ORIGINAL RESEARCH

Evaluation of Effect of Fabrication Steps on Marginal Adaptation of CAD/CAM Zirconia-based Crowns in Comparison to Sintered PFM Crowns: An *In Vitro* Study

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Abstract

Aims: This study aimed to compare and evaluate the effect of fabrication steps on marginal adaptation of CAD/CAM zirconia-based crowns in comparison to sintered PFM crowns.

Materials and methods: Forty typhodont mandibular molar teeth were collected, a standardized protocol was followed for tooth preparation, after the tooth preparation forty typhodont mandibular molar teeth were divided into two groups. Group I—20 CAD/CAM zirconia crowns and group II—20 sintered PFM restorations. Both the groups of crowns were analyzed for marginal fit during each step of fabrication, i.e., coping, after veneering, after cementation, and after thermomechanical loading. Each specimen was photographed using a stereomicroscope at 40× magnification to measure and evaluate the marginal discrepancy (MD). The results of a vertical MD of all tested fabrication stages were statistically analyzed using one-way analysis of variance (ANOVA), independent sample *T*-test.

Results: In this study, the marginal gap was increased after every tested stage for both the groups. The mean marginal adaptation values were least in each stage of fabrication for CAD/CAM zirconia-based crowns (coping—104.98 µm, veneering—108.46 µm, after cementation—110.11 µm, thermomechanical loading—116.41 µm) compared to sintered PFM crowns (coping—128.87 µm, veneering—132.41 µm, after cementation—135.51 µm, thermomechanical loading—136.9 µm).

Conclusion: The mean marginal adaptation values observed were all within the clinically acceptable range for both groups. Marginal adaptation of CAD/CAM zirconia-based crowns was better than sintered PFM crowns within each stage of fabrication.

Keywords: Computer-aided design and computer-aided manufacturing, Direct metal laser sintering PFM crowns, Fabrication steps, Marginal adaptation, Zirconia crowns.

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Introduction

Any successful dental restoration should have four distinct properties, i.e., marginal adaptation, biocompatibility, esthetics, and mechanical strength. The longevity of fixed prosthodontics depends on the condition of the marginal adaptation to the abutment teeth.[1] Marginal gaps (MGs) can form a favorable condition for biofilm deposition, thereby contributing to the development of caries and periodontal diseases. Moreover, regardless of the sort of cement, large gaps increase the wear of the cement.[1] The minimization of the crown and fixed partial denture MGs is an important goal in prosthodontics. Smaller MGs produce less gingival irritation and cement washout improving the clinical outcome and longevity of the restoration.[2]

Based on the available scientific evidence, no consensus exists on the maximum clinically acceptable marginal discrepancy (MD), with reported values varying between 50 and 200 µm. An increase in the MD values reduces the fracture resistance of the crown and the veneering porcelain. Four different terms have been used to define the marginal accuracy or adaptation of fixed dental restorations, i.e., MG, absolute MD (AMD), vertical MD, and horizontal MD.[3]

The use of zirconia ceramics has increased rapidly with the evolution of computer-aided design and computer-aided manufacturing (CAD-CAM) technology. This technology has decreased the material and fabrication costs, saved laboratory time, and increased productivity. The marginal fit obtained by different CAD-CAM systems is not consistent. Some studies have shown increasing cement thickness can improve the marginal fit of crown restorations, an internal gap of >120 µm might decrease the fracture resistance of ceramic crowns without significantly improving marginal fit. Many studies have advocated a maximum MD of <120 µm as clinically acceptable.[4]

Computer-aided design/computer-aided manufacturing technology which relies on exact dimensional predictions has demonstrated improved marginal adaptation. The MD of each crown system can be evaluated by comparing the measurement

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values obtained at different steps of the manufacturing process. Moreover, the assessment of mechanical and hydro-fatigue effects may provide information on the long-term stability of restorations.[5]

Metal ceramics are still the most widely used material for fabricating complete coverage crowns and fixed partial dentures. The marginal accuracy and internal fit of the restoration are the major determining factors for the success of the restoration. Any discrepancy at the marginal or internal level may be produced due to cumulative results of many variables, as multiple steps in the production increase the number of variables that can cause a misfit.[6] Thus, the fabrication technique plays an important role in providing accuracy. The conventional technique of fabrication is the lost wax technique that includes so many manual steps which always have a greater chance for errors.[7]

