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EFFECT OF DIFFERENT PROCESSING TECHNIQUES ON THE MARGINAL AND INTERNAL FIT OF MONOLITHIC LITHIUM DISILICATE AND ZIRCONIA-REINFORCED LITHIUM SILICATE RESTORATIONS

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ABSTRACT

Statement of problem. Information about the effect of different processing techniques on the marginal fit of lithium disilicate and zirconia-reinforced lithium silicate (ZLS) restorations is lacking.

Purpose. To evaluate the effect of different processing techniques on the marginal and internal fit of monolithic lithium disilicate and ZLS restorations.

Material and methods. Forty crowns were divided into 4 groups (n=10) according to the processing technique: IPS e.max CAD blocks (EC), IPS e.max Press ingots (EP), Celtra Duo blocks (CC); and Celtra Press ingots (CP). The dies and the ceramic crowns were scanned and then superimposed in a 3D engineering software. The 2D sections of the 3D superimposition analysis were used to measure the marginal and internal fit of each ceramic crown. The data obtained were statistically analyzed by using the Dunn post hoc test (α=.05).

Results. A statistically significant difference in the marginal discrepancy was found among all groups ($P<.001$); however, the difference between the EP and EC groups was not statistically significant ($P>.05$). A statistically significant difference in the internal discrepancy was found among all groups ($P<.001$); however, the difference between the EP and CP groups was not statistically significant ($P>.05$).

Conclusions. Monolithic zirconia-reinforced lithium silicate crowns processed by using the CAD-CAM technique showed significantly better marginal fit than other groups. Monolithic lithium disilicate crowns processed by using the CAD-CAM technique showed significantly better internal fit than other groups.

KEYWORDS. CAD-CAM, Lithium disilicate, ZLS, Marginal fit, Three-dimensional analysis.

CLINICAL IMPLICATIONS: The marginal and internal fit of monolithic lithium disilicate and zirconia-reinforced lithium silicate crowns is within clinically acceptable ranges for all the processing techniques investigated.

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INTRODUCTION

Advances in processing techniques and ceramic materials have led to the introduction of monolithic restorations, eliminating the delamination and chipping of veneering ceramic.[1-3] Monolithic ceramic materials, including synthetic lithium disilicate and zirconia-reinforced lithium silicate (ZLS) have become popular because of their excellent biocompatibility, desirable esthetics, and acceptable mechanical properties.[4-6] In prosthetic dentistry, these materials can be used to fabricate onlays, inlays, veneers, endocrowns, posterior or anterior crowns, and 3-unit fixed dental prostheses.[7-9] Lithium disilicate ceramics can be processed either by using the hot-pressing or computer-aided design and computer-aided manufacturing (CAD-CAM) techniques.[10-17] The IPS e.max CAD blocks contain an interlocking microstructure of a metasilicate phase incorporated in a glass matrix and provided in a partially crystallized state to expedite milling and lithium disilicate crystallization.[2] Conversely, the IPS e.max Press ingots are fully crystallized to expedite hot-pressing.[18] Although both types have 70% of crystal content, their crystal size and flexural strength are different. The flexural strength of IPS e.max CAD is 360 MPa, compared with 400 MPa for IPS e.max Press.[10]

Recently, ZLS ceramics with approximately10 wt% zirconia incorporated in a glass matrix have been introduced as a promising alternative to lithium disilicate ceramics combining the esthetic properties of glass-ceramics and the mechanical properties of zirconia.[6] These ceramics are provided in either a fully or a partially crystallized state and can be processed, either by using the hot-pressing or CAD-CAM techniques.[5,19] The Celtra Duo blocks are provided in a fully crystallized state to expedite milling and polishing. The flexural strength of polished restorations is 210 MPa; however, an additional crystallization improved the flexural strength to 370 MPa.[20] In addition, the recently introduced Celtra Press ingots are fully crystallized to expedite hot-pressing; however, an additional power firing improved the flexural strength to 500 MPa.[6,11] Although the clinical outcomes of both materials are satisfactory,[2] the dilemma about which ceramic material will result in better fit have been concerned by many clinicians; in addition, the adequacy of marginal and internal fit of these monolithic restorations fabricated by different processing techniques remains controversial.[10,21]

