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Marginal gap distance and cyclic fatigue loading for different all-ceramic endocrowns

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Abstract. – OBJECTIVE: The aim of the study was to evaluate the effect of the fabrication techniques of two types of glass ceramics on the marginal gap distance and the fracture resistance of endocrown restorations after cyclic loading.

MATERIALS AND METHODS: Forty extracted mandibular first molars were root canal treated. Decoronation was done for all the endodontically treated teeth 2 mm above the cemento-enamel junction. The teeth were individually fixed vertically into epoxy resin mounting cylinders. All teeth were prepared to receive endocrown restorations. The prepared teeth were randomly divided into four equal groups (n=10) according to the all-ceramic materials and technique used for endocrown construction as follows: Group I (n=10): Pressable lithium disilicate glass ceramics (IPS e-max Press), Group II (n=10): Pressable zirconia-reinforced lithium disilicate glass ceramics (Celtra Press), Group III (n=10): Machinable lithium disilicate glass ceramics (IPS e-max CAD), Group IV (n=10): Machinable zirconia-reinforced lithium disilicate glass ceramics (Celtra Duo). The endocrowns were cemented using dual-cure resin cement. All endocrowns were subjected to fatigue loading. The cycles were repeated 120,000 times to clinically simulate one year chewing condition. Marginal gap distance of all endocrowns was measured directly using a digital microscope with x100 magnification. The load required to failure was recorded in Newton. Data were collected, tabulated, and statistically analyzed.

RESULTS: Fracture resistance testing of all-ceramic crowns revealed a statistically significant difference between all different ceramic materials used in this study (*p*-value <0.001). On the other hand, there was a statistically significant difference between all the four ceramic crowns for the marginal gap distance either before or after fatigue cyclic loading.

CONCLUSIONS: After considering the limitation of the current study, the following conclusions were given: endocrowns are considered one of the promising minimally invasive restorations for root canal treated molars. CAD/CAM technology revealed better results than heat press technology regarding the fracture resistance of glass ceramics. Heat Press technology revealed better results than CAD/CAM technology regarding the marginal accuracy of glass ceramics.

Key Words:
Marginal gap distance, Fatigue loading, Endocrowns, All-ceramic, E-max press, Celtra press, E-max CAD, Celtra duo, Pressable ceramics, Machinable ceramics.

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Introduction

Definitive restoration of endodontically treated teeth denotes one of the interesting clinical challenges in prosthetic dentistry. Adhesive endocrown restoration option has been widely used recently as one of the successful alternatives for coronal seal restoration of root canal treated teeth. Conservatism, esthetics, minimal clinical and laboratory procedures give this technique its uniqueness in comparison to post and core and crown conventional techniques[1-5]. The clinical cases with insufficient coronal length, deficient interocclusal space, and massive loss of tooth structure that result in inadequate amount of ferrule, represent the main indications for the endocrowns[3]. Two significant viewpoints are important regarding this technique's success; the choice of the endocrown ceramic material and the adhesive system to obtain the monoblock concept[6,7]. Currently, the increased demand for esthetic restoration of destructed tooth tissue has led to the growing attractiveness of all ceramic techniques. The ceramic material type and processing technique used are important factors that increase the range of indications in the field of prosthodontics. Accordingly, the decision to select the correct material with its appropriate technique has become more widely covered[8].

Glass-ceramics are a popular widely used group of all-ceramics that gain their interest because of long-term survival rates and reliability results through different studies[9,10] in the literature according to different types of indications. The ongoing progress of their mechanical properties, improved microstructure and various processing techniques have made them an attractive unique group[7]. The commonly used full-contour monolithic lithium disilicate glass-ceramic group (IPS emax, Ivoclar, Vivadent) with adhesive resin cementation proved to be suitable for high stress situations[11,12].

