RESEARCH ARTICLE

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

KS Sumanth¹, S Poovani², NK Sonnahalli³

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 40 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 40x 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.

International Journal of Prosthodontics and Restorative Dentistry (2020): 10.5005/jp-journals-10019-1295

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

¹Department of Prosthodontics, MR Ambedkar Dental College and Hospital, Bengaluru, Karnataka, India  
²Department of Prosthodontics, RajaRajeswari Dental College and Hospital, Bengaluru, Karnataka, India  
³Department of Prosthodontics, Sri Siddhartha Dental College, Tumakuru, Karnataka, India  

Corresponding Author: KS Sumanth, Department of Prosthodontics, MR Ambedkar Dental College and Hospital, Bengaluru, Karnataka, India, Phone: +91 9880077752, e-mail: ks_sumanthks@yahoo.com

How to cite this article: Sumanth KS, Poovani S, Sonnahalli NK. 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. Int J Prosthdont Restor Dent 2020;10(4): 151–157.

Source of support: Nil  
Conflict of interest: None

© Jaypee Brothers Medical Publishers. 2020 Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by-nc/4.0/), which permits unrestricted use, distribution, and non-commercial reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The Creative Commons Public Domain Dedication waiver (http://creativecommons.org/publicdomain/zero/1.0/) applies to the data made available in this article, unless otherwise stated.
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.8–16

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.17–29

**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.30–35

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, Kalabhari 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, Kalabhari 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 40x 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 I luting glass ionomer cement (GC Gold Label 1 Glass Ionomer Mini, GC Dental corporation, Tokyo, Japan) to their corresponding prepared mandibular molar typhodont teeth.36–41 Each specimen was photographed using a stereomicroscope at 40x 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).
**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.\(^{43–47}\)
In the current study, a slight increase in the MD value was observed after cementation agreeing with previous studies. 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.

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.

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. 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.

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. 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 group I (CAD/CAM zirconia crowns) and group II (PFM restorations) using one-way ANOVA (n = 40)

|          | Buccal | Distal | Lingual | Mesial |
|----------|--------|--------|---------|--------|
| **Group I**—CAD-CAM zirconia crowns | 0.45  | 0.24  | 0.47  | 0.59  |
| **Group II**—PFM restorations | 0.18  | 0.32  | 0.17  | 0.16  |

**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.**

**CONCLUSION**

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

- CAD/CAM zirconia crowns have 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.