The marginal and internal fit is crucial for the clinical success of dental restorations.[22] Poor marginal fit may result in plaque accumulation, secondary caries, and pulp exposure.[23,24] The clinically acceptable marginal discrepancy has been reported to be less than 120 μm.[25-28] In addition, internal discrepancy greater than 70 μm may reduce the fracture resistance of restorations.[29] Several factors may influence the marginal and internal fit of dental restorations, including the finish line configuration, processing technique, measurement technique, materials evaluated, optical scanner, software parameters, and the number of rotation axes in the milling machine.[30-37]

Different methods have been suggested for evaluating the marginal and internal fit of dental restorations, including optical microscope, silicon replica technique, triple scan method, micro-computed tomography, and 2D sections of 3D superimposition analysis.[36,38] The precision of measurements in different studies varied because of the lack of standardization, varying conditions in the laboratory, and assessment methods used.[39]

Studies have reported better marginal fit of IPS e.max restorations fabricated by using the hot-pressing technique compared with restorations fabricated by using the CAD-CAM technique.[40-42] In contrast, contradictory results have been reported in other studies.[43-47] Reports on the effect of different processing techniques on the marginal and internal fit of monolithic lithium disilicate and

ZLS restorations are sparse. Therefore, the purpose of this in vitro study was to evaluate the effect of different processing techniques on the marginal and internal fit of monolithic lithium disilicate and ZLS restorations. The null hypothesis was that no difference would be found in the marginal and internal fit of monolithic lithium disilicate and ZLS restorations produced by different processing techniques.

MATERIAL AND METHODS

The materials evaluated in the present study are presented in Table 1. A power analysis of the marginal discrepancy data was calculated based on the results of a pilot study by using 3 samples in each group as the primary outcome. A sample size of 40 specimens (n=10 per group) had an effect size (F=0.239) and an 80% power with a significance level (α=.05) to test the null hypothesis that no difference would be found in the marginal and internal fit of monolithic lithium disilicate and ZLS restorations produced by different processing techniques. In 80% (the power) of those experiments, *P* was (<.05). The sample size calculation was performed by using a statistical software program (G*Power v3.1.9.2).

A stainless-steel master die was designed to simulate a maxillary first premolar prepared to receive monolithic ceramic crowns. The master die was milled to the following dimensions: 4.5-mm occlusogingival height, with a 1-mm uniform modified shoulder margin width and a total occlusal convergence of 6 degrees.[17,22,24,37] Impressions of the master die (n=40) were made with polyvinyl siloxane impression material (Express STD; 3M ESPE) and poured by using epoxy resin material (Polypoxy 700; CIC). Forty monolithic crowns were divided into 4 groups (n=10) according to processing technique and the tested materials: group EC, milled from IPS e.max CAD blocks by using a CAD-CAM system; group EP, pressed from IPS e.max Press ingots; group CC, milled from Celtra Duo blocks by using the same CAD-CAM system; and group CP; pressed from Celtra Press ingots.

For groups EC and CC, the epoxy resin die was scanned with an intraoral scanner (CEREC Omnicam; Dentsply Sirona). The monolithic crowns were designed with a CAD software program (CEREC Premium Software v.4.4; Dentsply Sirona) with a uniform wall thickness of 0.8 mm and a virtual cement space of 90 μm,[10] applied 1.0 mm above the margin. The virtual design obtained was sent to a 5-axis milling unit (CEREC inLab MC XL; Dentsply Sirona), where EC crowns (n=10) were fabricated from a milling block (LT A3/C14) and CC crowns (n=10) were fabricated from a milling block (LT A2/C14). Crystallization for the EC crowns and an additional firing for the CC crowns was performed in a calibrated furnace (Vacumat 40T; Vita Zahnfabrik) according to the manufacturers‘ instructions.