Moreover, the addition of 10% weight zirconia to the lithium silicate ceramic resulted in the invention of an added category to the glass ceramics under the scientific name of zirconia-reinforced lithium silicates, which is described as glass-ceramics reinforced with polycrystalline ceramics[8,12,13]. The reinforcement of zirconium oxide crystals acts as a nucleating agent to the main crystalline phase of lithium silicate, resulting in a strengthened ceramic structure by the crack interruption technique[9,14,15]. Glass-ceramic groups are primarily successfully constructed using the heat-pressing processing technique. Glass-ceramic ingots are heated so that the ceramic material flows under pressure into a mold formed with the lost wax technique[16]. Then again, glass-ceramics CAD/CAM blocks have been introduced as an alternative processing technique to the same all-ceramic category to expand the clinician's choices according to the clinical situation[13].

The technique of processing the same all-ceramic materials could affect the fracture strength and marginal quality of the final restoration, specifically with a challenging newly developed type of restorations as endocrown. Both lithium silicates and zirconia-reinforced lithium silicates could be fabricated using CAD/CAM technique as well as the heat-press technique[16]. Through the precise application of CAD/CAM technology, a more successful marginal quality and adequate strength of all-ceramic restorations, especially with sensitive types of restorations as endocrowns, could be accomplished through the exclusion of some traditional fabrication manual steps in the construction procedure. However, some additional steps may result in errors as the type of the scanner, the software design, milling machine and the milled material itself[7,17].

The physical and mechanical properties of glass-ceramics, lithium silicates or zirconia-reinforced lithium silicates, are characterized by being comparable to the physical and mechanical properties of sound tooth structure. Moreover, these ceramics can be adhesively bonded to tooth structure strongly due to the presence of the glassy phase[2,18]. To date, most of the materials used successfully with endocrown restorations must have these properties, which makes the glass ceramics group on top of the materials indicated with endocrowns[6]. Therefore, the aim of this study is to examine the marginal gap distance and fracture resistance of endocrowns, constructed using two different all-ceramic systems fabricated with two different processing techniques after cyclic loading. Null hypothesis was that the marginal gap distance and the fracture resistance of the endocrowns will not be affected by the ceramic material nor the fabrication technique after cyclic loading.

Materials and Methods

Teeth Selection

A total number of forty mandibular first molars, recently extracted for periodontal reasons, were gathered. The chosen teeth were inspected for lack of caries, restorations, or cracks using light magnification (Stemi DV4 8.0x; Carl Zeiss MicroImaging, Jena, Germany) and radiographed to confirm that they were free from cracks and internal resorption in the roots. The dimensions of the selected teeth were comparable buccolingually and mesiodistally throughout all the samples. The dimensions were measured using digital caliper (0-50 mm, 0.01 mm, Germany). Ultrasonic scaler was used to remove the plaque and calculus from the extracted teeth then disinfected in 0.5% sodium hypochlorite. The disinfected teeth were stored in water for one month until the study started.

Endodontic Process

Conventional root canal treatment was done for all teeth. Access cavity, working length determination through radiograph, cleaning and shaping using crown-down technique and rotary system; rotary contra-angle motor (Dentsply, Sirona, Canada) with Protaper Next (PTN) rotary filing system (Dentsply; Maillefer, Ballaigues, Switzerland) was done by the same operator. Copious irrigation was done in between the steps of the cleaning and shaping using NaOCl (The Clorox Co., Oakland, CA, USA). Afterwards, the final obturation for all the teeth was done using thermoplasticized gutta percha (Calamus Dual, Dentsply Maillefer, Woodinville, WA, USA) and root canal sealer sealer (AH 26 sealer, Dentsply Maillefer) according to manufacturer instructions.

Endocrown Preparation

Decoronation was done for all the endodontically treated teeth, parallel to the occlusal surface, 2 mm above the cemento-enamel junction, to remove occlusal tooth structure replicating massive tooth structure loss using diamond disc and copious water irrigation. The teeth were individually fixed vertically into epoxy resin mounting cylinders (Polypoxy 700, polymer, chemical industries for construction Co., CIC, Egypt). The cemen-to-enamel junction of each tooth is adjusted to be higher than the top of the cylinder by 1 mm. The internal walls of the cavity were prepared to remove any internal undercuts inside the pulp chamber accompanied by an internal coronal divergence of 8-10° using tapered diamond stone with rounded end mounted on standardized milling machine (C.N.C Premium4820, imes-icore, Germany). The internal axial walls were prepared to provide a standardized cavity with wall thickness of 2.0 ± 0.2 mm and this was confirmed by the digital caliper. All the internal line angles were rounded and smoothened using the same bur[7,19].

