Original Research
Prosthesis

Does cad software affect the marginal and internal fit of milled full ceramic crowns?

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Abstract: Although the effects of different intraoral scanners, model scanners, and CAM units on the marginal and internal fitting of restorations have been investigated, the effects of CAD software in particular has not been evaluated. The marginal and internal fit of indirect restorations may vary according to the CAD software used, even when using the same intraoral scanner and milling machine. The purpose of this study was to evaluate the marginal and internal fit of milled full ceramic crowns designed with three different CAD systems. Eleven typodont maxillary first premolar teeth were prepared and scanned using a 3Shape TRIOS Intraoral Dental Scanner. The obtained STL scan data were exported and used to design a full crown using three different CAD systems (CEREC, KaVo, and Planmeca). An independent milling unit was used to manufacture the crowns for each group ($n = 11$). The marginal and internal fit were evaluated for each restoration using 2D and 3D micro-CT analysis. For 2D analysis, 18 measurements for each sample were made, covering the marginal (Marginal Gap Buccal (MG-A), Marginal Gap Palatinal (MG-B), Finish Line Buccal (FL-A), Finish Line Palatinal (FA-B)) and internal fit locations (Axial Wall Buccal (AW-A), Axial Wall Palatinal (AW-B), Lingual Cusp (LC), Buccal Cusp (BC), and Occlusal Central Fossa (OCF)). Statistical analyses were performed using Open Source R Statistical Software ($\alpha = 0.05$) The results of Duncan's multiple range test showed that the values for the marginal measurement points MG-A, MG-B, FL-A, and FL-B in the Planmeca group were significantly higher than the values obtained in the CEREC and KaVo groups ($p < 0.05$). In AW1, values of the CEREC group were found to be higher than those of the KaVo and Planmeca groups ($p < 0.05$). CAD software showed an effect on the marginal fit values of crowns whereas no significant difference was observed in terms of the internal fit, except for a single measurement point made from the buccal direction.

Keywords: Computer-Aided Design; Software; Crowns; X-Ray Microtomography.

Introduction

The clinical success of dental restorations is influenced by three main factors: esthetics, fracture strength, and adaptation of the restoration to tooth preparation.[1] Marginal and internal fit is of great importance for long-term clinical success particularly in ceramic restorations.[2,3] In particular, poor and inadequate marginal adaptation between the crown and the restoration may result in plaque accumulation, secondary caries, microleakage, and endodontic lesions. Plaque accumulation may cause periodontal inflammation particularly in restorative margins ending subgingivally.[1,2,4,5]

Although there is no definite information about the clinically acceptable marginal fit, values below 120 micrometers have been reported as a marginal fit that can be considered successful in several studies.[2,6] In some studies, a marginal fit below 100 microns has been reported to be more acceptable[7,8] while others suggest that a value of 75 micrometers or below is required for a clinically-successful restoration.[2] The American Dental Association Specification No. 8 recommends a thickness of 25–40 micrometers for the cement pitch.[6] Although a value of 25–40 micrometers is a considered a desirable margin in restorations, it is difficult to achieve this value.[9] The marginal fit for restorations produced via Computer-Aided Design/Computed-Aided Manufacturing (CAD/CAM) is reported to be 58–200 micrometers.[6,10]

The use of CAD/CAM systems in dentistry has allowed ceramic restorations to be produced in a shorter time and with a more acceptable adaptation accuracy in dental laboratories and dental clinics.[11,12] This technology was developed for use in dental clinics and has become an alternative to conventional techniques.[13] Many factors can influence the success of restorations produced with a CAD/CAM system. These factors are dental preparation, scanning systems, CAD software, production stage, or type of material used.[6] The marginal disharmony of restorations has been influenced by every step and change in the CAD/CAM system, from optical measurement to mechanical processing.[13]

Numerous methods have been used to evaluate the marginal fit in dentistry.[1,2] Micro-computed tomography (micro-CT) is one of these methods. Although micro-CT is relatively more expensive than other methods, it is a non-destructive method for the evaluation of marginal fit.[14,15] This three-dimensional (3D) high-resolution imaging system provides detailed cross-sectional information regarding the adaptation of crown restoration to dental preparation without damaging the sample.[1,16,17]

There have been numerous studies examining the effects of different intraoral scanners, different milling devices and different versions of design programs on the marginal and internal fit of restorations. However, there are no studies to date examining the effect of different CAD software on the fit of restorations. Only different versions of the same CAD software have been analyzed. Many clinicians use only intraoral scanners in their clinics and send intraoral scanning data to external laboratories to design and produce the restorations. The fit of the restorations is thought to be affected not only by other parameters but also by CAD software. This study aims to investigate the effect of crown restorations designed using three different CAD software systems on marginal and internal fit. The null hypothesis of the study was that different CAD software would not affect the marginal and internal fit values.

