Evaluation of Marginal and Internal Adaptation of Endocrowns Fabricated from Three Different CAD/CAM Materials

Keywords

Marginal Adaptation
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ABSTRACT

Objectives: This in vitro study aimed to compare the internal and marginal discrepancies of endocrowns fabricated from different ceramics before and after adjustment. Methods and Materials: Thirty-six endocrowns were fabricated from lithium disilicate (IPS e-max CAD), zirconia-reinforced lithium silicate (Suprinity), and polymer-infiltrated ceramic network (Enamic) using a CEREC intraoral scanner and milling unit. A reference point matching scan protocol was used to measure the endocrowns fit. The mixed ANOVA was used to analyze the data, and α=0.5 was considered as the significance level. Results: There was no significant interaction between the fabrication materials and adjustment (P>0.05). Type of the materials did not change discrepancies at cavosurface, line angle, cavity wall, and pulpal floor (P>0.05). On the contrary, adjustment significantly decreased the discrepancies at all four sites (P<0.001). There were significant differences between every two sites before adjustment (P<0.001). After adjustment, except for cavosurface and cavity wall (P=0.058), the differences between other sites remained significant (P<0.001). Conclusions: IPS e-max CAD, Suprinity, and Enamic endocrowns were not significantly different regarding internal and marginal discrepancies. However, it is suggested that these materials be adjusted to fall in a clinically acceptable range to minimize the risk of caries and periodontal disease.

INTRODUCTION

Rehabilitation of endodontically treated teeth with excessive destruction is challenging due to the low mechanical resistance of the remaining tooth structures.[1] Conventionally, these teeth are restored with intracanal posts that provide retention for coronal structures. Despite being successful, intracanal posts weaken the tooth structure due to excessive canal preparation.[2] To compensate this drawback, endocrowns have been introduced in 1995.[3] Endocrowns are monoblock core and crown restorations which use the pulp chamber and surrounding walls for macro retention and adhesive bonding for micro retention. Endocrowns conserve root structure by eliminating the need for canal preparation and provide one-piece restorations which are resistant to fractures, stress, and dislodgement.[4,5] These restorations are clinically reliable for restoring severely damaged teeth and are resistant to unfavorably occlusal forces such as bruxism.[6] A recent systematic review reported that endocrowns are more resistant to fracture than posts and cores, direct composite resins, and inlay/onlay restorations. Moreover, besides acceptable fracture resistance, if fabricated from reinforced-ceramics, endocrowns can provide desired esthetics as well.[7]

The breakthrough in the application of endocrowns happened when the acceptable survival rate of adhesively placed CEREC models was confirmed in several studies.[8,9] However, similar to any newly developed and evolving technique, computer-aided design/computer-aided manufacturing (CAD/CAM) endocrown restorations still need to be evaluated for their potential deficiencies. Therefore, determining factors such as restoration fit, microleakage, and fracture resistance should be investigated to improve the clinical success rate.[10-12] These factors can be significantly influenced by fabricating materials. CAD/CAM endocrowns can be manufactured from a variety of materials such as composite resins, reinforced ceramics, sintered-alumina, and hybrid ceramics.[11,13] The most frequently used materials are ceramics due to their esthetic advantages. Lithium disilicate glass-ceramics such as IPS e-max CAD has been broadly used over the past ten years for manufacturing CAD/CAM restorations.[13-15] However, there are still some inherent drawbacks regarding its application,[16] that manufacturers try to address by developing new materials such as zirconia-reinforced lithium silicate (ZLS) and polymer-infiltrated ceramic network (PICN).