For groups EP and CP, 20 wax patterns were milled from a wax blank with the same design parameters of the previously constructed milled monolithic crowns. The wax patterns were divided into 2 groups (n=10) according to the tested materials, EP hot-pressed by using IPS e.max Press ingots (LT A1) and CP hot-pressed by using Celtra Press ingots (MT A2). All wax patterns were attached to the base of a silicon ring by using sprues of 3-mm diameter and 3-mm length and then invested by using a phosphate-bonded investment material (Bellavest SH; Bego). The silicone mold was heated in a ring furnace (Vulcan A 130; Dentsply Sirona) according to the manufacturers‘ instructions. Then, the mold was filled with IPS e.max Press ingots or Celtra Press ingots, and the crowns were hot-pressed in a pressing furnace (Programat EP 3010; Ivoclar Vivadent) according to the manufacturers‘ instructions. After cooling, the investment was removed by using 110-µm aluminum oxide particles (Cobra; Renfert) at 0.3 MPa pressure in a sandblasting device (Basic eco; Renfert). All crowns (n=40) were seated on the epoxy resin dies and evaluated for fit by using a silicone indicator paste (Fit Checker II; GC Corp). The crowns were then glaze fired in the calibrated furnace according to the manufacturers' instructions.

The epoxy resin dies, and the intaglio surface of the crowns were scanned by using an extra-oral scanner (Identica Hybrid; Medit) according to the manufacturer's instructions. The scanner has an accuracy of 7 μm and a resolution of 1.3 MP. The digital scans were converted into 40 standard tessellation language (STL) files for the evaluated crowns (scan data) and 40 reference STL files for the epoxy resin dies (reference data). The obtained STL files (n=80) were loaded into a 3D reverse engineering software (Geomagic Control X; Geomagic), whereas the reference data and scan data were superimposed over each other by using the best-fit algorithm method until the best alignment was achieved.[48]

The discrepancies between the external surface of the epoxy resin die and the intaglio surface of the crown were evaluated by using the 2D sections of the 3D superimposition analysis, whereas the deviation between the reference data and scan data for the entire area in the unit surface could be measured. The epoxy resin die was sectioned in the mesiodistal and buccolingual directions by using the function of multiple sections to obtain 2D sections. Sixteen reference points were selected on the mesiodistal and buccolingual sections and then classified into 4 measurement areas[36]: marginal discrepancy (MD), deep chamfer (DC), axial wall (AW), and occlusal area (OA). The marginal fit was represented by points 1, 8, 9, and 16, whereas the internal fit was represented with the remaining 12 points (Fig. 1).

For the discrepancy measurements, color difference images (n=40) were used to analyze the congruency of the epoxy resin dies and crowns. Dimensional differences between the epoxy resin dies and the crowns were computed for every data point captured during scanning. By using this method, for each superimposition, the root mean square (RMS) of the amount of deviation at each measurement point was recorded using the following formula[49]: RMS=$\sqrt{\frac{\sum_{i=1}^{n}(X_{1,i}-X_{2,i})^2}{n}}$ where $X_{1,i}$=the measuring point i on die; $X_{2,i}$=the measuring point i on crown, and n=the total number of measuring points. A total of 640 measurements were made for the 4 groups (2 sections×8 measurements×10 crowns×4 groups) (Fig. 2).

Numerical data were explored for normality by checking the data distribution and using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Marginal and internal discrepancy data showed non-parametric distribution. Data were presented as median, range, mean and standard deviation (SD) values. The Kruskal-Wallis test was used to compare between the groups. The Friedman test was used to compare between different areas of measurement within each group. The Dunn post hoc test was used for pair-wise comparisons when Kruskal-Wallis or Friedman tests are significant (α=.05). Statistical analysis was carried out by using a statistical software program (IBM SPSS Statistics, v23.0; IBM Corp).

