

Fracture strength of CAD/CAM fabricated lithium disilicate and resin nano ceramic restorations used for endodontically treated teeth

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The purpose of the present study was to evaluate and compare the fracture strength and failure modes of endocrowns, zirconia post, and fiber post supported restorations and predict the clinical outcomes of six different prostheses used for endodontically treated teeth. Sixty ($n=10$) maxillary central incisors were restored with zirconia post/resin-nano-ceramic crown (ZrRNC), fiber post/resin-nano-ceramic crown (FbRNC), zirconia post/lithium disilicate ceramic crown (ZrLDS), fiber post/lithium disilicate ceramic crown (FbLDS), resin-nano-ceramic endocrown (EndoRNC), and lithium disilicate ceramic endocrown (EndoLDS). Fracture strength test was performed. Fracture loads and modes were determined. The EndoLDS group had the highest fracture strength, followed by ZrRNC and EndoRNC group. However the results were not significantly different among groups ($p>0.05$). The failure modes of the restorations changed according to the restorative materials. Endodontically treated anterior teeth might be restored with endocrowns as well as other post-core restorations, however tooth fracture failures should be considered that affect reliability of endocrowns.

Keywords: Endocrown, Endodontically treated teeth, Fracture strength

INTRODUCTION

Endodontically treated teeth usually suffer from loss of extensive tooth structure therefore they often require partial or complete coverage restorations. Posts are commonly used for restoring teeth with insufficient coronal tooth structure to retain a core for the final restoration¹⁻³. Metal posts have been used for decades, however increasing esthetic expectations and demands of the patients have led the dentists to the use of esthetic restorative materials. A wide range of natural tooth colored and metal free post materials such as fiber reinforced and zirconia posts are available in the dental market^{1,4}. Zirconia posts have good chemical stability, high mechanical strength and toughness, and a Young's modulus resembling to stainless steel alloy¹. Positive effect of rigid post materials on the marginal integrity of composite core materials has been shown in a previous research⁵. However, if the tooth is overloaded high rigidity of zirconia posts may cause unrestorable vertical or deep root fractures. And also, when the minor fractures are decided to be restored with zirconia posts, removing the zirconia posts from the root canal may be difficult^{1,2,4}. Fiber reinforced post materials show similar elasticity modulus to dentin that allows post flexion to mimic tooth flexion and reduce the risk of root fractures^{3,6,7}. In addition, root fractures defined as restorable for fiber posts thus they can be easily removed from the root canal². However, elastic fiber posts may cause leakage by allowing the restorations to move and compromise the luting cement which may lead to fracture of the restoration, secondary caries or root canal infection^{5,8,9}. Findings of clinical studies may

confirm this *in-vitro* data that bond strength between the fiber posts and resin cement is the most frequent failure reason^{10,11}. In the light of these findings of the current research, optimal material for a post remains a controversial issue^{12,13}. Bindl and Mörmann¹⁴, described the endocrowns for the first time, and these restorations were defined as crowns are cemented and fixed to pulpless teeth. These crowns are fitted into the internal part of the pulp cavity chamber and margins, and cover all cusps^{7,15,16}. The advantages of the endocrowns are being a conservative technique, eliminating the technical steps during fabrication, being less time consuming, and decreasing the treatment cost^{7,17,18}. Endocrowns are indicated in cases of teeth have short, obliterated, dilacerated or fragile roots, and excessive loss of coronal tissue and limited interocclusal space¹⁹. Although a few number of studies have been conducted with respect to endocrowns, the fracture strength of the endocrowns was comparable to conventional crowns^{7,20}. Furthermore some clinical reports have demonstrated that endocrowns have adequate function and esthetics^{21,22}. In a recent *in vitro* study, fracture resistance of restorations of anterior endodontically treated teeth was investigated and promising results for endocrowns were found⁷. However, it is not possible to find more information on the use of endocrowns for restoration of incisor teeth in the current literature.

