Effect of cement space on marginal discrepancy and retention of CAD/CAM crown

Laila Azwa HASSAN and Chui Ling GOO

Department of Restorative Dentistry, Faculty of Dentistry, The National University of Malaysia, Jalan Raja Muda Abdul Aziz, 53000 Kuala Lumpur, Malaysia
Corresponding author, Chui Ling GOO; E-mail: clgoo@ukm.edu.my

This research aimed to evaluate the effect of cement space on the marginal discrepancy and retention of computer-aided design/computer-aided manufacturing (CAD/CAM) crowns. A total of 30 premolar Frasaco teeth were machined to receive crowns with cement spaces of 70, 90, and 110 μm. The marginal discrepancy measurements were done before and after cementation. Pull-off test was conducted using universal testing machine (UTM). Data was analyzed using two-way mixed ANOVA with post-hoc Bonferroni test and Kruskal-Wallis test. The crowns with cement space of 70 μm showed a significantly higher absolute marginal discrepancy than those with 90 and 110 μm. No significant effect on the crown retention was found. Within the limitations of this study, modifying cement space to 90 μm and 110 μm may improve the marginal adaptation of CAD/CAM crown, whereas adjusting cement space from 70 to 110 μm did not significantly affect the crown retention.

Keywords: Crowns, CAD/CAM, Dental marginal adaptation, Resin cements

INTRODUCTION

Digital workflow using computer-aided design/computer-aided manufacturing (CAD/CAM) system has become the future for clinical dentistry. CAD/CAM systems are now gaining acceptance among dentists, especially for fabricating fixed dental prostheses. It permits the clinician to work faster, easier, and allows the prosthesis to be fabricated and delivered in a single visit. Various types of CAD/CAM blocks are available for different indications according to the patient’s needs. One of the choices available is the fine-structured feldspathic blocks. Multiple long-term clinical studies reported a high survival rate of CAD/CAM feldspathic block of over 90% after 5 to 12 years of clinical follow-up. Various types of CAD/CAM blocks are available for different indications according to the patient’s needs. One of the choices available is the fine-structured feldspathic blocks. Multiple long-term clinical studies reported a high survival rate of CAD/CAM feldspathic block of over 90% after 5 to 12 years of clinical follow-up. These long-term studies demonstrated that feldspathic ceramic can be a reliable option for posterior indirect restorations.

Crown fabrications using CAD/CAM systems start from scanning the abutment tooth to designing and machining of the crown material. Each of these steps can influence the marginal adaptations of restorations, and this includes the cement space setting during the designing phase. Marginal fit of a crown can be assessed by the presence of space between the restoration margin and the finish line of the tooth preparation. This space is generally known as the marginal gap or marginal discrepancy and should be small enough to provide optimum marginal sealing and avoid saliva and bacterial infiltration. The presence of a significant marginal gap around the fixed prosthesis can lead to caries formation at the prosthesis margin and subsequent crown failure. Meanwhile, in the case of vital pulp, it can eventually lead to pulpal death if left unattended.

The absolute marginal discrepancy measurement was the most reliable measurement among various terminologies of a crown misfit as it can describe the total discrepancy of a crown as described by Holmes et al. in 1989. Previous studies that investigated the marginal discrepancy of conventionally fabricated casted crowns agreed upon the clinically acceptable value of 30 μm. Contrarily, for crowns made of leucite-reinforced glass ceramic and zirconia fabricated with different CAD/CAM systems, a wide range of clinically acceptable values of 30–120 μm were reported. The variety in the acceptable marginal discrepancy value could be attributed to the disparity in the morphology of a crown, for example, the presence of defects, overhang, and rounded crown margins. Moreover, crown adaptation can be influenced by factors, such as occlusal convergence angle and cement space.