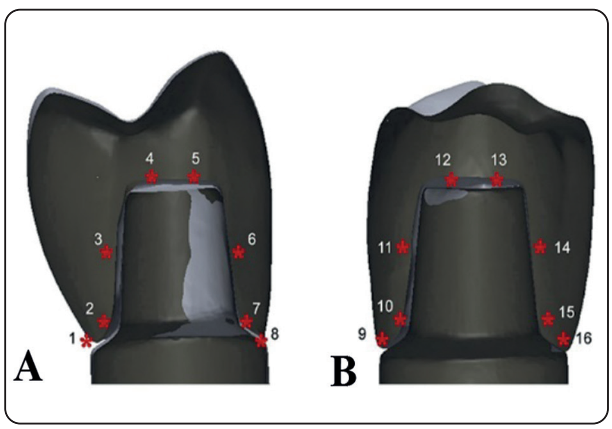

Fig. (1) Sixteen reference points on 2D sections. A, Buccolingual direction. B, Mesiodistal direction. 1, 8, 9, 16: marginal discrepancies. 2, 7, 10, 15: deep chamfer. 3, 6, 11, 14: axial wall. 4, 5, 12, 13: occlusal area.

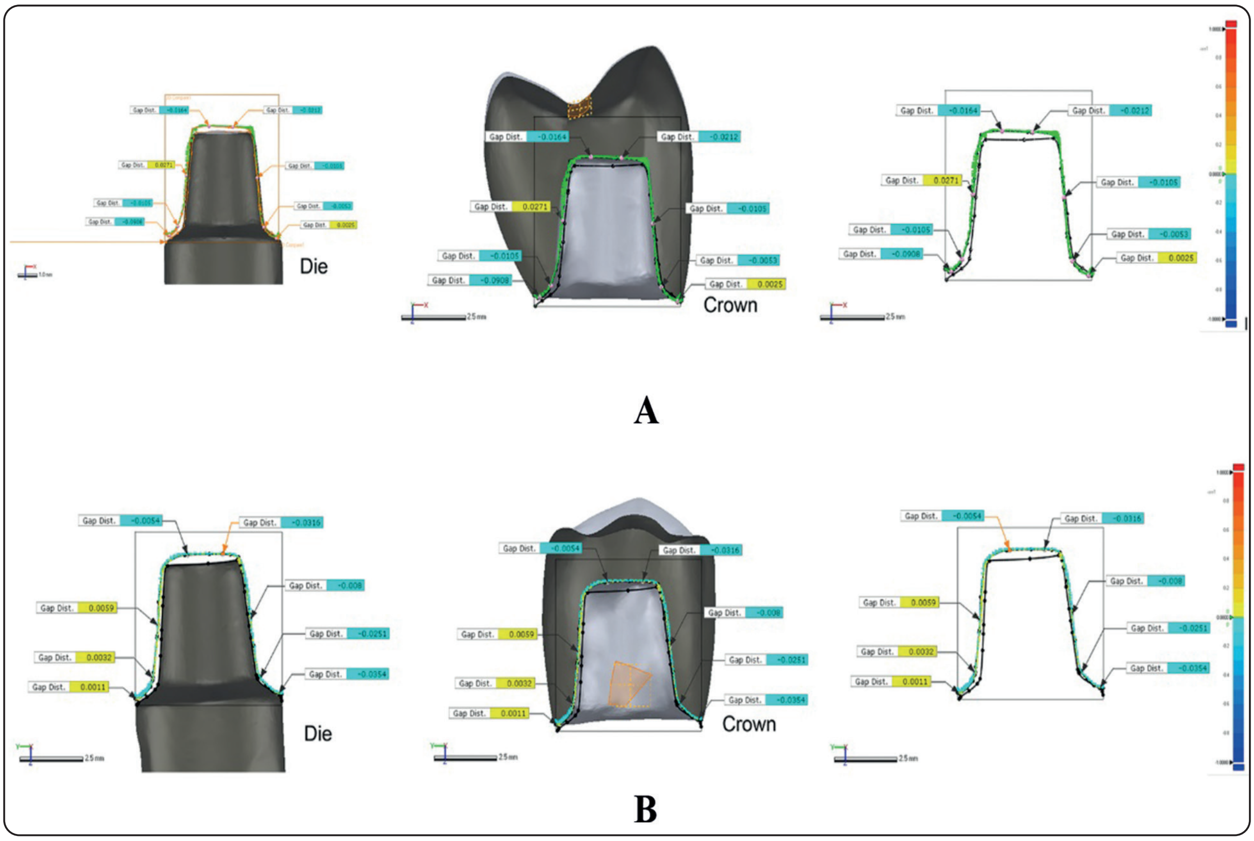

Fig. (2) Three-dimensional superimposition analysis of IPS e.max CAD crowns. A, Buccolingual direction. B, Mesiodistal direction.

