Comparative Evaluation of the Internal and Marginal Adaptations of CAD/CAM Endocrowns and Crowns Fabricated from Three Different Materials

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Purpose: To evaluate and compare the internal and marginal adaptations of chairside CAD/CAM (CEREC) endocrowns and crowns fabricated from lithium disilicate glass-ceramic (IPS e.max CAD), zirconia-reinforced lithium silicate glass-ceramic (VITA Suprinity), and hybrid ceramic (VITA Enamic). Materials and Methods: Dental models of the two first maxillary molars were selected. One was prepared for an endocrown, and the other for a standard all-ceramic crown. A total of 72 CAD/CAM restorations, including 36 endocrowns and 36 crowns made of IPS e.max CAD, VITA Suprinity, and VITA Enamic (n = 12 each), were fabricated. Discrepancies were measured in the buccal, mesial, lingual, and distal aspects of three sites (marginal, mid-axial wall, and occlusal/floor) using the non-contact ATOS scanner. Statistical analysis was performed using MANOVA and between-subject effects tests (α = .05). Results: Mesial axial wall discrepancy was significantly lower in endocrowns compared to occlusal discrepancy in crowns, while distal axial wall discrepancy was significantly higher. Moreover, floor discrepancy was found to be significantly lower in endocrowns compared to crowns. However, type of material had no significant effect on any kind of discrepancy. Conclusion: The marginal and internal adaptation values were within a clinically acceptable range for both kinds of restoration and all three materials. However, restoration type (crown vs endocrown) was significantly different in the mesial and distal axial wall and occlusal/floor discrepancies, regardless of restoration material.


The functional and esthetic restoration of severely damaged endodontically treated teeth is still a clinical challenge.1 A typical protocol to restore these teeth is to use posts and cores and a full-coverage crown. However, with the development of adhesive dentistry, this goal is easily made feasible by an endocrown.2 An endocrown is a one-piece, post-free ceramic restoration that assemble the crown and the pulp cavity part in one component.3 In comparison to the classical post-and-core approach, this modern alternative treatment modality offers several advantages, such as more preservation of tooth structure, less need for sufficient interocclusal space, reduced risk of root fracture, and possibility of retreatment in case of endodontic failure. Moreover, both the number of appointments and the cost decrease, as there is no need for the many technical steps for post cementation, core build up, and potential crown lengthening.4,5

A systematic review done by Wittneben et al6 revealed an overall survival rate of 91.6% after 5 years for computer-aided design/computer-assisted manufacture (CAD/CAM) single-tooth restorations, which is considered clinically similar to conventional restorations. However, the lowest rate was found in endocrowns (82.3%). This admits the concern that endocrowns might not always represent a predictable

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alternative treatment option, as Bindl et al7 and Otto and Mörmann8 declared regarding premolar endocrowns. In contrast, there are some studies that have reported a survival rate of > 90% for endocrowns, showing no significant differences between premolars and molars.4,9 However, as the endocrown concept was introduced about two decades ago, there are not sufficient long-term study results with large sample sizes on endocrown survival and success rates.

Although endocrowns have both macro- and micro-mechanical retention,3 their retention mainly relies on bonding; so, it is essential to use materials that can be bonded to tooth structure.10

CAD/CAM technology has witnessed widespread advances in materials over the past 10 years.5 Glass- and composite-based materials are the main categories of adhesive ceramics that can be used with CAD/CAM technology. Glass-based materials are nonmetallic inorganic ceramic materials that contain the glass phase. Lithium disilicate and its derivatives, including zirconia-reinforced lithium silicate (ZLS), are categorized into this group. Composite-based materials are categorized into different subgroups—polymer-infiltrated ceramic network (PICN) and composite resin—according to their chemical composition. The first is composed of a dual network: a dominant ceramic network infiltrated by a polymer network. The latter is comprised of materials with an organic matrix highly filled with ceramic particles.11

IPS e.max CAD (Ivoclar Vivadent) is a lithium disilicate available in partially crystallized block form that proceeds with crystallization at 850ºC after milling with 0.2% shrinkage. VITA Suprinity (VITA Zahnfabrik) is a ZLS ceramic enriched with highly dispersed zirconia (10% by weight) and is available in a partially crystallized form that contains lithium metasilicate crystals; therefore, it can be milled easily.12 Adding zirconia results in a round and slightly elongated crystalline structure with an average crystal size of 0.5 µm compared to the needle-shaped, interlocked, randomly oriented crystals with an average size of 1.5 µm found in lithium disilicate ceramic.13 VITA Enamic (VITA Zahnfabrik) is a PICN material with 14 by weight polymer and two distinct interpenetrating phases. This material was introduced to overcome the high modulus elasticity, hardness, and brittleness of glass-matrix ceramics. A more favorable brittleness index of this material makes it a suitable option for milling units compared to lithium disilicate and ZLS materials.14 Furthermore, these hybrid ceramics require less preparation of the tooth structure to provide sufficient durability.15