A thin layer of flowable composite was placed at the depth of the cavity to remove any undercuts in the cavity floor. This layer of flowable composite allowed a smooth cavity floor and ensured the depth of the cavity inside the pulp chamber to be 5.0 ± 0.2 mm depth in all samples (Figure 1). The chemical composition and manufacturers of the materials used in this study are presented in Table I. The prepared teeth were randomly divided into four equal groups (n=10) according to the all-ceramic materials and technique used for endocrown construction as follows:

- Group I (n=10): Pressable lithium disilicate glass ceramics was used for the fabrication of endocrowns (IPS e-max Press);
- Group II (n=10): Pressable zirconia-reinforced lithium disilicate glass ceramics was used for the fabrication of endocrowns (Celtra Press);
- Group III (n=10): Machinable lithium disilicate glass ceramics was used for the fabrication of endocrowns (IPS e-max CAD);
- Group IV (n=10): Machinable zirconia-reinforced lithium disilicate glass ceramics was used for the fabrication of endocrowns (Celtra Duo).

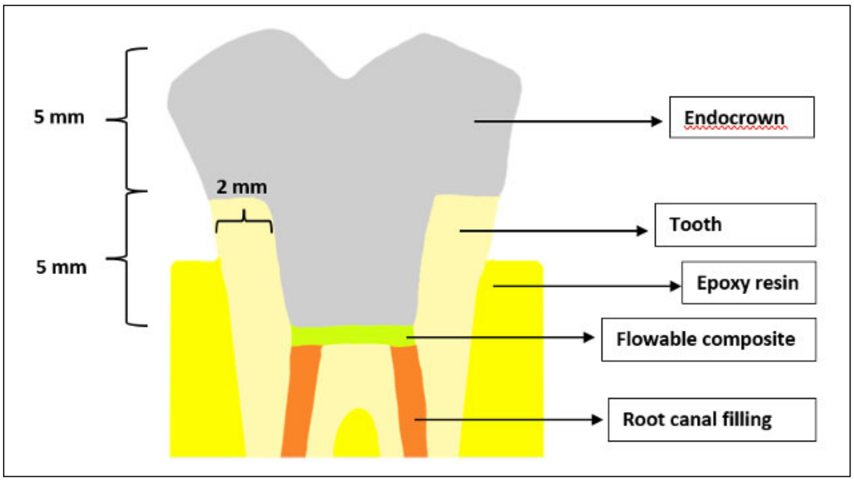

Figure 1. Diagram illustrating the cemented endocrown restoration.

Table I. The chemical composition and manufacturers of the materials used in this study.

Material	Composition	Manufacturer
IPS e-max Press	SiO_2, Li_2O, K_2O, P_2O_5, ZrO_2, ZnO, other oxides and ceramic pigments	Ivoclar Vivadent; Schaan, Liechtenstein
Celtra Press	SiO_2, Li_2O, ZrO_2, P_2O_5, Al_2O_3, K_2O, CeO_2, other oxides and pigments	Dentsply; Konstanz, Germany
Celtra Duo	SiO_2, Li_2O, ZrO_2, P_2O_5, Al_2O_3, K_2O, CeO_2, pigments	Dentsply; Konstanz, Germany
IPS e-max CAD	SiO_2, Li_2O, K_2O, P_2O_5, ZrO_2, ZnO, Al_2O_3, , MgO, pigments	Ivoclar Vivadent; Schaan, Liechtenstein
Variolink II	UDMA, inorganic fillers, ytterbium trifluoride, initiators, stabilizers, pigments	Ivoclar Vivadent; Schaan, Liechtenstein