Biological failure is a more common reason than mechanical failure for replacing metal-ceramic crowns. Direct metal laser sintering (DMLS) manufacturing systems have recently been introduced for fabricating metal frameworks for metal-ceramic crowns to overcome the disadvantages of the casting method. Direct metal laser sintering facilitate laboratory procedures and save time; however, little has been published on the marginal and internal adaptation of metal-ceramic crowns fabricated with these techniques.[8]

Hence, the present study was undertaken to compare and evaluate the effect of fabrication steps on marginal adaptation of CAD/CAM zirconia-based crowns in comparison to sintered PFM crowns during different fabrication stages namely; framework, after veneering, after crown cementation, and after thermomechanical loading.

Materials and Methods

Forty typhodont mandibular molar teeth were used. Their root portion was covered with modeling wax and embedded vertically in a self-cure acrylic resin block (DPI RR Cold Cure, The Hindustan Dental Products, Hyderabad) using standard protocols. Before tooth preparation, two silicone indices were made for each specimen to aid in the standardization of frameworks and veneering layer thickness. A standardized protocol was followed for tooth preparation. After the tooth preparation, 40 typhodont mandibular molar teeth will be divided into 2 groups of 20 each for CAD-CAM zirconia crowns—group I and 20 DMLS PFM restorations—group II (Fig. 1).

Fabrication of CAD-CAM Zirconia Crowns

Impressions of the 20 prepared typhodont mandibular molar teeth were made for the CAD-CAM zirconia group using the putty light body (FLEXCEED Vinyl Polysiloxane Impression Material, GC Asia Dental Pte Ltd.) and impressions were poured using type IV Die stone (Die Stone, Kalabhai Karson Pvt Ltd., India). Individual dies were scanned with the lab scanner (Intellidenta Lab scanner, Maestro Technologies Pvt Ltd., Bengaluru). Designing the copings was carried out using a standard protocol. Once the design phase is completed, it is proceeded with milling the individual selected zirconia blocks (KATANA Zirconia, Kuraray Noritake Dental Inc., Japan) using CAD-CAM milling machine (ROBOTO 5 Axis Milling machine, Confident Dental Equipments Ltd., Bengaluru) and individual CAD-CAM zirconia copings were fabricated, followed by layering the milled individual CAD-CAM zirconia copings with porcelain (Noritake Cerabien ZR, Kuraray Noritake Dental Inc., Japan).

Fabrication of Sintered PFM Restorations

Impressions of the 20 prepared typhodont mandibular molar teeth was made for PFM restorations using putty and light body (FLEXCEED Vinyl Polysiloxane Impression Material, GC Asia Dental Pte Ltd.) impressions were poured with type IV Die stone (Die Stone, Kalabhai Karson Pvt Ltd., India) following the manufacturer's instructions. Two uniform layers of die spacer were applied to within 1 mm of margin. The cobalt-chromium metal copings were fabricated using the DMLS method. Opaque body and enamel porcelains (Noritake Super Porcelain EX-3, Kuraray Noritake Dental Inc., Japan) were then added to the cobalt-chromium metal coping to the appropriate contour and color and baked in the ceramic furnace (Ceramic Master E20, VOP Dental Equipment Manufacturing, Bengaluru).

Methodology for Testing the Typhodont Teeth Specimens

At each fabrication stage, i.e., framework and veneering, each specimen was photographed using a stereomicroscope (Carl Zeiss—SteREO Discovery V20, Carl Zeiss Microscopy GmbH) at 40× magnification which was used to measure and evaluate the vertical MD of both group I and group II. Then, crowns of both the groups were cemented with conventional type 1 luting glass ionomer cement (GC Gold Label 1 Glass Ionomer Mini, GC Dental corporation, Tokyo, Japan) to their corresponding prepared mandibular molar typhodont teeth. Each specimen was photographed using a stereomicroscope at 40× magnification which was used to measure and evaluate the vertical MD of both group I and group II (Fig. 2). All the specimens were thermocycled in a thermocycling apparatus (Servological Water Bath, Growell Instruments, Bengaluru) for nearly 1,200 cycles from 5 to 55°C with 30 seconds dwell time, 20 seconds transfer time, followed by subjecting each specimen to a vertical load of 5 kg in the universal testing machine (Wilson®—Rockwell Hardness Tester Series 500, Wilson® Instruments, USA) (Fig. 3).