Advances in computer assisted design and computer assisted manufacturing (CAD/CAM) technology enabled clinicians to provide high quality esthetic restorations with a chairside approach. Furthermore, various esthetic restorative materials also came into used currently with CAD/CAM systems²³. Among these materials, the lithium disilicate ceramics appear to be the best solution with an esthetic appearance,

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strong bonding to tooth structure, and high mechanical strength in case of monolithic design^{19,24}. More recently, the ongoing research for biocompatible materials with physical mechanical properties similar to those of natural tooth tissues has introduced a new generation of resin nano ceramic restorative materials¹⁵. The unique composition of resin nano ceramic allows the material to have a modulus of elasticity (12.8 GPa) similar to that of dentin²⁵. The advantages of resin nano ceramic restorations are showing less crack propagations and providing better fracture resistance than some of CAD/CAM ceramics^{26,27}. The purpose of the present study was to evaluate and compare the fracture strength and failure modes of endocrowns, zirconia post, and fiber post supported restorations and predict the clinical outcomes of six different prostheses used for endodontically treated teeth.

MATERIALS AND METHODS

This study was approved by the Clinical Research Ethics Board of the Ankara University, Faculty of Dentistry with grant no.36290600/06. Sixty sound and freshly extracted maxillary central incisors which were free of carious lesions, cracks, and fractures were visually inspected by using a magnifying glass (Loupe opt-on, Orange Dental, Biberach, Germany) and selected for this study. The teeth were in similar dimensions and had straight roots. The dimensions and lengths of all teeth were measured using digital caliper (Powertechtools, China). Teeth which have 14–15 mm total root length were used for the study. All external debris was removed with an ultrasonic scaler and teeth were stored in saline solution. The anatomic crowns of all teeth were sectioned horizontally at 2 mm above the cemento-enamel junction with the use of water cooled diamond fissure rotary instrument. The pulp chamber was opened following a standardized procedure. Working length was determined visually by placing a size no. 10 K file (Dentsply, York, PA, USA) at the apical foramen. All root canals were prepared up to the F3 rotary file, and instruments were changed after every canal preparations. Root canals were irrigated between each of the instrumentation with sodium hypochloride (NaOCl) at a concentration of 2.5%. For the last irrigation, the root canals were irrigated with NaOCl at a concentration of 2.5%, ethylenediaminetetraacetic acid (EDTA) at a concentration of 5%, and serum physiologic to avoid the prolonged effect of NaOCl and EDTA. The root canals were dried with paper points (DentPlus, Diadent, Almere, Netherlands) and obturated with single taper sized F3 gutta-percha cones (Sure EndoF3; SureDent, Seongnam, Korea) in conjunction with AH Plus sealer (Dentsply). After the endodontic treatment, cervical root openings were filled with a provisional restorative material. All teeth were stored at 37°C and 100% humidity for 48 h to allow the setting of the sealers. Then, teeth were randomly divided into six groups ($n=10$). Groups 1, 2, 3, and 4 were restored with zirconia post and resin nano ceramic crown (ZrRNC), zirconia

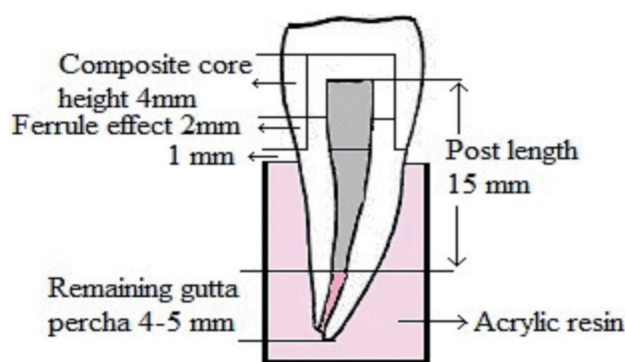


Fig. 1 Schematic diagram of post-core design.

