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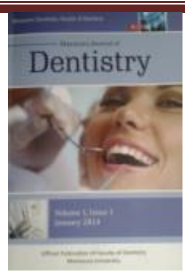

Fracture Resistance of Endocrowns Manufactured with Different Preparation Designs and Different CAD/CAM Materials

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Abstract:

Statement of problem: Different preparation designs and materials used for endocrown manufacturing are important factors for the success of the restoration, but the studies that evaluated the effect of the designs and materials on the fracture resistance are inadequate.
Purpose: This study evaluated the fracture resistance of endocrowns with two preparation designs and manufactured with two CAD/CAM ceramic materials. **Materials and Methods**: Forty endodontically treated maxillary 1st molar teeth were prepared to receive endocrown restorations and divided into two main groups according to the preparation designs: Group B (n=20) endocrowns with butt joint design; Group F (n=20) endocrowns with ferrule design. The main groups were subdivided into two subgroups according to the CAD/CAM material used: Subgroup E (n=20) endocrowns manufactured from lithium disilicate glass ceramic (LD) (IPS e.max CAD, Ivoclar-Vivadent, Liechtenstein); Subgroup C (n=20) endocrowns manufactured from hybrid nano-ceramic (HN) (Cerasmart 270, GC, Japan). The endocrown restoration were cemented to the prepared teeth using dual cured self-adhesive resin cement. The specimens were subjected to thermal aging up to 10.000 cycles in a thermocycling paths with 5^{o}C and 55^{o}C. All specimens were subjected to a compressive force until fracture occur by using universal testing machine. The maximum compressive force was recorded for all specimen; then the failure modes were examined using scanning electron microscope SEM. **Results:** The mean value of fracture resistance of BC group was statistically and significantly higher than the other tested groups; (BC group, 4361.01±554.32 N) and the lowest mean value was recorded with FE group (2693.04±638.69 N). B Group showed significant higher fracture resistance than F Group (B group, 3707.09±1156.06 N; F group, 2724.34±601.96 N). C subgroup showed significant higher fracture resistance compared to that of E subgroup (C subgroups, 3558.33±995.92 N; E subgroups, 2873.10±983.95 N). All groups showed a high rate of catastrophic failures but at loads greater than normal maximum masticatory forces. **Conclusions:** Butt joint design endocrowns exhibited significantly higher fracture resistance than ferrule design endocrowns. Hybrid nano-ceramic endocrowns showed higher fracture resistance than lithium disilicate endocrowns. Endocrown showed a high percent of irreparable failure mode but at loads larger than normal masticatory function.
Keywords: Endocrown, Endodontically treated teeth, CAD/CAM, Lithium disilicate, Hybrid nano-ceramics, Fracture resistance.

Introduction

The restoration of destructed endodontically treated teeth (ETT) is still challenging in daily dental practice, the long-term prognosis of such teeth is influenced by their biomechanical degradation[1]. Restoring ETT with post and crown has been declined in recent years with progress in the minimally invasive dentistry as the adhesive techniques became more reliable[2].

One of the minimally invasive restoration is endocrown (EC), which was early defined as "Monoblock" by **Pissis** in 1995[3]. Later in 1999 **Bindl and Mormann**[5] were the first who used the term "Endocrown". Endocrown is an adhesive monolithic ceramic restoration that get its retention from the pulp chamber. It can be easily produced, less expensive and may have better success rate than post crown restoration.

The survival of ETT restoration is dependent on the amount of remaining sound tooth structure following access cavity and caries removal; as a result, preserving as much tooth structure as possible is crucial. So, partial adhesive restorations are always preferable over full coverage crowns. Endocrown is an efficient and consistent substitute to post and crown restoration for posterior teeth with comparable high success rates. It is essential to follow a specific preparation criteria and even a precise adhesive technique to achieve a successful restoration[5].

Endocrowns have been proved to be an effective technique to restoring severely damaged posterior teeth, even in badly destructed teeth or occlusal discrepancies such as bruxism. Additionally, endocrown can be produced in shorter clinical time with lower cost and better aesthetic and mechanical behaviors than post and core[6].