Vita Suprinty is a ZLS which is enriched by zirconia (ZrO_2, 10 wt%).[17] This new glass ceramic combines the strength of zirconia with the translucency of glass ceramics. The lithium silicate crystals in Suprinity have a mean size of 0.5 to 1 μm which is six times smaller than lithium disilicate crystals. A smaller crystal size in the microstructure allows ZLS to be polished more efficiently than lithium disilicate ceramics.[18] ZLS has higher mechanical properties such as fracture toughness, flexural strength, elastic modulus, and hardness compared with lithium disilicate glass-ceramics; however, lithium disilicate has lower brittleness index which indicates superior machinability compared to ZLS.[19] Enamic is a PICN that composed of a feldspathic ceramic matrix (86 wt%) which is infiltrated by a polymer (14 wt%). This novel CAD/CAM material has a lower flexural modulus and Vickers hardness than lithium disilicate which result in better machinability.[10,20] Elastic modulus of Enamic restorations (30 GPa,) is closer to the reported value for dentine (20 Gpa) compared to other ceramics.[21,22] That being said, Enamic is more suitable for the posterior regions due to the poor optical properties.

Any fixed prosthetic restoration should adapt perfectly to the prepared teeth. High marginal accuracy and an adequate internal fit are the major predictors of successful clinical performance.[23] A poor-fitting restoration leads to cement dissolution and micro-leakage which in turn results in recurrent caries and periodontal disease.[24] Therefore, it is important to determine the most appropriate type of material for fabricating the endocrowns to have minimal marginal and internal discrepancies.[25] Also, previous studies showed that adjusted and none-adjusted restorations fabricated from different materials demonstrate different internal and marginal discrepancies.[26,27] Therefore, the aim of this *in vitro* study was to compare the marginal and internal discrepancies of endocrowns made from lithium disilicate (IPS e-max CAD), ZLS (Suprinity) and PICN (Enamic) before and after adjustment. The null hypotheses were that the type of material and adjustment would not influence the internal and marginal discrepancies.

MATERIALS AND METHODS

SPECIMEN PREPARATION

One acrylic resin maxillary upper first molar (Nissin Dental Prod. Inc.) was used as the master model. The tooth was mounted on an aluminum base with a star configuration which served as a geometric index during the measurements. The tooth was secured by a fast-cure acrylic resin (Fastray, Harry J. Bosworth Co.) so that it was embedded up to 2 mm below the cementoenamel junction (CEJ). Before any preparation, the optical impression of the master model was made using a digital intraoral scanner (CEREC Omnicam; Sirona Dental System), and the anatomy and nuances of the occlusal surface were copied. After that, a diamond-coated stainless steel bur (806314156012, Jota) was used to prepare the access cavity. Cavity preparation was followed by removing the undercuts of the pulp chamber. The internal taper of 11-22 degrees was obtained by aligning the axial walls using a round-end tapered diamond-coated stainless steel bur (G845KR, Edenta) held perpendicular to the pulpal floor. Next, the occlusal surface was reduced 3 and 5 mm from buccal and lingual cusps, respectively, and the intracoronal height (the distance from the pulpal floor to the inner margin of the occlusal surface) of 6 and 3 mm on the buccal and lingual surfaces were obtained. All surfaces were smoothed using finishing bur (806314141014, Jota). The completed prepared tooth was checked by two clinicians who had not performed the preparations.

DIGITAL IMPRESSION AND FABRICATION

The optical impression was made of the prepared tooth using an intraoral scanner (CEREC; Omnicam Sirona Dental System) to produce a die scan *(Figure 1)*. Designing the restorations was carried out using the CAD Software (CEREC premium SW v.4.0; Dentsply Sirona) using the biogeneric copy mode to transfer the original scan of the occlusal surface of the master model to the restorations. A 60 μm distance was considered for the spacer and marginal adhesive gap. After designing and assessing the restorations in milling preview, endocrowns were fabricated by a milling unit (CEREC MC XL, Dentsply Sirona) using 12s step and cylinder-pointed burs with a milling mode set to fine. The milling burs were replaced after every eight cycles.[28] Twelve endocrowns from each group of ceramics were fabricated: ZLS (Suprinity, VITA Zahnfabrik H. Rauter GmbH & Co.KG), PICN (Enamic, Zahnfabrik H. Rauter GmbH &

