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RESEARCH AND EDUCATION

Effect of cement space on the marginal fit of CAD-CAM-fabricated monolithic zirconia crowns

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ABSTRACT

Statement of problem. Monolithic zirconia crowns fabricated with computer-aided design and computer-aided manufacturing (CAD-CAM) have recently become a common practice for the restoration of posterior teeth. The marginal fit of monolithic zirconia crowns may be affected by different cement space parameters set in the CAD software. Information is scarce regarding the effect of cement space on the marginal fit of monolithic zirconia crowns fabricated with CAD-CAM technology.

Purpose. The purpose of this in vitro study was to evaluate the effect of cement space on the marginal fit of CAD-CAM-fabricated monolithic zirconia crowns before cementation.

Material and methods. Fifteen right maxillary first molar typodont teeth with standardized anatomic preparations for complete-coverage ceramic crowns were scanned with a 3-dimensional laboratory scanner. Crowns were designed 3-dimensionally using software and then milled from presintered monolithic zirconia blocks in a computer numerical control dental milling machine. The cement space was set at 25 μm around the margins for all groups, and additional cement space starting 1 mm above the finish lines of the teeth was set at 30 μm for group 25-30, 40 μm for group 25-40, and 50 μm for group 25-50 in the CAD software. A total of 120 images (3 groups, 5 crowns per group, 8 sites per crown) were measured for vertical marginal discrepancy under a stereoscopic zoom microscope and the data were statistically analyzed with 1-way analysis of variance, followed by the Tukey honestly significant difference test (α=.05).

Results. The results showed that different cement space values had statistically significant effect on the mean vertical marginal discrepancy value of tested crowns (P<.001). The mean marginal discrepancy was 85 μm for group 25-30, 68 μm for group 25-40, and 53 μm for group 25-50.

Conclusions. Within the limitations of this in vitro study, it was concluded that the cement space had a significant effect on the marginal fit of CAD-CAM-fabricated monolithic zirconia crowns. The marginal fit improved as the cement space decreased. (J Prosthet Dent 2016;116:890-895)

With the awareness of esthetics and biocompatibility, the demand for metal-free restorations has increased among patients.[1] A properly fabricated metal-free restoration may barely be distinguished from sound natural teeth.[2] Zirconia is a high-strength ceramic that unites the positive qualities of a metal-free restorative material and is indicated for both anterior and posterior fixed dental prostheses (FDPs).[1,3,4] The use of zirconia ceramics has increased rapidly with the evolution of computer-aided design and computer-aided manufacturing (CAD-CAM) technology.[5,6] This technology has decreased the material and fabrication costs, saved laboratory time, and increased productivity.[7,8] However, traditional zirconia ceramic restorations have some drawbacks related to their clinical use, for example, the need to veneer the opaque white appearance of the zirconia with feldspathic porcelain and the varying production accuracy depending on the sintering stage of the zirconia blocks and other manufacturing processes, including the CAD-CAM system itself.[9,10] Studies[11,12] have reported the fracture or chipping of the feldspathic porcelain layer over the zirconia framework. Suggestions for overcoming this complication have been reported.[13,14] With improvements and innovations in CAD-CAM technology, monolithic zirconia restorations have recently become popular because they are easier and less expensive to fabricate.[15-20] Complete veneer

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Clinical Implications

The results of this study suggest that clinicians may select a cement space greater than 30 μm to achieve improved marginal fit for CAD-CAM monolithic zirconia crowns fabricated on molars.

crown fabrication procedures, which are becoming a worldwide practice,[21] can be used to prepare posterior teeth for monolithic zirconia crowns instead of more expensive high-noble alloy crowns. Studies[17,18] have shown that monolithic zirconia crowns can withstand posterior masticatory forces without the fracture of veneering ceramic associated with their veneered precedents.[22-24]

CAD-CAM system settings allow the adjustment of different parameters such as restorative material thickness and cement space during the virtual 3-dimensional (3D) design of the restoration. Furthermore, with recently developed systems and modifications in fabrication methods, shaded monolithic zirconia blocks allow the fabrication of restorations with improved translucency characteristics.[25]

