Marginal Adaptation of Provisional CAD/CAM Restorations Fabricated Using Various Simulated Digital Cement Space Settings

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Purpose: *The ideal digital cement space value for the fabrication of provisional computer-aided design/computer-aided manufacturing (CAD/CAM) crowns with clinically acceptable marginal adaptation is not well known. The aim of this study was to evaluate the effect of different simulated cement space settings on the marginal fit of poly(methyl methacrylate) (PMMA) provisional CAD/CAM restorations.* ***Materials and Methods:*** *An extracted premolar tooth was prepared using ceramic crown preparation guidelines and represented both natural teeth and/or custom implant abutments. The prepared tooth abutment was scanned with a three-dimensional (3D) laboratory scanner (D900, 3Shape). CAD design software was used to subsequently design a premolar crown core with three different simulated cement space settings (20 to 40 µm, 20 to 50 µm, 20 to 60 µm). PMMA blocks were used to mill the specimens (n = 9, N = 27). Using a stereo zoom microscope, a total of 36 images for each of the 3 groups (9 crowns per group, 4 sites per crown) were captured to measure the mean vertical marginal discrepancy for every group. One-way analysis of variance (ANOVA) was used to analyze the data, and the post hoc Tukey multiple comparison test was performed.* ***Results:*** *The marginal gap values of the PMMA cores fabricated using the three cement space settings were significantly different from each other (P < .001). The marginal gap was smaller with a 20- to 60-µm setting compared with 20 to 50 µm and 20 to 40 µm, and the 20- to 50-µm setting allowed for smaller marginal gaps compared with 20 to 40 µm (P < .001).* ***Conclusion:*** *Within the limitations of this study, the marginal gaps of CAD/CAM-fabricated PMMA cores were smaller when the cement space was larger. The smallest marginal gaps were achieved when a 20- to 60-µm cement space was used (P < .001).*
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Marginal and internal fit of crowns play an important role in the long-term success of these restorations.[1–3] Open margins on a crown can cause microleakage, which may lead to decementation through dissolution of the cement.[4] These parameters are critical for the success of both provisional and permanent crowns, on natural teeth as well as implants. Provisional restorations are a critical part of fixed prosthesis treatments, and allow maintenance of necessary gingival tissue, natural teeth, and implant health, as well as provision of gingival and temporomandibular joint (TMJ) treatments, and the return of any traumatized soft tissues to optimal health.[4] Provisional restorations provide useful diagnostic value through assessment of functional, esthetic, and occlusal parameters before the completion of the definitive restoration.[4,5] In addition, implant provisional restorations provide a template for defining tooth contour, ideal emergence profile, and gingival tissues.[5] Marginal misfit may cause plaque retention, bacterial contamination, and related periodontal problems, in addition to delayed or inadequate healing of traumatized soft tissues.[6] The failure of the restoration and even the tooth or implant may be inevitable due to these complications.[7] Aside from biologic complications, mechanical

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complications may be observed with crowns with marginal gaps.[8] Veneering porcelain chipping can be experienced, particularly with zirconia crowns, if the strains increase within the crown.[5,9,10]

Computer-aided design/computer-aided manufacturing (CAD/CAM) restorations are becoming increasingly popular due to their efficient fabrication procedures, reported higher accuracy, and lower laboratory costs compared with conventional fabrication processes.[11–15] In addition, CAD/CAM-fabricated provisional restorations demonstrated superior marginal fit and integrity compared with conventional direct or indirect provisional crowns.[11] CAD/CAM systems present a variety of options during the scanning, design, and production of restorations. These systems also allow the restoration thickness and simulated die spacer (cement space) to be set to the desired thicknesses.[16–18] It was reported in several studies that die spacer thickness, finish line design, and type of cement may affect the marginal fit of CAD/CAM restorations.[16,19–32] These digital technologies that rely on exact dimensional predictions are claimed to demonstrate improved marginal adaptation.[25] However, some CAD/CAM systems with poor scan quality and inadequate design software have been reported to produce crowns with unacceptable marginal gaps.[19,20] Several studies consider marginal openings from 50 to 120 μm as clinically acceptable for fixed restorations, with the range coming down to 50 to 100 μm for CAD/CAM restorations.[28,29] The marginal gap of provisional crowns fabricated using different materials with the CEREC CAD/CAM system in a study by Abdullah et al ranged between 47 and 193 μm, though the mean marginal gap was within the acceptable limits of the 50- to 60-μm range.[30] In a study by Vojdani et al, the mean marginal gap for metal crowns cast from CAD/CAM wax patterns was reported to be 157.37 ± 20.63 μm versus 69.54 ± 15.60 μm for the conventional wax-up technique group.[33] The significant effect of other components of the CAD/CAM systems has also been emphasized in the literature.[17,29–38]