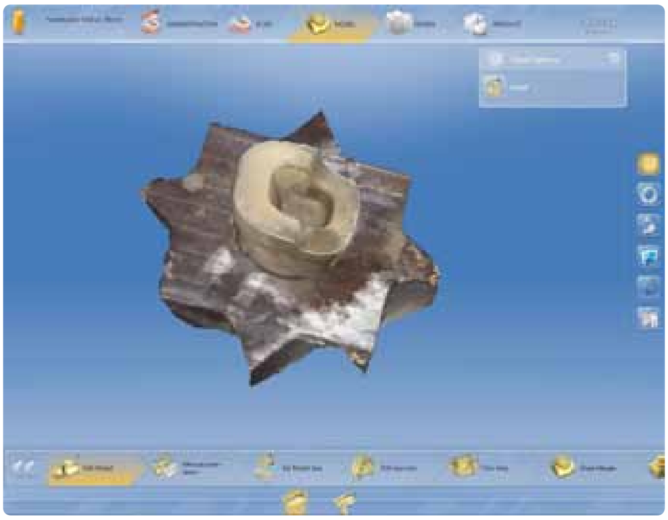

Figure 1: The scanned image of the prepared tooth (master die)

Figure 2A: Hex-shaped cylinder index fixed on the occlusal surface of the restoration

Co.KG), and lithium disilicate (IPS e-max CAD, Ivoclar Vivadent AG). Suprinity and IPS e-max CAD restorations needed an additional crystallization procedure. Therefore, these restorations were fired in a furnace (CEREC speed fire, Dentsply Sirona) to complete the crystallization. Overall, 36 endocrowns were obtained.

EVALUATING MARGINAL AND INTERNAL FIT

Marginal and internal discrepancies were measured both before and after adjustment. Restorations were sat three times on the master die before any adjustment to find the best seating pattern. For adjusting the restorations, a fine diamond bur (JOTA AG) was used under magnification of a dental loop (HDL 2.5 Macro, Orascoptic). Adjustment continued until the achievement of the best seating possible. An expert calibrated clinician checked the passivity of fit using a fit-checker (Kettenbach). Among the three measurements, the one with the least thickness was used, and the corresponding seating pattern was considered to have the best fit. A reference point matching scan protocol was used to measure the internal and marginal discrepancies. A non-contact triple scanner (ATOS Core 5Mp 80mm; Rev.02; GOM) working with blue-light technology was used for scanning. Four scans were obtained as follow: 1. the master die (prepared tooth) attached to the aluminum base as it was seen in Figure 1 2. the restorations sat on the master die in a correct position fixed by light body silicon (Speedex, Colten) 3. hex-shape cylinder index was fixed on the occlusal surface of restoration, and all parts including base, tooth, restoration, and hex-shape index assembly were scanned *(Figure 2A* and *B*) 4. the restoration was removed from the tooth by the index being in its place, and then the inner and outer surfaces of the endocrown and hex-shape index were scanned *(Figure 2C*).

The GOM software (GOM inspect v7.5, GOM mbH) was used to analyze the dataset of each specimen using the reference model matching technique. Mesh data were transferred into

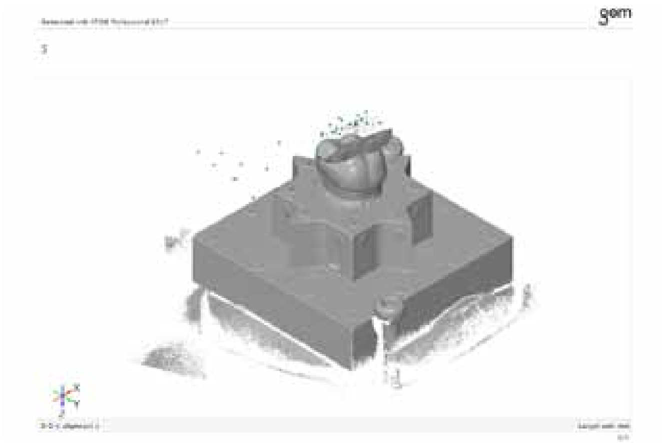

Figure 2B: Scan of the restoration and the hex-shaped cylinder index fixed on tits occlusal surface