Aside from improvements in optical properties and fracture resistance, the accuracy of marginal and internal fit is crucial to the quality and clinical success of ceramic restorations.[9,16,19,26,27] Excessive discrepancy at the crown margins may promote microleakage through increased cement dissolution,[28] which may lead to secondary caries and inflammation of dental pulp,[29,30] an increase in plaque accumulation,[31] and a predisposition to periodontal disease.[32,33] The accuracy of fit may depend on the differences between various CAD-CAM production lines, including scanning precision, CAD software efficacy, zirconia state at milling, or grinding protocol of the CAD-CAM system. In addition, after milling is completed, manual adjustments of CAD-CAM restorations by dental technicians have been shown to contribute significantly to the improvement of the restoration fit.[9,10,29,34] Recently, scientific investigations have focused on the precision of zirconia crown abutment adaptation,[1,8-10,19,26,27,29,35-45] and they report conflicting findings.[9] Some have stated that milling zirconia at its presintered stage provides more favorable marginal fit compared with milling after sintering.[37] Others have shown that milling restorations from sintered zirconia blocks results in less marginal discrepancy than milling from presintered blocks.[38,39] Another study comparing the marginal fit of ceramic crown frameworks fabricated from presintered and postsintered zirconia blocks found no difference between the 2 machining processes.[40] The marginal fit obtained by different CAD-CAM systems is not consistent. Some studies have reported results in favor of certain manufacturers and others just the opposite.[41-44] The difference in fabrication has been attributed mainly to the internal space provision,[37,38,43,46] which can be system sensitive and affect the seating of zirconia crowns.[38,47] Even though increasing cement thickness can improve the marginal fit of crown restorations,[47,48] an internal space of more than 120 μm might decrease the fracture resistance of ceramic crowns without significantly improving marginal fit.[49] Many studies have advocated a maximum marginal discrepancy of less than 120 μm as clinically acceptable,[50-54] and a few consider this threshold to be 100 μm.[35,39,47] A clear consensus of clinically acceptable marginal fit has still not been established for the crown restoration; as for internal fit, evidence in the literature is scarce.[9]

The purpose of this in vitro study was to evaluate the effect of cement space on the marginal fit of CAD-CAM fabricated monolithic zirconia crowns before cementation. The hypothesis tested was that no difference would be found in the marginal fit of monolithic zirconia crowns fabricated using the different cement space settings available in the software of the CAD-CAM system used.

MATERIALS AND METHODS

Fifteen ivorine right maxillary first molar typodont teeth (1860P03FC EP-TPR-860 #3/CVC; Columbia Dentoform) with standard anatomic preparations supplied by the manufacturer (0.5-mm axial reduction, 360-degree chamfer margin) for complete-coverage ceramic restorations[21] were divided into 3 groups. Each group was scanned with a 3D laboratory scanner (D900; 3Shape), and CAD design software (Dental System; 3Shape) was used to design a crown for each tooth in the groups. The designed crown data was processed with CAM software (CORiTEC iCAM V5; iMES-iCORE), and CAD-CAM ceramic crowns were milled from presintered monolithic zirconia blocks (StarCeram Z-Nature; H.C. Starck) in a 5-axis computer numerical control dental milling machine (CORiTEC 550i; iMES-iCORE). The same crown design with identical external contours for all groups simulated cement space of 25 μm around the margins and additional cement space of 30 μm, 40 μm, and 50 μm, starting 1 mm above the finish lines of the teeth for group 25-30, group 25-40, and group 25-50 (Fig. 1), respectively. After milling and sintering (Sinterofen HT-S Speed; Mihm-Vogt), the intaglio surface of the crowns (except for the margins) was manually adjusted by an experienced dental technician familiar with the CAD-CAM system used with a diamond rotary instrument (Komet ZR6856; Gebr. Brasseler) and a high-speed rotary handpiece under water cooling (Presto Aqua II; NSK) according to the manufacturer's instructions.[34] After seating adjustments, the crowns were glazed.