The marginal adaptation of indirect restorations is an important factor for clinical long-term success. The presence of a marginal gap can lead to dissolution of the luting agent, secondary caries, and periodontal disease.16–18 A marginal gap of less than 120 µm is considered clinically acceptable.19 In addition, the internal gap can also affect the clinical outcome because internal gaps greater than 70 µm can reduce the fracture resistance of dental crowns.20 However, there is no consensus on an acceptable threshold for internal gap.21 As a result, it is important to address two questions when restoring endodontically treated teeth: (1) Which restoration is preferable? and (2) Which material should be chosen to achieve highly adapted restorations? The purpose of this study was to evaluate and compare the marginal and internal adaptation values of chairside CAD/CAM (CEREC) endocrowns and crowns fabricated of lithium disilicate (IPS e.max CAD), ZLS glass-ceramic (VITA Suprinity), and hybrid ceramic (VITA Enamic). The null hypothesis was that there would be no difference in the internal and marginal adaptations between CAD/CAM endocrowns and crowns of these three materials.

**MATERIALS AND METHODS**

A sample size of 12 was calculated for each group for 80% power according to the two-sample t test power analysis (PASS 11), assuming the reported mean and standard deviations (SDs) reported by Shin et al22 (mean = 100 µm, SDs = 98 µm and 60 µm). A total of 72 specimens were used in this study, divided into two groups: 36 crowns and 36 endocrowns. The crown type groups were further divided into three subgroups each based on material: IPS e.max CAD, VITA Suprinity, and VITA Enamic (n = 12 each).

**Tooth Selection and Preparation**

Dental models of the two first maxillary molars (Nissin Dental Products) were selected. The teeth were embedded with self-curing acrylic resin (Fastray, Harry J. Bosworth) to 2 mm below the cementoenamel junction in an aluminum base with specified geometric features. In order to reproduce the surface anatomy, both models were scanned using an intraoral scanner (CEREC Omnicam, Dentsply Sirona). One of the teeth was prepared to receive an endocrown restoration. Accordingly, the buccal and lingual cusps received 3-mm and 5-mm occlusal reductions, respectively, with butt-joint margin designs. A tapered fissure diamond bur (G845KR, Edenta) was used to create the internal taper of the pulp chamber, which was 8 to 10 degrees in the mesial and distal, 22 degrees in the buccal, and 11 degrees in the lingual cavity walls. The depth of the cavity from the lingual wall was considered to be 3 mm. The finishing procedure was accomplished using a bur (806314141014 fine, Jota) with the same shape and taper, a larger diameter, and a finer particle size to allow for smooth internal transitions.
were obtained using the industrial noncontact ATOS scanner (ATOS III Triple Scan, GOM). First, the die and base, which had a star-shaped configuration, were scanned. In the second step, the restoration was placed on the die and fixed with light-body silicone (Speedex, Coltène). Then, the assembly of restoration, die, and base was scanned. In the third step, a hexagon-shaped cylindrical index was fixed on the top of the restoration, and the assembly was scanned again. Finally, the restoration was removed from the tooth with an index in its place, and the inner and outer surfaces of the endocrown/crown and the hexagon-shaped index were scanned. GOM software (Inspect 7.5) was used to analyze the dataset of each specimen using the reference model–matching technique. The superimposition of the mesh data was done with reference points on the hexagon-shaped and star-shaped indices of the base, which were equal for all samples in each scan. After processing the data, a uniform scan of the restoration seated on the die was obtained. Each model was sectioned mesiodistally and buccolingually across the intersecting edge of the star in the base. Each section was measured in the marginal, mid-axial wall, and occlusal/floor sites.

Data Analysis

Data were analyzed using statistical software (SPSS 22.0, IBM). Normality distribution was checked using Kolmogorov-Smirnov test. Group means and SDs were calculated for all the measurements obtained from the mesial, distal, buccal, and lingual marginal and axial wall discrepancies and for occlusal/floor discrepancies. In addition to the mean values at each region, the total marginal, axial, and occlusal/floor discrepancies were also calculated using the mean of the values obtained from all the regions for each group. Multivariate analysis of variance (MANOVA) was performed to investigate the following questions: (1) What are the main effects of...
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independent variables (restoration type and restoration material)? and (2) What is the interaction between the independent variables (restoration type and restoration material)? When MANOVA was significant, a univariate test was run for each variable (mesial, distal, buccal, and lingual) to interpret the respective effect. The results of between-subject effects tests were used to answer the above questions. In all analyses, the significance level was set to $P \leq .05$. Partial eta-squared analysis was also used to estimate the effect size. The interpretations of eta-squared values are presented in Table 1.