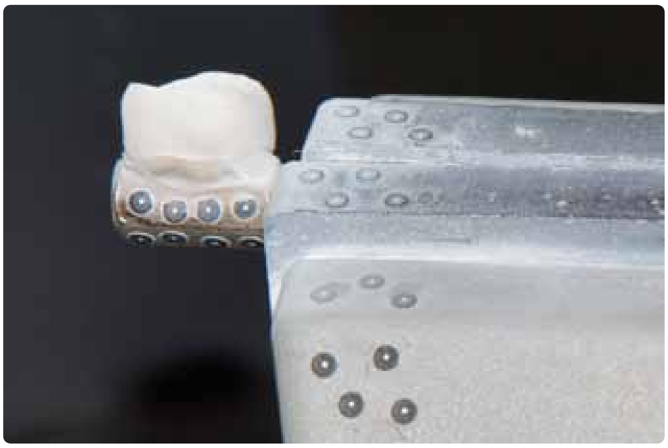

Figure 2C: The restoration and hex-shaped cylinder removed from the tooth a defined coordinate system by 3-2-1 alignment, which uses six 3D points to describe the coordinate. Intersecting edges of the star in the base served as these 3D points (*Figure 3*). Each model was digitally sectioned mesiodistally and buccolingually, and measurements were done in each of these two sections. Overall 14 points were measured in each specimen (*Figure 4*). In this study, the vertical marginal discrepancies and internal discrepancies were measured at the four sites: cavosurface, line angle, cavity wall, and pulpal floor. All analyses of discrepancies were performed by one of the authors who was blind to the restoration groups.

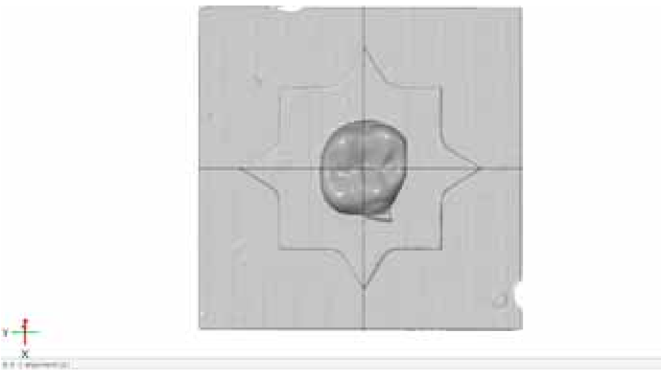

Figure 3: Buccolingual and mesiodistal sections across intersecting edges of the star in the base

SAMPLE SIZE CALCULATION

The sample size was calculated using Gpower v.3.1.9 software for Mixed-ANOVA.29 Considering an effect size of medium to large=0.30, α level=0.05, statistical power (1-β)=0.85, number of groups=3, number of measurements=2 the sample size of n=36 was sufficient for within-factor and within-between interaction analysis.

DATA ANALYSIS

All of the analyses were performed using the Statistical Package for the Social Sciences (SPSS, IBM Corp. Version 22.0). The quantitative data were presented by the mean and standard deviation. The Kolmogorov-Smirnov test was used to verify the normality of the collected data. Descriptive statistics including mean and standard deviation were reported for each group of material before and after adjustment. Mixed ANOVA was used to compare internal and marginal discrepancies between the three fabrication materials (between-subject factor), before and after adjustment (within-subject factor), and the fours sites, namely cavosurface, line angle, cavity wall, and pulpal floor (within-subject factor). A P value of less than 0.05 was considered to be statistically significant.