TABLE (1) Materials evaluated

Trade Name	Manufacturer	Composition	Fabrication Technique	Lot No.
Celtra Press	Dentsply Sirona	58% SiO_2, 18.5% Li_2O, K_2O, 5% P_2O_5, 1.9% Al_2O_3, 10% ZrO_2, 2% CeO_2, 1% Tb_4O_7, pigments	Hot-pressing	16004070
Celtra Duo	Dentsply Sirona	58% SiO_2, 18.5% Li_2O, K_2O, 5% P_2O_5, 1.9% Al_2O_3, 10% ZrO_2, 2% CeO_2, 1% Tb_4O_7, pigments	CAD-CAM	16004681
IPS e.max Press	Ivoclar vivadent AG	57-80% SiO_2, 11-19% Li_2O, 0-13% K_2O, 0-11% P_2O_5, 0-8% ZrO_2, 0-8% ZnO, 0-10% other oxides, 0-8% coloring oxides	Hot-pressing	Y38211
IPS e.max CAD	Ivoclar vivadent AG	57-80% SiO_2, 11-19% Li_2O, 0-13% K_2O, 0-11% P_2O_5, 0-8% ZrO_2, 0-8% ZnO, 0-12% other oxides	CAD-CAM	X15204
KATANA wax	Kuraray Noritake	45-55% Paraffin wax	CAD-CAM	NB07

RESULTS

Descriptive statistics displaying the median, mean values, and standard deviations of the marginal and internal discrepancy measured in μm were recorded for all groups and are summarized in Tables 2 and 3. Concerning the marginal fit, statistically significant differences in the marginal discrepancy were found among all groups (P<.001). The CP group recorded the statistically significant highest marginal discrepancy mean value, followed by the EP and EC groups, while the lowest statistically significant marginal discrepancy mean value was recorded with the CC group. No significant differences were found between the EP and EC groups (P>.05) (Table 2). Concerning the internal fit, statistically significant differences in the DC, AW, OA discrepancy were found among all groups (P<.001) (Table 3). For the overall internal discrepancy regardless of the area of measurement, statistically significant differences in the internal discrepancy were found among all groups (P<.001). The EP group recorded the statistically significant highest internal discrepancy mean value, followed by the CP and CC groups, while the lowest statistically significant internal discrepancy mean value was recorded with the EC group. No significant differences were found between the EP and CP groups (P>.05) (Table 3). When the internal fit was compared among different areas of measurement within each group, no significant differences were found among the DC, AW, and OA for the EC group (P=.273). However, the differences among the different areas of measurement for the CP, CC, and EP groups were statistically significant (P<.001) (Table 4).

TABLE (2) Descriptive statistics of marginal discrepancies in μm (mean values ±SDs) for all groups.

Marginal Discrepancy	**CC (n = 10)**	**CP (n = 10)**	**EC (n = 10)**	**EP (n = 10)**	**x^2 value**	***P***	**Effect Size (Partial Eta Square)**
Median (range)	5 (0.9-13)	70 (46-89)	26 (14-45)	21(10-49)	32.056	<.001	.807
Mean ±SD	6 ± 4^{C}	67 ± 13^{A}	26 ± 11^{B}	27 ± 14^{B}			

Different superscript uppercase letters within same row indicate significant difference (P < .05). CC, Celtra Duo; CP, Celtra Press; EC, IPS e.max CAD; EP, IPS e.max Press; SD, standard deviation.

