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Effect of conventional and digital fabrication techniques on marginal and internal fit of lithium disilicate endocrowns

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Abstract

Background This study aims to compare the marginal and internal fit of lithium disilicate endocrowns produced by conventional and/or digital impression and fabrication techniques.

Methods Endocrown preparations were performed on 40 mandibular first molars. The teeth were divided into four groups ($n = 10$) based on the impression and fabrication technique; CON: conventional impression/manuel wax patterns/heat-pressed endocrowns, DCD: digital impression/CAD-CAM milled wax patterns/heat-pressed endocrowns, D3D: digital impression/3D printed resin patterns/heat-pressed endocrowns, DC: digital impression/digital design/CAD-CAM milled endocrowns. The marginal and internal fits of the endocrowns were measured by using the silicon replica technique and stereomicroscope with 57x magnification. The statistical analysis was carried out using the Kruskal-Wallis and paired two-sample t-tests. The significance level was set at $p < 0.05$.

Results Marginal fit measurements revealed the following; CON: 111 µm, DCD: 96 µm, D3D: 91 µm, and DC: 93 µm. A statistically significant difference was found between the CON group and the other groups in the marginal fit measurement. Internal fit measurements revealed the following; CON: 120.75 µm, DCD: 112 µm, D3D: 114.88 µm, and DC: 122 µm. There was a statistically significant difference between the CON group and the DCD group in the internal fit measurement, while no significant difference observed between the other groups.

Conclusions It is concluded that all endocrowns had a clinically acceptable marginal and internal fit. The use of digitally generated patterns, CAD-CAM milled or 3D printed, in the fabrication of endocrowns can be effective in producing restorations with improved marginal and internal adaptation.

Clinical relevance The use of digital production methods can improve the marginal and internal adaptation of endocrown restorations.

Keywords 3D printing, CAD-CAM, Digital manufacturing, Endocrown, Internal fit, Marginal fit

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Background

With the developments in adhesive dentistry, endocrown restorations have begun to be applied as an alternative to post-cores used in the traditional restoration of endodontically treated teeth. Endocrowns were described by Bindl and Mormann in 1999 as adhesive endodontic crowns for the restoration of endodontically treated posterior teeth with coronal hard tissue loss [1]. In the restoration of endodontically treated teeth with coronal destruction, the application of endocrowns, which are in a monobloc structure that combines intraradicular post, core, and crown in one piece, is the most up-to-date treatment approach [2]. These restorations receive support from the pulp chamber and cavity wall. Macromechanical retention is provided from the pulpal walls, while micromechanical retention is provided by adhesive cementation [3]. The advantages of endocrowns are as follows: ease of production, preservation of intact tooth structure during preparation, application to teeth with short, calcified, obstructed canals, no risk of perforation and fracture in the intracanal of the tooth, and application in patients with insufficient occlusal distance [2, 4, 5].

Due to their high aesthetic and mechanical properties, feldspathic ceramics, resin matrix ceramics, leucite-based ceramics, lithium disilicate, and derivates are preferred in the construction of endocrowns [6]. Studies have shown that lithium disilicate is one of the best restorative material for the fabrication of endocrowns, and the use of reinforced ceramics positively affects endocrowns performance [5, 7–9]. Heat-press or CAD-CAM (Computer Aided Design-Computer Aided Manufacturing) techniques are used in the production of lithium disilicate glass ceramic endocrowns [10]. The CAD-CAM technique is based on milling restorations directly from blocks. The heat-press technique is based on obtaining wax patterns by laboratory technicians, burn-out, and obtaining restorations from ceramic ingots with pressure [9]. Subtractive milling with CAD-CAM systems or additive manufacturing with rapid prototyping are other methods for obtaining restoration patterns. Millable wax discs are synthetic waxes suitable for use in CAD-CAM systems that can be used to create wax patterns for the heat-press fabrication of restorations. The advantage of these CAD-CAM wax patterns is that they can be manually edited or added after the milling process [11, 12]. The use of CAD-CAM wax blocks ensures accuracy and dimensional stability in the processing of restoration design [13]. The additive method obtains a model from 3D data by combining layers [14]. After the digital design is completed, the digital model is sliced and cross-sections are created by printing layer on another layer with raw materials such as powder, solid or liquid [15]. It is more advantageous than conventional methods in terms of production speed, reliability, and economic aspects [14].

Marginal fit is defined as the distance between the finish line and the border of the restoration, while the internal fit is the distance between the axial wall of the prepared tooth and the inner wall of the resulting restoration [16, 17]. Marginal and internal fit are important clinical factors effecting the long-term success of the prosthodontic treatments. It has been reported that restorations with a high marginal fit are long-lasting, the tooth and the surrounding tissues are less damaged [17]. Low marginal fit can lead to cement exposure to oral fluids, leakage, plaque buildup, secondary caries, periodontal inflammations, and ultimately failure of the prosthetic treatment. Inadequate internal fit causes increased stress at the tooth and restoration interface and ultimately leads to fracture of the restoration [18–20]. These problems, which shortens the life of the restoration, not only require additional treatment procedures but also result in increased material and labor costs. Cross-sectional microscope, silicone replica technique, scanning electron microscope, stereomicroscope, profilometer, 3-dimensional scanning method, and computerized x-ray microtomography are examples of in vitro techniques used to measure marginal and internal fit [21]. The silicone replica technique is a technique that can be used to examine both marginal and internal fits of restorations. In this technique, light-body silicone impression material is placed inside the restoration; then the restoration is positioned on the master model to simulate the cementation process. After the material sets, the restoration is carefully separated from the master model. The silicone material indicates the cement gap or the internal fit of the restoration [22].