post and lithium disilicate ceramic crown (ZrLDS), fiber post and resin nano ceramic crown (FbRNC), and fiber post and lithium disilicate ceramic crowns (FbLDS), respectively. Groups 5 and 6 were restored with resin nano ceramic endocrown (EndoRNC) and lithium disilicate ceramic endocrown (EndoLDS), respectively. Glass fiber posts (Ika-Dent, Kutno, Poland), 1.5 mm in diameter were selected for the study. Zirconia posts were fabricated in same dimensions with fiber posts in Cerec Software 4.2 and inLab SW 4.2 (Sirona, Bensheim, Germany). Fiber posts were embedded into silicone molds and were scanned with an extraoral scanner (inEos X, Sirona). InCorisTZI zirconia blocks were used for zirconia posts and milling process was done with CEREC MC XL milling unit (Sirona). After the milling process, zirconia posts were sintered in a calibrated sintering furnace (Infire HTC Speed, Sirona) for 2 h. Roots were prepared with the drill of fiber post system. Four drills (one drill for each post system) were used. The gutta percha was removed with the drills leaving 4–5 mm apical seal and 10 mm post length space from the apex and 5 mm in the coronal part of the restoration (Fig. 1). Each post was tried in the root canal and sectioned at the adequate length. Prior to luting procedure, the post surfaces were cleaned with etching gel (K-Etchant Gel, Kuraray, Tokyo, Japan) and cleaned with an ultrasonic cleaner and then dried. Any surface roughening treatment was not applied to post surfaces. The dual-cured bonding agent (Clearfil TRI-S Bond Plus, Kuraray) was applied to the posts and root canals using micro brushes for 10 s. The bonding agent was dried for 5 s and then light cured for 10 s. Post cementation was performed with dual-cure resin cement (Panavia F 2.0, Kuraray) according to manufacturer's instructions. Mixed equal amounts of ED Primer II A and B (Panavia F 2.0, Kuraray) applied to the root canal. Then it was waited 30 s and gently air dried. Equal amounts of paste A and B dispensed and mixed for 20 s and applied to the root canals. The posts were quickly seated into the root canals under finger pressure. For easy clean-up, partially the excess cement was light cured for 2–3 s and removed. The cement was light cured for 20 s per surface. The cement was self cured by applying Oxyguard (Panavia F

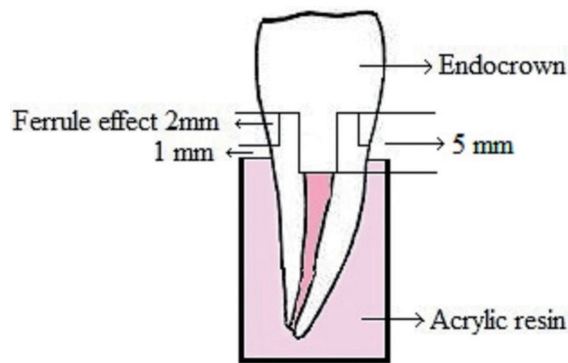


Fig. 2 Schematic diagram of endocrown design.