Endocrown Construction

Teeth assigned for groups III, IV were scanned using Cerec scanner (Cerec Omnicam, Sirona Dental Systems, Bensheim, Germany). Endocrowns were designed using CAD/CAM software (Cerec 3D, version 4.3, Sirona Dental Systems, Bensheim, Germany). All endocrowns were designed with the same occlusal anatomyand occlusogingival height (5 mm) and 50 µm cement thickness for standardization. E-max CAD (Ivoclar Vivadent, Schaan, Liechtenstein) and Celtra Duo (Dentsply, Konstanz, Germany) blocks were used in the CAD/CAM milling machine (Cerec-inLab MC XL, Sirona, Germany) for milling the endocrowns. IPS e-max CAD endocrowns (Group III) were crystallized in Programat furnace (Programat P500, Ivoclar, Vivadent, Schann, Lieichtenstein) at 850° for thirty minutes. The endocrowns of groups III, IV were examined for their fit on each corresponding tooth after milling. Celtra Duo endocrowns (Group IV) were polished using diamond stones and rubber polishers, (Celtra Tw's Tec® Polishing kit, Dentsply, Konstanz, Germany) according to the manufacturer's instructions, at low speed and minimum pressure.

As for IPS e-max press and Celtra press endocrowns, the same scanning procedure was used for the construction of groups III, IV crowns. To ensure standardization, wax patterns were designed and milled using the same parameters of groups III, IV. The CAD/CAM milled wax patterns were sprued and invested in the IPS Press Vest investment material (Ivoclar, Vivadent) for group I and the endocrowns were pressed in e-max pressable ceramic; while in group II, Celtra press investment material (Dentsply, Sirona) and the endocrowns were pressed in Celtra press ceramic. Afterwards, devesting using airborne particle abrasion (50 µm Al_2O_3 at 1 bar, 30 PSI) was done. Finally, the endocrowns were finished using fine diamond discs and grinding instruments according to manufacturer's instructions.

Endocrowns Cementation

The fitting surfaces of the endocrowns were etched using Hydrofluoric acid gel (IPS Ceramic etching gel 5%, Ivoclar Vivadent) for 20 seconds then rinsed and dried. Silane coupling agent (Bisco, USA) was applied for 60 seconds and dried with air. The teeth were etched using 37% phosphoric acid followed by primer for 15 seconds which was then air dried for 10 seconds and finally bonding agent for 10 seconds (Syntac Primer, Ivoclar Vivadent, Schaan, Liechtenstein). The crowns were adhesively cemented using a dual-cure resin cement (Variolink II, Ivoclar Vivadent, Schaan, Liechtenstein) according to manufacturer's instructions. The cemented crowns were loaded with a 3 kg static load on the occlusal surface; removal of excess cement and light-curing was done for 20 seconds from each surface using a light-cure unit (Mini LED, 1,250 mw/cm^2, Satelec, Acteon).

Cyclic Loading

All endocrowns were subjected to fatigue loading. All samples were individually mounted in the lower fixed compartment of a computer-controlled materials testing machine (Model 3345; Instron Industrial Products, Norwood, MA, USA) with a load cell of (5 kN) and data were recorded using computer software (Instron® Bluehill Lite Software). Mechanical aging was performed using a programmable equipment; the newly developed four stations multimodal ROBOTA chewing simulator integrated with thermo-cyclic protocol (Model ACH-09075DC-T, Ad-Tech Technology Co., Ltd., Frankfurt, Germany). The specimens were embedded in Teflon housing in the lower sample holder. A weight of 10 kg, which is comparable to 100 N of chewing force was exerted. The test was repeated 120,000 times to clinically simulate one year chewing condition, according to a previous study[20].

Marginal Gap Distance Measurement

Marginal gap distance of all endocrowns was measured directly using a digital microscope (KH-7700 Hirox Company, Hackensack, NJ, USA) with x100 magnification. For each sample, three equidistant marks were placed on every surface using a small round bur on the tooth 1 mm below the endocrown margin for the standardization of the location of the points of measurements throughout the whole samples. Vertical lines were placed and measured from the outer end of the butt margin of endocrowns to the predetermined equidistant marks with a total of 12 readings for each sample. All readings were arranged, tabulated and statistically analyzed.