The impressions taken after the preparation of fixed restorations and the restoration production method effect the marginal and internal fit and emerge as an important factor in the success of the restorations. There is a lack of research on the marginal and internal fit of endocrowns that have been produced using both traditional and digital manufacturing methods. This study examines the marginal and internal fit of heat-pressed and CAD-CAM lithium disilicate endocrowns fabricated using different restoration patterns. The hypothesis was that there would be no difference in the marginal and internal fit between endocrown restorations produced by traditional and digital techniques.

Methods

This research was approved by Ethics Committee of Zonguldak Bülent Ecevit University Faculty of Medicine (2022/02–11). The sample size was based on a previous study by Abduljawad et al. [23]. A power analyses was conducted and according to that sample size of 10

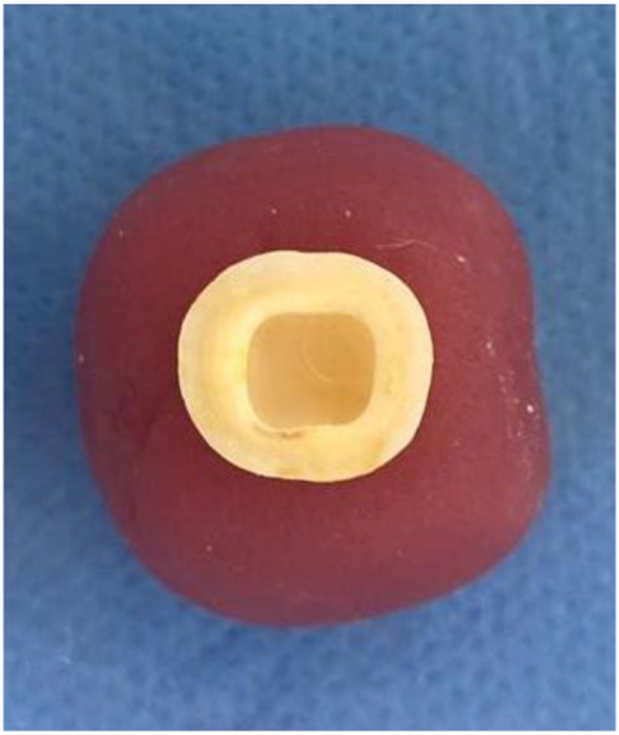

Fig. 1 Preparation of endocrown

samples per group was sufficient to detect a large effect size d = 0.99, with an actual power (1-β error) of 0.8 (80%) and a significance level (α error) of 0.05 (5%) type I error level.

Forty sound human mandibular 1st molars extracted for periodontal reasons were collected after written informed consent was obtained from all participants for the use of extracted teeth in this study. To ensure standardization, teeth with similar dimensions were used and cavity preparations were made by a experienced single operator (D.E.K). The crown portions were decoronated 2 mm above the cemento-enamel junction parallel to the occlusal surface and root canal treatments were performed. Endocrown preparations were done with a special bur set (Intensiv set, Montagnola, Switzerland). A diamond chamfer bur with a 4^0 inclination was used to shape the inner walls of pulp chamber to widen toward the occlusal plane. It was ensured that the cavity wall thickness was not less than 2 mm. The internal cavity margins were finished in a 90^0 butt-joint margin style. To prevent microleakage, the root canal orifices were covered with flowable composite and the bottom of the cavity was smoothed with a diamond bur. After these procedures, the endocrown preparations were obtained with a central retention cavity of 3 mm in depth (Fig. 1). All cavity dimensions were checked by using a digital caliper and graded dental probe. The prepared teeth were randomly divided into 4 groups ($n = 10$). The group names and production methods were as following:

Table 1 Materials used in the study

Material	Manufacturer	Type	Lot Number
GC Initial LiSi CAD-CAM Block	GC Corp., Tokyo, Japan	Lityum disilicate glass ceramic	2108181
GC Initial, LiSi Press Ingot	GC Corp., Tokyo, Japan	Lithium disilicate glass ceramic	190418 A
Geo Classic Modeling Wax	Renfert GmbH, Company, Hilzingen, Germany	Type 2 Modeling wax	PA242732
Zwax CAD-CAM Wax Disc	Zwax, Bursa, Turkey	CAD-CAM wax disk	183734ZWAX
Arma Resin Dental Model Cast	Arma Dental, Turkey	DLP based resin	20220929Cast01
DentapressA Heavy body	DentapressA, Indigodental GmbH, Germany	Base	264658
DentapressA Light body	DentapressA, Indigodental GmbH, Germany	Catalyst	264657

CON: Conventional impression, wax pattern obtained by conventional laboratory waxing, and endocrowns fabricated by heat-press technique.
DCD: Digital impression, the wax pattern obtained by milling from CAD-CAM wax disk, and endocrowns fabricated by heat-press technique.
D3D: Digital impression, resin pattern obtained by using 3D printer, and endocrowns fabricated by heat-press technique.
DC: Digital impression, digital design, and endocrowns milled directly from CAD-CAM blocks.

The materials and technical information used in the study are presented in Table 1.