Lithium disilicate glass ceramic (LD) has become increasingly used in dentistry since it had fulfilled the needs of both dentists and patients. It can produce a highly aesthetic restoration, and it can be etched with hydrofluoric acid (HF) that improving its bonding to tooth structure [7].

Metal-based posts with core materials may cause fracture extending to the root due to its high stiffness that delivers stresses to the tooth structure. As a result, flexible, or less stiff, materials such as resin composites are now being taken into account for the reconstruction of ETT, with an acceptable survival rate and a significantly reduced risk of root fractures as compared to traditional approaches[8].

A novel composite and ceramic hybrid materials have been recently released into the market, which can be milled to produce a thin restoration that allow a conservative tooth preparation. Thin occlusal veneers restoration produced from composite resin materials displayed a better fatigue resistant than other ceramic restoration. According to the producers, resin nanoceramic is not a composite nor a pure ceramic, it is actually a combination of the both material that is mainly composed of ceramics[9].

Up to our knowledge few studies compared the fracture resistance of different preparation designs of endocrown restoration produced to restore ETT maxillary molars, manufactured from different CAD/CAM materials. Therefore, the present study aimed to evaluate the fracture resistance of endocrowns with two preparation designs: butt joint design and ferrule design, manufactured from two CAD/CAM ceramic materials: lithium disilicate glass ceramic and hybrid nanoceramic.

Materials and methods:

Teeth selection:

Forty intact caries-free human maxillary 1st molar teeth were selected for this study. All teeth were mobile and periodontically compromised and indicated for extraction. These teeth were examined under proper light to ensure that they are free from caries, crack and fracture. The study received the ethical approval by the ethical committee in Faculty of Dentistry, Mansoura University, ethical approval for scientific research code number: A15110220.

Endodontic treatment:

The teeth were subjected to a standardized root canal treatment using crown-down technique and filled with gutta-percha points coated with root canal sealer using a single cone technique.

Teeth mounting:

The root portion of each tooth was fixed in an epoxy resin blocks using a specially designed centralizing device. Epoxy resin was used to produce the blocks, and poured inside the Teflon mold up to 2mm beneath the level of the cemento-enamel junction (CEJ), in order to mimic the level of the supporting alveolar bone.

Preparation of teeth with butt joint design (Group B: n=20):

Specimen Decapitation:

Specimens were prepared in a standardized manner perpendicular to long axis 3mm coronal to the buccal CEJ using milling machine with diamond grinding wheels.

Intracoronal Preparation:

The pulp chamber was prepared to eliminate the undercuts and produce a 4mm deep cavity[10] with a 8^o degree coronal divergence and maintaining a 2 mm of the remaining tooth structure[11]. A conical straight round end tungsten carbide bur with 8^o degree coronal divergence was used to prepare the axial walls following the morphology of the pulp chamber. The internal line angles were polished and finished by polishing stone burs. No extracoronal preparation was done for this group. Then, the pulp floor was sealed with a flowable composite. The floor was flattened and smoothened by polishing stone burs.

Teeth Preparation with Ferrule Design (Group F: n=20)

Specimen Decapitation:

Specimens were sectioned in a standardized manner perpendicular to long axis 3mm coronal to the buccal CEJ using milling machine with diamond grinding wheels.

Intracoronal Preparation

The pulp chamber was prepared to eliminate the undercuts and produce a 4mm deep cavity [10] with a 8^o degree coronal divergence [12] and maintaining a 2 mm of the remaining tooth structure[11]. A conical straight round end tungsten carbide bur with 8^o degree coronal divergence was used to prepare the axial walls following the morphology of the pulp chamber. All internal line angles were polished then finished using a polishing stone bur. Then, the pulp floor was sealed with a flowable composite. The floor was flattened and smoothened by polishing stone burs.

Ferrule preparation:

Extracoronally, the remaining vertical portion of the crown was prepared with a 1mm circumferential shoulder finish line using a 8^o degree tapered straight end tungsten carbide bur attached to the milling unit, producing 8^o degree convergence [13] ferrule with 2mm height [14] and 2 mm thickness [15].

