

Retention of different CAD/CAM endocrowns bonded to severely damaged endodontically treated teeth: An *in vitro* study

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Abstract

Aim: Assess the retention of endocrowns fabricated of different CAD/CAM materials.

Settings and Design: In vitro - comparative study.

Material and Methods: Root canal treated mandibular first molars were prepared in a standardized method. Standardized endocrowns were manufactured using four CAD-CAM blocks: resin infiltrated ceramic (Vita Enamic), partially stabilized tetragonal zirconia (Katana), lithium disilicate ceramic (IPS e.max CAD), and polyether-ether-keton (PEEK, BioHPP). After proper surface treatment, the restorations were cemented using a resin cement (Panavia F2.0) and were connected to a special attachment unit and secured to a universal testing machine. The amount of axial load required to dislodge the restoration from the tooth structure was measured ($n = 12$, $\alpha = 0.05$). Failures were classified as adhesive debonding from the tooth structure without damaging the supporting tooth structure and cohesive fracture of the supporting tooth structure

Statistical Analysis Used: One-way analysis of variance, Tukey's post hoc test.

Results: The retention of Vita Enamic (61 ± 11 N) and IPS e.max CAD (58 ± 9 N) was significantly higher ($F = 123$, $P < 0.01$) than Katana (33 ± 13) and Peek restorations (23 ± 11). Vita Enamic and IPS e.max CAD were associated with fractured tooth segments during debonding while Katana and PEEK specimens were adhesively debonded from the remaining tooth structure.


Conclusions: Within the limitations of this study, using lithium disilicate ceramics and resin infiltrated ceramics as restorative materials to fabricate endocrowns to restore severely damaged endodontically treated teeth, recorded significantly higher retention values. Meanwhile, using yttrium partially stabilized zirconia and polyether ether ketones for the same purpose recorded a favorable mode failure which avoided the possibility of tooth fracture.

Keywords: Computer-assisted design/computer-assisted manufacturing, endocrowns, retention

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INTRODUCTION

The progress made in adhesive dentistry and innovations of computer-assisted design/computer-assisted manufacturing (CAD-CAM) shifted the treatment decisions of root canal-treated teeth with great coronal loss toward more conservative modalities. Endocrowns were proposed for restoration of extensively damaged root canal-treated teeth where there is a lack of sufficient retention form.^[1,2] Several studies have proven the validity of bonded endocrown over conventional crowns by reporting that the stress levels in teeth with prosthetic crowns were higher than teeth with endocrowns.^[3,4]

Endocrown is a monoblock ceramic crown that extends inside the pulp chamber to gain retention by utilizing the macroretentive support achieved by friction to the pulp chamber axial walls in addition to micromechanical retention through the adhesive cementation.^[5] *In vivo* studies and *in vitro* trials have approved the validity of using the adhesive approach, especially for molars.^[6-9] Bindl and Mormann assessed the clinical quality and survival rate of nineteen endocrowns after 2 years. They reported that the clinical performance of the endocrowns was superior as single failure has occurred because of recurrent caries.^[7] The preliminary results of a study conducted by Otto^[8] also reported good clinical quality of endocrowns after 1 year, with no evidence of root fractures or loss of retention. Valentina *et al.*^[9] evaluate the clinical performance of endocrowns manufactured with Cerec CAD/CAM system and endocrowns manufactured with Empress II system and it was reported that the both systems have fabricated endocrowns with superior clinical quality in terms of retention and esthetics.