Fracture Resistance Testing

All samples were individually mounted on a computer-controlled material testing machine (Model 3345; Instron Industrial Products, Norwood, MA, USA) with a loadcell of 5 kN and data were recorded using computer software (Instron® Bluehill Lite Software). Samples were secured to the lower fixed compartment of testing machine by tightening screws. Fracture test was done by compressive mode of load applied occlusally using a metallic rod with a spherical tip (5.8 mm diameter for crown samples) attached to the upper movable compartment of the testing machine traveling at a cross-head speed of 1 mm/min with tin foil sheet in-between to achieve homogenous stress distribution and minimization of the transmission of local force peaks. The load at failure manifested by an audible crack and was confirmed by a sharp drop at load-deflection curve recorded using computer software (Instron® Bluehill Lite Software).

Statistical Analysis

Data were analyzed and tabulated using statistical analysis software SPSS (v. 28.0, IBM, Armonk, NY, USA). The fracture data were tested for normal distribution using Shapiro-Wilk test. Normal distribution was not found. Kruskall-Wallis' test was used to compare different materials; the Tukey HSD test was used for pair-wise post-hoc comparisons, while the margin data were tested for normal distribution using Shapiro-Wilk test. Normal distribution was found and comparison between the different groups was done using one-way ANOVA test. A *p*-value lower than 0.05 was considered significant.

Results

The results of this study showed that e-max CAD had the highest fracture resistance mean value (1,693.4 N) however, it was not statistically significant with Celtra Duo (1,693.4 N). E-max Press (1,231.1 N) had the lowest fracture resistance mean value though it was not statistically significant with Celtra Press (1,296.2 N). E-max CAD fracture resistance mean value had statistically significant difference with E-max CAD and Celtra Press (Table II, Figure 2). Celtra Duo fracture resistance mean value as well had statistically significant difference compared to E-max CAD and Celtra press.

The results of this study showed that Celtra Duo had the highest marginal gap mean value (60 µm) which was not statistically significant with E-max CAD (54.7 µm). E-max Press had the lowest marginal gap mean value (25.5 µm); however, no statistical significance was found with Celtra Press (31.4 µm). E-max CAD marginal gap mean value had statistically significant difference with E-max CAD and Celtra Press (Table III, Figure 3). Celtra Duo marginal gap mean value, as well, had statistically significant difference with E-max CAD and Celtra Press.

Discussion

Endocrowns are a unique type of minimally invasive restorations used to restore and protect root canal treated teeth without the need for intra-radicular means of retention through post placement. This type of restoration depends mainly on macro retentive features through the extension in-

Table II. The chemical composition and manufacturers of the materials used in this study.

	E-max Press	Celtra Press	E-max CAD	Celtra Duo
Mean of fracture resistance (standard deviation)	1,231.1 (71.9)[a]	1,296.2 (70.8)[a]	1,693.4 (92.1)[b]	1,633.8 (84.5)[b]

Rows with different letters indicate a statistically significant difference. [a]$p \leq 0.05$; [b]$p \leq 0.001$.