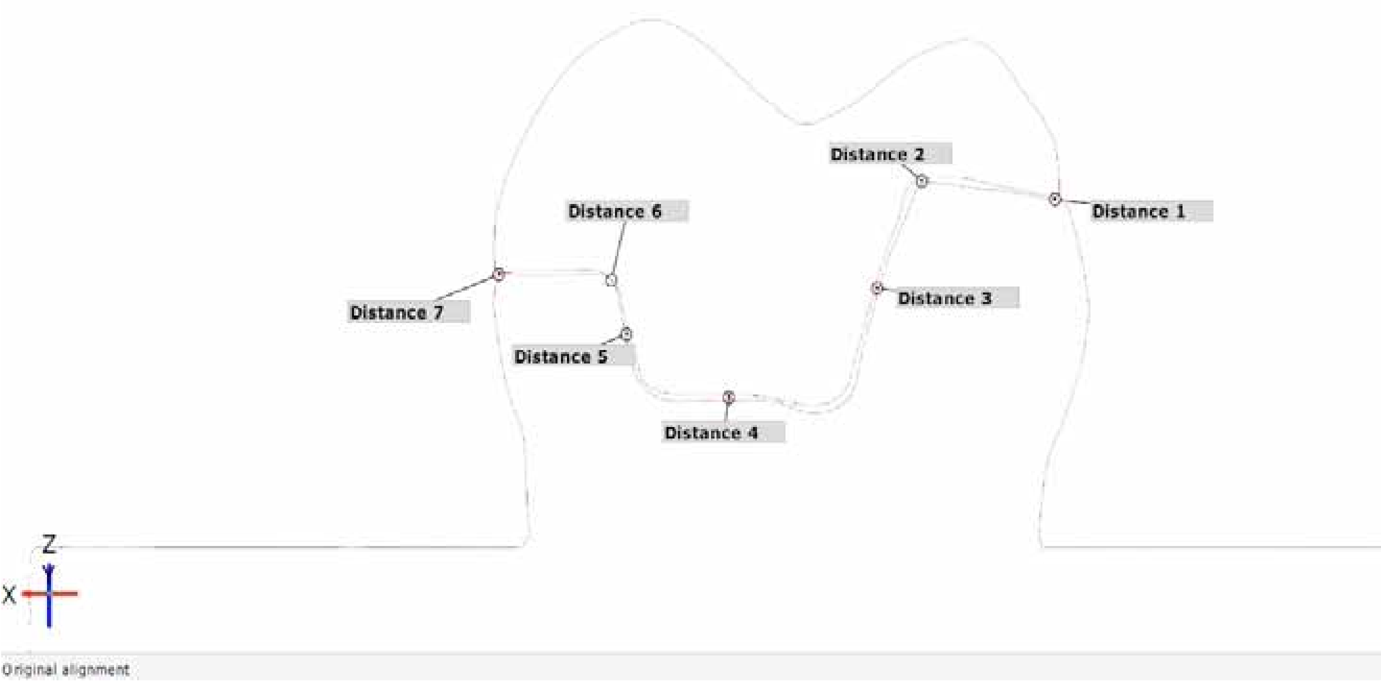

Figure 4: Measurement points in buccolingual section: cavosurface (Distance 1, 7), line angle (Distance 2, 6), cavity wall (Distance 3, 5), and pulpal floor (Distance 4)

Table 1. Mean (standard deviation) of discrepancies (µm) for the three materials at four sites before and after adjustments.

Site		IPS e-max CAD	Enamic	Suprinity	P Value
Cavosurface	Before adjustment	155.20 (47.38)	153.37 (34.21)	190.20 (84.26)	0.73
	After adjustment	59.27 (29.19)	61.75 (31.13)	60.56 (13.27)	
Line angle	Before adjustment	97.00 (24.38)	98.08 (27.21)	105.83 (47.31)	0.43
	After adjustment	53.58 (28.18)	51.70 (28.20)	40.68 (13.38)	
Cavity wall	Before adjustment	46.70 (9.28)	50.27 (15.05)	46.37 (13.62)	0.24
	After adjustment	68.12 (17.46)	75.89 (24.63)	67.93 (17.70)	
Pulpal floor	Before adjustment	206.08 (39.05)	181.83 (34.76)	225.20 (86.34)	0.19
	After adjustment	99.70 (17.13)	87.50 (45.67)	89.00 (14.12)	