2.0, Kuraray) to the margins, 3 min waited and removed with water spray. After luting the fiber and zirconia posts, the cores were built up using dual-cured composite (Charisma, Heraeus Kulzer, Wehrheim, Germany). The core preparations were finished with diamond rotary instruments. The total dimensions of the restorations were 6 mm abutment height, 2 mm ferrule, and 1 mm marginal width. Endocrown preparation was limited to removal of the pulp chamber, excessively retentive areas, and alignment of the pulpal walls. The canals were deepened for 5 mm (3 mm seated in the root) (Fig. 2)⁷. The dimensions of the prepared teeth were checked using digital caliper (Powertechtools) with a magnifying glass (Loupe opt-on, Orange Dental). The canal and core portions were considered as a 1 component milled from lithium disilicate and resin nano-ceramic restorative materials. Digital impressions of prepared abutments were made using an intraoral camera (Cerec Omnicam, Sirona Dental Systems, Bensheim, Germany). A special software (inLab SW 4.2.1.61068, Sirona Dental Systems) was used to design the restorations. “Biogeneric Copy” was selected as the design mode and “Crown Restoration” was selected as a restoration type. With the aim of preparing and designing standardized crowns, a “reference maxillary central incisor” with intact and unprepared crown was selected. Digital impression of the “reference tooth (reference maxillary central incisor)” was made with digital impression of each abutment. Using “Biogeneric Copy” function of the software, crown morphology and dimensions of the “reference tooth” was copied to the each restoration design. Spacer thickness of 50 μ m was determined. The restorations were made from lithium disilicate (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein) and resin nano ceramic (Lava Ultimate, 3MESpe, Seefeld, Germany). Ceramic surfaces of crystallized lithium disilicate restorations were conditioned with 5% buffered hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) for 20 s and silanized (Monobond Plus, Ivoclar Vivadent) for 60 s. Resin nano ceramic restorations were sandblasted with 50 μ m aluminum oxide particles (Korox 50; BEGO, Bremen, Germany) at 2 bars pressure and silanized

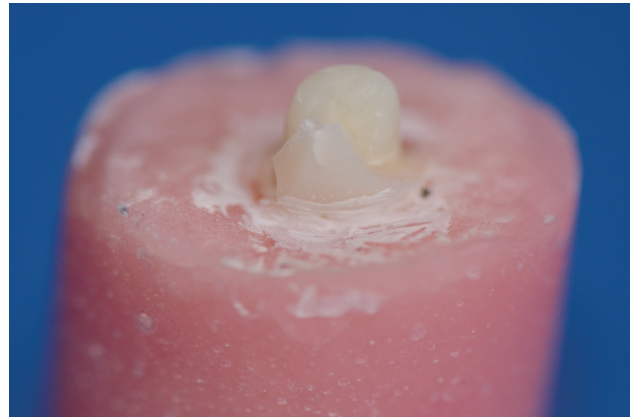


Fig. 3 Type of failure mode: fracture of restoration.

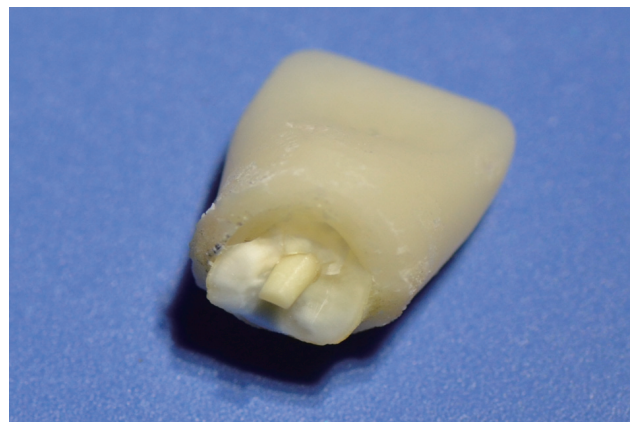


Fig. 4 Type of failure mode: fracture of post.

(Monobond Plus, Ivoclar Vivadent) for 60 s. Crowns were seated on the abutment teeth under finger pressure and crown cementations were performed with transparent dual-cure self adhesive resin cement (Bifix SE, Voco, Cuxhaven, Germany) according to manufacturer’s instructions. Excess cement was removed. Restorations were cured for 20 s from each side and all margins were finished and polished with abrasive disks.