**REFERENCES**

1. Kale E, Seker E, Yilmaz B, et al. Effect of cement space on the marginal fit of CAD-CAM-fabricated monolithic zirconia crowns. J Prosthodont Dent 2016;116(6):890–895. DOI: 10.1016/j.jprosdent.2016.05.006.
2. Tan PL, Gratton DG, Diaz-Arnold AM, et al. An in vitro comparison of vertical marginal gaps of CAD/CAM titanium and conventional cast restorations. J Prosthodont 2008;17(5):378–383. DOI: 10.1111/j.1532-8499.2008.00302.x.
3. Papadiochou S, Pissiotis A. Marginal adaptation and CAD/CAM technology: a systematic review of restorative material and fabrication techniques. J Prosthodont 2018;19(4):545–551. DOI: 10.1016/j.prosdent.2017.07.001.
4. Ferrari M, Giovannetti A, Carrabba M, et al. Fracture resistance of three porcelain-layered CAD/CAM zirconia frame designs. Dent Mater 2014;30(7):163–168. DOI: 10.1016/j.dental.2014.02.004.
5. El-Dessouky RA, Salama MM, Shalaik MA, et al. Marginal adaptation of CAD/CAM zirconia-based crown during fabrication steps. Tanta Dent J 2015;12(2):81–88. DOI: 10.1412/2014.12.002.
6. Weaver JD, Johnson GH, Bales DJ. Marginal adaptation of castable ceramic crowns. J Prosthodont 1991;66(6):747–753. DOI: 10.1016/0022-3913(91)90040-X.
7. Krejci I, Lutz F, Reimer M. Marginal adaptation and fit of adhesive ceramic inlays. J Dent 1993;21(1):39–46. DOI: 10.1016/0300-5712(93)90048-U.
8. Tamac E, Toksasuvi S, Toman M. Clinical marginal and internal adaptation of CAD/CAM milling, laser sintering, and cast metal ceramic crowns. J Prosthodont Dent 2014;112(4):909–913. DOI: 10.1016/j.jprosdent.2013.12.020.
9. Nicolaisen MH, Bahrami G, Finlay S, et al. Comparison of fatigue resistance and failure modes between metal-ceramic and all-ceramic crowns by cyclic loading in water. J Dent 2014;42(12):1613–1620. DOI: 10.1016/j.jdent.2014.08.013.
10. Campbell SD, Sirakian A, Pelletier LB, et al. Effects of firing cycle and surface finishing on distortion of metal ceramic castings. J Prosthodont Dent 1995;74(5):476–481. DOI: 10.1016/S0022-3913(05)80348-8.
11. Beschmidt SM, Strub JR. Evaluation of the marginal accuracy of different all-ceramic crown systems after simulation in the artificial mouth. J Oral Rehabil 1999;26(7):582–593. DOI: 10.1046/j.1365-2842.1999.00449.x.
12. Groten M, Axmann D, Pröbstler I, et al. Determination of the minimum number of marginal gap measurements required for practical in-vitro testing. J Prosthodont Dent 2000;83(1):40–49. DOI: 10.1016/S0022-3913(00)70087-4.
13. Nakamura T, Deli N, Kojima T, et al. Marginal and internal fit of Cerec 3 CAD/CAM all-ceramic crowns. Int J Prosthodont 2003;16(3):244–248.
14. Quintas AF, Oliveira F, Bottino MA. Vertical marginal discrepancy of ceramic copings with different ceramic materials, finish lines, and luting agents: an in vitro evaluation. J Prosthodont 2004;13(2):250–257. DOI: 10.1016/j.prosdent.2004.06.023.
15. Balkaya MC, Cinar A, Pamuk S. Influence of firing cycles on the margin distortion of 3 all-ceramic crown systems. J Prosthodont Dent 2005;93(4):346–355. DOI: 10.1016/j.prosdent.2005.02.003.
16. Goldin EB, Boyd NW, Goldstein GR, et al. Marginal fit of leucite-glass pressable ceramic restorations and ceramic-pressed-to-metal restorations. J Prosthodont Dent 2005;93(2):143–147. DOI: 10.1016/j.prosdent.2004.10.023.
17. Wang H, Aboushelib MN, Feizier AJ. Strength influencing variables on CAD/CAM zirconia frameworks. Dent Mater 2008;24(5):633–638. DOI: 10.1016/j.dental.2007.06.030.
18. Beuer F, Edelhoff D, Gernet W, et al. Effect of preparation angles on the precision of zirconia crown fabrications by CAD/CAM system. Dent Mater J 2008;27(6):814–820. DOI: 10.4012/dmj.27.814.
19. Beuer F, Aggtsteller H, Richter J, et al. Influence of preparation angle on marginal and internal fit of CAD/CAM-fabricated zirconia crown copings. Quintessence Int 2009;40(3):243–250.
20. Limkangwalmongkol P, Kee E, Chiche GJ, et al. Comparison of marginal fit between all-porcelain margin versus alumina-supported margin on procera alumina crowns. J Prosthodont 2009;18(2):162–166. DOI: 10.1111/j.1532-849X.2008.00396.x.
21. Kashinatha HM, Mohamed Ateeq P, Jagadeesh KN, et al. Tooth preparation and cementation guidelines for zirconia based restorations - a scientific perspective. J Dent and Oral Biosci 2011;2(2):30–33.
22. Zarone F, Russo S, Sorrentino R. From porcelain-fused-to-metal to zirconia: Clinical and experimental considerations. Dent Mater J 2011;27(1):83–96. DOI: 10.1016/j.dental.2010.10.024.
23. Dejak B, Młotkowski A, Langot C. Three-dimensional finite element analysis of molars with thin-walled prosthetic crowns made of various materials. Dent Mater 2012;28(4):433–441. DOI: 10.1016/j.dental.2011.11.019.
24. Güth JF, Wallbach J, Stimmelmayer M, et al. Computer-aided evaluation of preparations for CAD/CAM-fabricated all-ceramic crowns. Clin Oral Investig 2013;17(5):1389–1395. DOI: 10.1007/s00784-012-0812-3.
25. Contrepois M, Soenen A, Bartala M, et al. Marginal adaptation of ceramic crowns: a systematic review. J Prosthodont Dent 2013;110(6):447–454. DOI: 10.1016/j.prosdent.2013.08.003.
26. Benetti P, Kelly JR, Della Bona A. Analysis of thermal distributions in veneered zirconia and metal restorations during firing. Dent Mater 2013;29(11):1166–1172. DOI: 10.1016/j.dental.2013.08.212.
27. Demir N, Oztruk AN, Malkoc MA. Evaluation of the marginal fit of full ceramic crowns by the microcomputed tomography (micro-CT) technique. Eur J Dent 2014;8(4):437–444. DOI: 10.4103/1305-7456.143612.
28. Lee KH, Yeo IS, Benjamin M, et al. Effects of computer-aided manufacturing technology on precision of clinical metal-free restorations. Bio Med Res Int 2015;1:5–9.
29. Preis V, Behr M, Hahnel S, et al. Influence of cementation on in vitro performance, marginal adaptation and fracture resistance of CAD/CAM-zirconia crowns and sintered DMLS PFM crowns.
Marginal Adaptation of CAD/CAM Zirconia Crowns and Sintered DMLS PFM Crowns

CAM-fabricated ZLS molar crowns. Dent Mater 2015;31(11):1363–1369. DOI: 10.1016/j.dental.2015.08.154.