Methodology

A total of 11 typodont enamel–dentin–pulp-based hard thermosetting plastic material maxillary first premolar teeth (ANA-4 ZSPD, Frasaco GmbH, Tettnang, Germany) were prepared by a single operator using standard diamond bur sets (Frasaco) by checking the relationship between the maxillary and mandibular teeth. A shoulder finish line with a rounded internal line angle was created for the crown by using diamond burs (839014; Hager & Meisinger GmbH, Neuss, Germany). First, guide grooves (Q92491; Hager & Meisinger GmbH) were opened and then axial and occlusal reductions were completed by following the principles of dental preparations (635314; Hager & Meisinger GmbH).

The relationships of the 11 prepared teeth with neighboring teeth and occlusion were scanned using a 3Shape TRIOS Intraoral Dental Scanner (3Shape, Copenhagen, Denmark) and the scan data were received from the system in the form of an STL file and were used in three different CAD systems (CEREC (inLab 15.1), KaVo (multicad. PC_V4.0.3), and Planmeca (Romexis PlanCad Easy5.9.2.09)). All designs were created by a single operator. The design proposed by the program was not altered except for minor corrections in the margin drawing to eliminate operator-related errors. In all three systems, the cement gap was set to 80 micrometers in margins and 120 micrometers in other regions. There was no intervention in any other parameters. A total of 33 crowns were milled (11 using each CAD software) using feldspathic ceramic blocks (62790; VITA Zahnfabric, Bad Säckingen, Germany) in an independent five-axis milling unit (DMC5020, DentMaster, Istanbul, Turkey).

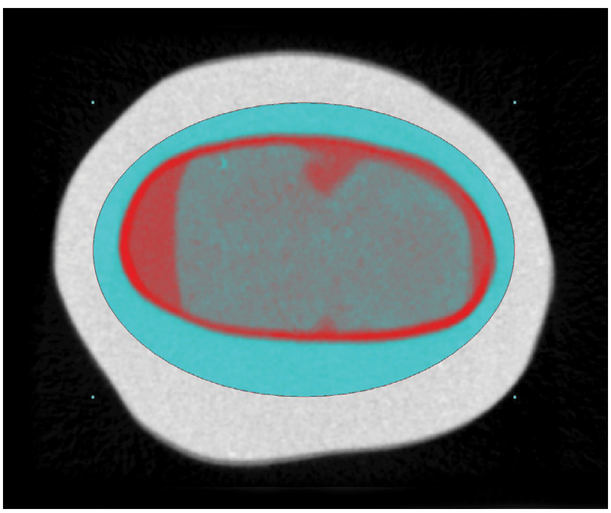


Figure 1. Colored and 3D images, obtained from the samples using CTvox and CTvol software.

The fabricated crowns were placed on each prepared tooth, and attached with radiolucent paraffin tapes to prevent any movement during micro-CT scanning. The micro-CT scans (Skyscan 1275; Bruker MicroCT, Kontich, Belgium) were performed using an aluminum (Al) filter (1 mm) with a rotation step of 0.2 in the cross-sectional range of 125 kVp, 80 mA and 24 µm. Raw micro-CT data were reconstructed using NRecon software (version 1.6.4.8 Bruker Corp.) and axial projections were obtained. These data were then transferred to CTan software (version 1,14,4,1 Bruker Corp.) for 3D analysis.[2,15,16,18-20]

For the 3D analyses, crowns and substructure were included in the Region of Interest (ROI) and threshold values were determined. To calculate the volume of the gap (mm^3), the original grayscale images were processed. Grayscale thresholds were defined to separate root material from crown and gap. The global threshold method was used for this. The amount of gap between the substructure and the crown was calculated. Then, the measurements were subject to statistical comparison. Colored and 3D images were obtained from the samples using CTvox and CTvol software[18,21,22] (Figure 1).