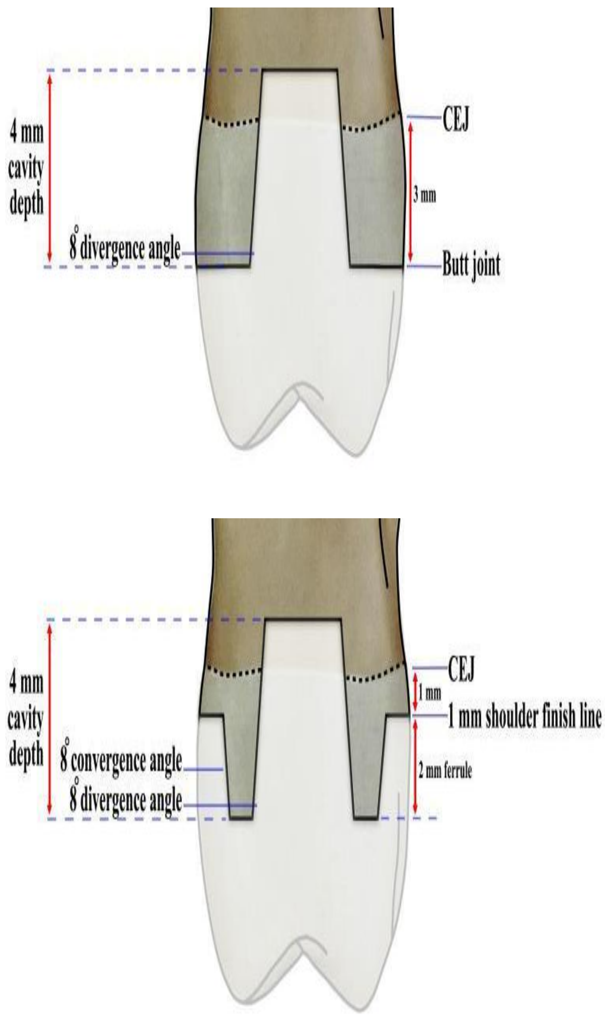

Figure 1. Preparation criteria for the study groups.

Fabrication of Endocrown Restoration:

Digital scanning:

The prepared tooth was air dried for 10 seconds and sprayed with an optical anti-reflection scan powder spray then placed on the scanning tray. Different images from different angles were captured and sent to the computer that connected to the scanning unit. The images were computed and automatically processed to get the final three dimensions animated optical images for the prepared specimens with the use of Colab Scan 2017 software, then saved as Standard Tessellation Language files (STL).

Endocrowns designing and milling:

The Endocrown restorations were designed using a software package. The endocrown restorations were designed in standardized form by using the biogeneric reference option in the software. A special milling machine was used to mill IPS e.max CAD and Cerasmart 270 blocks following the manufacturer's instructions.

IPS e.max CAD restorations finishing and glazing:

The milled restorations were checked for adaptation, then glaze gel was applied on IPS e.max CAD endocrowns and crystallization firing accomplished following manufacturer recommendations in a ceramic furnace. The endocrown restorations were placed on the crystallization tray inside the firing chamber and the firing process started using saved firing program. At the end of the program the crystallization tray was removed and allow the endocrown restorations to cool to room temperature in dry place.

Cerasmart 270 restorations finishing:

Cerasmart 270 endocrown restorations were finished using polishing stone burs without glazing and firing according to manufacturer recommendations.

Cementation process:

A combination of total etch bonding system and self-adhesive resin system was used in the cementation process. Before cementation, the prepared teeth surface and the intaglio surfaces of the restorations were treated according to the manufacture's recommendations.

Surface treatment of the prepared teeth

The teeth surfaces were treated with 37% phosphoric acid gel for 30 seconds, then the etching gel were washed off with copious amount of air-water spray for 10 seconds. Universal adhesive bonding agent was applied to the etched surface using bond applicator then light curing was applied for 20 seconds.