Conventional and digital impressions/scans and designs

For the CON group impressions, the base and catalyst of the putty-like impression material were combined as directed by the manufacturer and then put into a plastic mould. The light-bodied consistency impression material (DentapressA, Indigodental GmbH, Germany) was placed in the preparation area and the mould, then the air was squeezed to distribute it evenly over the entire cavity. The tooth was then inserted on the plastic mould and the endocrown cavity impression was taken in one step. The impressions were then cast with a Type IV dental stone (Fig. 2). Wax patterns of endocrowns were fabricated by using modeling wax (Geo Classic Modeling Wax, Renfert GmbH, Company, Hilzingen, Germany) (Fig. 3). Modeling was performed in accordance with the anatomy of

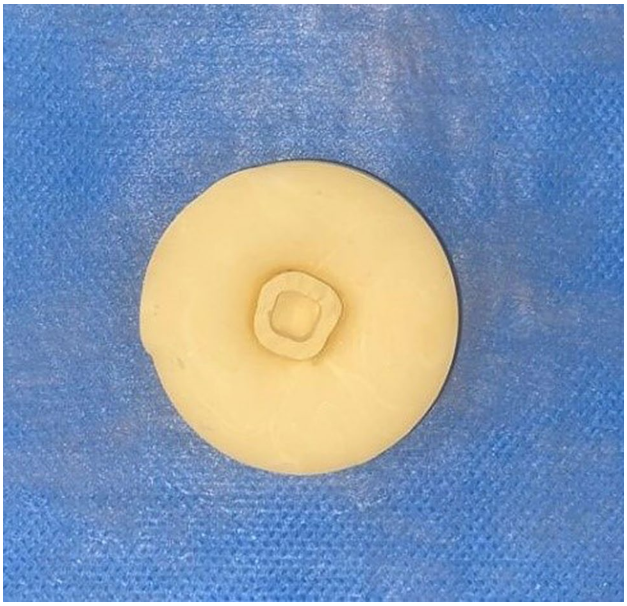

Fig. 2 Stone model

Fig. 3 Wax modeling of samples in the CON group

the lower 1st molar, and the total crown length did not exceed 7 mm.

The digital scans of endocrown preparations of groups DCD, D3D, and DC were made directly using an powder-free intraoral scanner which is based on the triangulation imaging method (Cerec Omnicam, Sirona Dental Systems, Bensheim, Germany). The crown length of the endocrowns was digitally designed not to exceed 7 mm. Wax patterns of DCD group were obtained by milling

Fig. 4 Milling of wax endocrown patterns in the DCD group

Fig. 5 Printed endocrown patterns in the D3D group

from CAD-CAM wax disc (Zwax CAD-CAM Wax Disc, Zwax, Bursa, Turkey) (Fig. 4), the resin patterns of D3D group were obtained by using a 3D printed resin (Arma Resin, Arma Dental, Turkey) and a DLP based 3D printer (Asiga Max, Asiga, Sydney, Australia) (Fig. 5). The DCD, D3D and DC group endocrowns were digitally designed using the software (InLab Software 3D, and CEREC Software 4.6.1 Sirona Dental Systems, Bensheim, Germany).

Fabrication of endocrowns

Endocrowns of CON, DCD and D3D groups were produced by the heat-press technique. Wax, CAD-CAM wax, and 3D printed patterns of CON, DCD, and D3D groups were transferred to the silicone ring system after sprueing. The investment material, powder, and liquid, were mixed with a vacuum mixer for 60 s, poured into the silicone ring, and left to set for 60 min. The investment was removed from the silicone cylinder and placed in a preheating furnace (Mikrotek MFX 1005, Mikrotek Dental, Ankara, Turkey) at 850 °C for 45 min to burn out the patterns. GC Initial LiSi Press (LT, A2) ceramic ingots are placed into the investment ring and heat-pressed in a press furnace (Programat EP 5010, Ivoclar Vivadent, Schaan, Liechtenstein). The endocrowns were dissected from the sprue using a separating disk and the remaining investment material was removed by sandblasting. The specimens were mounted on a special specimen holder and blasted with 50 µm aluminium oxide at a distance of 10 mm for 10 s. Each endocrown was positioned on its corresponding specimen to verify fit.

The 'Production' tab was activated for the DC group with completed digital designs, initiating the process of milling the restorations from the blocks. The software determined the position of the restorations and the rod within the block, as well as the block's length. Ceramic block (GC Initial LiSi Block) was placed in the milling device (Sirona, Cerec MC XL, Bensheim, Germany) and endocrowns were milled (Fig. 6). The produced endocrowns were removed from the milling device, and after refining the crowns with a fine-grained diamond bur, each endocrown was placed on its corresponding tooth to verify the fit.

The endocrowns of all groups were polished using fine-grit discs (Sof-Lex Spiral, 3 M ESPE, St Paul, USA) at 15,000 to 20,000 cycles with light pressure, following the manufacturer's instructions. After the endocrowns were fabricated, occlusion spray was applied to the inner surfaces of the restorations and the fit was checked by placing them in the cavity. Compatibility of the restoration was evaluated by using a binocular loup (HR 2.5x, Heine Optotechnik GmbH & Co. KG, Herrsching, Germany) and no modification was required.

