IN-VITRO EVALUATION OF MARGINAL ACCURACY AND FRACTURE RESISTANCE OF MANDIBULAR PREMOLAR ENDOCROWNS MADE OF TWO MONOLITHIC CERAMIC MATERIALS.

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ABSTRACT

Aim: The purpose of this study was to compare the marginal accuracy and fracture resistance of endodontically treated mandibular premolars restored with endocrowns using two different monolithic CAD/CAM ceramic materials.

Materials and Methods: Twenty freshly extracted human mandibular premolars were sectioned coronally and were prepared for endocrown restorations. The teeth samples were randomly assigned two groups (n =10): (LD) lithium disilicate (IPS E-max CAD) and (SH) resin hybrid ceramic (SHOFU Block HC). The CEREC AC system was used to create CAD/CAM endocrown restorations. With dual cured adhesive resin cement, endocrowns were cemented to their corresponding tooth samples. After cementation, marginal gaps were measured using a stereomicroscope, and fracture resistance for each sample was tested using a universal testing machine. Each endocrown sample's mode of failure was assessed. Data was recorded using computer software and statistically evaluated using the student t-test and the Chi square test.

Results: There were no statistically significant differences in margin adaptation across the tested groups, although the E-.max CAD (LD) group had a statistically significant higher fracture resistance mean value (1022.83±127.68 N) than the Shofu HC (SH) group (659.50±110.79 N). LD group showed catastrophic fracture, while 50% of SH composite hybrid ceramic samples showed favorable fracture.

Conclusions: Even though that LD endocrowns had higher fracture resistance than SH endocrowns, the mode of Shofu HC Hybrid ceramic material was more favorable than LD.

Clinical significance: The mechanical performance of dental ceramic materials depends greatly on their microstructure and mechanical characteristics. As a result, more research towards the biomechanical behaviors of new materials when employed as endocrowns is always required prior to clinical investigations.

KEYWORDS: Endodontically treated teeth, Composite-hybrid ceramic, lithium disilicate glass-ceramic, endocrowns, marginal Accuracy, fracture resistance.

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Introduction

Rehabilitation of endodontically treated teeth with significant destruction of the coronal portion is a clinical problem due to loss of tooth strength characteristics. The extra removal of sound natural tissue required for adapting the post into the root canal is one major drawback of interradicular posts. Other procedures to restoration, such as endocrown restorations, have also been proposed [1-4].

Endocrown restoration is a monoblock restoration that unites the interradicular post, core, and crown into a single component. Unlike traditional techniques that use interradicular post and core, endocrown restorations are retained in the pulp chamber and bonded onto the margins of the cavity, resulting in both micro- and macro-mechanical retention provided by the adhesive cementation and the pulpal wall surfaces. Furthermore, endocrowns have the benefit of requiring less removal of sound tooth structure and requiring significantly less clinical time than other methods [1, 5, 6].

The material used for fabrication of endocrown may affect the performance of the restoration. A wide variety of ceramic materials are available on the market and manufactured using the CAD/CAM technique, ranging from low-strength feldspathic ceramic and Lucite glass ceramic to high-strength lithium disilicate glass ceramic and zirconium oxide [7-9].

E-max CAD is a monolithic lithium disilicate glass-ceramic restoration that is both aesthetically pleasing and biocompatible. It also possesses outstanding mechanical qualities, including high flexural strength and elastic modulus. It is stiff, hard, and brittle, though, which may limit its durability and machinability [10].

A resin nanoceramic for permeating CAD/CAM restoration was recently introduced. Changes in manufacturing methods, such as high temperature and/or high-pressure new polymerization modes, and structure (glass ceramic networks), have recently resulted in CAD/CAM hybrid ceramic materials with improved physical and mechanical characteristics. Due to their lower hardness and stiffness than monolithic ceramics, CAD/CAM hybrid ceramics reduce wear on the opposing tooth structure clinically. They are also less brittle than ceramics, making them easier to mill and fabricate with less chipping and higher marginal quality. Resin hybrid ceramic CAD/CAM blocks have mechanical properties that are more similar to those of human dentin. The manufacturer claims that Shofu Block HC as a CAD/CAM composite hybrid ceramic material provides high esthetic results, fast milling and polishing, and high flexural strength together with high elasticity which allows stress absorption [11-13].