Surface Treatment of Endocrown restorations

Surface Treatment of IPS e.max CAD Endocrowns

The intaglio surface of IPS e.max CAD endocrown restorations were treated with 9.5% hydrofluoric acid gel for 20 seconds. Then acid gel was washed off with a copious amount of air water spray for 30 seconds, then dried with dry oil free air for 5 seconds. A silane coupling agent was applied on the etched surfaces then enabled to dry for 60 seconds.

Surface Treatment of Cerasmart 270 Endocrown

The intaglio surfaces of Cerasmart 270 endocrown restorations were etched with 9.5% hydrofluoric acid gel for 60 seconds. Then acid gel washed off with a copious amount of air water spray for 30 seconds. The etched surfaces were dried with dry oil free air for 5 seconds. A silane coupling agent were applied on the etched surfaces then enabled to dry for 60 seconds.

Cementation:

The endocrown restorations were cemented using self-adhesive dual-cured resin cement. The resin cement was applied to the fitting surface of the restoration and to the prepared tooth surface. The restoration was seated on the prepared tooth then placed on a specially designed cementation device with 1kg constant load for 5 minutes. Light curing was applied to the endocrowns for 20 seconds on each surface to insure full polymerization of the resin cement.

Thermocycling (Thermal fatigue)

An artificial aging was applied by means of cyclical temperature changes; all specimens were submitted to 10.000 cycles in thermocycling machine. The protocol involved 10.000 cycles of three consecutive rounds each: (1) 20 seconds at 5 °C; (2) 10 seconds at ambient air temperature; and (3) 20 seconds at 55 °C.

Fracture Resistance test

All specimens were separately attached to a computer controlled universal testing machine with a loadcell of 5. KN then records were documented by computer software. Fracture resistance tests was done by applying a compressive force which was applied vertically with a metal bar with a spherical tip (6 mm diameter) connected to the upper part of the testing device traveling at cross-head speed of 1mm/min with tin foil sheet in-between to get homogenous stress dissemination. The loads needed to fracture were documented in Newton.

Failure mode analysis with electron microscope scanning:

After fracture resistance test, the failure mode was analyzed using digital camera and scanning electron microscope SEM. The fractured specimens were examined to identify the various fracture modes if repairable or irreparable. Failure is considered repairable when the fracture is beneath the CEJ, while irreparable failure is considered as restorable when the failure is beyond the CEJ which require extraction of the tooth in clinical situations.

Results

As shown in table (1), Within Cerasmart 270 subgroup: Butt joint Group (4361.01±554.321N) showed a significant increase in Maximum Compressive load compared to that of Ferrule group (2755.65±595.70 N) (p=<0.001*). Within IPS e. max CAD subgroup: Butt joint Group (3053.16±1250.57 N) showed non-significant different compared to that of Ferrule group (2693.04±638.69 N) (p=0.42).

Within Butt Joint Group: Cerasmart 270 subgroup (4361.01±554.32 N) showed a significant increase in Maximum Compressive load compared to that of IPS e. max CAD subgroup (3053.16±1250.57 N) (p=0.007*). Within Ferrule Group: Cerasmart 270 subgroup (2755.65±595.701N) showed non-significant different compared to that of IPS e. max CAD subgroup (2693.04±638.69 N) (p=0.82).

Table 1: Mean and standard deviation of maximum compressive loads.

Groups	Butt joint design		Ferrule design	
Subgroups	IPS e. max CAD	Cerasmart 270	IPS e. max CAD	Cerasmart 270
(N)	10	10	10	10
mean± SD	3053.16±1250.57	4361.01±554.32	2693.04±638.69	2755.65±595.70
mean± SD	3707.09±1156.06		2724.34±601.96	

Two-Way ANOVA:

Butt joint Groups (3707.09±1156.06 N) showed significant a higher fracture resistance than Ferrule Groups (2724.34±601.96 N) so the effect of Groups alone on Fracture Resistance Test showed significance(P=<0.001*). Cerasmart 270 subgroup (3558.33±995.92 N) showed significant higher fracture resistance compared to that of IPS e. max CAD subgroup (2873.10±983.95 N) (p=0.01*) so the effect of Subgroups alone on Fracture Resistance Test showed significance(P=0.01*). The effect of both group Groups & Subgroups on Fracture Resistance Test showed significance(P=0.02*)

One-Way ANOVA:

One-way ANOVA and post hoc tests (Tukey-Kramer HSD) revealed that the fracture resistance of the Butt joint Cerasmart 270 group was statistically and significantly higher than the other tested groups, while no significant differences were found between the other groups.