Fig. 6 Milled endocrowns

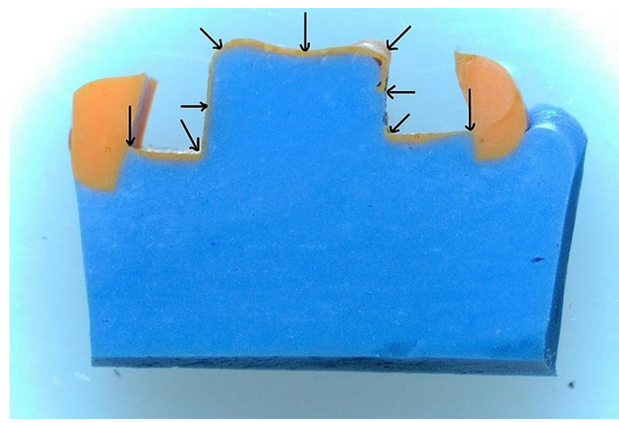

Fig. 7 Measured points

Marginal and internal fit measurement

The marginal and internal fits were measured using the silicone replica technique. A light-bodied silicone material (DentapressA, Indigodental GmbH, Germany) was placed in each prepared cavity. The endocrown restoration was fitted over the cavity and force was applied until the silicone material set. Then, the restoration was removed from the cavity, the heavy-bodied impression material was placed over the cavity. Once the impression material was set, it was separated from the tooth to obtain silicone replicas. Each replica was divided into nine parts, mesio-distally and bucco-lingually, using a sharp scalpel (Galena Health Industry and Trading Corporation, Hamburg, Germany). The sections of the silicone replicas were examined with a stereomicroscope (Olympus SZ61, Tokyo, Japan) at 57x magnification and the images were transferred to the computer using a microscope camera (Olympus SC100, Tokyo, Japan) and a software program (cellSens Standard, Olympus Corporation, Shinjuku, Tokyo, Japan). Marginal and internal fit measurements were made with the software program (Digimizer, MedCalc Software Ltd, Ostend, Belgium) on the images obtained. A total of 13 points were measured at 2 marginal sites and 11 internal sites (2 axio-marginal, 4 axial, 2 axio-pulpal, and 3 pulpal) (Fig. 7).

Statistical analysis

The analysis was conducted using SPSS V23 (IBM Corp. IBM SPSS statistics for Windows, Armonk, NY, USA). Normality was assessed using the Kolmogorov-Smirnov test. The Kruskal-Wallis test was employed to assess differences among groups for parameters that were not normally distributed, while Dunn's test was utilized for making multiple comparisons. The paired two-sample t-test was employed for comparing normally distributed values within each group, while the Wilcoxon test was utilized for values that did not adhere to the normal distribution. The significance level was set at $p < 0.05$.

Table 2 Mean, standard deviation (SD), median, minimum and maximum marginal, axio-marginal, axial, axio-pulpal, and pulpal gap values of the groups

	CON Mean ± SD Median (Min-Max)	DCD Mean ± SD Median (Min-Max)	D3D Mean ± SD Median (Min-Max)	DC Mean ± SD Median (Min-Max)	*P*
Marginal	133.99 ± 75.94 111 (52–387)[b]	94.52 ± 19.51 96 (52–166)[a]	95.64 ± 32.72 91 (43–230)[a]	98.72 ± 32.08 93 (49–268)[a]	**< 0.001**
Axio-Marginal	122.39 ± 50.17 109 (56–349)[a]	96.69 ± 18.75 95 (52–162)[b]	110.77 ± 25.62 111 (54–176)[a]	113.24 ± 29.56 109.5 (51–219)[a]	**< 0.001**
Axial	81.7 ± 52.59 70 (28–462)[a]	84.51 ± 22.07 84 (35–223)[b]	89.16 ± 30.87 87 (33–194)[b]	74.27 ± 33.97 67.5 (31–300)[a]	**< 0.001**
Axio-Pulpal	234.34 ± 72.25 215.5 (100–454)[b]	177.69 ± 44.69 172.5 (75–269)[a]	202.22 ± 43.77 206,5 (86–292)[c]	168.44 ± 42.67 171.5 (61–291)[a]	**< 0.001**
Pulpal	176.95 ± 68.45 166.5 (58–372)[a]	134.74 ± 45.3 130 (45–265)[b]	125.69 ± 49.21 122 (42–275)[b]	174.57 ± 40.34 177 (67–292)[a]	**< 0.001**

*Kruskal-Wallis test, a-c: No difference between groups with the same letters

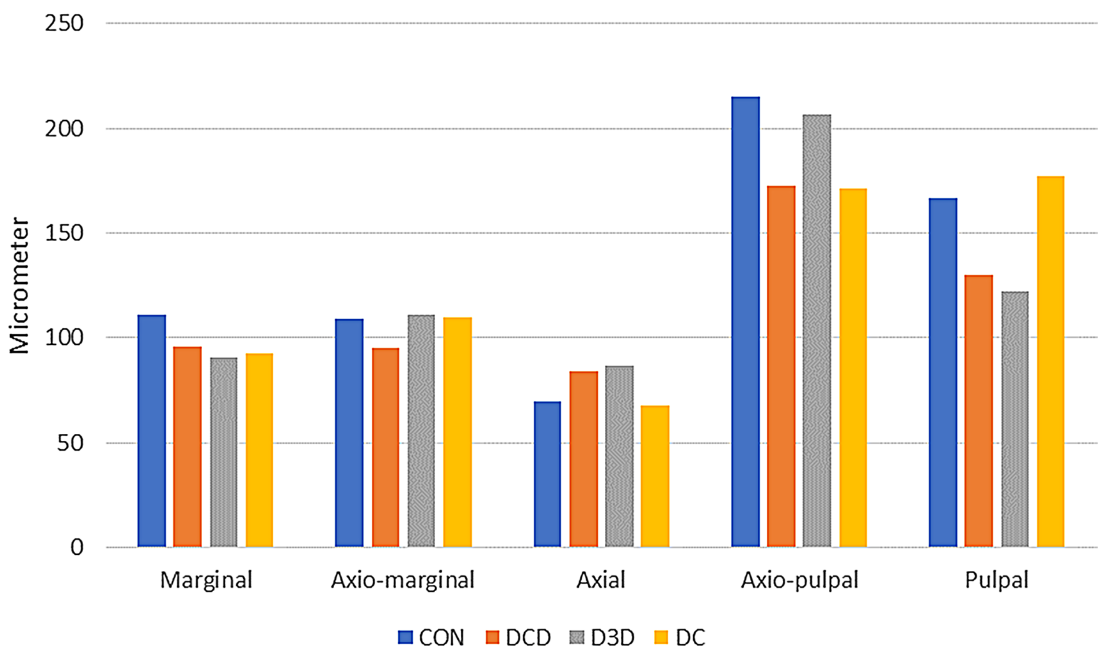

Fig. 8 Median gap values of groups measured from five different areas

Results

Table 2; Fig. 8 present the marginal, axio-marginal, axial, axio-pulpal, and pulpal fit values of the groups. A significant statistical variance was observed among the groups concerning fit values across all sites ($p < 0.001$). The CON group had the highest marginal and axio-pulpal fit values, the D3D group had the highest axio-marginal and axial fit values, the DC group had the highest pulpal fit values. The results showed that the lowest marginal and pulpal fit values were found in D3D, axio-marginal fit values in DCD, and axial and axio-pulpal fit values in DC group.