Various CAD/CAM restorative materials are obtainable for endocrowns. Lithium disilicate glass ceramics are one of the most successful materials used for the fabrication of a wide variety of restorations combining superior esthetics, strength, and excellent adhesion properties to the tooth structures.^[10] Resin-infiltrated ceramics have an interconnected ceramic porous microstructure filled with a resin polymer, thus providing mechanical properties that fall between glass ceramics and resin composites. Its hybrid surface is conditioned in the similar way as an etchable ceramic.^[11] In addition, its ability to be restorable if a failure occurred favoring its use for endocrown fabrication.^[12]

Polyetheretherketone (PEEK) material provides high mechanical properties and superior biocompatibility,^[13] allowing the use of PEEK for endocrowns fabrication.^[10] It required veneering to improve the esthetics as it has

nonesthetic whitish opaque color.^[14] Yttrium partially stabilized zirconia provides extremely fracture toughness and high strength.^[15] Newer types provide superior esthetics and improved translucency.^[11,16]

In cementing the indirect adhesive restorations, resin bonding is considered an important step adhesion as it considered the primary feature of retention.^[17] Resin cements have the ability bond to many substrates, including the tooth structure, ceramics, gold and other metallic alloys, and indirect resin composites^[18] through the use of specific primers which promote bonding between the tooth structure and the restorative material.^[19] To assess the retentive properties of a restoration, a retention test could be used to simulate the clinical conditions, leading to dislodgment of the restoration.^[20] Therefore, the aim of this *in vitro* study was to evaluate the retention of endocrowns fabricated using four different materials. The proposed null hypothesis in this study was that the material type will not influence the retention of the endocrowns restoration.

MATERIALS AND METHODS

The study was approved by the institutional review board. Forty-eight freshly extracted human intact mandibular first molars were selected from patients suffering from loosening of their teeth due to severe periodontal disease or uncontrolled diabetes that has no treatment other than extraction. This research was approved by Research Ethics Committee of Faculty of Dentistry, Tanta University (approval number: FP-09-2017). The inclusion criteria were freshly extracted, defects free, completely formed roots and similar in shape and size by measuring the mesiodistal and buccolingual dimension at the cemento-enamel junction (the buccolingual diameter was 9 mm and mesiodistal width 11 mm) allowing maximum 10% deviation. The teeth were cleaned ultrasonically and stored until experimentation in 0.1% thymol disinfectant dissolved in distilled water at room temperature.

The materials tested and the compositions are displayed in Table 1. For the purpose of standardization, all the teeth were root canal treated in the same sequence by one operator. The pulp chamber of the teeth was accessed following its pulp chamber morphology. Root canal treatment was done using Protaper system (Dentsply-Maillefer; Ballaigues, Switzerland) and resin-based sealer (ADseal, META BIOMED, Chungbuk, Korea).^[21] To standardize the preparation of the specimens, a computerized numerical control milling machine (C. N. C Vertical

Table 1: Materials used in the study

Material	Manufacturer	Product	Composition
Yttrium partially stabilized zirconia	Kuraray Noritake, Japan	KATANA Zirconia STML	8.15% Y2O3 (10% mol), 89.792% ZrO2, 0.253% Al2O3, 1.78%, HfO2 and 0.025% others Consisting of 4 layers: enamel layer 35%, dentin layers 35%, 1st transition layer 15% and 2nd transition layer 15%
Lithium disilicate glass ceramic	Ivoclar Vivadent, Schaan, Liechtenstein	IPS e.max CAD	High-strengthened glass ceramic, based on lithium disilicate, with two phases: Li2SiO3 which are integrated in the glassy phase forming the 40% partially crystallized phase and fine-grain lithium disilicate crystals integrated in the glassy matrix forming the 70% fully crystallized phase
Resin infiltrated ceramic	VITA Zahnfabrik H. Rauter, Germany	VITA ENAMIC	Polymer network (14%), is infiltrated in ceramic network (86% by weight) and the networks are fully integrated with one another. The MMA-free modified PMMA is embedded in the polymer network
Polyether ether ketone Composite veneering material	Bredent, Germany	BreCAM BioHPP Visio.lign	Polyetheretherketone consists of high temperature-resistant thermoplastic partially crystalline, high-performance polymers integrated with 20% of a 0.3–0.5 µm ceramic fillers Composed of 2 items Cera.Lign composite: Light curing composite filled with nano ceramics Crea.lign modelling Liquid: which increase the Crea.Lign fluidity through reducing the material elastic modulus
Fluorapatite glass-ceramic veneering material	Ivoclar Vivadent, Schaan, Liechtenstein	IPS e.max ceram	Low-fusing nano-fluorapatite glass-ceramic integrated in alumino-silicate glasses