Creating cement space for CAD/CAM crown fabrication is important to facilitate proper adaptation of coping to the abutments, improves the outflow of excess cement, and reduces the force needed to adapt the crown on the abutment tooth during cementation. A cement space of 20–40 μm was agreed by several authors to be optimum for full seating of a conventional crown. Meanwhile, crown fabrication using the digital method produces a wide range of marginal discrepancies due to processing errors from the abutment teeth scanning to the milling process. Previous marginal discrepancy study on CAD/CAM crown that used a wide range of cement space settings reported an improvement in the marginal crown adaptation when the cement space was increased.

A study on casted crowns using zinc phosphate and zinc polycarboxylate cements revealed higher retention value for the crowns without cement space compared to...
crowns with cement space. Mehl et al. investigated the effect of cement thickness on retention of 96 implant-retained CAD/CAM crowns and found significant reduction in crown retention when cement space was increased from 15 to 50 μm. Contrarily, Özyılmaz et al. demonstrated a significant increase in retention of laser-sintered metal copings cemented on dental implant abutments when the cement space was increased from 20 to 40 μm. Meanwhile, CAD/CAM zirconia crowns with cement space of 80 μm had significantly higher retention compared with crowns with cement space of 100 and 120 μm.

The marginal adaptation improves when cement space increases, however at the same time, the effect of increasing cement space on retention of crown is unclear. Currently there are no study which link the three parameters together. The available scientific literature on the optimum value of cement space that can produce CAD/CAM crowns with acceptable marginal fit and good retention remains limited and inconclusive. Therefore, the purpose of the current study was to investigate the effects of three different luting cement space settings on marginal discrepancy and retention of CAD/CAM fabricated feldspathic crowns. The null hypothesis is that no difference exists in the marginal discrepancy and retention for CAD/CAM crowns utilizing different cement space settings.

**MATERIALS AND METHODS**

**Sample preparation**

This in-vitro experimental study involved maxillary right first premolar typodont teeth prepared to receive all-ceramic CAD/CAM crowns. The sample size was calculated on the basis of the previous similar marginal discrepancy study by Hmaidouch et al. showing 10 samples were needed for each group. A master maxillary right first premolar typodont tooth was prepared for placement of an all-ceramic crown with features of 10° total occlusal convergence angle (TOC), 1.2-mm-depth circumferential shoulder margin, and 3 mm axial wall height. Sharp angles were rounded to avoid high-stress areas in the crown fitting surface. The prepared tooth was then sent to the Frasaco manufacturing company (Frasaco, Tettnang, Germany) for the fabrication of 30 standardized duplicates of the prepared tooth. The 30 duplicates were randomly divided into three groups according to different cement spaces of 70, 90, and 110 μm.

**Crown preparation**

Each prepared tooth was fixated onto the Frasaco model. Then, the CEREC Optispray scanning powder (Sirona Dental Systems, Bensheim, Germany) was sprayed onto the prepared teeth before scanning the model using the CEREC Bluecam intraoral scanner to record for digital impression. This step was followed by virtual model trimming, and the crown margin was demarcated along the finishing margin of the prepared tooth. The cement space settings were adjusted according to the groups during the designing phase. CEREC blocs PC (Sirona Dental Systems) with polychromatic layers were milled using the MC XL milling machine (Sirona Dental Systems) to produce the crowns. Materials involved in this study were listed in Table 1.

**Marginal discrepancy measurement**

After milling, all crowns were subjected to marginal discrepancy measurements. The milled crowns were seated on the respective prepared teeth parallel to the long axis of the tooth and fastened onto a pre-calibrated customized device. The device was fabricated with a spring load component which functions to direct a constant exerted pressure of 14 N on the respective prepared teeth during marginal discrepancy measurements. In addition, the measuring device can rotate the mounted crown and abutment in 360 degrees. Ten markings were distributed around the abutment tooth. The samples were then rotated and ten images were captured at the marked areas using a camera connected to a computerized digital image analysis software, Leica LAS EZ software application. Absolute marginal