Table 3 illustrates the marginal and internal fit measurements for each group. A statistically significant difference was found in terms of marginal and internal fit evaluation within each group ($p < 0.001$). A significant difference in the marginal discrepancy was revealed between the CON and the other groups, with the marginal discrepancy of CON (111 µm) being significantly higher than that of DCD, D3D and DC ($p < 0.001$). Significant statistical variances were noted among the groups concerning internal fit values ($p < 0.001$). The DC group had the highest internal fit value (122 µm), while the DCD had the lowest (112 µm), and in pairwise comparisons of the groups, a significant difference was obtained between CON and DCD groups ($p < 0.001$).

Measurements of bucco-lingual directions are presented in Table 4 and the mesio-distal directions in Table 5. In the bucco-lingual directions, marginal fit values of the CON group was significantly higher when compared to the other groups ($p < 0.001$). For internal fit values, a statistically significant difference was observed between the CON and DCD groups ($p = 0.003$). In the

Table 3 Mean, standard deviation (SD), median, minimum and maximum marginal and internal gap values of each group

	Marginal Gap		Internal Gap		*P**
	Mean ± SD	**Median (Min-Max)**	**Mean ± SD**	**Median (Min-Max)**	
CON	133.99 ± 75.94	111 (52–387)[b]	129.06 ± 57.92	120.75 (36–422)[b]	**< 0.001**
DCD	94.52 ± 19.51	96 (52–166)[a]	110.09 ± 26.8	112 (35–165)[a]	**< 0.001**
D3D	95.64 ± 32.72	91 (43–230)[a]	114.98 ± 32.95	114.88 (41-195.5)[ab]	**< 0.001**
DC	98.72 ± 32.08	93 (49–268)[a]	116.04 ± 38.78	122 (31–300)[ab]	**< 0.001**
*P***	**< 0.001**		**0.002**		

*Wilcoxon test, **Kruskal Wallis test, a-b: There is no difference between groups with the same letters in columns

Table 4 Mean, standard deviation (SD), median, minimum and maximum marginal and internal gap values of each group in bucco-lingual direction

	Marginal Gap			Internal Gap	*P**
	Mean ± SD	**Median (Min-Max)**	**Mean ± SD**	**Median (Min-Max)**	
CON	133.83 ± 70.38	113.5 (52–373)[b]	130.64 ± 63.63	118.38 (32–462)[b]	**< 0.001**
DCD	91.91 ± 17.81	94 (52–123)[a]	106.11 ± 26.81	106 (35-172.5)[a]	**< 0.001**
D3D	92.75 ± 36.78	88.5 (43–222)[a]	114.79 ± 32.01	114 (39–194)[ab]	**< 0.001**
DC	99.83 ± 36.08	92.5 (54–268)[a]	111.73 ± 34.37	120.75 (39-215.25)[ab]	**< 0.001**
*P***	**< 0.001**		**0.006**		

*Wilcoxon Test, **Kruskal Wallis test, a-b: There is no difference between groups with the same letters in columns

mesio-distal directions, the CON group showed significantly higher marginal fit values then the D3D ($p = 0.025$) and DC groups ($p = 0.005$), while no difference was observed between the DCD group ($p > 0.05$). No significant difference was observed for internal fit between the groups ($p > 0.05$).

Discussion

This study was designed to evaluate the marginal and internal fit of endocrowns fabricated using different impression, pattern production, and fabrication techniques by obtaining silicone replicas. This technique is a fast and reliable method for evaluating thin surface

Table 5 Mean, standard deviation (SD), median, minimum and maximum marginal and internal gap values of each group in mesio-distal direction

	Marginal Gap		Internal Gap		*p**
	Mean ± SD	**Median (Min-Max)**	**Mean ± SD**	**Median (Min-Max)**	
CON	134.15 ± 81.56	107 (56–387)[b]	129.97 ± 50.8	126.63 (46–296)[a]	**< 0.001**
DCD	97.13 ± 20.85	100 (53–166)[ab]	115.1 ± 25.48	116.5 (46–168)[a]	**< 0.001**
D3D	98.54 ± 28.02	95 (57–230)[a]	116.07 ± 34.14	116.63 (33-192.75)[a]	**< 0.001**
DC	97.61 ± 27.7	93 (49–217)[a]	120.6 ± 39.53	125 (44–249)[a]	**< 0.001**
*p***	**0.004**		0.088		

*Wilcoxon Test, **Kruskal Wallis Test, a-b: There is no difference between groups with the same letters in columns

intervals, easy to apply and evaluate, and cheap. It has been preferred in many studies in the literature evaluating marginal and internal compliance [24–26]. The silicone replica technique, which is noninvasive and ensures the restoration is not damaged during measurement, was used in this study to measure marginal and internal fits.

Numerous studies indicate that the marginal fit value deemed clinically acceptable ranges from 50 to 120 µm, while internal fit values typically fall between 200 and 300 µm [24–31]. The marginal fit values obtained in this study were between 91 µm and 111 µm and the internal fits were between 112 µm and 122 µm in all groups and were found to be within clinically acceptable limits.