Y2O3: Yttrium oxide, ZrO2: Zirconium dioxide, Al2O3: Aluminum oxide, HfO2: Hafnium oxide, Li2SiO3: Lithium metasilicate crystals, MMA: Methyl methacrylate, PMMA: Polymethylmethacrylate, CAD: Computer-aided design, CAM: computer-aided manufacturing, BioHPP: Biocompatible, high performance polymers, STML: Super translucence multi-layered

Machining Center VB-1000, Taiwan)^[21] was used. Specimens were scanned using handheld scanners (SCAN 3D™, Creaform, USA). Then, the software was used to design the preparation (SOLDWORKS premium 2018, Massachusetts, USA).

The design [Figures 1-3] included a flat butt joint at the tooth restoration interface and an intracoronal 3 mm extension from the internal cavity margin to the floor of the pulp chamber with an 8° divergence of the walls.^[22]

The specimens were randomly divided into four groups ($n = 12$) to receive endocrowns using four materials: PEEKs (BioHPP), yttrium partially stabilized zirconia (KATANA Zirconia), a lithium disilicate (IPS e.max CAD), and a resin infiltrated ceramic (VITA ENAMIC). A standardized occlusal form was selected for all restorations.^[23]

Wet/dry five-axis milling machine (Cam 5-S1, VHF camfacture AG, Germany) was used to fabricate the endocrowns. Dry milling was done for zirconia blocks (Katana blank: A3 T14) and PEEK (blank: BreCAM. BioHPP), whereas wet milling was done for IPS e.max CAD (block: HT A3/C14) and Vita Enamic (block: 3 M2-T EM-14). Each material was further processed using manufacturing recommendations. The design of the restoration included small undercuts placed on each surface to ensure proper engagement of the attachment unit.

Surface treatment of the fitting surface of restoration was done according to the manufacturer's instructions as follows: etching with hydrofluoric acid gel (Ultradent porcelain etch, South Jordan, Utah, USA) for 60 s for Vita Enamic group and 20 s for IPS e.max CAD group followed

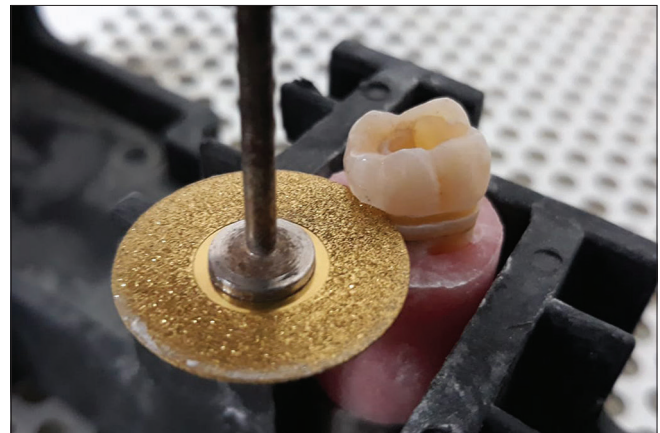


Figure 1: Digital color image, demonstrating reduction of crown to (1 mm) above cemento-enamel junction with 90° flat butt margin

by rinsing with water for 30 s and drying for 20 s, and then, according to the manufacturer's instruction, two thin coats of a silane agent silane coupling agent (Ultradent, South Jordan, Utah, USA) was applied with a micro brush to the treated surface for two 60-s intervals. Air was sprayed to spread it homogeneously and to disperse the excess.