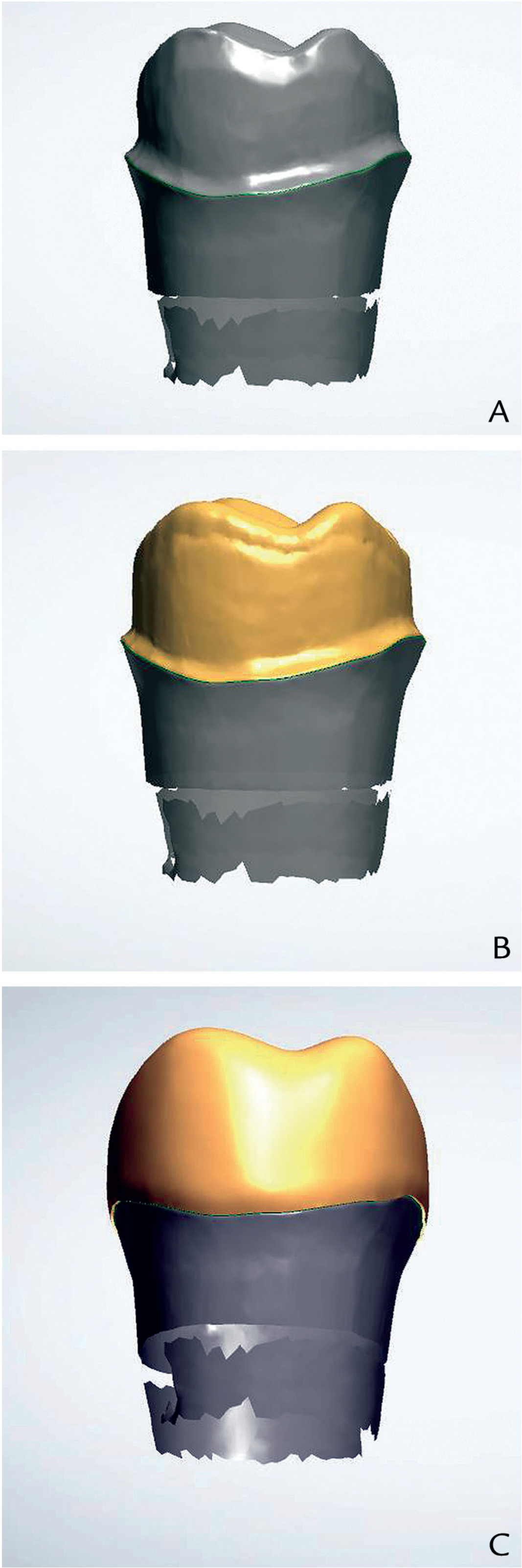

Figure 1. A, Computer-aided design software image of scanned typodont tooth. B, Simulated cement space on tooth image. C, Virtual crown design.

Figure 2. Cast-metal ring guide used for standardization of measurement locations.

The vertical marginal discrepancy of the crowns was measured circumferentially at 8 consecutive locations (mesiopalatal, mesial, mesiobuccal, buccal, distobuccal, distal, distopalatal, and palatal) using a ×3.5 to ×180 zoom stereomicroscope (SM-3TZZ-54S-10M; AmScope) equipped with 10 MP digital camera (MU1000; AmScope) and light-emitting diode (LED) ring light (LED-54S; AmScope).[8,55] The microscope camera was calibrated using a single calibration slide (MR100; AmScope) with a precision stage micrometer (0.01 mm).[8,55] The crowns were seated onto their corresponding teeth without the use of any medium. The specimens were aligned perpendicular to the evaluation sight of the microscope and manually rotated to measure each point.[8,55] To standardize the measurement locations, a cast-metal ring guide with 8 horn-like projections, each indicating the locations to be measured, was fabricated to fit on the cervix of the typodont teeth (Fig. 2). The measurements were performed in real-time on 3584×2748 resolution live-video-stream computer image at ×100 magnification by means of software (AmScope x86, v3.7.3980; AmScope) that measured the shortest distance between 2 parallel lines drawn at the crown margin and the finish line of the teeth (Fig. 3).[55] All measurements were made by a single operator (E.K.).

A total of 120 measurements were made (3 groups of 5 specimens, 8 measurement locations per specimen). The average value of the 8 measurement points was calculated for each specimen and considered as the circumferential vertical marginal discrepancy value for each specimen. The means and standard deviations were calculated for each group and statistically analyzed for significant differences with 1-way ANOVA and the Tukey honestly significant difference (HSD) test using statistical software (IBM SPSS Statistics v21.0; IBM Corp)

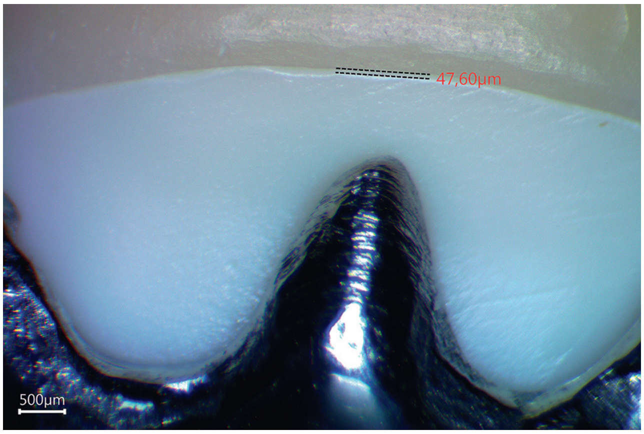

Figure 3. Marginal discrepancy measurement (original magnification ×100).