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Materials used in the study</th>
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<tbody>
<tr>
<td><strong>Material (Trade name)</strong></td>
<td><strong>Major composition</strong></td>
</tr>
<tr>
<td>Scanning powder (CEREC Optispray)</td>
<td>1,1,1,2,3,3,3-heptafluoropropane, Pentane</td>
</tr>
<tr>
<td>Feldspar ceramic, polychromatic (CEREC blocs PC)</td>
<td>SiO₂ (56–64 wt%), Al₂O₃ (20–23 wt%), Na₂O (6–9 wt%), K₂O (6–8 wt%), CaO (0.3–0.6 wt%), TiO₂ (0.0–0.1%)</td>
</tr>
<tr>
<td>Porcelain Etch Gel</td>
<td>9.6% hydrofluoric acid</td>
</tr>
<tr>
<td>Self-adhesive resin cement (Rely-X™ U200)</td>
<td>Base: methacrylate monomers containing phosphoric acid groups, initiators, stabilizer, rheological additives Catalysts: methacrylate monomers, alkaline fillers, silanated fillers, initiator components, stabilizer, pigments, rheological additives</td>
</tr>
</tbody>
</table>
discrepancy measurement (Fig. 1) was done under 35× magnification using Leica EZ4 HD stereo microscope (Leica Microsystems, Heerbrugg, Switzerland) by a single calibrated examiner. The validity and reliability of marginal discrepancy measurements were calibrated with a qualified prosthodontist.

Five random measurements were recorded for every captured image yielding a total of 50 readings for every crown\(^{32}\). Subsequently, all fabricated crowns were etched using 9.6% hydrofluoric acid (Pulpdent Porcelain Etch Gel, Pulpdent, Watertown, MA, USA) for 60 s. All crowns were cemented using self-adhesive Rely-X™ U200 luting cement (3M ESPE Dental, Seefeld, Germany) resin luting cement with firm finger pressure for 20 s. Then the tooth was mounted on the customised device incorporated with a spring load and a constant force of 14 N was directed on the crown during cementation for five minutes. A silicon padding was placed on the plunger surface to avoid damage to the crown. Excess cement was removed using micro brush. The cemented crowns were then light cured for 20 s on each surface. The teeth were subsequently stored in distilled water for 24 h. The marginal discrepancy after cementation was again recorded.

**Retention test**
All samples were then embedded in the acrylic block for the retention test. A universal testing machine (Autograph AGS-X Series Shimadzu Precision Universal Tester, Shimadzu, Kyoto, Japan) was used for the pull-off test during crown removal from the abutment tooth. The acrylic block was secured to the bottom component to keep it steady during the test. A customized jig fabricated for the pull-off tests was fixed at the upper portion of the UTM to accommodate the bar on the occlusal surface of the crown. Following that, the crown was subjected to dislodgement forces until it dislodged from the abutment tooth at a crosshead speed of 0.5 mm/min. The experimental design process is described in Fig. 2. The crowns were then inspected to determine the mode of crown failure, whether it was cohesive, adhesive, crown fracture, or tooth fracture.

**Statistical analysis**
The data of the mean absolute marginal discrepancy was normally distributed when assessed for normality by the Shapiro-Wilk’s test (\(p>0.05\)). Levene’s and Box’s M tests were not significant, thus, showing homogeneity of variances (\(p>0.05\)) and covariances (\(p>0.05\)). Therefore, the mean absolute marginal discrepancy data were analyzed using two-way mixed ANOVA and the *post hoc* Bonferroni tests. As the data for mean difference of crown removal force between groups were not normally distributed, a non-parametric Kruskal-Wallis test was used with the significance level of \(p<0.05\).
RESULTS

The degree of agreement between the two examiners was assessed using the intraclass correlation coefficients (ICC). The results revealed that the an intra-examiner coefficient value was 0.93 and a score of 0.99 for inter-examiner reliability was obtained. The mean absolute marginal discrepancy in all groups was within a clinically acceptable range in before and after cementation except the crowns with cement space of 70 μm, whereby the mean values after cementation were beyond the acceptable values.