The variation in different systems' production steps mostly depends on internal cement space differences. Internal cement space directly influences the crown fit, depending on the precision of the system.[27,39–41] The ideal cement space setting was reported to be 50 μm in the literature; 30 μm to create space for cement, with a theoretical cement space thickness between 25 and 40 μm[28,29]; and an additional 20 μm to compensate for manufacturing errors.[42] It was shown in several studies that the marginal gap is reduced when cement space is increased, either digitally or through additional application of die spacer layers.[2,42–44] However, marginal gap improvements were not observed for cement space greater than 120 μm, which may also significantly decrease the strength of ceramic restorations due to a large potential inner misfit as well as polymerization shrinkage of the cement.[29–33,44] Several studies advocate that a marginal gap below 120 μm is clinically acceptable.[33–50] However, the field of dentistry still remains without a clear agreement regarding the establishment of a clinically acceptable marginal gap value. Marginal gaps ranging from 10 to 500 μm have been variously reported in literature as acceptable.[28,29] Moldovan et al rated the values of 100 μm for marginal misfit as good and values of 200 to 300 μm as acceptable.[40] Nonetheless, discrepancies between 50 and 120 μm are generally considered clinically acceptable.[28–30,33,35,40] To the authors' knowledge, there is also no consensus regarding the simulated die spacer setting to be used for CAD systems, with studies reporting 50 to 100 μm[28,29] and 24 to 110 μm as acceptable.[35] Moreover, most of these earlier studies evaluated the vertical marginal gaps pre- or post-cementation of the permanent crowns, utilizing various die/cement space thicknesses during the manufacturing process. To the authors' knowledge, studies that have evaluated the cement space effect on provisional restoration fit are limited.

The aim of this study was to compare the marginal gaps of CAD/CAM poly(methyl methacrylate) (PMMA) crown substructures fabricated using different cement space values. The null hypothesis was that no difference would be found in the marginal fit of the cores fabricated according to different cement space values available in the CAD/CAM software.

MATERIALS AND METHODS

For this study, the authors used an extracted premolar tooth and fixed it in a self-curing PMMA resin matrix (Jet, Lang Dental) (institutional approval obtained from Eskişehir Osmangazi University Medical School Clinical Research Ethics Committee 23/07/2015-14). One prosthodontist (B.Y.) prepared the premolar tooth with a 1.0-mm chamfer margin circumferentially, using a high-speed diamond (no. 6856, Brasseler USA) with an air-rotor handpiece (no. 846, KaVo) under water and air coolant, to receive a crown substructure (core). The prepared tooth in this study was used as a representative for both natural teeth and implant abutments. The D900 laboratory scanner (D900, 3Shape) was used to scan the preparation.

The PMMA core was designed using the scanned STL images with CAD software (CAD Design Software, 3Shape). The cement space was set to 20 μm at the core margins and 40 μm (20 to 40 μm), 50 μm (20 to 50 μm), and 60 μm (20 to 60 μm) at the other intaglio surfaces of the core.[16] These values are similar to the ones

Table 1 One-Way ANOVA Results for Marginal Gap Measurements

Source of variation	Sum of Squares	df	Mean square	F	*P* value
Between groups	19,501.556	2	9750.778	109.415	< .001*
Within groups	2,138.811	24	89.117		
Total	21,640.367	26			

* Indicates significance ($P < .05$). ANOVA = analysis of variance.