The specimens were perpendicularly embedded in self-curing acrylic resin poured in identically shaped cylinders, leading a distance of 1 mm between the top of the acrylic and cement-enamel junction. A jig was used to fix the cylinders at the angle of 45 degrees. A compressive load was palatally applied with a round tip 2 mm in diameter at a cross-head speed of 1 mm/min until fracture occurred. The maximum load at which the specimens fractured was recorded in Newtons. Mode of fracture was examined for each specimen and categorized according to the 4 failure modes (Figs. 3, 4, 5, and 6). Figure 3 shows the Type 1 failure: fracture of the restoration, Fig. 4 shows the Type 2 failure: fracture of the post with or without fracture of the restoration, Fig. 5 shows the Type 3 failure: dislodgement of the

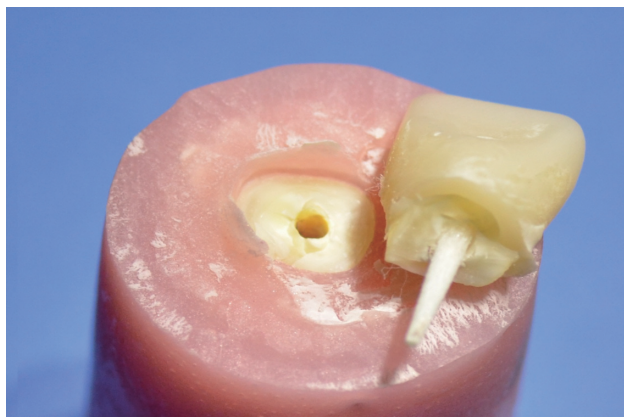


Fig. 5 Type of failure mode: dislodgement without fracture.

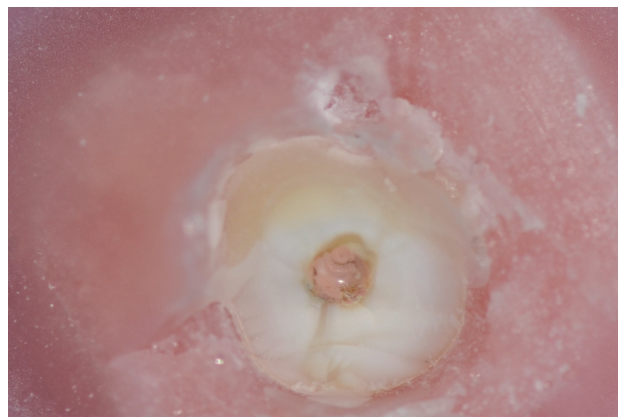


Fig. 6 Type of failure mode: fracture of tooth.

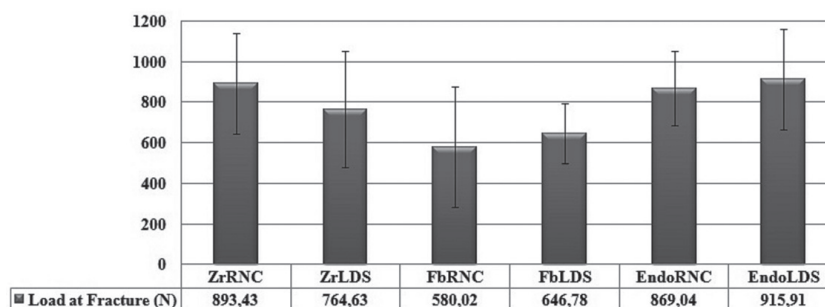


Fig. 7 Fracture strength values of six groups composed of different post and crown materials. Differences among the groups were not statistically significant ($p>0.05$).

posts without fracture, Fig. 6 shows the Type 4 failure: fracture of the tooth.

Results were analyzed with statistical software (SPSS version 20.0, SPSS, Chicago, IL, USA) using a 1-way analysis of variance (ANOVA) and the Tukey honestly significant difference test was used for the *post hoc* pairwise comparisons ($\alpha=0.05$).

RESULTS

The results of the fracture test of the six experimental groups are shown in Fig. 7. The results of the EndoLDS group (915.91 ± 182.06) had the highest fracture strength value, followed by ZrRNC group (893.43 ± 248.79) and EndoRNC group (869.04 ± 247.77). FbRNC group (580.02 ± 295.37) showed the lowest fracture strength value. However, the results were not significantly different among all groups ($p>0.05$).