Marginal accuracy, which is measured as the distance between the finish line and the restoration margin, is an important criterion influencing the ceramic restoration's long-term prognosis. If there is a significant marginal space between the tooth finish line and the restoration margin, the luting cement material will be exposed to the oral environment, resulting in disintegration and subsequent microleakage, which will cause periodontal tissue irritation, secondary caries, and, eventually, prosthetic failure (14, 15).

The impact of various ceramic materials on the marginal accuracy and fracture resistance of endodontically treated mandibular premolar endocrowns has not yet been fully demonstrated. The current study compares the marginal accuracy and fracture resistance of endodontically treated mandibular premolars restored with endocrowns fabricated of two different types of CAD/CAM ceramic materials in vitro. The endocrown restorations made from the different examined groups did not differ from one another in terms of marginal accuracy or fracture resistance, which was the null hypothesis tested.

Materials and Methods

This study has been registered and exempted by Institutional Review Board Organization IORG0010868, Faculty of Oral & Dental Medicine, Ahram Canadian University. Research Number: IRB00012891 #15.

The CAD/CAM ceramic materials used in construction of endocrowns, manufacturers, types, and their compositions are presented in Table (1).

Table (1): The CAD/CAM ceramic materials used in fabrication of endocrowns

Material	Manufacturer	Type	Composition
IPS E.max CAD (L.D)	Ivoclar Vivadent Inc., New York, USA	Lithium disilicate glass ceramic	About 97% wt. SiO_2, AL_2O_3, K2O, Li_2O, ZrO_2, P_2O_5, ZnO, Others and coloring oxides.
Shofu Block HC (SH)	Dental GmbH, Ratingen, Germany	Hybrid ceramic	Made of zirconium silicate (61%) is embedded in a high temperature/high pressure polymer matrix, creates a skeleton.

Sample selection:

The study included twenty caries-free freshly extracted human mandibular premolars. Immediately after extraction. All teeth were ultrasonically cleaned to remove external debris before being stored at room temperature in distilled water with 0.1 percent thymol disinfectant (Caelo, Hilden, Germany) until they were required. The criteria for inclusion were complete root formation, one radiographically visible root canal, absence of carious lesions, absence of cracks or visible root fractures, and similar dimensions at the cemento-enamel junction (CEJ) with maximum deviation of 10% in dimension.

The measurements of the teeth were evaluated using a caliber, and the average values were taken at the CEJ (15 ± 1.0 mm length of the root, 8 ± 1.0 mm Bucco-lingual, and mesio-distal 5 ± 0.05 mm).

To ensure procedure standardization, all specimen preparation, endodontic procedure, and endocrown preparation steps for each premolar were completed by the same operator in the exact same order.

Endodontic procedure

Each tooth was cut 2 mm above the CEJ using a low-speed diamond disc with a water-cooled. The root canal preparation was done using the Protaper system (Dentsply-Maillefer; Ballaigues, Switzerland) and an electric motor (X-Smart Dentsply Maillefer; Ballaigues, Switzerland). F2 files were chosen as the master files for Canal. Between each file, 2.5% sodium hypochlorite was sprayed on for 10 seconds. Obturation was performed using a gutta-percha cone (DiaDent Group International, Seocho-dong, South Korea) with lateral condensation technique and a resin-based sealer (Adseal, Metabiomed, Korea). All excess gutta-percha was removed from the pulp chamber and 1 mm below the orifice of each canal with a carbide diamond bur. The canals were then filled to the pulp chamber level with a flowable resin composite (Filtek Z350XT flowable, 3M ESPE, St Paul, MN, USA). Each tooth's access cavity was filled with a temporary filling, and all teeth were maintained in distilled water at 37°C for 24 hours.

Specimen mounting and periodontal simulation.

To create a 0.2-0.4 mm thickness for artificial periodontal ligament around the teeth, the root of each premolar was dipped in molten wax 2 mm apical to the CEJ to simulate bone level.[16] The thin layer of wax was created to replicates the average thickness of periodontal ligaments. Each tooth was placed into a plastic mold filled with auto-polymerization resin (Acrostone; Acrostone dental plant, Industrial Zone, Cairo, Egypt) until the apical to CEJ was 2 mm. After the starting of polymerization occurred, the sample was taken from the resin, and the wax spacer was removed with hot water. After injecting the light body impression material (Speedex, Coltene whaledent, Switzerland) into the acrylic socket, the tooth was reinserted. As a result, a uniform silicon layer to replicate the periodontal ligament was developed [17-19].