Statistical Analysis

The mean and standard deviation were calculated from the collected data and statistically analyzed for the significant difference using independent sample *T*-test between the groups for each stage of fabrication and one-way analysis of variance (ANOVA) for comparison between each stage of the same group using SPSS statistical analysis software (IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY, USA: IBM Corp). Statistical significance was set at 5% ($p < 0.05$).

Results

When compared between two groups for mean MD at various stages of fabrication process, results showed statistical difference between group I and group II. Group II showed increased MD at all stages of fabrication process on buccal, distal, lingual, and mesial side [at framework stage—p value is 0.04, 0.05, 0.05, and 0.007 ($p < 0.05$), at veneering stage—p value is 0.05, 0.05, 0.05, and 0.00 ($p < 0.05$), at cementation stage—p value is 0.04, 0.03, 0.04, and 0.00 ($p < 0.05$), at thermomechanical loading stage—p value is 0.04, 0.05, 0.04, and 0.02 ($p < 0.05$)] (Tables 1 to 4).

There are no statistically significant changes in the MD of four surfaces at various stages of the fabrication process in both the groups (group I—p value is 0.71, 0.86, 0.70, and 0.62, group II—p value is 0.90, 0.81, 0.91, and 0.91) (Table 5).

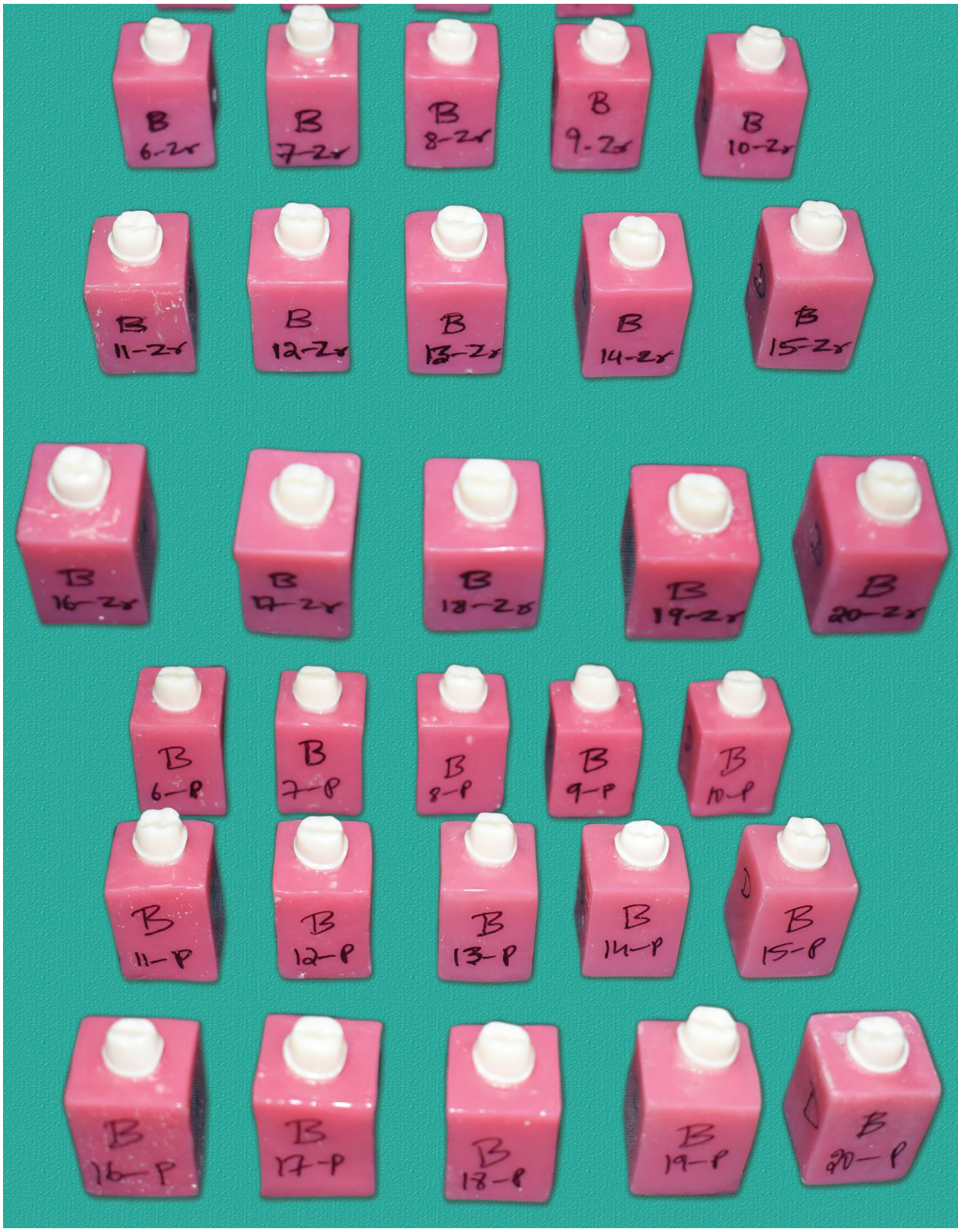


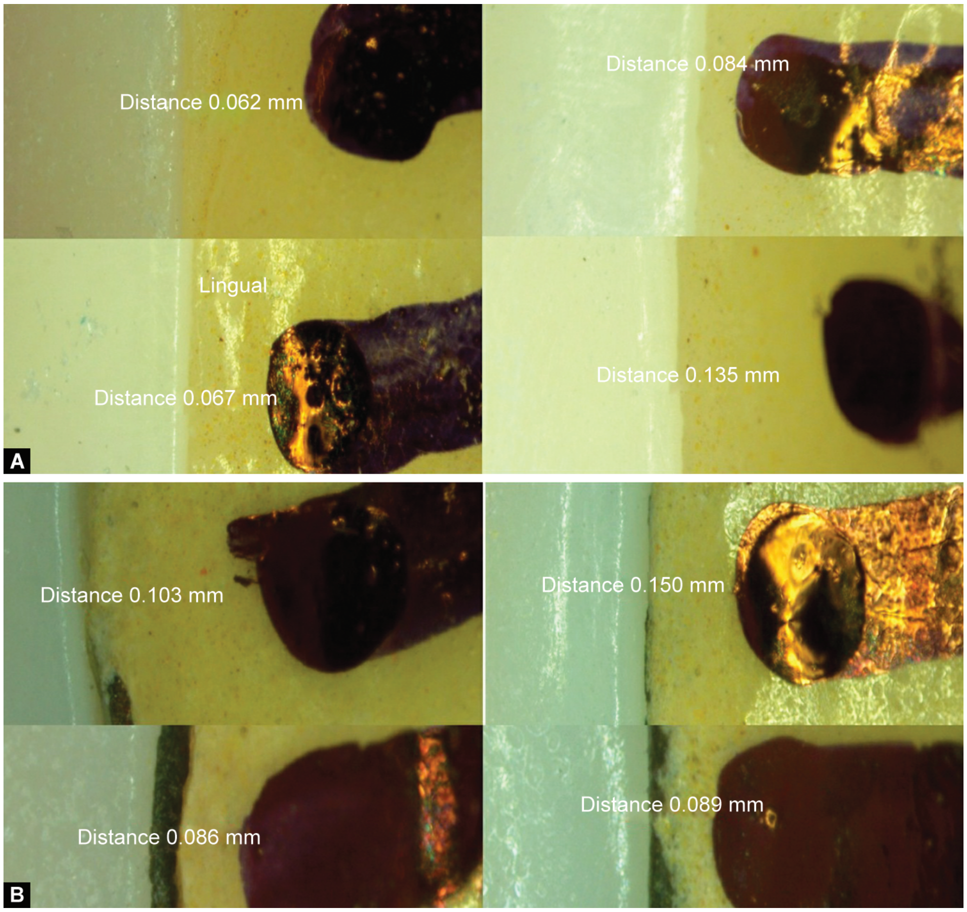
Fig. 1: Prepared mandibular typhodont teeth for group I and group II

Discussion

A variety of methods has been used to evaluate the marginal adaptation of dental restorations such as direct viewing, cross-section view, impression replica technique, and clinical examination.[11,37,41] In the current study, the direct viewing technique was selected because it is a non-destructive, rapid, easy, and convenient method and has been most frequently used to measure MD at various steps of crown fabrication.[15,21] There is no agreement in the literature concerning the number of measuring sites necessary to evaluate marginal fit.[26]