The two-way mixed ANOVA revealed no statistically significant interaction effect between the timing of cementation and the cement space (p=0.204). Analysis of the data showed a statistically significant effect of cement space settings and timing of cementation on the mean absolute marginal discrepancy (p<0.05). The post hoc Bonferroni test revealed that the crowns with cement space of 70 μm showed a significantly higher mean absolute marginal discrepancy than the crowns with cement spaces of 90 and 110 μm. Ultimately, no statistically significant difference existed between the crown with cement spaces of 90 and 110 μm (p>0.05). Concerning the timing of cementation, the mean absolute marginal discrepancy after cementation was significantly greater than before cementation (p<0.05) (Table 2).

In this study, 28 out of 30 crowns broke at the crown margin before the cemented crowns were removed completely from their abutments during the retention test (Fig. 3). The other two crowns were removed without crown fracture leaving cement attached mostly on the intaglio surface of the crown. Therefore, the data for the maximum withstandable force before the crowns fractured or dislodged were taken into account. The data analysis discovered that there were no statistically significant differences in maximum force between the group with p=0.440. The mean and standard deviation (SD) of crown removal force for cement space of 70, 90, and 110 μm were 118.30±58.68, 145.33±64.32, and 150.46±85.66, respectively.

DISCUSSION

Our initial pilot study used six cement space settings between 60 to 110 μm. The 70 μm was the manufacturer’s recommended cement space setting. In the pilot study, the crown produced with a cement space of 60 μm resulted in a crown with unacceptable marginal discrepancy visible even to the naked eye. Therefore, that setting was excluded from our study. The cement space settings of 90 and 110 μm were selected to standardize a 20 μm interval between groups.

The crowns in this study were fabricated on a standardized preparation using Frasaco teeth to control confounding factors other than cement space settings. The marginal discrepancy was measured before and after cementation to compare the effect of adjusting cement space in both conditions. Although there are certain studies that revealed no significant effect of increasing luting cement space on marginal discrepancy measurements, their values were more than clinically acceptable marginal discrepancy values after cementation. It is thus a question of whether their luting space setting of 50 or 80 μm was adequate to ensure acceptable marginal gaps after cementation of crowns. The findings in our study support the proposition that the marginal gap improves when cement space is increased, as reported by previous studies. Therefore, the null hypothesis was rejected.

![Fig. 3 Material fracture at the crown margin after being subjected to retention test.](image)

Table 2  Absolute marginal discrepancy measurement of different luting cement space before and after cementation

<table>
<thead>
<tr>
<th>Cement space (μm)</th>
<th>Number of sample</th>
<th>Before cementation</th>
<th>After cementation</th>
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<tbody>
<tr>
<td>70</td>
<td>10</td>
<td>92.5 (23.7)\textsuperscript{a}</td>
<td>161.5 (60.9)\textsuperscript{b}</td>
</tr>
<tr>
<td>90</td>
<td>10</td>
<td>68.1 (22.9)\textsuperscript{a}</td>
<td>108.4 (32.1)\textsuperscript{b}</td>
</tr>
<tr>
<td>110</td>
<td>10</td>
<td>47.6 (13.3)\textsuperscript{a}</td>
<td>87.1 (30.9)\textsuperscript{b}</td>
</tr>
</tbody>
</table>

Mean values and standard deviations in parenthesis. The mean denoted with different uppercase letters (before and after cementations) within the same row are significantly different (p<0.05). The mean denoted with different lowercase letters (among different cement spaces) within the same column are significantly different (p<0.05). p-Value calculated using pairwise comparisons: Bonferroni test.
All samples included in this study demonstrated an increase in marginal discrepancy after cementation. Marginal discrepancy after cementation in the group with luting cement space of 70 μm was significantly higher than 90 and 110 μm. This finding was consistent with previous similar studies8,36-39. The type of dental cement used for cementation must also be considered. Self-adhesive resin cement was the material of choice used in this study as it has high wear resistance, good retentive strength, and low solubility40. A study comparing film thickness of various dental cements found most of the cement in question, including resin cement, adhered to ISO standards set for film thickness, which is less than 25 μm41).