Teeth Preparation for endocrowns

After sectioning of the coronal part to establish a circular butt joint margin in agreement with Abdel-Aziz et al; Lise et al [19, 20], all teeth were prepared for endocrown restorations. After the temporary restorations were removed, a flat end tapered diamond stone placed on a high-speed handpiece was used to construct a standardized central retention cavity that reaches 5mm deep into the pulp chamber and with 8° divergent axial walls to facilitate the removal of any axial undercuts. In the pulp chamber, a central retention inlay-type cavity with an anti-rotational oval form and a depth of 5 mm from the Cavo-surface edge, a 2-mm mesial-distal space, and buccal-lingual width 4.5-mm at the top was produced. The internal Cavo-surface angle was rounded.

Samples grouping:

The twenty tooth samples were divided into two groups at random, (n = 10) and given endocrowns constructed from two types of CAD/CAM ceramic materials operated in endocrown production, lithium disilicate (IPS E-max CAD) and resin hybrid ceramic (SHOFU Block HC).

Endocrowns fabrication:

To fabricate CAD/CAM endocrown restorations, a CEREC AC system with Omnicam (Dentsply Sirona GmbH, Bensheim, Germany) was used. All the prepared teeth were scanned with an Omnicam intraoral scanner. The endocrown restorations were designed using the CEREC 3D software (version 4.2, Sirona Dental Systems GmbH, Bensheim, Germany). The bio-generic reference feature in CEREC software was used to ensure a standardized restoration design with similar occlusal surface anatomy and occluso-gingival height for all endocrown restorations (Figure 1). The MCXL 4-axis wet milling and grinding machine (Dentsply Sirona, Bensheim, Germany) was used to mill all the restorations. Sprues were cut and finished with diamond finishing stones after milling was completed. The 10 milled specimens in the LD (E-Max CAD) group were crystallized and glazed in a Programat P310 ceramic furnace (Ivoclar Vivadent Inc., New York, USA) according to the manufacturer's crystallization and glazing parameters. The 10 milled specimens in the SH group were finished and polished according to manufacturer instructions using the Cera-Master Kit (SHOFU Dental GmbH, Ratingen, Germany). Finally, the digital caliper was used to check and verify the occlusal and intracoronal thicknesses of all specimens.

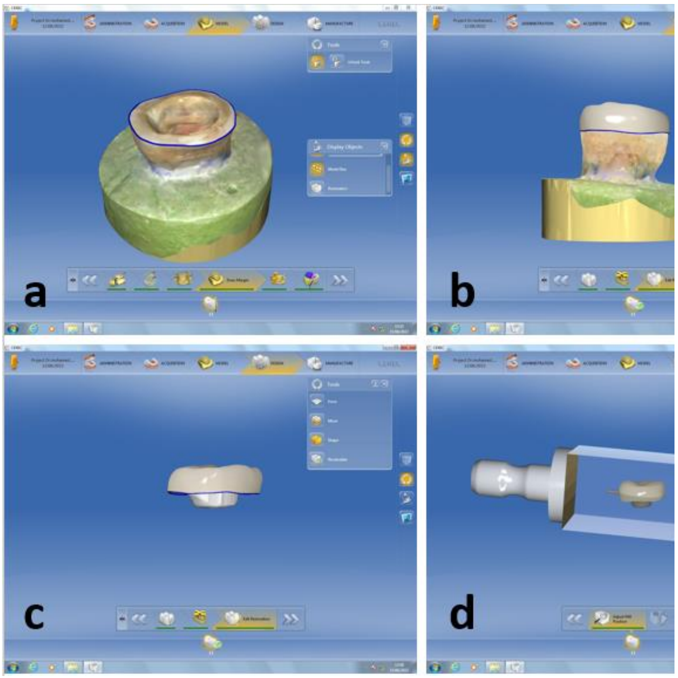


Figure (1): Fabrication of CAD/CAM endocrown restorations using CEREC AC system; a) Scanning the preparation, b &c) Designing endocrown restoration using the CEREC 3D software, d) Manufacturing the restoration.

Bonding of endocrown samples:

All endocrown restorations were cleaned for 3 minutes in an ultrasonic cleaner. The intaglio surface of each IPS E.max CAD (LD) restoration was etched for 60 seconds with 9.5% hydrofluoric acid gel (Porcelain Etchant 9.5%, BISCO, USA), then thoroughly cleaned and dried using oil-free compressed air. Prior to cementation, a silane coupling agent (BISCO-USA Porcelain Primer Bis-silane) was used for 1 minute and then air dried.