(α=.05). Post hoc power analysis was also performed on the results. The power of the ANOVA test was equal to 1 (0.998) with type I error at α=.05.

RESULTS

The results of 1-way ANOVA indicated that different cement space values significantly affected the vertical marginal discrepancy values of tested crowns (P<.001). The post hoc Tukey HSD test revealed statistical differences between group 25-30 and group 25-40 (P=.019), group 25-30 and group 25-50 (P<.001), and group 25-40 and group 25-50 (P=.048), with mean marginal discrepancy values of 85 µm for group 25-30, 68 µm for group 25-40, and 53 µm for group 25-50 (Fig. 4). Table 1 shows the mean marginal discrepancy values, standard deviations, and minimum-maximum range values for each group with their respective statistical significance.

The highest marginal discrepancy value measured in 1 of the 8 measurement locations in group 25-30 was 187 µm. The number of discrepancy values above the clinically acceptable threshold (120 µm) measured per location was 9 in this group, and the number of values over 100 µm was 12. The marginal discrepancy values over 100 µm in group 25-40 were 7 with 1 value over 120 µm being measured as 157 µm. The largest discrepancy per measurement point in group 25-50 was 122 µm and was the only one greater than 120 µm; even so, only 2 values were greater than 100 µm.

DISCUSSION

The results of the current study showed significant differences for all the groups tested, thus the hypothesis was rejected. For the CAD-CAM fabricated monolithic zirconia crowns investigated in this study, the smallest mean marginal discrepancy was observed in group 25-50 (53 µm). The mean marginal discrepancy in group 25-40 (68 µm) and 25-30 (85 µm) was higher. To the authors' knowledge, no other published study is available on

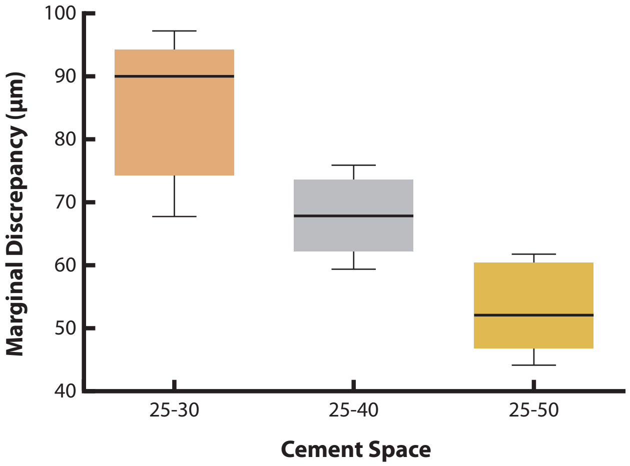

Figure 4. Box-plot diagrams for marginal discrepancy of groups with different simulated cement space.

Table 1. Minimum-maximum range of vertical marginal discrepancy measurements (µm) according to cement space

Group	Specimens, n	Mean	SD	Min	Max
25-30	5	85[a]	12	68	97
25-40	5	68[b]	6	60	76
25-50	5	53[c]	7	44	62

Different superscript letters indicate significant difference between group pairs according to Tukey HSD test (P<.05).

marginal fit of monolithic zirconia FDPs. Therefore, the direct comparison of the results of the present study with other studies was not possible. Nonetheless, the results derived from this study can be compared with other studies focused on marginal discrepancy and cement space evaluation in different types of crowns, especially those fabricated using CAD-CAM technology. According to Grajower and Lewinstein,[56] the cement space of a crown should be set to be at least 50 µm, of which 30 µm would serve for clearance for cement thickness and reduction of friction due to surface roughness, and the remaining 20 µm would be a precaution for potential distortion in the restoration caused by the production. This recommendation was supported with the results of the present study as the group 25-50 with 50 µm of cement space presented significantly smaller marginal discrepancies compared with the other groups. The mean discrepancies of the specimens in group 25-50 were smaller than 100 µm except 2 points in 2 different specimens being greater than 100 µm. The individual marginal discrepancy measurements of group 25-50 were within the threshold of clinical acceptability (120 µm) except for 1 measurement being 122 µm. The individual marginal discrepancy measurements of group 25-40 with 40 µm of cement space were clinically acceptable (120 µm) except for 1 measurement being over 120 µm. Nevertheless, there were 3.5-fold more individually measured values greater than 100 µm in group 25-40 compared with group 25-50. The fact that the number of measurement points was low should be considered when interpreting the current study results in terms of clinical acceptability. Group 25-30 with 30 μm of cement space presented with 6-fold more individually measured values greater than 100 μm than in group 25-50, of which only 3 were less than and as much as half were far more than 120 μm. Despite the clinically acceptable overall mean marginal discrepancy results of the specimens in group 25-30, the measured points greater than 120 μm in this group should be taken into consideration. The significant improvement in marginal fit with the increase in cement space observed in the current study is in accordance with the literature.[29,49,56,57] Further research is needed to investigate the effect of increase in cement space on the marginal fitting accuracy in relation with the retention and fracture strength of monolithic zirconia crowns as well.