The findings of this study led to the rejection of the initial hypothesis since notable distinctions were observed in both marginal and internal adaptation among the groups under investigation. A statistically highest marginal fit value was obtained in full-conventionally fabricated endocrowns. In terms of internal fit a statistically difference was obtained between the fabrication methods. It was noted that internal fit values of heat-pressed endocrowns were lower than CAD-CAM endocrowns.

When reviewing existing studies in the literature, it was observed that the choice between conventional and digital impression methods effects the marginal and internal fit of restorations [32–34]. Memari et al. [32] concluded that restorations made with digital impressions had lower marginal fit values compared to those made with conventional impressions, indicating that digital impressions yield a higher marginal fit. Falahcha et al. [33] compared the marginal fit of endocrowns produced by digital and conventional impressions. As a result, they reported that endocrows produced by digital scanning and conventional impression techniques have similar marginal fit (70 µm, and 74 µm respectively). Abduljawad et al. [23] produced endocrowns with conventional impression/heat-press technique; conventional impression/

model scanning with intraoral scanner/CAD-CAM; conventional impression/model scanning with laboratory scanner/CAD-CAM; digital scanning/CAD-CAM technique to compare the marginal and internal fit. They reported that endocrowns produced by digital methods (120 ± 27 µm) showed a lower marginal fit than those produced by conventional methods (150 ± 35 µm) and when compared to conventionally fabricated endocrowns, digitally fabricated endocrowns demonstrated superior marginal and internal adaptation.

Endocrown restorations can be fabricated using the heat-press technique or CAD-CAM technology [34, 35]. The heat-press technique is based on obtaining restoration patterns, burn-out the patterns and forming ceramic ingots under pressure [36]. When using this method, the patterns can be prepared manually by waxing, milling using CAD-CAM or printing via 3D printers.

El Ghoul et al. [37] compared the marginal and internal adaptation of lithium disilicate endocrowns (with a 4 mm deep retension cavity) obtained by CAD-CAM and heat-press techniques. Patterns were milled from a wax disc in order to press the lithium disilacate endocrowns. As a result of this study, they reported that the marginal and internal conformity of both manufacturing techniques were within clinically acceptable limits, but the endocrowns produced with CAD-CAM system had better marginal and internal conformity.

Homsy et al. [38] compared the marginal and internal fit of inlay restorations fabricated using conventional wax, milled wax or 3D printed patterns. They reported that digital scan/CAD-CAM wax patterns showed better marginal and internal fit compared to conventional impression/fabrication or 3D resin pattern production. Fit values were similar for both 3D printed resin patterns and conventionally produced wax patterns.

Gudugunta et al. [39] compared the marginal fit of onlay restorations produced with the CAD/CAM system and the heat-pressure method in their study. As a result of this study, they reported that restorations with lower marginal gaps were obtained in production with the CAD/CAM system compared to the heat-pressure method.

Anadioti et al. [40] obtained impressions with conventional and digital methods and produced lithium disilicate crowns by heat-pressure technique and CAD/CAM milling. They examined the marginal fit of these crowns and reported that the crowns produced with conventional impression and heat-pressure technique showed lower marginal gap values.

Elsayed et al. [41] investigated the marginal compatibility of pressed and CAD-CAM lithium disilicate glass ceramic endocrowns. Restorations were fabricated using CAD-CAM wax patterns in the heat-press technique. As a result, they reported that heat-press fabrication showed lower marginal fits compared to direct CAD-CAM milling. While full digital fabrication of endocrowns gave more compatible marginal fit results compared to conventional heat-press fabrication, no statistical difference was observed between DCD and DC in terms of marginal fit in our study.

In current study, the marginal fit value of endocrowns produced with 3D printed resin patterns (91 µm) was lower than those produced with conventional technique (111 µm), and the internal fits were found to be lower in endocrowns fabricated with 3D printed resin patterns (114.88 µm) compared to those with conventional technique (120.75 µm). In the literature there are contricting results with the present study [25, 42]. Eftekhar Ashtiani et al. [26] evaluated the marginal adaptation of heat-pressed onlay restorations manufactured by conventional impression/fabrication, conventional impression/3D printed resin pattern, and digital impression/3D printed resin pattern. The results showed that in terms of marginal fit, the onlays produced by the conventional method showed a lower marginal fit value compared to the 3D printer. Jamshidi et al. [42] compared the marginal adaptation of endocrowns produced by 3D printer and conventional wax technique. As a result of their study, it is reported that 3D printed endocrowns showed lower marginal conformity compared to the conventional method. It is thought that the reason for the better marginal fit of the 3D printed endocrowns compared to the conventional technique may be the incorrect positioning of the marginal line in the conventional technique, manual waxing, and possible errors in the die spacer placement and casting process may have affected the marginal fit.

In this study, the internal fit of endocrowns obtained by milling CAD-CAM wax (112 µm) was lower than that of conventional endocrowns (120.75 µm). Mansour et al. [43] investigated the effect of CAD-CAM wax milling and conventional wax technique on the internal fit of metal frameworks. As a result of this study, it is reported that a lower marginal fit with the conventional technique was obtained (103.89 µm) compared to the CAD-CAM wax disc milling method (104.10 µm), but there was no statistical difference between the two techniques and reliable results could be obtained with both techniques. The reasons for these differences may be due to the different types of restorations obtained, the digital scanner used and the software design. In order to minimise technician error in manual waxing, wax patterns can be obtained from wax discs by CAD-CAM. The CAD-CAM wax modelling procedure aims to prevent errors in the casting process by reducing the production steps.

The highest internal fit values were seen in the axio-pulpal region of full conventionally fabricated endocrowns. The lowest internal fit values were obtained at the axial walls of full digitally fabricated endocrowns.