Table 2 Mean Values and SDs of Marginal Gap (µm) Measurements According to Different Cement Space Values (µm)

Cement space	n	Mean (SD)*
20–40 µm	9	122.47 (5.69)[a]
20–50 µm	9	95.92 (13.85)[b]
20–60 µm	9	57.03 (6.54)[c]

*Values with different lowercase superscript letters were significantly different according to post hoc Tukey test ($P < .05$).

reported in the literature for various CAD/CAM cement space settings.[16,28,29,33] After finalizing the core design, the information was sent to CAM software (CORiTEC iCAM V5, imes-icore GmbH), and PMMA substructures were milled (CNC; CORiTEC 550i; imes-icore GmbH) from PMMA provisional blocks (CORiTEC, imes-icore GmbH) (n = 9 for each cement space measurement from the laboratory scanner; N = 27). After milling, they were examined to detect any defects or cracks, and were left as is without any additional postmilling treatments or modifications. A polyvinyl siloxane (PVS) impression material (Aquasil, Dentsply Caulk) was used to stabilize the crowns on the tooth.[16,47–50] This PVS material used for the purpose of cementation is based on the replica technique for marginal gap measurement, previously described in the literature.[30]

For measurement of the vertical marginal gaps, the following procedure was used. A microscope digital camera (10 MP USB 2.0 microscope digital camera, AmScope) was calibrated (Calibration kit, AmScope), and vertical marginal gaps were measured with the stereoscopic zoom microscope (×3.5 to ×180 inspection trinocular stereo zoom microscope, AmScope).[48] The measurements were made by one experienced observer (E.S.). The prepared tooth was indexed at four sites with red vertical lines using a marking pen—midfacial, mid-palatal, midmesial, and middistal surfaces—in order to standardize the marginal gap measurement location for each crown. To systematize the measurement position, silicone jigs were fabricated individually for every one of the four surfaces. All specimens' long axes were positioned parallel to the long axis of the microscope lens, and the magnification of the microscope was adjusted. Images were transferred to a computer from the digital camera and were analyzed using special software (ToupView, vx86, 3.7.2608; ToupTek).

The software allowed the measurement of microgaps between the crown and tooth margins in micrometers (µm). Each site was measured three times, and a mean value was calculated. A total of 108 image measurements (3 groups, 9 crowns per group, 4 sites per crown) were recorded. The average of the four mean site gap measurements was calculated to obtain each core's mean vertical marginal gap, and the mean marginal gap was computed for all nine cores per group. One-way ANOVA and computer software (IBM SPSS Statistics for Windows v21.0, IBM Corp) were used for data analysis. According to the assumption of homogeneity of variance, the post hoc Tukey multiple comparison test was used ($\alpha = .05$).

RESULTS

Results of one-way ANOVA indicated that the different cement gap settings significantly affected the marginal gap values ($P < .001$) (Table 1). The power of the ANOVA test was equal to 1 with type I error, $\alpha = .05$. Table 2 shows the mean marginal gap values (µm) and standard deviations for each group and the statistical analysis results. Results of the study indicated that the mean marginal gap recorded was smaller when the cement gap was increased ($P < .001$). The mean marginal gap measurements for cement spaces of 20 to 40 µm, 20 to 50 µm, and 20 to 60 µm were 122.47 ± 5.69 µm, 95.92 ± 13.85 µm, and 57.03 ± 6.54 µm, respectively, which were significantly different from each other ($P < .001$).

DISCUSSION

The null hypothesis of this study was rejected. There were significant differences among PMMA core vertical marginal gaps when different cement space settings were used ($P < .001$).

The smallest marginal gaps (57.03 µm) were observed when the 20- to 60-µm cement space setting was used ($P < .001$). This mean value is within the recommended marginal gap range reported by Euán et al,[29] Abdullah et al,[30] Vojdani et al,[33] and Jalali et al.[35] The marginal gap values (122.47 μm) measured with the 20- to 40-μm cement space setting was slightly above the commonly reported clinically acceptable highest marginal gap value of 120 μm.[28–35,45–54] Though some studies in the literature have reported marginal and internal gap width values in the range of 50 to 200 μm, suggesting a lack of a clear scientific evidence-based objective limit, 50 to 100 μm for internal fit and 120 μm for the marginal gap is considered the practical range of clinical acceptability in most studies.[28–35,46,47,51,52] In a previous study, a negative correlation between the cement space and crown adjustment time was reported, and larger marginal gaps were observed when the cement space was less than 40 μm.[36] Other studies have used specimens with cement space settings of 10 to 20 μm (Baig et al, 2016)[42]; 50 to 100 μm (Hmaidouch et al, 2011)[48]; and 90, 120, and 150 μm (Miwa et al, 2016).[50] The results from these studies helped determine the cement spaces tested in the present study. Smaller marginal gaps were reported in the literature when cement space is increased, and the results of this study support those other results.[2,28–45]

In a previous study,[54] when the cement space was set at 60 μm, the vertical mean marginal gap value was 104 μm, which is almost two times more than the present study values for the same cement space setting. In other studies, when the cement space was set at 50 μm, vertical marginal gaps were between 59 and 68 μm[27] and 53 and 64 μm.[28] These values are smaller than the marginal gap values observed with the same cement space setting in the present study. These differences in the marginal gap values observed in different studies, even though the same cement space setting was used, may be due to the differences between the technical features/abilities of CAD/CAM milling machines used in those studies.