### RESULTS

Three specimens, including one VITA Suprinity endocrown, one VITA Enamic crown, and one VITA Suprinity crown, were excluded due to rocking after the adjustment. The mean values of the descriptive analyses of the margin, axial, and occlusal/floor discrepancies are summarized in Table 2 and are also shown graphically in Figs 3 to 5. The results indicated that the range of marginal discrepancies was 23.55 μm (buccal aspect of VITA Enamic crown) to 110.55 μm (distal aspect of VITA Suprinity crown), and the mean marginal gaps in all six groups were less than 80 μm. The MANOVA result was not significant for the margin discrepancies ($P > .05$), implying that the changes of the four points were highly correlated. However, the multivariate result was significant for axial wall discrepancy ($P < .001$). Therefore, the four axial points were separately analyzed. The between-subject effects tests showed that there was no significant difference in the marginal, buccal, or lingual axial wall discrepancies between crowns and endocrowns. The mesial axial wall discrepancy was significantly lower in the endocrowns compared to the crowns ($P < .001$, partial eta squared = .301), while the distal axial wall discrepancy was significantly higher ($P < .001$, partial eta squared = .198). Furthermore, floor discrepancy was found to be significantly lower in endocrowns compared to the occlusal discrepancy in the crowns ($P < .001$, partial eta squared = .664). In the marginal, axial, and occlusal/floor discrepancy analyses, no significant differences were observed among the three materials. Moreover, the interaction between restoration type and restoration material was not always significant.

### Table 1

<table>
<thead>
<tr>
<th>Values</th>
<th>Interpretation</th>
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<tr>
<td>0.01</td>
<td>Small effect</td>
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<tr>
<td>0.06</td>
<td>Moderate effect</td>
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<tr>
<td>0.14</td>
<td>Large effect</td>
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### Table 2

<table>
<thead>
<tr>
<th></th>
<th>IPS e.max</th>
<th>VITA Suprinity</th>
<th>VITA Enamic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marginal Crown</td>
<td>65.93 ± 26.42</td>
<td>77.88 ± 36.68</td>
<td>56.09 ± 16.68</td>
</tr>
<tr>
<td>Endocrown</td>
<td>69.22 ± 23.49</td>
<td>77.52 ± 13.39</td>
<td>71.00 ± 31.76</td>
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<tr>
<td>Axial Crown</td>
<td>71.72 ± 17.17</td>
<td>74.13 ± 20.57</td>
<td>80.72 ± 19.35</td>
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<tr>
<td>Endocrown</td>
<td>70.18 ± 14.03</td>
<td>73.36 ± 19.86</td>
<td>77.16 ± 23.78</td>
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<tr>
<td>Occlusal/floor Crown</td>
<td>222.66 ± 58.67</td>
<td>230.50 ± 65.51</td>
<td>204.09 ± 36.59</td>
</tr>
<tr>
<td>Endocrown</td>
<td>102.62 ± 26.30</td>
<td>100.04 ± 14.93</td>
<td>93.91 ± 44.62</td>
</tr>
</tbody>
</table>

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DISCUSSION

In the scenario of restoring severely damaged endodontically treated teeth, the challenging decision that determines the long-term success of the treatment is what type of restoration and material best meet the aesthetic, biologic, and functional requirements. In addition to the many other factors that contribute to the answer to this question, the marginal and internal adaptations are decisive factors. It has been demonstrated that different factors, such as type of scanner, type of milling machine, cement space, design of preparation, type of material, and measuring method, could influence the marginal and internal discrepancies.\(^{23-25}\) In this study, the effect of restoration type (crowns and endocrowns) and material (IPS e.max CAD, VITA Suprinity, and VITA Enamic) were investigated by considering all other factors equal in all samples. The null hypothesis was partially rejected. While neither type of restoration nor material affected the marginal gap, the internal gap was affected by the type of restoration regardless of the type of material. The results indicated that the endocrowns had statistically higher occlusal/floor adaptation in comparison to the occlusal adaptation of the crowns and that the mesial axial wall discrepancy was higher in the crowns than in the endocrowns, while the results were vice versa for distal axial wall discrepancy. It should be noted that partial eta-squared analysis showed that the effect sizes were large (> 0.14) in these three dependent variables.