Lins L, Bemfica V, Queiroz C, et al. In vitro evaluation of the internal and marginal misfit of CAD/CAM zirconia copings. J Prosthodont 2015;113(3):205–211. DOI: 10.1016/j.prosdent.2014.09.010.

Sorrentino R, Trulizio C, Tricarico MG, et al. In vitro analysis of the fracture resistance of CAD-CAM monolithic zirconia molar crowns with different occlusal thickness. J Mech Behav Biomed Mater 2016;61:328–333. DOI: 10.1016/j.jmbbm.2016.04.014.

Ates SM, Yelis Duymus Z. Influence of tooth preparation design on fitting accuracy of CAD-CAM based restorations. J Esthet Restor Dent 2016;28(4):238–246. DOI: 10.1011/jerd.2014.09.010.

Hamza TA, Sherif RM. In vitro evaluation of marginal discrepancy of monolithic zirconia restorations fabricated with different CAD-CAM systems. J Prosthodont Dent 2017;117(6):762–766. DOI: 10.1016/j.prosdent.2016.09.011.

Rai R, Kumar S, Prabhu R, et al. Evaluation of marginal and internal gaps of metal ceramic crowns obtained from conventional impressions and casting techniques with those obtained from digital techniques. Indian J Dent Res 2017;28(3):291–297. DOI: 10.4103/ijdr.IJDR_81_17.

Arora A, Yadav A, Upadhyaya V, et al. Comparison of marginal and internal adaptation of copings fabricated from three different fabrication techniques: an in vitro study. Indian Prosthodont Soc 2018;18(2):102–107. DOI: 10.4103/jipsjpjps_327_17.

Kohorst P, Brinkmann H, Dittmer MP, et al. Stresses and distortions within zirconia-fixed dental prostheses due to the veneering process. Acta Biomater 2009;5(8):3231–3239. DOI: 10.1016/j.actbio.2009.04.025.

Fahmy NZ. Influence of veneering materials on the marginal fit and fracture resistance of an alumina core system. J Prosthodont 2011;20(1):45–51. DOI: 10.1111/j.1532-8499.2010.00626.x.

Gemalmaz D, Alkumru NN. Marginal fit changes during porcelain firing cycles. J Prosthodont Dent 1995;73(1):49–54. DOI: 10.1016/S0022-3913(05)80272-0.

Kim JW, Covel NS, Guess PC, et al. Concerns of hydrothermal degradation in CAD/CAM zirconia. J Dent Res 2010;89(1):91–95. DOI: 10.1177/0022034509354193.

Sulaiman F, Chai J, Jameson LM, et al. A comparison of the marginal fit of In-Ceram, IPS Empress, and proceras crowns. Int J Prosthodont 1997;10(5):478–484.

Vigolo P, Fonzi F. An in vitro evaluation of fit of zirconium-oxide-based ceramic four-unit fixed partial dentures, generated with three different CAD/CAM systems, before and after porcelain firing cycles and after glaze cycles. J Prosthodont 2008;17(8):621–626. DOI: 10.1111/j.1532-8499.2008.00366.x.

Atw W, Komine F, Gerds T, et al. Marginal adaptation of three different zirconium dioxide three-unit fixed dental prostheses. J Prosthodont 2009;10(4):239–247. DOI: 10.1016/S0022-3913(09)60047-0.

Gonzalo E, Suárez MJ, Serrano B, et al. A comparison of the marginal vertical discrepancies of zirconium and metal ceramic posterior fixed dental prostheses before and after cementation. J Prosthodont 2009;10(6):378–384. DOI: 10.1016/S0022-3913(09)60198-0.

de Almeida JGDSP, Guedes CG, Abi-Rached FO, et al. Marginal fit of metal-ceramic copings: effect of luting cements and tooth preparation design. J Prosthodont 2019;28(1):e265–e270. DOI: 10.1111/jopr.12685.

Blatz MB, Oppes S, Chiche G, et al. Influence of cementation technique on fracture strength and leakage of alumina all-ceramic crowns after cyclic loading. Quintessence Int 2008;39(1):23–32.

Albert FE, El-Mowafy OM. Marginal adaptation and microleakage of proceras AllCeram crowns with four cements. Int J Prosthodont 2004;17(5):529–535.

Al Rifaiy MQ. Evaluation of vertical marginal adaptation of provisional crowns by digital microscope. Niger J Clin Pract 2017;20(12):1610–1617.