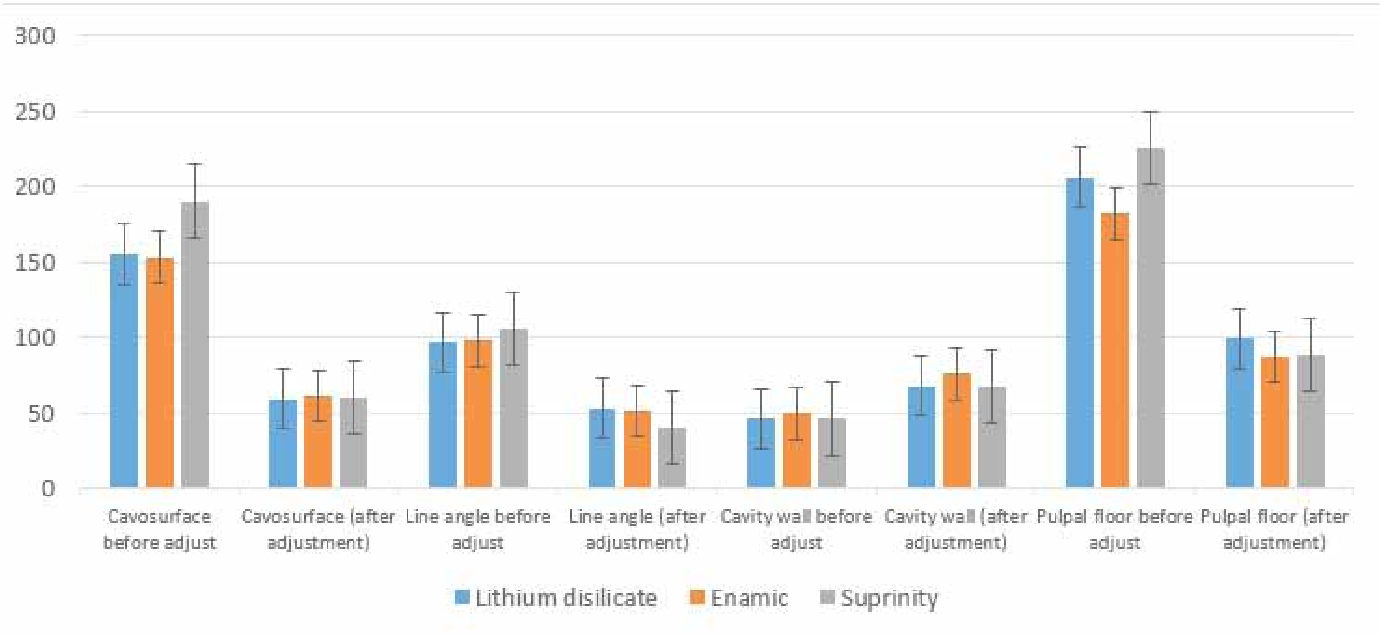

Figure 5: Mean and standard error of discrepancies (µm) between the endocrowns and master model at the four studied sites before and after adjustment

RESULTS

Although the discrepancies for Suprinity changed more than IPS e-max CAD and Enamic after adjustment, the two-way ANOVA showed that there was no significant interaction between type of the materials and adjustment at cavosurface (P=.70), line angle (P=.81), cavity wall (P=.92), and pulpal floor (P=.61). The adjustment itself had a significant impact on discrepancies in each of the four sites (P<.001). On the contrary, the type of material could not alter the results meaningfully at cavosurface, line angle, cavity wall, and pulpal floor *(Table 1)*.

There was no interaction between the type of material and evaluated sites before (P=.114) and after (P=.407) adjustment. That being said, there were significant differences between every two sites before adjustment (P<.001). After adjustment, except for cavosurface and cavity wall (P=.058), the differences between other sites remained significant (P<.001). The results from the four-scan protocol revealed that the discrepancies in the pupal floor were higher than other sites for all three fabrication materials before and after adjustment (P<.001). The cavity wall was the only site that showed higher discrepancies after adjustment *(Figure 5)*.