Failure mode

Failure mode showed that under vertical compression load, the majority of failures were irreparable fracture of restoration/tooth complex below CEJ. Butt joint group showed 15 % of reparable failures mode (n=3) type III and IV failure modes, and 85 % showed irreparable failures mode (n=17) type V failure mode. While Ferrule group showed 20 % of reparable failures mode (n=4): type III failure mode, type IV failure mode, and 80 % of samples showed irreparable failures mode (n=16) type V failure mode.

Cerasmart 270 subgroups showed 100% irreparable failures mode (n=20) (type V), while the IPS e. max CAD subgroups showed 35% of reparable failures (n=7): type III and IV failure mode, and 65% of irreparable failures mode (n=13) type V failure mode. All the failures in this study were at loads much greater than recorded under normal masticatory function.

Table 2. Distribution of repairable and irreparable failure mode in the study groups.

	Butt joint Group		Test of sig.	Ferrule Group		Test of sig.
Type	IPS e. max CAD	Cerasmart 270		IPS e. max CAD	Cerasmart 270	
Reparable	3(30.0%)	0	FET P=0.21	4(40.0%)	0	FET P=0.08
Irreparable	7(70.0%)	10(100.0%)		6(60.0%)	10(100.0%)	

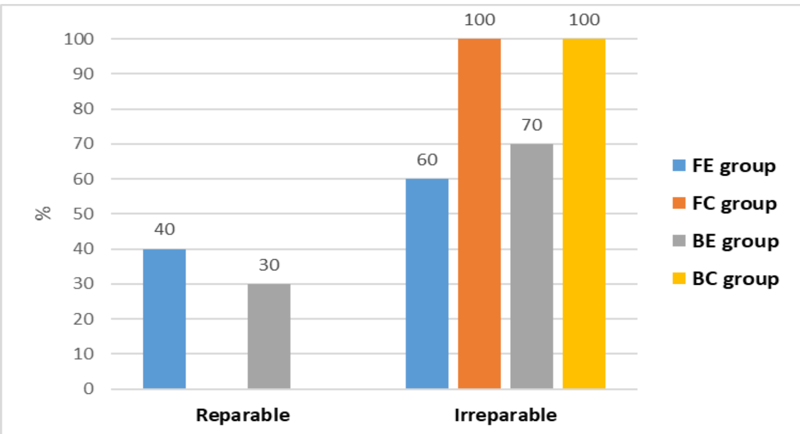

Figure2: fracture mode classification among studied group

Discussion:

The results of this study showed that the highest mean value of the fracture strength was found in BC group (Butt joint design with Cerasmart 270 endocrown group); mean = (4361.01±554.32 N), followed by BE group (Butt joint design with IPS e.max CAD endocrown group); mean = (3053.16±1250.57 N) and the lowest mean value of the fracture strength was found in FC group (Ferrule design with Cerasmart 270 endocrown group); mean = (2755.65±595.70 N) and FE group (Ferrule design with IPS e.max CAD endocrown group); mean = (2693.04±638.69 N). Therefore, the null hypothesis of this study was rejected. This result was in agreement with Al-khafaji and Jasim[16] who concluded that the butt joint margin design increased the fracture resistance of endocrown restoration more than those made from endocrowns with shoulder finish line (ferrule design). This result also was in accordance with Chang et al[17] and Biacchi et al[18] who reported that creating a ferrule might cause loss of sound tooth structure and thus result in compromised bonding strength because enamel is favored to dentin for bonding.

The result in this study was opposed by other studies[14,10,19] which reported that endocrowns with ferrule marginal design provide a greater fracture resistance. The difference in the results of their study is related to differences in the criteria and lack of standardization of ferrule preparation.