Interestingly, the mean marginal discrepancies yielded by the crowns with cement space of 70 μm in our study exceeded the clinically acceptable marginal discrepancy which ranges from 30–120 μm13-15. A possible explanation could be because, in narrower spaces, the resin cement is subjected to higher intracoronal hydraulic pressure, which may translate to higher resisting forces during cementation, possibly preventing a more complete seating of the crown. In addition, any changes on other factors, such as the tooth type, taper of tooth preparations18), types of materials42) and the CAD/CAM systems25) may yield different outcomes and therefore the results in this study could not be generalized to all situations.

In our study, we noted most crowns failed via material fracture at the crown margins while only two crowns were removed without crown fracture. The result of pull-off test showed no significant difference in the retention force among the three groups. Similar studies by Gultekin et al.20) and Taha and Ibraheem31), which used different cement space settings, were in agreement with our study where the crown retention was not drastically influenced by the cement space setting. Other studies20,31) which reported a significant influence of cement space on retention, used cast coping and the retention strength was primarily derived from the frictional forces between the crown fitting surface and the abutment tooth. These studies20,28,31,43) however, failed to draw a conclusion on whether the better retention strength was accompanied by acceptable marginal discrepancies after cementation as it was not investigated.

Adhesive failure was the mode of failure in crowns that were successfully removed without fracture. Adhesive failure is described as having the cement attached mostly on the intaglio surface of the crown when the crown is removed from the abutment tooth44. Although our study used Frasaco teeth as samples, the mode of failure found in our research agreed with other retention studies using extracted teeth31,43) where the predominant mode of failure was adhesive failure rather than cohesive or mixed failure. This suggests that the type of tooth, Frasaco or extracted tooth, may not have an important influence on the mode of failure for crown retention tests. The role of bonding of cement to the abutment tooth is therefore not under scrutiny as no bonding mechanism could be expected to occur between the cement and the Frasaco tooth. The purpose of using typodont tooth instead of extracted tooth in our study was to standardized the prepared tooth as much as possible. Thus, other factors, such as the difference in total surface area of the tooth, preparation geometry as well as the micromechanical bond to the tooth that may influence the retention of the crown could be eliminated. Our study showed that the material failed at lower force values in crowns with cement space of 70 μm. This may be due to higher induced internal stress on the feldspathic ceramic crown margins during cementation. A multifactorial analysis of variables found that in all-ceramic crowns, higher maximum principal stress was found in the crowns with reduced cement space compared with larger cement space45. Material thickness can affect the tensile stress concentration on the restorations46. Thus, most of the crown fractures occurred near the margins where the material was thinnest. Moreover, crown milling may induce micro-cracks in the material and surface flaws on the final crowns47). Crown fractures can be initiated from these surface flaws when tensile forces are directed at the crown48.

There are a few limitations in our study. The most important limitation was the type of ceramics used in this study. Feldspathic ceramics are relatively weak in terms of fracture toughness compared to zirconia and lithium disilicate49. Other studies utilising stronger ceramics did not report any crown fractures31,43) Studies using more durable materials are needed before the conclusion on the effect of cement space setting on marginal adaptation and retention could be drawn and applied in the clinical settings. Furthermore, findings of our study are relevant for similar conditions and may not be extrapolated for all situations as the outcome might be different when different CAD/CAM systems and materials, taper or size of the prepared tooth are used. Another limitation of our study was the exclusion of the thermocycling process to simulate the ageing of cemented crowns. In our pilot study, some of the crowns subjected to the thermocycling process started to exhibit fine crack lines in the ceramic before completion of 3,000 cycles, prior to the pull-off test. Therefore, the thermocycling procedure was omitted to reduce inaccuracies in the results of retention tests due to pre-existing cracks in the ceramics caused by the thermocycling process.

CONCLUSIONS

Within the limitations of this in-vitro study, it can be concluded that increasing cement space can improve the marginal adaptation of CAD/CAM fabricated CEREC crowns. The marginal discrepancy of crowns increases significantly after cementation but remains within clinically acceptable values except for the crowns with luting cement space of 70 μm. Adjusting cement space to 90 and 110 μm may be considered to improve the crown margin adaptation without critically influencing the crown retention.
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