DISCUSSION

Based on the results, the null hypotheses that the type of material and adjustment would not change the internal and marginal discrepancies were partially rejected. While the type of material could not change the discrepancies, adjustment resulted in more accurate internal and marginal fit. Up to the authors' knowledge, no study has yet compared the fitting accuracy of endocrown restoration fabricated from IPS e-max, Suprinity, and Enamic with each other. These materials were selected due to their CAD/CAM applicability, routine use, and distinct microstructure differences. Several factors may play a role in the final internal and marginal discrepancies such as CAD/CAM device, preparation design, measuring method, and type of the master model,[12,30,31] which were matched in this study. Therefore, if there were differences in the marginal and internal fit, they could be stemmed out from the type of the material and CAM procedure that were not matched.

It was found that mechanical properties of Suprinity such as fracture toughness, flexural strength, elastic modulus, hardness, and material wear were higher than IPS e-max CAD.[19] However, the brittleness index, which is the ratio of hardness to the fracture toughness and can determine the machinability of the ceramics,[32] was also higher for Suprnity (2.84 ±0.26 μm−1/2) than IPS e-max CAD (2.72 ±0.17 μm−1/2).[19] On the contrary, Enamic has shown weaker mechanical properties (except for resilience) than IPS e-max CAD.[33,34] Nevertheless, Enamic provides both strength and elasticity as its mechanical properties are in the range of the natural teeth and can be considered a desired material for restoring the damaged teeth.[35] Brittleness index of Enamic is claimed to be 1.67 μm−1/2,[36] which is lower than most of the values that have been reported for the IPS e-max in the literature,[19,37] Moreover, when evaluated directly with the scanning electronic microscope (SEM) and digital microscope, Enamic was more machinable[38] and less rough on the margins[34] than IPS e-max CAD. Higher machinability, less edge chipping, and less edge roughness can lead to a higher marginal fit.

Based on the mechanical properties, it was anticipated that Enamic would result in the lowest and Suprinity in the highest marginal and internal discrepancies. However, there were no significant differences between the materials in this study. These results might have been obtained because brittleness index of all the materials was below 4.3 μm−1/2 which is the acceptable threshold for machinability;[32,39] therefore, all restorations could be milled accurately. The MC XL milling unit was used in this study which has been shown to be as accurate as the CEREC 3 milling unit for forming the marginal gap.[40] Another reason for the insignificant differences could be due to the high flexural strength of Suprinity and IPS e-max CAD which made them resistant to the chipping and crack propagation and compensated the unfavorable effect of hardness and brittleness index.[20] Besides that, new sets of burs were used for each material; It has been shown that bur wear can affect the cutting efficiency of the milling device, particularly when the hard materials are fabricated. It is suggested the burs to be changed after every eight cycles.[28] Moreover, according to the previous studies, the design of the finish line, which was a circumferential shoulder in this study, could not change the obtained results as well.[41]

In this study, the values recorded for all the three fabrication materials at the cavosurface before the adjustment were above 120 μm, which is clinically accepted threshold[42] but after the adjustment fell below 120 μm. Regarding the internal fit, no standard cut-off point has been defined for clinical success and longevity of the restorations, but the values between 23 and 230 μm have been reported in the literature.[43] All of the values for internal discrepancies fell within this range after adjustment and did not exceed 100 μm. These findings suggest the necessity of the adjustment for all three materials in the clinical settings. Moreover, the pulpal floor showed higher discrepancies than cavosurface, line angle, and axial wall for all the fabrication materials both before and after adjustment, which agrees with the results of previous studies.[12,27,44] The reason behind the high discrepancies at the pulpal floor may be due to the overmilling since milling instruments are available in limited diameters and flat surfaces such as occlusal and pulpal floors may not be milled accurately.[27] Also, limited optical depth of the scanner resulting in a blurred image on the pulpal area can be considered another reason behind the high discrepancies on the pulpal floor. Another interesting finding was that discrepancies between the restoration and cavity wall increased unlike the other sites after adjustment, probably because a layer from the axial walls were removed during the adjustment. Although insignificant, the Suprinity showed the most decrease in discrepancies after the adjustment which could be due to its smaller crystals which in turn resulted in higher polishability.[35,45]