In the conventional method, the impression stages are important factors affecting the accuracy of the cast, increasing the possibility of error [44, 45]. With the digital impression method, the data required to produce the restoration can be transferred directly to the CAD-CAM device. Direct transfer of the data obtained during impression-taking and modelling reduces the number of steps in the process and provides more accurate results [46]. A study also showed that endocrowns with higher internal fit have higher fracture resistance [47].

The limitations of this study are that it is an in vitro study, the in vivo simulation conditions such as pH changes, saliva and bacterial presence do not reflect the intraoral environment and the restorations could not be aged. Further studies of endocrowns fabricated by different techniques are needed to support the results of this study.

Conclusions

Based on the constraints of the research, it was determined that:

(1) All of the endocrown production techniques used in the study showed clinically acceptable marginal and internal adaptation.
(2) Increased marginal compliance can be achieved by using 3D printing technology in the production of endocrown patterns.
(3) Endocrowns produced with the digital technique can achieve higher marginal and internal adaptation compared to the conventional technique.

Abbreviations

CAD-CAM	Computer Aided Design-Computer Aided Manufacturing
3D	Three Dimensional

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Author contributions

DEK; Methodology, investigation, data curation, writing original manuscript and editing, visualization, project administration, funding acquisition. GS; Conceptualization, methodology, data curation, writing original manuscript and editing, project administration, funding acquisition. ŞEG; Conceptualization, data curation, investigation, writing original manuscript and editing, visualization.

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Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This research was approved by Ethics Committee of Zonguldak Bülent Ecevit University Faculty of Medicine (2022/02–11) and conducted in accordance with relevant guidelines and regulations of Declaration of Helsinki. Written informed consent was obtained from all participants for the use of extracted teeth in this study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Bindl A, Mörmann WH. Clinical evaluation of adhesively placed cerec endocrowns after 2 years–preliminary results. J Adhes Dent. 1999;1(3):255–65.
2. Çelik Güven M, Yıldırım G. Endokron restorasyonlar. Selcuk Dent J. 2019;6(2):201–5.
3. Azeez GM, Çekiç Nagaş I. Aşırı Harabiyet gösteren endodontik Tedavili Dişlerin protetik restorasyonları. 7tepe Klinik. 2019;15(2):231–41.
4. Biacchi GR, Basting RT. Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. Oper Dent. 2012;37(2):130–6.
5. Papalexopoulos D, Samartzi TK, Sarafianou A. A thorough analysis of the endocrown restoration: A literature review. J Contemp Dent Pract. 2021;22(4):422–6.
6. Bindl A, Richter B, Mörmann WH. Survival of ceramic-computer aided/manufacturing crowns bonded to preparations with reduced macroretention geometry. Int J Prosthodont. 2005;18(3):219–24.
7. Otto T. Computer-aided direct all-ceramic crowns:preliminary 1-year results of a prospective clinical study. Int J Periodont Restor Dent. 2004;24(5):446–55.
8. Valentina V, Aleksandar T, Dejan L, Vojkan L. Restoring endodontically treated teeth with all-ceramic endo-crowns case report. Serbian Dent J. 2008;55(1):54–64.
9. Ishibe M, Raigrodski AJ, Flinn BD, Chung KH, Spiekerman C, Winter RR. Shear bond strengths of pressed and layered veneering ceramics to highnoble alloy and zirconia cores. J Prosthet Dent. 2011;106(1):29–37.
10. Yamalı AY, Turhan Bal B. Properties and clinical applications of lithium disilicate ceramics. Curr Res Dent Sci. 2023;33(2):122–30.
11. Fathi HM, Al-Masoody AH, El-Ghezawi N, Johnson A. The accuracy of fit of crowns made from wax patterns produced conventionally (Hand Formed) and via CAD/CAM technology. Eur J Prosthodont Restor Dent. 2016;24(1):10–7.
12. Farjood E, Vojdani M, Torabi K, Khaledi AA. Marginal and internal fit of metal copings fabricated with rapid prototyping and conventional waxing. J Prosthet Dent. 2017;117(1):164–70.
13. Byun SS. Dimensional stability of CAD/CAM patterns: A longitudinal study. Baltimore: Diss. University of Maryland; 2020.
14. Van Noort R. The future of dental devices is digital. Dent Mater. 2012;28(1):3–12.
15. Goiato MC, Santos MR, Pesqueira AA, Moreno A, dos Santos DM, Haddad MF. Prototyping for surgical and prosthetic treatment. J Craniofac Surg. 2011;22(3):914–7.
16. Topkara C, Keleş A. Examining the adaptation of modified endocrowns prepared with CAD-CAM in maxillary and mandibular molars: a microcomputed tomography study. J Prosthet Dent. 2022;127(5):744–9.
17. Holmes JR, Bayne SC, Holland GA, Sulik WD. Considerations in measurement of marginal fit. J Prosthet Dent. 1989;62(4):405–8.
18. Kokubo Y, Ohkubo C, Tsumita M, Miyashita A, von Vult P, Fukushima S. Clinical marginal and internal fits of procera allceram crowns. J Oral Rehabil. 2005;32:526–30.
19. Knoernschild KL, Campbell SD. Periodontal tissue responses after insertion of artificial crowns and fixed partial dentures. J Prosthet Dent. 2000;84(5):492–8.
20. Zhang Y, Kim JW, Bhowmick S, Tompson VP, Rekow ED. Competition of fracture mechanisms in monolithic dental ceramics: flat model systems. J Biomedical Mater Res Part B: Appl Biomaterials. 2009;88(2):402–11.