Katana specimens were sandblasted using aluminum oxide powder (2.5 bar, 50 µm), whereas PEEK specimens were sandblasted using aluminum oxide powder (2.5 bar, 110 µm) and then coated with Visio.Link primer (Bredent, rinsed with water GmbH and Co. KG, Germany). For tooth conditioning, as recommended by the manufacturer, the enamel areas were etched with 35% phosphoric acid gel (Ultra-Etch, South Jordan, Utah, USA) for 30 s, then and gently dried, then an equal amount of the ED primer (Kuraray Noritake Dental Inc, Japan) was mixed and was applied to the dentin followed by 15 s gentle drying.

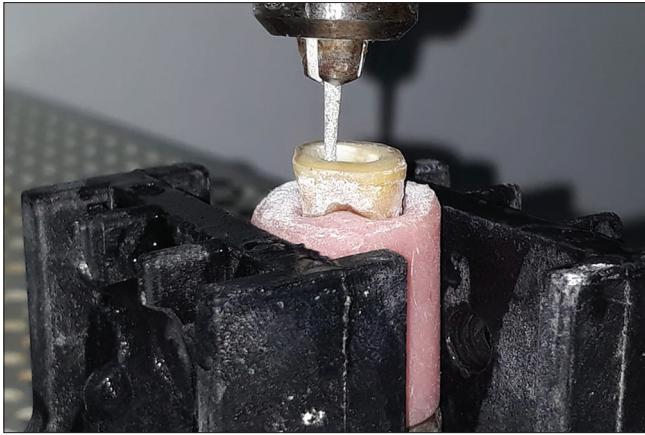


Figure 2: Digital color image, demonstrating adjustment of the divergence of pulp chamber walls and preparation of retention cavity with (3 mm) in depth

Regarding the cementation of the endocrowns, Paste A and B (Panavia F2.0, Kuraray Noritake Dental Inc, Japan) were equally mixed and were applied to the intaglio surface of endocrowns. Then, static finger pressure was applied on the endocrowns to allow their seating on their relevant preparations. To standardize the cementation process, endocrowns were seated in a universal testing machine and a uniform vertical static load of 10 Newton was applied for 5 min and then light-curing was performed briefly for only 2 s, and then, a scaler was used to remove the excess cement.^[21] To prevent oxygen inhibition of polymerization and to allow self-curing of the cement, Oxyguard was applied. Then, 20 s light-curing was performed per each tooth surface. The cemented specimens were stored in distilled water at 37°C with 100% humidity for 1 week.^[24] To evaluate the retention strength, the root portion of each specimen was individually secured to the lower compartment of a universal testing machine (LRX-Plus, Lloyd Instruments, UK) using a screw attachment unit. The restoration part was connected to the upper compartment of the testing machine using a multiaccess screw ring engaging the undercuts placed on the surface of the restoration. An axial tensile load was applied at a crosshead speed of 0.5 mm/min till the dislodgment of the restoration. The load required for debonding was recorded in Newton. One-way analysis of variance was performed (SPSS 16.0, SPSS, Inc., Chicago, IL, USA) with Tukey's *post hoc* test.

RESULTS

The retention of Vita Enamic (61 ± 11 N) and IPS e.max CAD (58 ± 9 N) was significantly higher ($F = 123$, $P < 0.01$) compared to Katana (33 ± 13 N) and Peek restorations (23 ± 11 N), which demonstrated much lower retention values. Vita Enamic and IPS e.max CAD were associated with cohesive fracture of the supporting tooth



Figure 3: Digital color image, demonstrating occlusal view of prepared teeth with flat butt joint occlusal surface and 3 mm depth retention cavity

structure during debonding of the restorations [Figure 4]. On the contrary, Katana and PEEK specimens were adhesively debonded from the remaining tooth structure without damaging the supporting tooth structure [Figure 5].

DISCUSSION

The type of the material used reported a significant influence on retention for all tested groups. Lithium disilicate and resin infiltrated ceramics showed the highest retention value compared to yttrium partially stabilized zirconia and PEEKs which were easily dislodged at much lower force. The proposed hypothesis was rejected.