The measuring method seems to be one of the most influential parameters that impact the reported results.[12,31] In this study, a reference matching scan method was used to evaluate the restoration fit. The precursor of this method, the triple scan, was described in previous studies.[46,47] However, to improve the accuracy of the triple technique, a hex shape matching index was served as a reference point. Due to the three-dimensional nature of this evaluation, it was not beneficial to compare the results with studies used 2D techniques. Furthermore, it is not well-meaning to compare the results with studies which evaluated the fitting accuracy of restorations other than endocrowns such as full crowns, inlays, and onlays. Endocrowns have more complex design than other restorations, mainly related to the internal angles, which may be more challenging to be fabricated by the CAD/CAM milling units due to the limited instrument geometries. However, it is noteworthy to mention that one study which used the same materials as ours reported different results. Yildirim *et al*. fabricated single crowns and showed that Suprinty had lower discrepancies than IPS e-max CAD, and Enamic less than both.[48]

Until now, few studies have reported on the internal and marginal discrepancy of endocrowns considering material types, and the combination of materials used in previous studies were different from ours. In a recent study, ZLS (Celtra Duo), leucite-reinforced silicate ceramic (Empress CAD), and resin nano-ceramic (Lava Ultimate;) were assessed.[27] The results showed that Celtra Duo had the worst marginal discrepancy (182.3±24.0 µm, without adjustment) which is similar to the before-adjustment discrepancy of Suprinity in this study (190.20±84.26.27 µm). The possible reasons for the similarity can be attributed to using materials from ZLS family (Celtra Duo vs. Suprinity), and almost similar cement thickness (80 µm vs. 60 µm). The study by Darwish *et al*. [31] showed that cavity depth and divergence did not affect the endocrowns internal discrepancies, and Lava Ultimate resulted in more accurate endocrowns than IPS e-max CAD. However, in Darwish *et al*. study, the values recorded for IPS e-max were considerably higher than the highest value recorded in our study both before (600.80 ± 131.99 µm vs. 206.08±39.5) and after adjustment (476.00 ± 56.91 µm vs. 99.70±17.33 µm). The main reason for the differences can be due to the different measuring methods used for assessing the fitting accuracy. Darwish *et al*. used cone beam computed tomography (CBCT) imaging to measure the internal discrepancy. It has been reported that CBCT results in an about 200 µm overestimation compared with other techniques such as x-ray microtomography (micro-CT).[49] In a study by Gaintantzopoulou *et al*.,[30] micro-XCT was used for evaluating the fitting accuracy, but it was not mentioned if the restorations were adjusted or not. That being said, considering the same cavity depth (3 mm) but different spacer (0 vs. 60 µm) and preparation design, both before and after adjustment values for the present study were lower than Gaintantzopoulou *et al*. study.

Some notes should be considered when interpreting the result of this study. First, the master die used in this study could be affected by attrition as a result of multiple fitting procedures by different restorations. Second, although the cement space was considered 60 µm digitally, transferring this value with the same precision to the milled restorations may be questionable. Parameters related to milling units such as the drill diameter, milling material, and application time, as well as the preparation design of the master model, can affect the precision.[50] Rotary instruments with smaller diameters can yield improved details and more accurate restorations. Moreover, only one cement thickness was evaluated, but the internal fit may be influenced by altering the spacer thickness. Third, measuring the internal gap was done before cementation, which disregards the influence of the luting procedure and cement type on the internal gap. Fourth, the *in vitro* nature of this study prevents extending results to clinical settings, and whether these marginal and internal discrepancies are clinically acceptable remains unknown. It is also suggested that in future studies different CAM procedures to be applied for different materials. CAM parameters such as instrument diameter and milling paths as well as 4-axis and 5-axis milling can affect the accuracy of the final restorations;[51] applying specific settings for each material can improve the results.

CONCLUSION

Within the limitations of this study, the restorations fabricated from IPS e-max CAD, Enamic, and Suprinity were not different regarding the marginal and internal fit before the adjustment. After the adjustment, the restorations fitted more accurately, and the differences between the materials were further diminished. When the internal and marginal fit are similar, other properties of materials such as esthetic, fracture resistance, wear resistance, and microleakage should be considered for fabricating the CAD/CAM endocrowns.

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