21. Koyuncu B, Özpınar B, Çağlar AB. Farklı Yöntemler Ile üretilen tüm Seramik restorasyonların Marjinal Uyumu. EÜ Dişhek Fak Derg. 2021;42(2):151–8.
22. Laurent M, Scheer P, Dejou J, Labord G. Clinical evaluation of the marginal fit of cast crowns–validation of the silicone replica method. J Oral Rehabil. 2007;35:116–22.
23. Abduljawad DE, Rayyan MR. Marginal and internal fit of lithium disilicate endocrowns fabricated using conventional, digital, and combination techniques. J Esthet Restor Dent. 2022;34(4):707–14.
24. Rinke S, Huls A, Jahn L. Marginal accuracy and fracture strength of conventional and copy-milled all-ceramic crowns. Int J Prosthodont. 1995;8(4):303–10.
25. Pera P, Gilodi S, Bassi F, Carossa S. In vitro marginal adaptation of alumina porcelain ceramic crowns. J Prosthet Dent. 1994;72(6):585–90.
26. Eftekhar Ashtiani R, Nasiri Khanlar L, Mahshid M, Moshaverinia A. Comparison of dimensional accuracy of conventionally and digitally manufactured intracoronal restorations. J Prosthet Dent. 2018;119(2):2338.
27. Suarez MJ, Villaumbrosia PG, Lozano JFL. Comparison of the marginal fit of procera allcream crowns with two finish lines. Int J Prosthodont. 2003;16(3):229–32.
28. Gemalmaz D, Alkumru HN. Marginal fit changes during porcelain firing cycles. J Prosthet Dent. 1995;73(1):49–54.
29. Bjorn AL, Bjorn H, Grkovic B. Marginal fit of restorations and its relation to periodontal bone level. II Crowns Odontologisk Revy. 1970;21(3):337–46.
30. Souza RO, Özcan M, Pavanelli CA, Buso L, Lombardo GH, Michida SM, Mesquita AM, Bottino MA. Marginal and internal discrepancies related to margin design of ceramic crowns fabricated by a CAD/CAM system. J Prosthodont. 2012;21(2):94–100.
31. de Almeida JGDSP, Guedes CG, Abi-Rached FO, Trindade FZ, Fonseca RG. Marginal fit of metal-ceramic copings: effect of Luting cements and tooth Preparation design. J Prosthodont. 2019;28(1):265–70.
32. Memari Y, Mohajerfar M, Armin A, Kamalian F, Rezayani V, Beyabanaki E. Marginal adaptation of Cad/cam all-ceramic crowns made by different ımpression methods: a literature review. J Prosthodont. 2019;28(2):536–44.
33. Falahchai M, Babaee Hemmati Y, Neshandar Asli H, Emadi I. Marginal fit of monolithic zirconia endocrowns fabricated by using digital scanning and conventional impressions. J Prosthet Dent. 2021;125(2):325–30.
34. Fages M, Bennasar B. The endocrown: a different type of all-ceramic reconstruction for molars. J Can Dent Assoc. 2013;79:d140.
35. Sedrez-Porto JA, Rosa WL, da Silva AF, Münchow EA, Pereira-Cenci T. Endocrown restorations: A systematic review and meta-analysis. J Dent. 2016;52:8–14.
36. Schaefer O, Watts DC, Sigusch BW, Kuepper H, Guentsch A. Marginal and internal fit of pressed lithium disilicate partial crowns in vitro: a three-dimensional analysis of accuracy and reproducibility. Dent Mater. 2012;28(3):320–6.
37. El Ghoul W, Salameh Z. Marginal and internal adaptation of lithium disilicate endocrowns fabricated by Heat-Pressable and subtractive techniques. J Prosthodont. 2021;30(6):509–14.
38. Homsy FR, Özcan M, Khoury M, Majzoub ZAK. Marginal and internal fit of pressed lithium disilicate inlays fabricated with milling, 3D printing, and conventional technologies. J Prosthet Dent. 2018;119(5):783–90.
39. Gudugunta L, Mynampati P, Jeevan MB, Kumar SM, Akkaloori A, Tejavath SK. The marginal discrepancy of lithium disilicate onlays: Computer-aided design versus press. J Conserv Dent. 2019;22(4):336–9.
40. Anadioti E, Aquilino S, Gratton D, Holloway J, Denry I, Thomas G, Qian F. 3D and 2D marginal fit of pressed and CAD/CAM lithium disilicate crowns made from digital and conventional impressions. J Prosthodont. 2014;23(8):610–7.
41. Elsayed SM, Emam ZN, Abu-Nawareg M, Zidan AZ, Elsisi HA, Abuelroos EM, Fansa HA, Shokier HMR, Elbanna KA. Marginal fit distance and Cyclic fatigue loading for different all-ceramic endocrowns. Eur Rev Med Pharmacol Sci. 2023;27(3):879–87.
42. Jamshidi S, Darabi R, Azarian M, Mahabadi M, Nilli M. Marginal fit of endocrowns fabricated by three-dimensional printing and the conventional method: an in vitro study. Dent Res J. 2023;20(53):1–6.
43. Mansour FK. Comparison of the internal fit of conventional casting versus CAD wax. in-vitro study. EDJ. 2021;67:583–7.
44. Breeding LC, Dixon DL. Accuracy of casts generated from dual-arch impressions. J Prosthet Dent. 2000;84(4):403–7.
45. Luthardt RG, Walter MH, Weber A, Koch R, Rudolph H. Clinical parameters influencing the accuracy of 1- and 2-stage impressions: a randomized controlled trial. Int J Prosthodont. 2008;21(4):322–7.
46. Lee KB, Park CW, Kim KH, Kwon TY. Marginal and internal fit of all- ceramic crowns fabricated with two different CAD-CAM systems. Dent Mater J. 2008;27(3):422.
47. El-Farag SAA, Elerian FA, Elsherbiny AA, Abbas MH. Impact of different CAD/CAM materials on internal and marginal adaptations and fracture resistance of endocrown restorations with: 3D finite element analysis. BMC Oral Health. 2023;23(1):421.

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