In this study, the fracture strength of Butt joint design (3707.09±1156.06 N) is higher than the fracture strength of Ferrule design (2724.34±601.96 N). This can be clarified by the difference of the cervical thickness between butt joint design endocrowns and ferrule design endocrowns[20]. It can be explained too by the wide and stable occlusal surface of the prepared tooth in butt joint design that resists the occlusal stresses where it was prepared parallel to the occlusal plane to ensure stress resistance along the major axis of the tooth[16].

Another possible explanation for high fracture resistance value of Butt joint design group was the bonding surface area that includes enamel and dentin instead of only dentin as in ferrule design group because enamel thickness at 3 mm above CEJ is more than that at 1 mm above CEJ at which the shoulder finish line was prepared in Ferrule group. Ferrule preparation of the teeth leads to some parts with restricted dentinal wall thickness at the cervical area of the tooth[14].

The result of this study showed that the mean value of fracture resistance of Cerasmart 270 endocrowns (4361.01±554.32 N) is higher than the mean value of fracture resistance of IPS e.max CAD endocrowns (3053.16±1250.57 N). The results of this study were in agreement with El-Damanhoury et al[21] and Al-shibri and Elguindy[22]. This results was opposed by Acar and Kalyoncuoğlu[23] who reported that lithium disilicate ceramic endocrowns showed higher fracture resistance (1913.84 ± 501.18 N) than nano-hybrid endocrown(1406.56 ± 369.49 N). This differences in results might be due to the differences in the methodology in their study; where teeth were sectioned 1 mm above CEJ junction, and the pulp extension was 2 mm. Other studies; Gresnigt et al[24], El Ghoul et al[25] and Taha et al[26] reported a comparable fracture strengths between endocrown restorations made of lithium disilicate ceramic and resin nano-ceramic on molars.

Industrial fabrication of Cerasmart 270 blocks at high temperatures and pressures has resulted in a greater volume fraction filler and greater conversion rates (85%) than indirect composite resin manufactured in dental labs, resulting in considerable improvements in mechanical qualities[27]. This high fracture values may be attributed to the stress absorption feature of the nano-hybrid ceramic structure with breaking energy (2.2 MPa), while the lithium disilicate glass ceramic has breaking energy (0.6 MPa). Furthermore, due to the low Flexural Modulus of Cerasmart 270 (7.9 GPa) and high Flexural Modulus of IPS e.max CAD (32.3 GPa). When compared to feldspathic and reinforced ceramics, the inclusion of resin material in Cerasmart 270 blocks should improve bonding to resin cement materials, resulting in more homogeneous stress distribution and hence higher fracture resistance[21].

Regarding fracture mode, the result of this study shows a high proportion of unfavorable mode of fracture for both butt joint and ferrule designs endocrowns with 20 % favorable mode of fracture in ferrule designs. This mode of failure was in agreement with Khafaji[16],Al-shibri & Elguindy[22] and Einhorn et al[14] in which these studies found that endocrowns present with unfavorable mode of fracture mode.

This can be explained by the difference in cervical thickness between butt joint design and ferrule design. The butt joint design provides a restoration with much thicker cervical margins than ferrule design does and it is more conservative to enamel tissue which enhance bonding and strength of the restoration. The fracture resistance in the butt joint design group was at much greater loads than ferrule design group in this study. The cervical extension of the restoration in ferrule design is thinner than cervical margin in butt joint design and the cervical portion of the prepared tooth in the ferrule design is thinner than the cervical portion of the butt joint design and this allow the ferrule designed endocrowns to be fractured under lower compressive force in much favorable modes. Einhorn et al[14] reported in their study that 2-mm ferrule endocrown preparations showed a catastrophic failures. The endocrown with 1 mm ferrule showed fewest catastrophic failures, although with high percent of non-restorable fractures. Therefore, endocrowns, regardless of ferrule presence, exhibited a high percent of non-restorable failures. Alarami et al[28] reported that adding ferrule around the axial walls might result in areas with a thin dental structure at the cervical part causing over-milling of the intaglio surface on the restoration due to limited bur thickness, and causing less adaptation of the restoration at the axial extension.