Since coping mainly determines the overall adaptation of the final crown. This difference can be attributed to the more complex geometric form of FPDs in the other studies rather than individual crowns tested in ours. Different axial tapering, core thickness, and different measurement techniques also may contribute to this difference. Moreover, lower values of MD were reported in the literature.[2,11,19]

Additionally, a significant increase in the MD was observed after firing the veneering porcelain agreeing with other studies.[15,37,42] Porcelain veneering substantially widened the MG**,** marginal fit can significantly vary, depending on the veneering material used. For metal-ceramic crowns, contamination of the internal surface of the coping by the veneering material could cause a widening of the MG.[43,44]



Figs 2A and B: Evaluation of vertical marginal discrepancy of group I and group II using a stereomicroscope

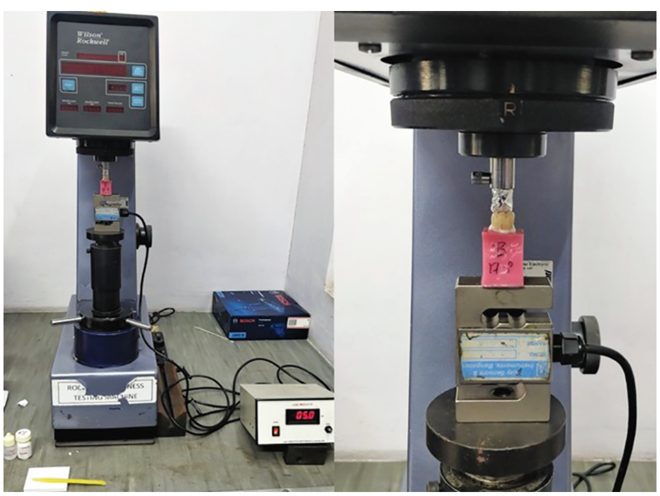


Fig. 3: Application of vertical load of 5 kg using a universal testing machine

In the current study, a slight increase in the MD value was observed after cementation agreeing with previous studies.[48,49] Christensen suggested that all fixed restorations should have a cementation line thickness ranging from 25 to 40 µm. After cementation, some authors observed that cementation always increases the MG of the restoration, to a greater or less extent, depending on the film thickness values of the luting cement that is directly related to its consistency. The physical properties of the luting cement, specifically its consistency, are a relevant factor to achieve a suitable marginal fit of the restoration.[50]

A small cement space could lead to premature contacts between the internal surface of the crown and the abutment tooth and hinder the evacuation of excess cement from the occlusal surface of the tooth, thus widening the MG. Another assumption is the different seating force applied in this study instead of finger pressure can also lead to an increase in the MG due to distortion of weaker crown margin under static load.[26]

Evaluation of the marginal discrepancies in this study revealed a significant increase after artificial aging as the degradative effect of thermocycling in an aqueous atmosphere on dental ceramics.[51] A more reasonable explanation of this increase in MD suggests that it is related to the luting cement. Some portions of the cement film were washed out during the aging procedures, resulting in a clearer image under a microscope and, thus, creating the possibility for increased measurements of the MD particularly, when using water-soluble cement such as glass-ionomer which deteriorate over time due to the deleterious effects of thermocycling.[48,52]

Several studies concluded that a marginal opening of no >120 µm was clinically acceptable. Based on the available scientific evidence, no consensus exists on the maximum clinically acceptable MD, with reported values varying between 50 and 200 µm.[3,33,35] This finding is in line compared to the results of the study wherein the mean MD of four surfaces at various stages of CAD-CAM zirconia crown fabrication is within the range of 120 µm. And mean

Table 1: Comparison of the group I (CAD-CAM zirconia crowns) and group II (PFM restorations) at framework stage using independent sample *T*-test ($n = 40$)

