [13].

Another study by Guo et al., cofirmed similar fracture resistance value of premolar teeth when restored using post, core and crowns versus endocrowns. Similar to this study, teeth were restored using IPS e.max CAD. The author concluded that even though fracture resistance was similar in both groups, they were less than an intact premolar tooth [42].

With regards to the mode of fracture in e.max endocrown group, findings were consistent with El-Damanhoury et al.'s study [27]. Fracture in their study in the endocrown group restored using e.max was mostly below the height of bone level simulation which they considered as catastrophic failure. This shows that even though e.max endocrowns may have high fracture resistance, their mode of failure is not favorable and is not repairable and may lead to extraction in a lot of cases.

Furthermore, results show that PEEK is a promising material in restoration of endodontically treated teeth with endocrowns. The material has a closer modulus of elasticity to the tooth structure than other materials tested. This allows the PEEK core to absorb stresses and thus better protects the underlying tooth structure.

PEEK also can be veneered with esthetic composite veneer that has high bond strength to the underlying core and is easy to repair if needed although this entails more steps that can be time consuming when compared to monolithic restorations, specially when a chairside approach is considered.

In a study by Bogna et al., done on fixed partial dentures (FPD) utilizing PEEK, after thermocycling, all FPDs showed cracks in the veneering composite resin material in the pontic region, regardless of the PEEK pretreatment or the adhesive system used [51].

This is consistent with this study's mode of failure findings in the PEEK endocrown group in which all endocrown restorations failed within the restoration due to the fracture of the veneering composite without PEEK core and tooth structure failure denoting repairable mode of failure.

This may be due to the closer modulus of elasticity of PEEK to that of the tooth structure and so had a cushion like effect under load.

Further studies are needed for clinical performance of PEEK restorations intraorally. Also the color stability of PEEK restorations and marginal fit need to be studied and compared to existing materials used for endocrown restorations [52].

Limitations of this study include invitro testing, in which extraoral testing conditions were carried out. This may be different intraorally with other factors affecting the results. As the specimens in this study were not aged, further investigations with additional aging through chewing simulation or thermal cycling are required for more longitudinal clinical aging data or at least trends. Limitations also include that teeth tested were prepared by an operator. Although this may closer mimic the clinical situation, preparations are not totally standardized.

CONCLUSION

Within the limitations of this study, the following conclusions were made:

- All fracture resistance loads were beyond the maximum masticatory forces, hence those restorations can withstand intraoral masticatory forces in the maxillary premolar region.
- Endocrown restorations have similar fracture resistance compared to conventional crowns in restoring endodontically treated premolar teeth.
- Lithium disilicate endocrowns have similar fracture resistance as lithium disilicate conventional crowns placed on post and core restored teeth.
- PEEK endocrowns have similar fracture resistance compared to lithium disilicate endocrown

restored teeth and post, core and crown systems but with a more favorable mode of failure.

Recommendations

Further investigations are required to:

- Evaluate the clinical performance of PEEK intraorally as an endocrown restoration.
- Evaluate the effect of aging on PEEK endocrown restoration color stability and esthetics.
- Evaluate the marginal adaptation and internal fit of milled PEEK restorations versus lithium disilicate and other restorative materials.
- Evaluate the fracture resistance of PEEK endocrowns after cyclic loading and fatigue.
- Perform stress analysis on similar design and materials
- Evaluate the effect of different cement types
- Evaluate fracture resistance after thermal cycling of specimens

Summary

The purpose of this in-vitro study was to measure the fracture resistance of different types of restorations with different designs proposed for restoring endodontically treated teeth.

A comparison was made between traditional post, core and lithium disilicate crowns, lithium disilicate endocrowns and PEEK endocrowns veneered with composite.

Thirty-three caries free human maxillary premolars were collected for the study. The teeth were randomly divided into 3 groups according to the type of restoration:

Group A: Endodontically treated maxillary premolars with 2 mm ferrule restored with glass fiber post, core build up and prepared for full coverage lithium disilicate crowns

Group B: Endodontically treated maxillary premolars with 2 mm butt margin restored with lithium disilicate CAD/CAM endocrowns

Group C: Endodontically treated maxillary premolars with 2mm butt margin restored with PEEK CAD CAM endocrown restorations

Teeth were endodontically treated and prepared to receive their respective restorations according to their assigned group.

Teeth were mounted in epoxy resin blocks, 2 mm below the cemento enamel junction to simulate the level of bone, along the long axis of the tooth.

Teeth in Group A received posts and cores, and were prepared for full coverage restorations. Teeth in Group B and C were prepared to receive endocrowns by creating a 2 mm butt margin above the CEJ.

All teeth were scanned using CEREC primescan and designed on CEREC software. All designed restorations were milled using the inLab MCX5 machine. PEEK endocrowns were designed and milled with cutback then veneered with composite according to the manufacturer’s instructions.

All restorations were standardized during design phase to have similar dimensions to decrease variances in final restoration.

Restorations were then surface treated and made ready for cementation then cemented using dual cured resin cement and excess cement was removed and cured accordingly.

Samples were subject to fracture resistance testing under compressible load parallel to the long axis of the tooth. Universal testing machine with a mounted rounded tip rod was used to apply vertical force while touching both cusp inclines. The testing machine had a load cell of 5 kilo newton and moved at a crosshead speed of 0.5mm/min.

The load at failure was manifested by an audible crack and confirmed by a sharp drop at load-deflection curve and was recorded using a computer

software. Data was collected and statistically analyzed. Mode of failure was examined and evaluated also.

The following results were obtained from the study:

All fracture resistance values were higher than the maximum masticatory force recorded for the premolar region.

Endocrowns had fracture resistance similar to those of traditional post, core and crown restorations.

PEEK endocrowns were found to have similar fracture resistance to lithium disilicate endocrowns and so are considered a good option for endocrowns.

PEEK mode of failure was found to be the most favorable between the 3 groups in which only the veneering composite failed while protecting the underlying tooth structure.

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