DataViewer software (version 1,5,6.2 Bruker Corp.) was used to prepare for 2D analyses. The midcoronal and midsagittal images of axial sections were obtained using this software (Figure 2a, 2b). Then, 2D linear measurements were re-performed with CTan software in these sections. For the 2D analyses, the measurement points previously described in the literature were

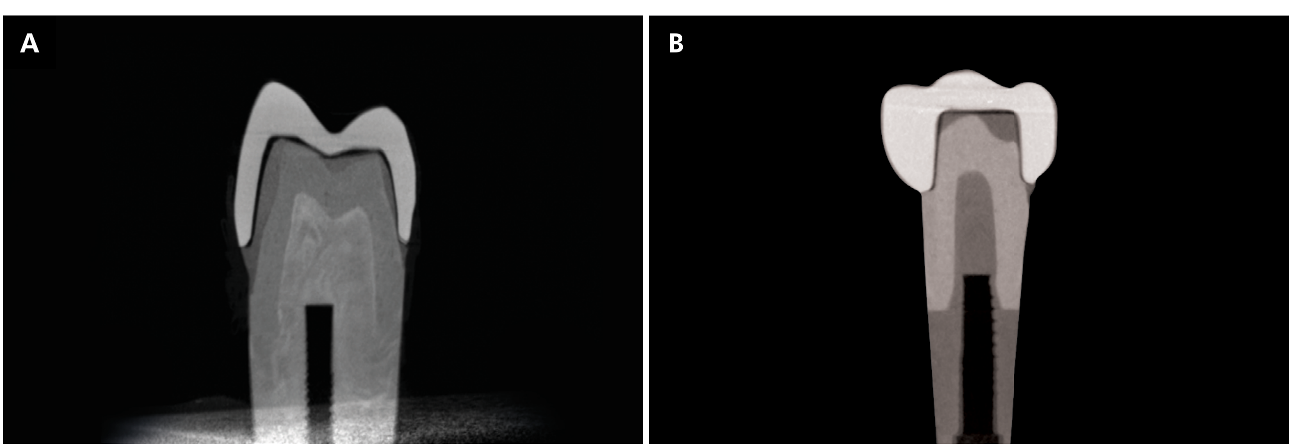


Figure 2. a) Midcoronal, and **b)** midsagittal cross-sectional images.

used (Riccitiello et al. 2018) (Figure 3). A total of 594 measurements, 18 measurements for each sample, were made. Measurement locations MG-A, MG-B, and FL-A, FL-B were evaluated for the marginal gap whereas measurement locations AW-A, FL-B, LC, BC, and OCF were evaluated for internal fit.

All statistical analyses were performed using Open Source R Statistical Software. The Shapiro-Wilk test was used to evaluate the parametric or nonparametric distribution of the groups. One-way ANOVA was used to determine any significant differences between groups, and Duncan's multiple range test was used to determine intra-group differences. A p-value of < 0.05 was considered statistically significant in all tests.

Results

Descriptive statistical analysis of the mean and standard deviation values of linear and volumetric measurements for all groups is shown in Tables 1 and 2. Repeated ANOVA measurements showed significant differences for MG-A, FL-A, AW-A, FL-B and MG-B values ($p < 0.05$).

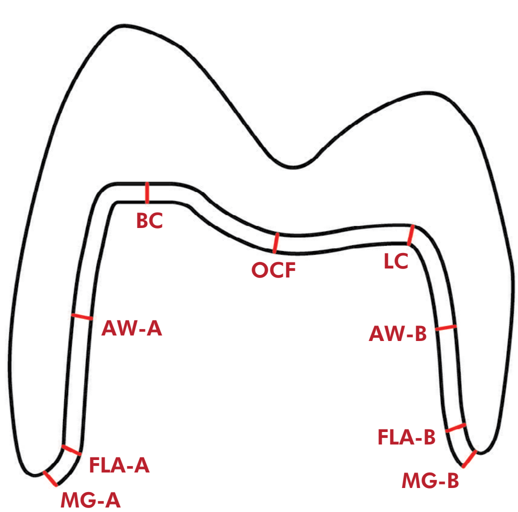
The results of Duncan's multiple range test showed that the values for the measurement point MG-A in the Planmeca group (114.9 ± 72.1) were significantly higher than the values in the CEREC (34.0 ± 82.0) and KaVo (38.0 ± 85.0) groups.

The highest values for the measurement point FL-A were seen in the Planmeca group (224.8 ± 76.7) and this value was significantly different from the other two groups ($p < 0.05$). The values of the CEREC group (118.0 ± 69.9) were higher than those of the KaVo group (69.7 ± 66.1), but the difference was not statistically significant ($p > 0.05$).

In AW-A, which was one of the measurement points used to evaluate internal fit, values of the CEREC group (132.5 ± 43.4) were found to be higher than those of the KaVo group (82.3 ± 38.1) and the Planmeca Group (95.6 ± 40.4) ($p < 0.05$). However, there was no significant difference between the KaVo and Planmeca groups ($p > 0.05$).

The values of FL-B measured using CEREC (101.2 ± 80.4) were higher than those using KaVo (87.6 ± 69.7), but this difference was not significant ($p > 0.05$). The values measured using Planmeca (218.4 ± 79.9) were found to be significantly higher than those measured with CEREC or KaVo ($p < 0.05$).