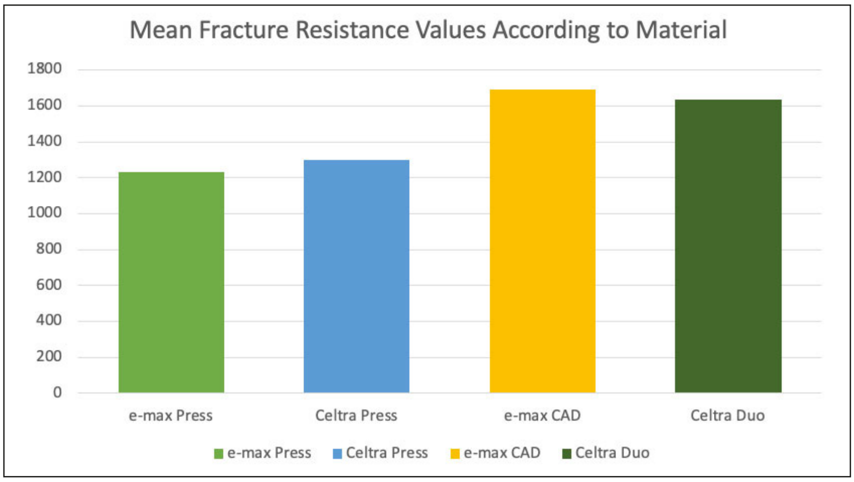

Figure 2. Bar chart representing mean fracture resistance values according to materials.

Table III. Means (standard deviations) of marginal gap according to the material used.

	E-max Press	Celtra Press	E-max CAD	Celtra Duo
Mean of marginal gap (standard deviation)	25.5 (7.04)[a]	31.4 (5.89)[a]	54.7 (5.79)[b]	60 (8.23)[b]

Rows with different letters indicate a statistically significant difference. [a]$p \leq 0.05$; [b]$p \leq 0.001$.

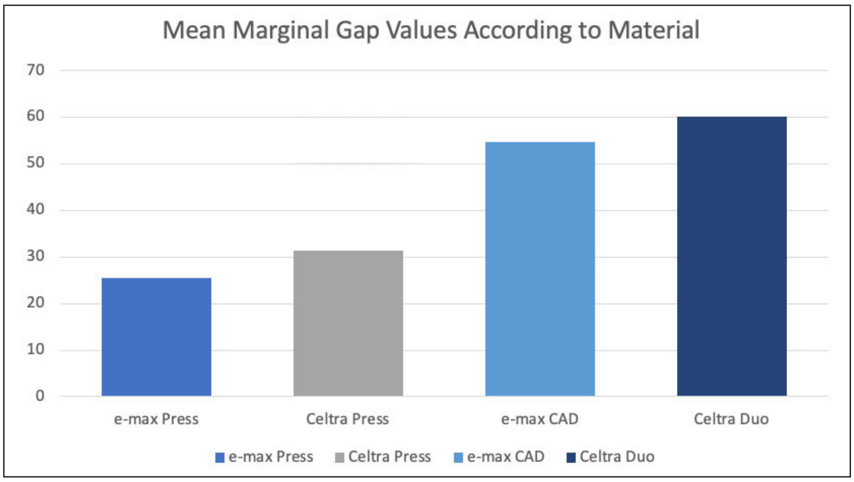

Figure 3. Bar chart representing mean marginal gap values according to the material.

side pulp chamber as well as the micromechanical retention obtained by adhesive bonding[19]. The endocrowns are characterized by the preservation of the maximum amount of sound tooth structure in addition to the advantage obtained by the recent technologies in ceramic materials and their techniques besides the recent bonding systems[3]. Glass ceramics group of materials including lithium disilicate ceramics and its innovative zirconia reinforced lithium silicate modification have gained a great acceptance due to their high fracture resistance and excellent esthetic properties making them very strong substitute in many clinical situations[21,22]. Not only the CAD/CAM technology, but also the heat pressing technique has been used for the construction of this class of ceramics with the benefits of decreased porosity, enhanced flexural strength and outstanding marginal fit[23]. Thus, the selection of the suitable fabrication technique with the correct material is a prerequisite for obtaining a durable successful endocrown restoration[24,25]. After the analysis of the results, the suggested hypotheses of this study were partially rejected as the type of the material significantly affected the marginal gap distance and fracture resistance of the endocrown restoration, however the technique of construction did not.

Recently extracted human molars were used in this study to simulate the clinical situation regarding the bonding properties of the enamel and the dentin with the adhesive resin cement and the ceramic materials, in addition to resembling the elastic modulus of the hard dental tissues and force dissipation on the whole complex as if it is a real clinical situation[17,19]. However, the human teeth might have caused some degree of variability in the results due to complexity in standardization, although the preparation of the teeth was done using the milling machine[26].