Results of the failure modes of the six groups were presented in Table 1. When the general failure modes of the restorations were evaluated; the failure modes of the fiber posts were the fracture of the restoration without post or dislodgement of the posts from the root canal. In zirconia post groups; fracture of the restoration with or without post were generally observed. The failure modes of endocrowns were noted as tooth fractures while no

tooth fracture was noted for post-core restorations.

DISCUSSION

Zirconia posts and fiber posts are the most popular post materials in today's dentistry. In the present study, a commercially available, prefabricated fiber post and a milled zirconia post was used for post-core restorations. The zirconia post fabrication process included scanning the fiber post and reproducing the post from zirconia using CAD/CAM system so, standardization of size and shape of the posts was aimed in different test materials. With the aim of standardization of the test specimens, direct built-up composite resin cores were fabricated by a single clinician. Previous studies proved that direct core restorations with fiber and zirconia posts were appropriate in respect to fracture resistance²⁾. Furthermore, indirect core technique offers no advantage over direct composite cores with regard to strength and it is time consuming due to laboratory fabrication process. Another effort to standardize test specimens, all-ceramic crown restorations of all specimens were fabricated using "Biogeneric copy" function of Cerec CAD/CAM system. All restorations were fabricated in similar shape and dimensions from prefabricated blocks (Lava Ultimate and IPS e.max CAD), and also standardizing the point

Table 1 Failure modes of the experimental groups

Group	Fracture type (n)			
	Type 1 (fracture of the restoration)	Type 2 (post fracture with or without the fracture of the restoration)	Type 3 (dislodgement without fracture)	Type 4 (fracture of the tooth)
ZrRNC	7	3	0	0
ZrLDS	3	6	1	0
FbRNC	3	0	7	0
FbLDS	8	0	2	0
EndoRNC	0	0	0	10
EndoLDS	3	0	0	7
Total	24	9	10	17

of load application during testing was provided.

In the present study, artificial periodontium simulation was not placed around the root and direct embedding in acrylic was preferred instead. An artificial periodontium is necessary to simulate clinical conditions for *in-vitro* testing of all-ceramic bridges because its increasing the tensile force at the gingival part of the connector area. However, in single crowns, some disadvantages for covering roots with silicone were reported in the literature²⁸. The mobility of the abutment may compromise the axial force, dissimilar elasticity of artificial materials from the periodontium does not represent clinical status, and the thickness of the silicone is not standardizable which leads to uncontrolled and unstandardized mobility of the abutment teeth^{28,29}.

Several studies have been conducted on the fracture resistance of endodontically treated incisor teeth restored with different esthetic posts including zirconia and fiber posts^{1-3,6}. However, direct comparison of fracture resistance values obtained from these studies is improper because of several variations in the study designs such as using human teeth or artificial teeth, luting procedure of the post, tooth preparation, crown restoration, artificial aging, or loading conditions. The evaluation of the literature generally revealed the fact that higher fracture resistance was found for zirconia posts when compared with fiber posts⁶, however zirconia posts demonstrated catastrophic fractures while fiber posts generally displayed restorable fractures^{1,3,7,16}. These results may attributed to the fact that fiber posts have low, and zirconia posts have high elasticity modulus. The results of the present study is in agreement with previous studies with regard to fracture strength of post-core restorations^{2,3,6}, however fracture patterns of study groups were differed from the reported data. Tooth fracture was not observed in the present study for post-core restorations although it is common failure type in the literature particularly for zirconia posts^{3,16}. In these studies, prefabricated zirconia posts in 1.7 mm diameter were used for mandibular premolars^{3,16}, load

was applied at a 90 degree angle to the long axis of the endodontic post and tooth⁹, and core was prepared from heat pressed glass ceramic¹⁶. These factors may affect the fracture type of the restorations. Fracture of the restoration was commonly observed in ZrRNC group and fracture of the restoration with post was observed in ZrLDS group. Difference in failure type of zirconia post groups may result from different mechanical properties of crown material.