In the measurements of the MG-B measurement point, the values in the Planmeca group (151.9 ± 93.1) were significantly higher than the other two



LEGEND ABBREVIATION	MEASUREMENT LOCATION
MG-A	Marginal Gap Buccal/Mesial
FL-A	Finish Line Buccal/Mesial
AW-A	Axial Wall Buccal/Mesial
BC	Buccal Cusp
OCF	Occlusal Central Fossa
LC	Lingual Cusp
AW-B	Axial Wall Palatal/Distal
FL-B	Finish Line Palatal/Distal
MG-B	Marginal Gap Palatal/Distal

Figure 3. Reference points for micro-CT measurements of midcoronal and midsagittal sections.

Table 1. Descriptive statistical analysis of 2D analysis

Linear analyss	n	Mean± SD (µm)	p-value
MG-A			
Cerec[a]	11	34.0 ± 82.0	
KaVo[a]	11	38.0 ± 85.0	0.040
Planmeca[b]	11	114.9 ± 72.1	
FL-A			
Cerec[a]	11	118.0 ± 69.9	
KaVo[a]	11	69.7 ± 66.1	0.000
Planmeca[b]	11	224.8 ± 76.7	
AW-A			
Cerec[b]	11	132.5 ± 43.4	
KaVo[a]	11	81.3 ± 38.1	0.018
Planmeca[a]	11	95.6 ± 40.4	
BC			
Cerec[a]	11	78.7 ± 86.6	
KaVo[a]	11	93.3 ± 69.6	0.862
Planmeca[a]	11	73.3 ± 106.0	
OCF			
Cerec[a]	11	113.7 ± 48.4	
KaVo[a]	11	106.7 ± 82.3	0.916
Planmeca[a]	11	120.4 ± 91.9	
LC			
Cerec[a]	11	79.0 ± 77.4	
KaVo[a]	11	80.0 ± 49.6	0.678
Planmeca[a]	11	57.0 ± 75.9	
AW-B			
Cerec[a]	11	94.3 ± 42.1	
KaVo[a]	11	85.6 ± 33.1	0.489
Planmeca[a]	11	73.0 ± 47.6	
FL-B			
Cerec[a]	11	101.2 ± 80.4	
KaVo[a]	11	87.6 ± 69.7	0.001
Planmeca[b]	11	218.4 ± 79.9	
MG-B			
Cerec[a]	11	25.6 ± 47.3	
KaVo[a]	11	31.3 ± 65.5	0.000
Planmeca[b]	11	151.9 ± 93.1	

n: number of samples; Within group significant differences are indicated by different superscript letters.

(p < 0.05). The values in the CEREC (25.6 ± 47.3) and KaVo (31.3 ± 65.5) groups were close to each other and there was no statistically-significant difference between the groups (p > 0.05).

Table 2. Descriptive statistical analysis of 3D analysis.

Volumetric analyss	n	Mean± SD (mm^3)	p-value
Volume			
Cerec[a]	11	9,7088 ± 3,0897	
KaVo[a]	11	8,0980 ± 3,1229	0.119
Planmeca[a]	11	7,0931 ± 2,4216	

n: number of samples; Within group significant differences are indicated by different superscript letters.

In volumetric measurements made in 3D, the values in the CEREC group were higher than the values in the KaVo group which in turn were higher than the values in the Planmeca group. However, no statistically-significant difference was found between the three groups (p > 0.05).

Discussion

This study investigated the effect of crown restorations designed with three different CAD software systems with a focus on marginal and internal fit. Based on the results of this study, different CAD software affected the marginal fit, however the internal fit was not affected except for one measurement point. While there was no significant difference according to the results of 3D analysis, there was a difference in the 2D analysis. Thus, the null hypothesis of the study has been partially rejected.

The data obtained from the results of this study showed a significant difference between the restorations designed and produced using three different CAD software systems in terms of marginal fit. However, the internal fit between ceramic restoration and tooth preparation was not affected by the use of different CAD software, except for one measurement point. The marginal fit values of crowns designed using Planmeca CAD software were found to be significantly higher than the other two CAD software. There was no significant difference between CEREC and KaVo software. The internal fit of a ceramic crown affects its fracture strength.[23,24] Since large internal misfits would result in a thick layer of a low elastic modulus material (cement), misfit may be structurally important for brittle materials, such as ceramic restorations.[24] In a study conducted by Lee et al.,[25] the effect of two different CAD/CAM systems on the internal gap was examined and the internal fit was reported to be affected by the different systems used. In the present study, there was no significant difference between the crown restorations produced using the three different CAD software systems in terms of internal fit, except for a single measurement point. For the measurement point AW-A made from the buccal surface of the tooth, the CEREC group showed significantly higher values than the KaVo group whereas no significant difference was observed between the Planmeca group and the other two groups.