	Groups	*Minimum*	*Maximum*	*Mean*	*Std. deviation*	*Mean difference*	*t value*	*p value*
Buccal	CAD-CAM Zr	44	183	102.15	35.21	−24.5	−2.03	0.04*
	PFM	52	187	126.70	40.77			
Distal	CAD/-CAM Zr	47	179	108.45	42.07	−22.7	−1.9	0.05*
	PFM	72	184	131.20	28.94			
Lingual	CAD-CAM Zr	54	169	102.90	32.37	−22.5	−1.9	0.05*
	PFM	39	180	125.45	39.00			
Mesial	CAD-CAM Zr	61	159	106.45	28.20	−25.7	−2.8	0.007*
	PFM	51	179	132.15	28.68			

*Significant

Table 2: Comparison of the group I (CAD-CAM zirconia crowns) and group II (PFM restorations) after veneering stage using independent sample *T*-test ($n = 40$)

	Groups	*Minimum*	*Maximum*	*Mean*	*Std. deviation*	*Mean difference*	*t value*	*p value*
Buccal	CAD-CAM Zr	57	189	106.65	34.48	−23.8	−1.9	0.05*
	PFM	57	190	130.45	40.81			
Distal	CAD-CAM Zr	52	179	110.30	41.61	−24.6	−2.1	0.03*
	PFM	76	187	134.90	29.43			
Lingual	CAD-CAM Zr	57	170	106.75	31.89	−22.7	−2.0	0.05*
	PFM	43	185	129.50	38.84			
Mesial	CAD-CAM Zr	63	161	110.15	28.57	−24.6	−2.7	0.00*
	PFM	54	180	134.80	28.31			

*Significant

Table 3: Comparison of the group I (CAD-CAM zirconia crowns) and group II (PFM restorations) after crown cementation stage using independent sample *T*-test ($n = 40$)

	Groups	*Minimum*	*Maximum*	*Mean*	*Std. deviation*	*Mean difference*	*t value*	*p value*
Buccal	CAD-CAM Zr	57	190	108.15	34.24	−24.5	−2.0	0.04*
	PFM	59	190	132.65	39.98			
Distal	CAD-CAM Zr	54	181	112.20	41.23	−25.4	−2.2	0.03*
	PFM	79	189	137.60	28.93			
Lingual	CAD-CAM Zr	59	170	108.20	31.36	−22.9	−2.0	0.04*
	PFM	47	185	131.15	38.33			
Mesial	CAD-CAM Zr	65	161	111.90	28.35	−24.7	−2.7	0.00*
	PFM	58	180	136.65	27.70			

*Significant

Table 4: Comparison of the group I (CAD-CAM zirconia crowns) and group II (PFM restorations) after thermomechanical loading stage using independent sample *T*-test ($n = 40$)

	Groups	*Minimum*	*Maximum*	*Mean*	*Std. deviation*	*Mean difference*	*t value*	*p value*
Buccal	CAD-CAM Zr	65	190	114.50	32.02	−21.4	−1.9	0.04*
	PFM	66	186	135.95	38.35			
Distal	CAD-CAM Zr	61	186	118.75	37.97	−20.7	−2.0	0.05*
	PFM	82	180	139.45	25.81			
Lingual	CAD-CAM Zr	60	168	114.40	28.96	−19.6	−1.8	0.04*
	PFM	53	189	134.05	38.57			
Mesial	CAD-CAM Zr	73	166	118.00	26.51	−20.1	−2.3	0.02*
	PFM	61	180	138.15	27.69			

*Significant

Table 5: Comparison of various stages in four surfaces in group I (CAD-CAM zirconia crowns) and group II (PFM restorations) using one-way ANOVA ($n = 40$)

		F value	*p value*
Group I—CAD-CAM zirconia crowns	Buccal	0.45	0.71
	Distal	0.24	0.86
	Lingual	0.47	0.70
	Mesial	0.59	0.62
Group II—PFM restorations	Buccal	0.18	0.90
	Distal	0.32	0.81
	Lingual	0.17	0.91
	Mesial	0.16	0.91

MD of four surfaces at various stages of sintered PFM restoration fabrication is within the range of 150 µm. The variations in the results of this study with the other studies could be because of the difference in the materials used and the difference in the fabrication techniques.[52]

Conclusion

Within the limitations of this *in vitro* study, it can be concluded that:

- CAD/CAM zirconia crowns less MD compared to sintered PFM crowns at various stages of the fabrication process, but all were within the clinically acceptable values.
- There were no statistically significant changes in the MD between each stage of the fabrication process in both CAD/CAM Zirconia and sintered PFM crowns.

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