The intaglio surface resin of hybrid ceramic (SHOFU Block HC) was etched for 30 seconds with 9.5% hydrofluoric acid gel, cleaned, and air dried before applying a specific primer (HC Primer, SHOFU Dental, Ratingen, Germany) and leaving for 30 seconds before being air dried. All prepared tooth surfaces were etched for 30 seconds using 37% phosphoric acid etchant gel (Etch-37TM, BISCO-USA), rinsed, and air dried. Using a micro brush, the surfaces were then coated with two layers of bonding agent (All-Bond Universal, BISCO-USA), thinned with an air syringe, and light cured for 20 seconds.

All endocrowns were cemented to their corresponding tooth samples using a 5 kg load applied vertically by a specifically constructed loading mechanism and dual-cured adhesive resin cement (Breeze, USA, dual-cure resin cement). The extra cement was removed after spot curing using a light curing device, and each surface was light cured for 40 seconds. All specimens were kept in distilled water at 37°C for 24 hours prior to testing.

Marginal gap assessment:

Following cementation, the cervical vertical marginal discrepancies were measured. A USB digital microscope with a built-in camera (Scope Capture Digital Microscope, Guangdong, China) connected to an IBM compatible computer was used to acquire four stereomicrographs of each specimen at a fixed magnification of X30. The photographs were then transmitted to a computer system to be analyzed.

The vertical discrepancies between the cervical edge of the endocrown restoration and the outer end of the butt margin were measured using image analysis software (Image J 1.43U, National Institutes of Health, USA) in each stereomicrograph at five uniformly spaced points on each surface of the specimen (Distal, Mesial, Lingual, and Buccal).

Each measurement point was measured five times. As a result, measurements were taken at 20 places on each endocrown (Figure 2). The data was calculated and statistically analyzed. For each specimen the mean vertical gap was calculated in (μm) [14, 21].

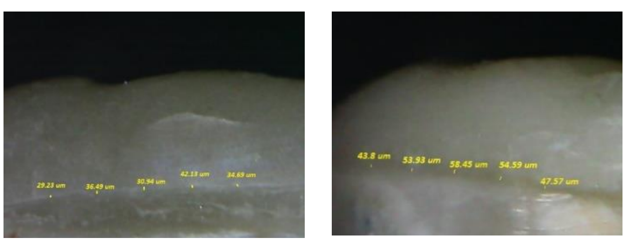


Figure (2):

A-Representative microscopic image for L.D sample showing 5 measurement points.

B- Representative microscopic image for SH sample showing 5 measurement points.

Fracture resistance test:

All samples were mounted separately on a computer-controlled testing machine equipped with a 5 kN load cell (Model 3345; Instron Industrial Products, Norwood, MA, USA), and data were collected using software (Instron® Bluehill Lite Software).

Tightening screws secured the samples to the testing equipment's lowest fixed compartment. The fracture test was carried out as described published studies [7, 21] (Figure 3).

The load at failure was indicated by an audible crack and confirmed by a sharp decrease in the load-deflection curve as represented by computer software. The fracture load was measured and calculated in Newtons .

Figure (3): Fracture resistance test of a sample using Instron testing machine.

Failure mode:

The mode of failure for each endocrown sample was seen and evaluated based on the following two modes of failure:

a) Repairable fracture: (fracture of endocrown restoration and/or tooth above the cemento-enamel junction).
b) Catastrophic fracture: (fracture of endocrown restoration and tooth below the cemento-enamel junction).

Statistical analysis:

Data were reported as mean, standard deviation (SD), and range (Minimum-Maximum) for values. The data was checked for normality using the data distribution and the Kolmogorov-Smirnov and Shapiro-Wilk tests. To compare mean values, the student t-test was utilized. The significance level was set at P ≤ 0.05 and the 95% confidence interval was established at 95%. A Chi square test was used to compare failure modes. Graph Pad Instat (Graph Pad, Inc.) programme for Windows was used for statistical analysis.

<u>Results</u>

Marginal gap:

The mean ±SD value of the marginal gap was reported for the E.max CAD (L.D) group (29.097 ± 3.785 m), whereas the mean ± SD value for the Shofu Block HC (SH) group was (34.699 ± 5.657 m). The t-test revealed that the difference in marginal gap mean value between the two groups was statistically insignificant (t=2.18, P=0.0501 > 0.05). as shown in in table (2) and figure (4).