Previous studies have shown that poor marginal fit results in microleakage, periodontal problems, and secondary caries.[1,2,4,5] Although there is no definite information about the clinically-recommended marginal fit, a marginal fit up to 200 micrometers for CAD/CAM restorations is usually considered clinically acceptable.[6,10] In the present study, the marginal fit values for crown restorations in the Planmeca group were found to be close to or above 200 micrometers on average, whereas they were less than 200 micrometers in the CEREC and KaVo groups.

Many studies reported in the literature investigated the effects of different intraoral scanners, model scanners and CAM units, CAD/CAM systems, and different versions of design programs on the internal and marginal fit of restorations.[15,18,26-29] Haddai et al.[26] evaluated the effect of different versions of a design program on the fit of a restoration and different versions of the software were shown to affect the adaptation of the restoration. Similarly, different results were obtained from different CAD software in the current study. However, our literature review revealed that there is no other study investigating the effect of CAD software alone, using the same independent scanner and CAM unit, as in the present study.

Different methods are described and recommended in the literature to measure the marginal and internal adaptations of indirect restorations, such as stereomicroscopy, scanning electron microscopy, optical microscopy, and micro-CT.[14,27,30-34] In line with the previously-published studies,[15,16,27] micro-CT was used to evaluate the marginal and internal fit of crown restorations in the present study. At present, micro-CT has gained an important place as one of the best and most recommended methods of evaluating marginal and internal fit, since it ensures high-resolution images, repeated measurements and that measurements can be performed without damaging the specimens.[1,2,17]

Micro-CT provides 3D volumetric analysis as well as 2D linear analysis.[17] Yildirim et al,[35] reported that cement space volume is a 3D parameter that represents more accurate values than 2D measurements. In the present study, the marginal and internal fit measured in 3D showed no significant difference between the three groups in which different CAD software were used. Although there was no difference between the groups according to the results of volumetric analysis, a statistically-significant difference was observed between the groups in terms of the marginal fit values. Thus, the 3D analysis provided useful information regarding the gap values between the restoration and the teeth. The average gap per area obtained through such methods better represents the entire restoration rather than a random portion of it. However, it was insufficient to assess the adaptation of the restoration in that it could not reflect the differences in marginal fit in particular.

Kim et al.[32] used different scanners to determine the cement space volume of IPS molar crowns and reported values ranging between 25.3 and 40.7 mm^3. In this study, the measured 3D value of the premolar teeth was approximately 8 mm^3. This could also be related to the tooth type used. Typodont is frequently used in investigations evaluating the marginal and internal fit of restorations.[15,25,27] Ayad et al.[36] investigated the difference in crown preparation between natural teeth and typodont, and reported that the results were not affected by the type of tooth prepared. Therefore, in this study, typodont was used for crown preparation to evaluate the marginal and internal fit.

In the present study, restorations were fixed with radiolucent paraffin tapes to ensure that they remained stable in the micro-CT device where the sections were made. Since the produced crown restorations were going to be placed in the same tooth preparation to evaluate the three different groups, it was thought that cement residues could not be cleaned away completely and would cause measurement error.[2] Paraffin tapes were able to hold the restoration fixed on the dental preparation and yet could be easily removed from the tooth leaving no residue. Thus, the prepared teeth were not damaged and it was more convenient to conduct measurements without cementing the crown.[1]

In the literature, aluminum filters have been used to prevent radiological artifacts in scans of ceramic objects. In our study, we scanned with an aluminum filter and adjusted all other parameters accordingly.[2,15,18] Shim et al.[37] in their study, concluded that parameter settings affect the fit of CAD/CAM restorations. In this study, all parameters were kept constant in the three groups. Thus, the marginal and internal adaptation was not affected by the other parameters.

In one previous study, the learning curves for the finish line of two different CAD software systems were examined with the findings that the learning curves could affect the results.[38] In the present study, minor corrections were made to minimize the effect of different learning curves where the system failed in the automatic margin drawing. No intervention was made other than these corrections. The findings should be verified on other preparations and construction designs.

Conclusion

Based on this study, the following could be concluded:

a. CAD software showed an effect on the marginal fit values of crowns.
b. The lowest marginal fit values were obtained with the CEREC and KaVo CAD software.
c. No significant difference was observed between the different CAD software in terms of internal fit, except for the measurement point made from the buccal direction.

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