The marginal and internal adaptations of CAD/CAM restorations depend on how accurately the scanner can capture the data and how precisely the milling machine can grind the blocks. The geometry of the preparation could affect data capture. Crowns and endocrowns are completely different in preparation, since a prepared die for a crown is a projected object with approximately parallel walls, while endocrowns have a cavity and the accuracy of the scan depends on the cavity depth. The other point is the access direction of the scanner, as digital impressions are imperfect on the distal side at a specific angle. The access direction creates a shadow distal to the illuminated object, which is called the distal shadow phenomenon. However, the tooth structure is placed in reverse in endocrowns. This theoretically might cause a shadow on the mesial cavity surface.\(^{26}\)

Machinability of blocks can be defined as the ease with which a given material is cut, which depends on the brittleness index, which can be derived from the hardness and fracture toughness, chipping factor, and microstructure of the material.\(^{27,28}\) It was found that the penetration rate of a cutting bur was higher in polymer-containing ceramics than IPS e.max and ZLS ceramics\(^ {29}\) and that low hardness and modulus of elasticity were associated with greater amounts of material being removed during grinding.\(^ {30}\) In addition, the other factor is resistance to crack propagation during grinding, which is correlated with flexural resistance.\(^ {31}\)

The results showed that neither type of restoration nor restoration material significantly affected the marginal discrepancy. The mean marginal gaps in all six groups were less than 80 μm. This result could be mainly due to the fact that the distal shadow phenomenon was limited by using a single tooth mounted in an aluminum base and/or that measurements were done after the adjustment. To the authors’ knowledge, there is no previous study that compares crowns and endocrowns fabricated of different materials considering the marginal and internal adaptations. As a result, comparing the present results to existing studies was done separately for each restoration type.

Yildirim et al\(^ {25}\) measured the vertical marginal discrepancy (absolute marginal discrepancy [AMD]), the horizontal marginal discrepancy (MD), and the axial and occlusal discrepancies of crowns made of different materials. They found that the AMD values for the IPS e.max (155.5 μm), VITA Enamic (102 μm), and VITA Suprinity (132 μm) crowns were higher than the present values of the IPS e.max (65.93 μm), VITA Enamic (56.09 μm), and VITA Suprinity (77.88 μm) crowns. However, the range of axial (70.18 to 80.72 μm) discrepancies and the mean occlusal (219 μm) discrepancy in the present study fell outside the range of 41.5 to 51.7 μm and outside the mean value of 191.5 μm in Yildirim et al.\(^ {25}\) These results are contrary to the Yildirim et al findings, which suggest that the discrepancy values of the IPS e.max CAD crowns were significantly higher than those made of VITA Suprinity and that the discrepancy values of Lava Ultimate and VITA Enamic blocks were significantly lower than those of others.\(^ {25}\) These conflicting results are due to whether the restorations were adjusted and the amount of spacer, which was set at 40 microns in their study. As a result, a lower cement space led to a higher marginal gap and a lower axial discrepancy.

Shin et al\(^ {22}\) measured the marginal and cavity wall discrepancies of IPS e.max CAD endocrowns according to the cavity depth. The range of the marginal gap (99 to 120 μm), the axial discrepancy (118 to 152 μm), and the pulpal floor discrepancy (229 to 243 μm), were all slightly higher than the marginal (69.22 μm), axial (70.18 μm), and floor (102.62 μm) discrepancies of the IPS endocrowns in the present study. This could be attributed to a difference in the internal taper of the cavity walls, which was higher in the present study. Moreover, the floor discrepancy in the present study was found to be significantly lower in the endocrowns compared to the occlusal discrepancy in the crowns. This result is probably due to the flat surface of the pulpal floor in endocrowns, while occlusal reduction of crowns follows anatomical planes, and these details in the occlusal surface lead to overmilling of the restoration.
It was found that the measurement technique can affect the marginal and internal values. A novel technique was used in this study in order to improve the previous version of digital measurement techniques. A hexagon-shaped occlusal index and star-shaped basal index were used as reference points to correlate the mesh data more accurately. In a triple-scan protocol, scans are correlated according to surface point matching, which is not as accurate as reference point matching.

One of the limitations of the present study was that all discrepancies were measured without luting cement. It has been revealed that marginal discrepancy mostly increases after cementation. The vertical marginal discrepancies of all-ceramic crowns nearly doubled once cemented. However, in Shin et al’s study, the discrepancy was reduced or did not change. Even with the additional gap caused by cementation, the present results seem to be still in a clinically acceptable range. Since cements have a certain thickness, evaluations should also be accomplished after cementation. Another limitation was that only the vertical marginal discrepancies were assessed; however, it is better to assess the vertical and horizontal discrepancies differently because they have different clinical implications.

Currently, the “replica technique” is the only 3D technique for evaluation of restoration adaptation in clinical studies. The noncontact scanning technique used in this study, although more accurate, could only be used in vitro. It is important to consider that due to the inherent limitations of in vitro studies, the results could not be simply generalized to a clinical situation, and further clinical studies are recommended.

CONCLUSIONS

Based on the present in vitro study, neither type of restoration nor material affected the marginal gap. However, the internal gap was affected by the type of restoration. As a result, the endocrowns had higher floor and mesial adaptation and less distal adaptation in comparison with the crowns. Both kinds of restoration made of all three materials exhibited a clinically acceptable range for the marginal and internal adaptation values.

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The authors report no conflicts of interest.

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