Table (2): Comparison of marginal gap test results (Mean ±SD) between both material groups:

Variables		*Mean*	*SD*	*95% CI*		*Range*	
				Lower	*Upper*	*Mini.*	*Maxi.*
Material group	*L.D*	29.097	3.785	26.293	31.900	17.45	36.834
	SH	34.699	5.657	30.509	38.891	24.85	54.594
t-test	*t-value*	2.18					
	P value	0.0501 ns					

*; significant ($p < 0.05$) ns; non-significant (p>0.05)

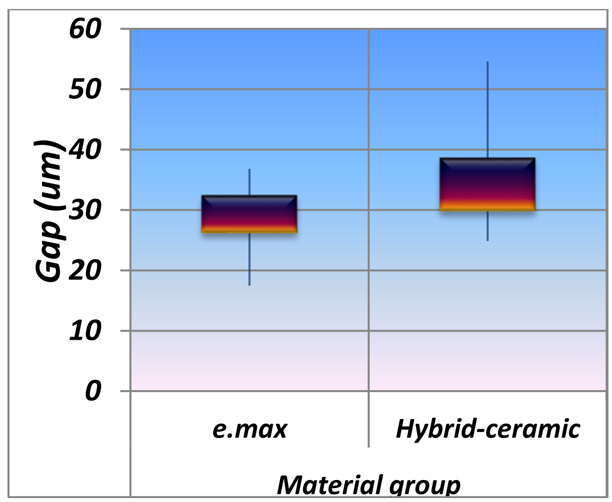


Figure (4): Box plot showing the mean values of marginal gap for both groups

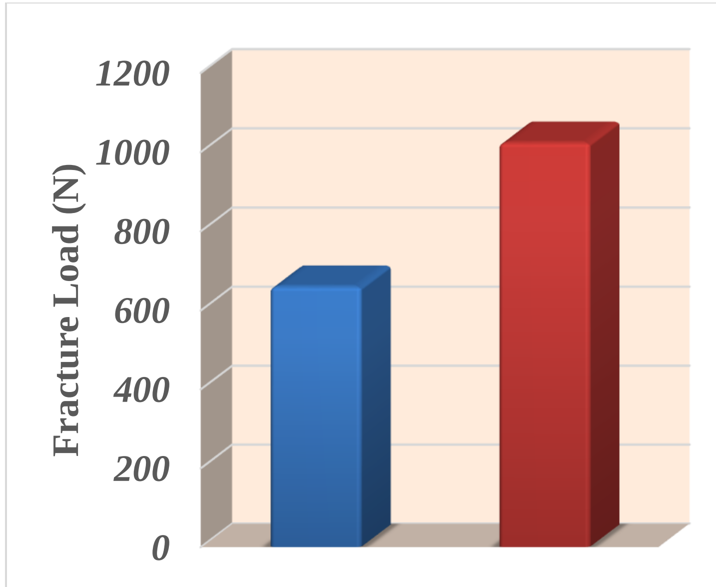
Fracture resistance test:

Table (3) summarizes the description statistics for fracture resistance test results measured in Newton (N) (mean values and standard deviations) as a function of ceramic material groups, which are graphed in figure (5). The mean ± SD values of fracture resistance for Shofu Block HC (SH) were (659.50 ± 110.79 N), while the mean SD value for IPS E.max CAD (LD) was (1022.83 ± 127.68 N). According to the t-test (t=6.8, P=<0.0001 < 0.05), the E.max CAD (L.D) group had a statistically significant higher fracture resistance mean value than the Shofu HC (SH).

Table (3): Comparison of fracture resistance test results (Mean ±SD) between both material groups:

Variables		*Mean*	*SD*	*Range*		*t-test*	
				Mini.	*Maxi.*	*t-value*	*P value*
Material group	*SH*	659.50	110.79	468.31	824.2	6.8	<0.0001*
	L.D	1022.83	127.68	833.5	1215.4		

*; significant ($p < 0.05$) ns; non-significant (p>0.05)



SH Group LD Group
Endocrown ceramic material

Figure (5): Column charts displaying the mean fracture resistance values for both endocrown ceramic material groups.