Retention tests were developed to simulate the clinical condition because it considers the substrate's configuration complexity to which the restoration is being cemented.^[25] Despite, it a problem to pull out the ceramic it remains restorations from the underlying substrate without causing fracture of the supporting tooth or the restoration. A pervious study that fabricated crowns with a pull-out loop as an complementary part of the crown reported loop fracture during testing.^[26] Carnaggio *et al.*^[27] designed a macroretentive attachment features to the crown, by adjusting the crowns to have projecting bars, which were either placed on the sides of the crowns or on the occlusal surface. Failures were reported in the crowns with occlusal surface bars, whereas crown-sided bars reported no failure. Arcoria^[28] used a retentive undercuts which were reported to increase the retentive strength crowns. Therefore, the undercuts made in the endocrowns allowed engagement of the screws of the attachment unit without inducing extra stress on the specimens during pulling.

Resin bonding of ceramic material restorations permits a robust bonding between the tooth structure and the

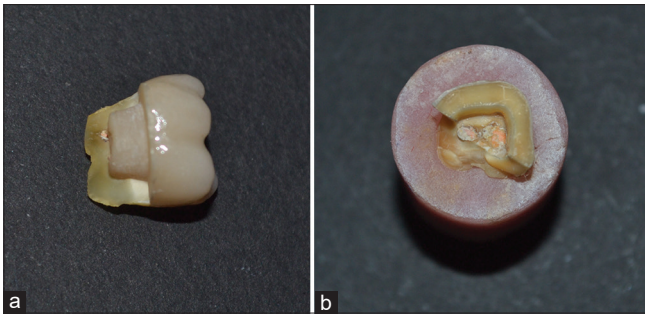


Figure 4: Digital color image, demonstrating cohesive fracture of the supporting tooth structure (a) fractured restoration with part of the tooth and (b) remaining fractured tooth structure

restoration.^[29] Panavia F2.0 contains the famous phosphate monomer, 10-methacryloyloxydecyl dihydrogen phosphate (MDP), in the applied primers. MDP has a multipotential power to bond to crystalline ceramics, metals, and to tooth structure as well.^[30] The double-sided process of the adhesive cementation requires pretreatment steps of both the dental hard tissues and the restorative material.^[31]

Regarding the surface treatment of tooth structure, enamel area was etched with phosphoric acid that dissolves the hydroxyapatite crystals resulting in producing micro-irregularities leading to the formation of resin micro tags which provide micromechanical retention, thus improving adhesion potential.^[32] Bonding to dentin involves the application of a 30%–40% phosphoric acid, which removes the smear layer, demineralizes the dentin, and opens the dentinal tubules to a depth of several microns followed by application of primer^[33] containing monomers with specific phosphate groups, such as 10-MDP, which are capable of chemical bonding through primary ionic binding resulting in more strong chemical bonds.^[34]

Regarding the intaglio surface treatment of lithium disilicate restorations, because it consists of two main ingredients: Silica, which act as the glassy matrix and provides good bonding characteristic to resin adhesive, and almost 70% lithium oxide crystals which provides superior mechanical properties.^[35] Etching with hydrofluoric acid for 20 s was performed to produce a roughness in the ceramic material surface to promote bonding between the resin cement and ceramic material. After etching, coating the ceramic surface with a silane coupling agent was performed to create a chemical bond between the resin cement and the ceramic material to enhance the retention of the restorations.^[36] Therefore, the composition of fully crystallized lithium disilicate ceramics contributed to establish a strong bond, which was associated with the highest retention value in this study. This result is in agreement with previous studies,^[37,38] where the highest