For fiber post groups, neither post fracture nor tooth fracture was observed. In FbRNC group, which was consisted of more elastic post and restoration materials, restorations were generally bodily displaced without fracture. The adhesion of fiber posts to the root dentin determines their resistance to dislodgement³⁰. So, the fundamental requirement is to achieve an effective bond among cements, composite resin matrix of fiber posts, and root canal dentin by providing high retention and avoiding microleakage and degradation^{31,32}. *In vitro* studies evaluated adhesion of fiber posts³³⁻³⁵. Recent studies showed that three steps total etch systems showed higher strength than self-etch and total-etch adhesive system³⁶⁻³⁹. In the present study, self-etch bonding agent was used for the post cementation. This may be the fact that observing dislodgement of fiber posts from the root canal.

On the other hand, glass ceramic crown which is the most rigid-brittle component of the FbLDS system was mostly fractured. In accordance with previous studies, variations in fracture patterns may be attributable to the different elastic modulus of the post and crown materials^{2,4}. Endocrown which is a contemporary reconstruction option for endodontically treated teeth with a severely damaged coronal structure is especially indicated for molars^{14,15,18,19}. There is limited number of studies on mechanical strength of endocrowns and they reported higher fracture resistance for endocrowns compared with post-core restorations^{7,15,16,25}. Lin *et al.*⁴⁰ stated that reducing the effect of multiple interfaces as in endocrowns reduces adhesive interface failure.

Furthermore, endocrowns have greater thickness at the occlusal portion and have higher fracture load when compared to classical crowns⁴⁰. The success and survival of the endocrowns are directly related to correct preparation of the abutment tooth, selection of the suitable ceramic restorative materials and the bonding material^{14,19,22,41}. However these findings are valid for molar endocrowns. For endocrowns used to restore premolars, Bindl *et al.*⁴¹ reported more failures compared with molars due to smaller adhesion surface of the pulpal chamber. In an *in-vitro* study, endocrowns were not recommended over treatment of post-core restorations for mandibular premolars when lithium disilicate crown material was used¹⁶. The use of endocrowns for the restoration of endodontically treated anterior teeth was mentioned by two studies^{7,42}. Aversa *et al.*⁴² performed a finite element analysis to evaluate the effect of endocrown material rigidity on alveolar bone process. A recent *in vitro* study performed to evaluate fracture strength of endodontically treated anterior teeth restored with endocrown or fiber post, composite core, and all ceramic crown restoration⁷. It was reported that the highest fracture strength for endocrowns which is in agreement with the present study. The findings of this study may indicate that endodontically treated anterior teeth may be restored with endocrowns which is a restoration type without a post. However long term, randomized controlled clinical studies should be conducted before recommending clinical use of endocrowns for anterior teeth. In the present study, the comparison of lithium disilicate ceramic and resin nanoceramic restorations revealed that their fracture resistances varied according to post type. Although it was not statistically significant, LDS endocrowns showed higher fracture strength than RNC which is in contrast to a previous finding²⁵. In the present study, a higher fracture strength was found for RNC crowns compared with LDS when zirconia posts were used. For fiber post restorations, however, LDS exhibited higher fracture strength. These findings may lead to conclude that besides ceramic type in cemented restorations on endodontically treated teeth, several factors contribute to the mechanical behavior of restoration/tooth system.

CONCLUSIONS

Within the limitations of this study, following conclusions can be made:

Lithium disilicate ceramic endocrowns (EndoLDS) showed the highest fracture resistance and fiber post groups (FbLDS and FbRNC) had the lowest fracture resistance among all groups. The failure modes of the fiber posts were the fracture of the restoration without post or dislodgement of the post from the root canal. The failure modes of the endocrowns were the tooth fractures however no tooth fracture was noted for the post-core restorations. Endodontically treated anterior teeth might be restored with endocrowns as well as other post-core restorations, however tooth fracture failures should be considered that affect reliability of endocrowns.

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