Failure mode:

The chi square test found a statistically significant difference in the failure modes of the different groups (P<0.05), as shown in table (4) and graphically drawn in figure (6). LD e-max CAD group showed catastrophic fracture as the fracture occurred below CEJ, while 50% of SH composite hybrid ceramic samples showed favorable fracture (above CEJ) and can be repaired.

Table (4) Failure modes frequency distribution (%) For both groups.

Variable		Failure Mode		Chi square test	
		Repairable	Catastrophic		
Material group	LD	0	100	Chi	P value
	SH	50	50	66.67	0.0001*

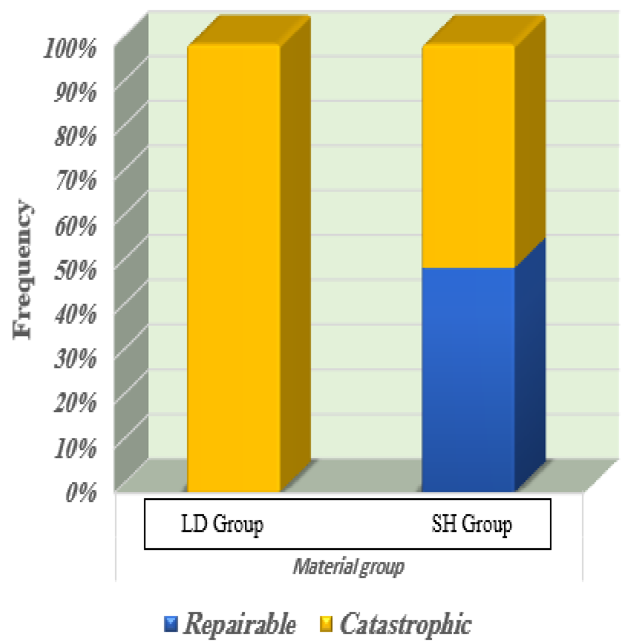


Figure (6) Schematic drawing of different categories of failure modes recorded for both groups.

Discussion

According to some clinicians, ceramic endocrown restorations are a better restorative option for endodontically treated posterior teeth than post-and-core and conventional crowns. Because it is made of ceramic, it can preserve residual tooth structure and produce a more cosmetic result while eliminating the need for macro-retentive geometry. Many studies on endocrown restoration have recently been conducted. It's being considered as a restorative possible treatment option for severely destructed posterior endodontically treated molars[14, 21, 22]. Many clinicians proposed the concept of endocrown restorations as a restoration for endodontically treated premolars [21, 23].

Bindl and Mörmann [9] discovered that premolars had more failures than molars after endocrown restoration. They attributed this to premolars' lower surface area for adhesion in comparison to molars. Furthermore, premolars have a higher crown height, which impairs the endocrown's mechanical qualities under occlusal stresses. According to recent researches, the endocrown is a conservative, attractive, and clinically feasible restorative option for endodontically treated premolars[14, 23, 24].

In the current study, extracted human teeth were used because they resembled clinical conditions in terms of bonding to natural tooth structure (enamel and dentin), strength, the pulp chamber’s contours, and the elastic modulus of hard dental tissue, which was used to simulate the distribution of forces on the radicular portion of the tooth structure [21].

The severe damage of an endodontically treated tooth may limit the availability of a ferrule in some clinical situations. Premolars were rebuilt with endocrowns with butt joint in this study to mimic restorative techniques for severely damaged teeth.

In this study, Shofu Block HC material was selected as a new type of CAD/CAM material that relates the benefits of both ceramic and composite materials. Also, IPS e-max CAD lithium disilicate ceramic was chosen for comparison, as this material was used in most in-vitro studies for endocrown fabrications [21]. Shofu HC is a CAD/CAM composite hybrid ceramic which is high temperature polymerized. This high temperature treatment is used to decrease polymerization shrinkage of the material and delivers modulus of elasticity close to that of dentine which result in reducing brittleness and stresses compared to the stiff lithium disilicate ceramics [25, 26].

To minimize errors, all measurements in this study were made by the same person using a stereomicroscope for direct viewing and external measurements. The technique of measuring marginal gap employed in this study has the benefit of not requiring any invasive procedures. The method only measures the distance externally—not internally—between endocrown and tooth, which reduces the possibility of error accumulation from multiple procedures and ultimately has an effect on the accuracy of results, making it less expensive and time-consuming than other techniques [14, 21, 25].