Cerasmart 270 subgroups showed 100% irreparable failures mode, while the IPS e. max CAD subgroups showed 35% reparable failures and 65% irreparable failures mode. The difference between the fracture modes of both materials might be attributed to the modulus of elasticity of the tested ceramics. The elasticity modulus of the resin in the hybrid ceramic is consistent with that of dentin, so this resin material tends to bend when exposed to forces that lead to better stress absorbing and distribution features[29]. In the other hand, IPS e. max CAD is a brittle material that recorded flexural strength of 262–360 MPa and a fracture toughness of 2.0–2.5 MPa and produce stress concentrations at critical areas[30]. Lithium disilicate is more strong than hybrid ceramics, but it is also more brittle, in the other hand, hybrid ceramic displayed a higher flexural strength of 219 MPa and lower flexural modulus 9.7 MPa which result in a less brittle and more flexible material so as to absorb high stress loading[29] . In this study, it was found that there was no adhesive failure at the ceramic-cement interface for both materials. This might be due to the excellent micromechanical retention between the ceramic surface of this materials and the cement after surface treatment with hydrofluoric acid etching in addition to the chemical bonding after silane application.

Limitations of this in vitro study include: The in vitro study cannot simulate all oral environments and the minor variations in the proportions after teeth preparation can be considered as a possible limitation in this research.

Conclusion:

Within the limitation of this study, the following conclusions can be drawn:

- Endocrowns with butt joint design showed a higher fracture resistance in comparison with endocrown with ferrule preparation design.
- Hybrid nano-ceramic endocrowns showed a higher fracture resistance than lithium disilicate endocrowns.
- Endocrown showed a high percent of irreparable failure mode but at loads larger than normal masticatory function.

References

1. *Schwartz R, and Robbins J . Post placement and restoration of endodontically treated teeth: A literature review. J Endod; 2004; 30: 289–301.*
2. *Magne P . It should not be about aesthetics but tooth-conserving dentistry. Br Dent J; 2012; 213: 189–191.*
3. *Pissis P . Fabrication of a metal-free ceramic restoration utilizing the monobloc technique. Pract Periodontics Aesthet Dent; 1995; 7: 83—94.*
4. *Bindl A, and Mormann H. Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years--preliminary results. J Adhes Dent; 1999; 1: 255–265.*
5. *Govare N, and Contrepois M . Endocrowns: A systematic review. J Prosthet Dent; 2019; 19: 1–17.*
6. *Belleflamme M, Geerts O, Louwette M, Grenade F, Vanheusden J, and Mainjot K . No post-no core approach to restore severely damaged posterior teeth: An up to 10-year retrospective study of documented endocrown cases. J Dent; 2017; 63: 1–7.*
7. *Alharbi F, Nathanson D, Morgano M, and Baba Z . Fracture resistance and failure mode of fatigued endodontically treated teeth restored with fiber-reinforced resin posts and metallic posts in vitro. Dent Traumatol; 2014; 30: 317–325.*
8. *Tsitrou A, Helvatjoglu M, and Van R . A preliminary evaluation of the structural integrity and fracture mode of minimally prepared resin bonded CAD/CAM crowns. J Dent; 2010; 38: 16–22.*

9.http://www.gcamerica.com/products/digital/cerasmart/gca_cerasmart_270_brochure-08-05-2020_ver2.pdf.