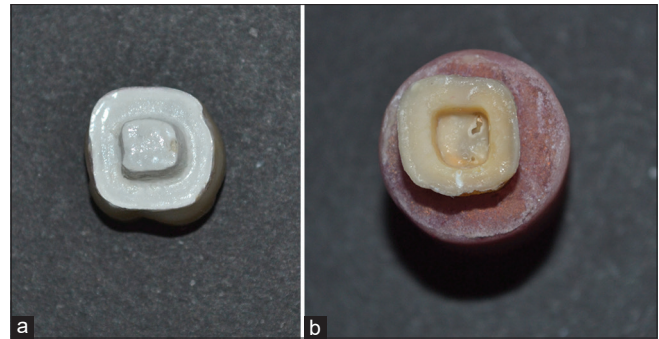


Figure 5: Digital color image, demonstrating adhesive debonding from the tooth structure without damaging the supporting tooth structure (a) dislodged specimen without any traces of resin cement and (b) resin cement remnant on intact tooth structure

retentive strength was reported using lithium disilicate in combination with Panavia resin cement.

For resin-infiltrated ceramics, it is composed of a dual network of presintered feldspar porous ceramic matrix integrated with an organic polymers forming the polymer-infiltrated ceramic network.^[39] Hydrofluoric acid etching for 60 s eliminates some of the glass matrix, producing microporosities.^[40] Exposed etched glass is silanated to promote active bonding formation of a chemical bond.^[11] In the current study, resin-infiltrated ceramics showed high retention values which were comparable to lithium disilicate ceramic.^[41,42] This high bond strength of resin-infiltrated ceramics could be interpreted due to its hybrid surface that resulting in that superior chemical bonding.^[39]

Regarding yttrium partially stabilized zirconia, due to its chemical composition and the absence of etchable glass phase, it complicate the bonding procedure of this material.^[43] The preferred treatment method is airborne-particle abrasion with Al₂O₃ followed by the application of MDP- resin cement as (Panavia F2.0) to provide superior bond strengths.^[44] However, other studies reported that using sparsely fused glass pearls or plasma spraying as a pretreatment step of the zirconia surface may increase the strength of the bond to the resin cement.^[45] Therefore, bonding difficulty due to its chemical composition may interpret the low retention values reported in the current study, which was comparable to other studies.^[46,47]

For PEEKs, bonding to PEEK is still quite challenging.^[13] Airborne particle abrasion improved its microroughness, while pretreatment with methyl methacrylate-based (Visio. Link) adhesives increased wetting with the veneering material and demonstrated adequate chemical bond to PEEK.^[48] However, the present study showed the

lowest retention values. This result was comparable to other studies.^[13,48] The material was easily separated from the supporting tooth structure, which reflects the poor nature of the established bond. This may be interpreted using the airborne particles for surface treatment before cementation leads to roughing the fitting surface and therefore, altering the retention force. On the other hand, the milling process may be difficult to provide adequate adaptation of the pulp chamber extension of endocrowns. Therefore, the revision of the software program must be done periodically to ensure the right milling angle on the inner surface.^[49] Several trials were conducted to improve surface properties as acid etching, and plasma coating, or laser applications.^[50]

The failure mode of yttrium partially stabilized zirconia and PEEK was an adhesive failure because the restorations were debonded from the remaining tooth structure without damaging the supporting tooth structure. However, using lithium disilicate ceramics and resin-infiltrated ceramics have resulted in cohesive failure because fracture of the supporting tooth structure occurred. Selecting the best restorative material for making endocrowns is a controversial decision. If the priority is directed toward saving the tooth, using yttrium partially stabilized zirconia or PEEKs would be the proper choice. If the priority is directed toward saving the restoration, using lithium disilicate ceramics or resin-infiltrated ceramics would be the proper choice. The priority should be determined by both the dentist and the patient. Marginal adaptation is an important criterion that should be considered during the selection of the restorative material. Therefore, a further investigation about the marginal adaptation of endocrowns is needed to ensure the durability of the endocrown materials to withstand the clinical performance.

CONCLUSIONS

Within the limitations of this study, using lithium disilicate glass ceramics and resin-infiltrated ceramics as restorative materials to fabricate endocrowns to restore severely damaged endodontically treated teeth recorded significantly higher retention values. Meanwhile, using yttrium partially stabilized zirconia and PEEKs for the same purpose recorded a favorable mode failure which avoided the possibility of tooth fracture.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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