According to the t-test, there were no statistically significant differences in marginal accuracy between the Shofu HC and IPS E.max CAD (LD) groups ($p > 0.05$). The null hypothesis was therefore accepted partially. The marginal discrepancy values were obtained to be within clinically acceptable limits in both groups, where they were less than 120µm, as reported by several studies [14, 21, 25, 26] . This might be explained that the shofu ceramic material is milled in its final form without the need of crystallization processing step, which results in no dimensional changes. Furthermore, the manufacturer believes that the material's unique polymer component might result in the ideal fit of restorations [14, 21]. Moreover, the butt margin design used in our study provides a configuration that is free of complexity and thin margins, resulting in precise seating and adaptation of all endocrowns while minimizing vertical marginal gaps. As well, the butt joint tooth/restoration interface of the endocrowns facilitates an improved bonding mechanism between the tooth structure and resin cement. Also, it increases the bulk of the ceramics at the margins [14, 21, 26]. The results of the present study are in agreement with Taha et. Al. [14] who demonstrated after cementation, the difference in marginal gap values of molar endocrowns fabricated of different glass ceramics and hybrid ceramic materials was statistically insignificant.

Also, Hasanzade et. Al. [26] stated that in their study, neither the restoration type (crown or endocrown) nor the material (IPS E.max CAD, VITA Suprinity and VITA Enamic) has a significant effect on marginal adaptation.

On the other hand, Elsharkawy A. [21] demonstrated that the E. Max CAD premolar endocrowns group had statistically higher vertical marginal gap mean values than the Brillient crios group, ($p<0.05$). She claimed that post-milling crystallization was required for lithium disilicate to achieve supreme aesthetic and mechanical properties. which may result in 0.2 % -0.3 % shrinkage of lithium disilicate restorations following crystallization firing, resulting in an increase in the marginal gap.

The results of this study showed that Shofu HC (SH) endocrown group recorded statistically significant lower fracture resistance than IPS E.max CAD (LD) endocrown group. As a result, the null hypothesis was partially rejected. This finding agreed with the findings of Altier et al.[27] who concluded that endocrowns constructed from lithium disilicate ceramic had higher fracture resistance than that constructed from indirect composite. They explained that lithium disilicate ceramic provides adequate mechanical strength.

On the contrary, endocrowns restored with resin hybrid ceramics had a statistically significant greater mean value fracture load than those restored with lithium silicate glass ceramic, according to Al-shibri et al. [7]. They attributed this to the resin hybrid ceramic restoration's excellent bonding strength to the tooth structure and its stress absorption qualities.

The mode of failure for each group was also examined in the current investigation. The results indicated that the failure modes recorded for composite hybrid ceramic (SH) endocrowns were more favorable compared with lithium disilicate glass ceramic (LD) endocrowns. The reason may be that composite hybrid ceramic restoration is susceptible to deformation before fracture, which permits stress distribution on the restored tooth and has a properties of stress absorbing [28]. In contrast, lithium disilicate ceramic materials are stiff materials that cause stress concentrations in dangerous areas, that can lead to catastrophic failure [27]. Under axial loading, the mean fracture strengths of the two groups were greater than the mean fracture strengths of human masticatory forces in the molar regions (600-900 N) [28,29]. Axial loading can be used to approximate occlusal stresses, where the modulus of elasticity and thickness of the restorative material are important factors in the material's lifetime.

Conclusions

Within the limits of this investigation, it is possible to conclude that:

- Premolar endocrowns constructed from Shofu HC Hybrid and E.max CAD/CAM ceramic materials exhibit comparable marginal accuracy.
- Endocrowns produced from lithium disilicate E.max CAD glass ceramic had stronger fracture resistance than those manufactured from Shofu HC resin-hybrid ceramic.
- The fracture failure mode of Shofu HC Hybrid CAD/CAM ceramic material was preferable when compared to lithium disilicate glass ceramic (LD) endocrowns.

Clinical significance: The mechanical performance of dental ceramic materials depends greatly on their microstructure and mechanical characteristics. As a result, more research into the biomechanical behaviors of new materials when employed as endocrowns is always required prior to clinical investigations.

Author contribution Abdel Aziz M. contributed to the study's conception and design, supervision, visualization and evaluation of the results, study administration, and writing (review and editing). R. Salem contributed to the study's conception and design, as well as, Methodology, investigations, data collection, and manuscript writing.

Conflict of interests: None of the authors had any potential conflicts of interest.

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