Digital scanners enable fabrication of crowns with clinically acceptable marginal gaps.[12,14,15,29,30,48] The digital model used in this study was generated from the 3D scan of a prepared natural tooth using a laboratory scanner. The reason for the selection of a natural tooth as the test material was to eliminate the potential dimensional stability and wear issues reported in the literature when acrylic resin, stainless steel, or stone tooth models were scanned and crowns were tried on those dies.[6,36,37] Moreover, the results generated from this study can be employed for natural teeth crowns as well as implant crowns, particularly those fabricated on custom abutments. Fabrication of both involve the dental laboratory scanning of the die or the implant abutment using a laboratory scanner. In addition, the primary purpose of this study was to only test the effect of cement space on the marginal gap. Therefore, a laboratory scanner used in this study, to scan the preparation, helped minimize the influence of other possible variables, such as potential inaccuracies with the use of less-accurate intraoral scanners or with conventional impression making and stone pouring. For the same reason, CAD/CAM PMMA, a stable material throughout the production process, was used, instead of zirconia, which incorporates shrinkage as a part of its fabrication process. Further, in another study, it was also found that while fabricating restorations from materials like zirconia, which are normally processed after milling, every fabrication stage had a negative effect on the vertical marginal adaptation of zirconia crowns.[54] Therefore, the results of this study can be applicable to PMMA provisional as well as definitive CAD/CAM crown materials that do not require sintering.

The fit of PMMA interim restorations is an important clinical requirement for the successful maintenance of the health of the prepared tooth structure as well as the gingival/periodontal tissues. In addition, for implant restorations, a well-fitting provisional will help in achieving healthy gingival contour, also allowing for its modification as per the clinical situation. In addition, it gives the patient a chance to test the crown out, and any changes requested and required can be accordingly incorporated into the definitive restoration. Also, in the case of poor marginal adaptation of provisional restorations, the definitive restoration may be delayed, or the gingival appearance may not turn out as expected after the definitive restoration is delivered, especially in the esthetic zone. Thus, a well-fitting provisional crown directly affects the success of the definitive restorations to be delivered. This maintenance may be even more important when the long-term use of interim restorations is necessary during oral rehabilitation. A core shape was used instead of a complete contour crown. Regardless, this study enables a relative comparison among different cement spaces and their effects on the marginal fit. The results of this study should be interpreted considering this relative comparison among groups. Because it was reported that horizontal misfit may potentially be adjusted more easily than the crown vertical misfit, the aim was to test vertical misfit in this study.[38]

The milled cores in this study were not adjusted by any means prior to marginal measurements. Two sets of techniques have been reported in the literature to measure marginal and internal gaps: cementation, embedding, and sectioning specimens for measurement; and using PVS for cementation and noninvasive measurement of this PVS replica of the internal and marginal gaps.[5,30] It has been reported that the die/abutment margin could be damaged during cementation, and therefore, might result in larger marginal gaps than actual gaps.[21,22] Thus, no cement was used in the present study, and the crowns were stabilized on the tooth using a light-body PVS impression material to ensure crown retrievability and minimal damage. The measurements were made using a modified form of the PVS replica technique, as has been previously described in the literature.[5,13,30,48–50] Thus, the results of this study should be interpreted taking this methodology into consideration.

CONCLUSIONS

Within the limitations of this study, *(1)* the marginal gap values for the PMMA cores were within the clinically acceptable range for 20- to 40-μm, 20- to 50-μm, and 20- to 60-μm cement space settings; *(2)* when the cores were designed and manufactured with increased cement space, the vertical marginal gap values decreased ($P < .001$); *(3)* the smallest marginal gap values were observed when the 20- to 60-μm cement space setting was used ($P < .001$); *(4)* the PMMA cores showed similar results to the previous studies evaluating permanent restorative materials.

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