TABLE (3) Descriptive statistics of internal discrepancies in μm (mean values ±SDs) for all groups

Area of Measurement	**CC (n = 10)**	**CP (n = 10)**	**EC (n = 10)**	**EP (n = 10)**	**x^2 value**	***P***	**Effect Size (Partial Eta Square)**
Deep chamfer							
Median (range)	18 (13-36)	36 (16-49)	8 (3-21)	88 (67-113)	32.845		.829
Mean ±SD	19 ± 6^{C}	32 ± 10^{B}	9 ± 5^{C}	89 ± 16^{A}			
Axial							
Median (range)	19 (8-32)	10 (1-23)	8 (4-14)	98(72-139)	25.403		.622
Mean ±SD	17 ± 7^{B}	11 ± 7^{B}	9 ± 4^{B}	97 ± 19^{A}		<.001	
Occlusal							
Median (range)	53 (38-77)	137 (111-163)	14 (5-31)	13(5-37)	32.963		.832
Mean ±SD	55 ± 13^{B}	136 ± 15^{A}	15 ± 8^{C}	17 ± 11^{C}			
Overall							
Median (range)	31 (23-40)	59 (50-73)	10 (6-17)	69(50-86)	33.841		.857
Mean ±SD	30 ± 6^{B}	60 ± 7^{A}	11 ± 3^{C}	68 ± 10^{A}			

Different superscript uppercase letters within same row indicate significant difference (P<.05). CC, Celtra Duo; CP, Celtra Press; EC, IPS e.max CAD; EP, IPS e.max Press; SD, standard deviation.

TABLE (4) Descriptive statistics of internal discrepancies in μm at different areas of measurement (mean values ±SDs) within each group

Area of measurement	CC (n = 10)	CP (n = 10)	EC (n = 10)	EP (n = 10)
Deep chamfer				
Median (range)	18 (13-36)	36 (16-49)	8 (3-21)	88 (67-113)
Mean ±SD	19 ± 6^B	32 ± 10^B	9 ±5	89 ± 16^A
Axial				
Median (range)	19 (8-32)	10 (1-23)	8 (4-14)	98 (72-139)
Mean ±SD	17 ± 7^B	11 ± 7^C	9 ±4	97 ± 19^A
Occlusal				
Median (range)	53 (38-77)	137 (111-163)	14 (5-31)	13(5-37)
Mean ±SD	55 ± 13^A	136 ± 15^A	15 ±8	17 ± 11^B
x^2 value	15.2	20	2.6	15.2
P	.001	<.001	.273	.001
Effect size (w)	.760	1	.130	.760

Different superscript uppercase letters within same column indicate significant difference (P<.05). CC, Celtra Duo; CP, Celtra Press; EC, IPS e.max CAD; EP, IPS e.max Press; SD, standard deviation.

DISCUSSION

This in vitro study examined the effect of different processing techniques on the marginal and internal fit of monolithic lithium disilicate and ZLS restorations. The null hypothesis that the marginal and internal fit of monolithic lithium disilicate and ZLS restorations would not be affected by the processing techniques was rejected. The overall mean marginal discrepancy values were 67 ±13 μm for the Celtra Press group, 27 ±14 μm for the IPS e.max Press group, 26 ±11 μm for the IPS e.max CAD group, and 6 ±4 μm for the Celtra Duo group. These results indicate that the processing technique significantly affects the marginal fit of all tested groups.

In the present study, the milled crowns were fabricated by using a chairside milling unit. The improved marginal fit of these crowns could be attributed to the improved accuracy in capturing a digital impression and recent advances in CAD-CAM technique.[10] The wax patterns for pressed crowns can be fabricated by using conventional waxing, additive manufacturing (3D printing), and CAD-CAM techniques.[38] However, the main drawbacks of the conventional waxing technique include a high coefficient of thermal expansion, distortion during removal, and thermal sensitivity.[15] Homsy et al[4] concluded that the conventional waxing technique resulted in poor marginal and internal fit compared with the subtractive waxing technique. Therefore, in the present study, the wax patterns were milled from a solid blank to achieve consistent and more reliable results.

Multiple factors may affect the mechanical properties of lithium disilicate restorations, including chemical composition, microstructure, heat treatment, amount of nucleating agent, crystal morphology, size, and alignment.[18,50] It has been reported that the mechanical properties of ceramic materials are directly related to the degree of marginal chipping.[51] In the present study, the poor marginal fit of the Celtra Press crowns compared with other groups could be attributed to the high content of zirconium oxide in the glass matrix. The presence of the 10% zirconium oxide as a modifier and lithium metasilicate phase indicates that this ceramic was produced at a lower temperature resulting in an incomplete crystallization of lithium metasilicate into lithium disilicate.[50] This resulted in increased material's viscosity and limited flow[52]; thus, predisposing the crowns to poor fitting margins.