Fatigue loading was applied to all samples in this study to examine restoration performance under clinically mimicking situations. Repeated stresses happening during clinical performance may result in subcritical crack growth within brittle ceramics which will affect the mechanical behavior as well as the marginal accuracy[27]. A properly fit margin of a restoration is crucial to avoid cement dissolution and plaque accumulation which will result in caries and subsequent failure of the restoration[10].

The results of the current study revealed that the machinable ceramics had statistically significantly higher mean marginal gap distance values than pressable groups. Marginal fractures of the restoration might have occurred due to the pressure exerted from the milling instrument and the material resistance. This is very familiar with brittle ceramics. A previous study[28] reported that the glass matrix is brittle and ceramic crystallites may be easily disrupted if the pressure of the milling instrument is applied. However, the heat press technology allows efficient compressibility and flowability of the material during pressing, especially with smaller crystals Celtra press material[29]. Non-significant statistical difference in marginal gap distance values was found between IPS E-max CAD and Celtra Duo ceramics. This was consistent with a previous study[10]. The results of the marginal gap distance for all groups are within the clinically acceptable range of 120 µm[17,30].

No statistically significant difference was found between mean fracture resistance values of IPS E-max CAD endocrowns and Celtra Duo endocrowns. Both of them revealed the highest mean fracture resistance. Similar results were obtained by previous studies[31] upon examination of the same two materials. Studies[10,31] explained the enhanced fracture resistance through the mechanism of strengthening this class of ceramics by the incorporation of fine highly interlocking lithium disilicate crystals as a crystalline content embedded in the glassy matrix after crystallization in addition to the controlled grain size growth which aids in the enhancement of the flexural strength. Moreover, other studies[32-34] attributed the increased flexural strength of the E-max CAD to the crack deflection, with following opposition to crack propagation after tangential compressive stresses introduction. Conversely, it was expected that Celtra Duo would have given higher fracture strength values than E-max CAD due to the addition of zirconia which might aid in the improvement of the strength; however, this was not the case[10,35,36]. On the contrary to this study, a previous study[30] revealed higher flexural strength values of IPS E-max CAD upon its comparison with Celtra Duo. Similarly, the same results were also obtained with the heat press technique where there was no statistically significant difference between E-max Press endocrowns and Celtra Press endocrowns fracture resistance values. This was consistent with previous study[37] where the authors stated that there was an increase in viscosity of the Celtra Press material during heat pressing due to the addition of zirconia and subsequent decrease in crystal growth with no increase in strength values.

Conclusions

In the current study, the fracture resistance values of CAD/CAM endocrowns had statistically significant higher mean values than the pressable endocrowns regarding both materials. This may be due to the technique of fabrication of all-ceramic endocrown which might have changed the mechanical properties of the material with subsequent alteration in its microstructure[23]. Further investigations are needed to examine the fracture resistance and marginal fit of other types of ceramics as endocrown restoration with different preparation designs and different cementation protocols. After considering the limitation of the current study, the subsequent conclusions were given: endocrowns are considered one of the promising minimally invasive restorations for root canal treated molars; CAD/CAM technology revealed better results than heat press technology regarding the fracture resistance of glass ceramics; heat Press technology revealed better results than CAD/CAM technology regarding the marginal accuracy of glass ceramics.

Ethics Approval
Ethical approval was obtained from IEC of Oral and Maxillofacial Surgery and Rehabilitation Department, Faculty of Dental Medicine, Umm Al-Qura University, Saudi Arabia.

Informed Consent
Not applicable.

Availability of Data and Materials
All data are provided in this study and raw data can be requested to corresponding author.

Conflict of Interests
Authors do not have anything to disclose and declare not conflict of interests.

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No financial support was obtained for this research.

Authors' Contributions
SMES, ZNE and KAE: concepts, design, data analysis, statistical analysis, manuscript preparation, manuscript review, guarantor.
MAN, AZZ, HAE, EMA, HAF and HMRS: definition of intellectual content, literature search, experimental studies, data acquisition, manuscript editing.

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