10. *Adel S, Abo-madina M, and Abo-el-Farag S . Fracture Strength of Hybrid Ceramic Endocrown Restoration with Different Preparation Depths and Designs. 2019; 18: 17–23.*
11. *Zhu J, Rong Q, Wang X, and Gao X . Influence of remaining tooth structure and restorative material type on stress distribution in endodontically treated maxillary premolars : A fi nite element analysis. J Prosthet Dent; 2016; 108: 1–10.*
12. *Zhu J, Wang D, Rong Q, Qian J, and Wang X . Effect of central retainer shape and abduction angle during preparation of teeth on dentin and cement layer stress distributions in endocrown-restored mandibular molars. Dent Mater J; 2020; 39: 464–470.*
13. *Strain K, Mackie J, Bonsor S, and Macfarlane T . Crown Taper Angles Achieved by Dental Students: A Systematic Review. J Dent Educ; 2018; 82: 1203–1212.*
14. *Einhorn M, DuVall N, Wajdowicz M, Brewster J, and Roberts H . Preparation Ferrule Design Effect on Endocrown Failure Resistance. J Prosthodont; 2019; 28: 237–242.*
15. *Fontana P, Bohrer T, Wandscher V, Valandro L, Limberger I, and Kaizer O . Effect of ferrule thickness on fracture resistance of teeth restored with a glass fiber post or cast post. Oper Dent; 2019; 44: E299–E308.*
16. *Al-khafaji S, and Jasim H . Fracture Resistance of Endodontically Treated Teeth Restored by Full Crown and Two Endocrowns Preparation Design Made from Lithium Disilicate Material (A Comparative in Vitro Study). Int Med J; 2020; 25: 2531–2542.*
17. *Chang C, Kuo J, Lin Y, and Chang Y . Fracture resistance and failure modes of CEREC endo-crowns and conventional post and core-supported CEREC crowns. J Dent Sci; 2009; 4: 110–117.*
18. *Biacchi G, and Basting R . Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. Oper Dent; 2012; 37: 130–136.*
19. *Taha D, Spintzyk S, Schille C, Sabet A, Wahsh M, Salah T et al . Fracture resistance and failure modes of polymer infiltrated ceramic endocrown restorations with variations in margin design and occlusal thickness. J Prosthodont Res; 2018; 62: 293–297.*
20. *Fages M, and Bertrand B . The Endocrown : A Different Type of All-Ceramic Reconstruction for Molars. Can Dent Assoc jor; 2013; 29: 40–79.*
21. *El-Damanhoury H, Haj-Ali R, and Platt J . Fracture resistance and microleakage of endocrowns utilizing three cad-cam blocks. Oper Dent; 2015; 40: 201–210.*
22. *Al shibri S, and Elguindy J . Fracture Resistance of Endodontically Treated Teeth Restored with Lithium Disilicate Crowns Retained with Fiber Posts Compared to Lithium Disilicate and Cerasmart Endocrowns: In Vitro Study. Dentistry; 2017; 7: 1–9.*
23. *Acar D, and Kalyoncuoğlu E . The fracture strength of endocrowns manufactured from different hybrid blocks under axial and lateral forces. Clin Oral Investig; 2020; 8: 1–9.*
24. *Gresnigt M, Özcan M, Van M, Schipper L, and Cune M . Fracture strength, failure type and Weibull characteristics of lithium disilicate and multiphase resin composite endocrowns under axial and lateral forces. Dent Mater; 2016; 32: 607–614.*
25. *El Ghoul W, Özcan M, Silwadi M, and Salameh Z . Fracture resistance and failure modes of endocrowns manufactured with different CAD/CAM materials under axial and lateral loading. J Esthet Restor Dent; 2019; 31: 378–387.*
26. *Taha D, Salah T, Wahsh M, and Sabet A . Assessment of marginal adaptation and fracture resistance of endocrown*

restorations utilizing different machinable blocks subjected to thermomechanical aging Assessment of marginal adaptation and fracture resistance of endocrown restorations utilizing dif. J Esthet Restor Dent; 2018; 96: 1–9.

27. Lauvahutanon S, Takahashi H, Shiozawa M, Iwasaki N, Asakawa Y, Oki M et al . Mechanical properties of composite resin blocks for CAD/CAM. Dent Mater J; 2014; 33: 705–710.

28. Alarami N, Sulaiman E, and Al-Haddad A . Fracture resistance of endodontically- Treated mandibular molars restored with different intra-radicular techniques. Am J Dent; 2017; 30: 197–200.

29. Awada A, and Nathanson D . Mechanical properties of resin-ceramic CAD/CAM restorative materials Presented at the American Association of Dental Research/Canadian Association of Dental Research Annual Meeting, Charlotte, NC, March 2014. J Prosthet Dent; 2015; 114: 587–593.

30. Eisa N, Essam E, Amin R, and EL-Sharkawy Z . Fracture Resistance and Retention of Three Different Endocrown Materials. Al-Azhar Dent J Girls; 2020; 7: 189–198.