In the present study, the improved marginal fit of Celtra Duo crowns compared with IPS e.max CAD crowns could be attributed to the fact that the Celtra Duo crowns were milled from a fully crystallized block, whereas the IPS e.max CAD crowns were milled from a partially crystallized block resulting in more shrinkage after heat treatment due to densification of the ceramic material; thus, increasing the marginal discrepancy in the IPS e.max CAD crowns. This was consistent with the results of Gold et al,[30] who reported a mean marginal discrepancy value of 42 μm for the unfired IPS e.max CAD and 57 μm for the fired IPS e.max CAD. Conversely, Zimmermann et al[31] reported no significant differences between the marginal fit of Celtra Duo crowns fabricated by using a CAD-CAM system before and after firing. Another possible explanation for the improved marginal fit of the Celtra Duo crowns could be attributed to the zirconia-reinforcement resulting in slightly improved edge chipping damage in ZLS compared with lithium disilicate ceramics; however, edge chipping is still a technical challenge in milling of both glass-ceramics.[5]

The obtained results for the IPS e.max crowns were consistent with previous studies that reported no significant difference in the marginal discrepancy between the IPS e.max CAD and IPS e.max Press crowns.[10,40] Different studies reported better marginal fit of pressed crowns compared with milled crowns.[13,14,38,42] Anadioti et al[41] reported a smaller mean marginal discrepancy value of 48 μm for the IPS e.max Press crowns compared with 84 μm for the IPS e.max CAD crowns. Conversely, other studies reported poor marginal fit of pressed crowns compared with milled crowns.[43-47] Mostafa et al[44] reported a lower mean marginal discrepancy value of 33 μm for the IPS e.max CAD crowns compared with 51μm for the IPS e.max Press crowns.

The overall mean internal discrepancy values were 68 ±10 μm for the IPS e.max Press group, 60 ±7 μm for the Celtra Press group, 30 ±6 μm for the Celtra Duo group, and 11 ±3 μm for the IPS e.max CAD group. The differences in the internal fit between the milled and pressed groups could be explained by the softer nature of wax resulting in more material removal at sharp internal angle of the premolar preparation during milling.[18] In the present study, the improved internal fit of the IPS e.max CAD crowns compared with Celtra Duo crowns could be attributed to the machinability of these ceramics. The ZLS ceramics displayed poorer machinability with higher tangential forces compared with lithium disilicate ceramics confirming that this ceramic is the most difficult material to machine among all glass-ceramics.[5] The obtained results for the IPS e.max CAD crowns were in conflict with those of Miwa et al,[43] who reported higher mean marginal discrepancy values than this study. The difference could be attributed to the cementation and measurement techniques used in their study.

In the present study, the 2D sections of the 3D superimposition analysis were used to provide a 3D analysis of marginal and internal discrepancies by superimposing the scanned internal surface of the crown over the scanned external surface of the epoxy resin die.[36] This resulted in more clinically relevant marginal and internal discrepancies without the loss of data because of specimen sectioning or destruction.[16] However, studies investigating the precision of 2D sections of 3D superimposition analysis are relatively rare.

The results obtained in this study revealed excellent marginal and internal fit when compared with that of other studies; however, data about the marginal and internal fit of ZLS restorations are scarce. Limitations of the study included that the crowns were not cemented, and the method used to measure the discrepancies cannot be used to simulate the clinical conditions. Further clinical studies are recommended to substantiate the results.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Monolithic zirconia-reinforced lithium silicate crowns processed by using the CAD-CAM technique showed significantly better marginal fit than other groups.
2. Monolithic lithium disilicate crowns processed by using the CAD-CAM technique showed significantly better internal fit than other groups.
3. The hot-pressing and CAD-CAM techniques produced monolithic lithium disilicate and zirconia-reinforced lithium silicate crowns with marginal discrepancy values of less than 120 μm and internal discrepancy values of less than 70 μm, within the clinically acceptable range.

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