Evidence suggests that the cement space of CAD-CAM zirconia crown restorations should be set at no smaller than 60 μm for better seating on the abutment with minimal need of manual adaptation.[29] An et al[36] evaluated the marginal fit of zirconia copings with simulated die spacer set at 60 μm and calculated overall mean vertical discrepancy value of 104 μm. Prasad and Al-Kheraif[58] also investigated the vertical marginal discrepancy in zirconia copings. The simulated cement space was 50 μm and the overall mean results were 59 μm for postsintered and 68 μm for presintered zirconia restorations. Euán et al[59] reported vertical marginal discrepancy values of 53 μm for rounded shoulder and 64 μm for chamfer finish line zirconia copings with a 50 μm of simulated die spacer. All these findings are within the range of 120 μm clinically acceptable limit and most of them support the results of the present study, however it is not clear how the veneering process and glazing would have affected the marginal fit of the zirconia copings in those studies. It was reported in previous studies that repeated firing cycles could induce tendency for distortion in the zirconia framework and veneering could have an adverse effect on the marginal fit of zirconia restorations.[9,37,44] The different stages of crown fabrication up to before-cementation stage may alter the marginal fit of the restorations particularly in terms of vertical marginal deficiency. Many studies evaluated the marginal discrepancies of zirconia copings or veneered zirconia crowns presenting only data of combined vector values of vertical and horizontal marginal discrepancy measurements (absolute marginal discrepancy).[19,26,29] Therefore, whether the discrepancy is associated with the horizontal or the vertical component of the vector more is not clear.[35] If the discrepancy is related to a horizontal over-extension rather than a vertical under-extension, as often cited in the literature,[19,35] the fit of the horizontal component can be improved by recontouring the finish line under appropriate laboratory conditions before cementation. However, if the discrepancy is due to a vertical under-extension, the marginal fit can be improved ideally by only remaking the restoration. Therefore, the current study focused on the vertical marginal fit of ceramic crowns at the before-cementation phase.

Many investigators have conducted research on the marginal adaptation of ceramic crowns. Of the studies published in the last 5 years, some performed measurements on 4 to 8 points,[8,26,36,45,55] some on 16 to 24 points,[29,58,59] and others on 80 to 360 points,[19,35] per specimen. Accordingly, there is still no consensus on how many measurements per specimen are required to obtain an optimal, clinically relevant, conclusion on the accuracy of marginal adaptation of crown restorations. In the authors' opinion, as many points as could be included should be used to evaluate the marginal fit. However, it may be beneficial to report not only the mean marginal discrepancy values, but also the highest values (peak) at measurement locations, to avoid misleading conclusions. Matta et al[35] investigated the marginal adaptation of crown copings at 360 different measurement points with 1 degree distance in between per specimen. They showed that even though their mean results were within 100 μm threshold, many individual marginal discrepancy values were greater than 150 μm. They also stressed on the importance of reporting the individual measurement values in these studies, and stated that the conclusions drawn from combined vectorial values, like the absolute marginal discrepancy, may mislead the clinicians when interpreting the results regarding their clinical acceptability. In the authors' opinion, consensus should be established among investigators for standardization of methodology for evaluation of marginal fitting accuracy of fixed restorations, which may allow for improved definition of clinical acceptability.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. The cement space had a significant effect on the marginal fit of CAD-CAM fabricated monolithic zirconia crowns with a chamfer finish line.
2. The marginal discrepancy values increased when the cement space decreased.
3. The mean marginal discrepancy values were within the clinically acceptable limits for all groups (<120 μm).

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