

Marginal and Internal Adaptation of Zirconium Dioxide Ceramic Copings and Crowns with Different Finish Line Designs

Futoshi KOMINE^{1,2}, Takayuki IWAI¹, Kazuhisa KOBAYASHI¹ and Hideo MATSUMURA^{1,2}

¹Department of Fixed Prosthodontics, Nihon University School of Dentistry, 1-8-13, Kanda-Surugadai, Chiyoda-ku, Tokyo 101-8310, Japan

²Division of Advanced Dental Treatment, Dental Research Center, Nihon University School of Dentistry, 1-8-13, Kanda-Surugadai, Chiyoda-ku, Tokyo 101-8310, Japan

Corresponding author, Futoshi KOMINE; E-mail: komine@dent.nihon-u.ac.jp

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The present study evaluated the marginal and internal adaptation of single-tooth zirconium dioxide (ZrO₂) ceramic copings or crowns with three different finish line designs. Twenty-four steel dies were prepared for maxillary central incisor crowns with the following finish line designs: shoulder (S), rounded shoulder (RS), and chamfer (C) preparations. Twenty-four standardized ZrO₂ ceramic copings were manufactured with a CAD/CAM system (Cercon Smart Ceramics), and the crowns were finalized by veneering with a feldspathic ceramic. Measurements for marginal and internal adaptation were performed at two stages: the copings and the completed crowns. No significant differences were observed between the three groups in terms of marginal discrepancy median value: S, 73/69; RS, 61/60; C, 64/55 (μm). However, significant differences in internal adaptation were widely found among all groups: S, 117/111; RS, 72/75; C, 56/57 (μm). As for intra-group comparisons of marginal and internal adaptation values for all groups, the differences were not significant. It was found that the finish line design seemingly wielded no influence on marginal adaptation of single-tooth ZrO₂ ceramic copings and crowns. It was also observed that the marginal and internal adaptation values in the present study were all within the clinically acceptable range.

Keywords: Adaptation, Zirconium dioxide, Finish line

INTRODUCTION

The adaptation of a restored tooth to the abutment tooth can be one of the most important factors that affects restoration prognosis. Numerous studies have evaluated the marginal and internal adaptation of single-tooth crown restorations fabricated from various systems and materials¹⁻⁵. Factors such as type of finish line design, ceramic firing effect, and materials used reportedly influence the marginal adaptation of all-ceramic crown restorations⁶⁻¹⁰.

Studies that examined the influence of finish line design on adaptation yielded contradictory results. Pera *et al.*¹¹ showed that better marginal adaptation was obtained for In-Ceram crowns fabricated on a chamfer or 50-degree shoulder tooth preparation compared with a 90-degree shoulder finish line. Lin *et al.*¹² further reported that the feather-edge finish line resulted in the largest marginal discrepancies for Procera crowns as compared with the chamfer, 0.8-mm rounded shoulder, and 0.5-mm rounded shoulder finish lines. On the other hand, some studies demonstrated that adaptation was not influenced by finish line design^{8,13}.

As for the ceramic firing effect, there is no sufficient evidence about its influence on adaptation of all-ceramic restorations. Balkaya *et al.*¹⁰ reported that the ceramic firing procedure affected the marginal adaptation of all-ceramic crowns. However, Shearer *et al.*⁸ reported a conflicting result that

ceramic firing did not affect marginal adaptation.

Presently, most researchers concur that crown marginal discrepancies within the range of 120 μm are clinically acceptable in terms of crown longevity^{14,15}. On this note, previous *in vitro* studies have shown that marginal discrepancies of all-ceramic crowns fabricated using the CAD/CAM technique ranged from 64 μm to 83 μm ^{12,16,17}. It should also be highlighted that with all-ceramic restorations, poor internal adaptation could result in reduced resistance to fracture¹⁸. Although no conclusive evidence is available concerning the optimal internal space, 50–100 μm is considered acceptable in due respect of the physical and clinical properties of resin-based luting agents¹⁹⁻²¹. *In vitro* studies of machine-milled, all-ceramic crowns revealed that the mean internal gaps ranged from 30 to 204 μm ^{5,22-24}.

To satisfy the demands of both patients and dentists when using dental ceramics, high strength and good esthetics are the essential properties. Some high-strength ceramics, such as aluminum oxide (Al₂O₃) or zirconium dioxide (ZrO₂), have been made available over the last decade with the help of CAD/CAM technology. ZrO₂ ceramics are composed of many small particles without any glassy phase at the crystallite border and are distinguished by a crack initiation mechanism. ZrO₂ ceramics demonstrate excellent material properties such as high flexural strength (900–1200 MPa) and high fracture

toughness ($K_{IC} = 9 - 10 \text{ MN/m}^{3/2}$)²⁵), enabling their use in posterior fixed partial dentures (FPDs). Although this ceramic finds its greatest application in posterior regions, long-term stability can likewise be expected from using this ceramic restoration in the anterior area. CAD/CAM systems use ZrO_2 ceramics for fabricating copings that are individually veneered with ceramics.

ZrO_2 ceramic materials are classified according to the state of the ceramic blanks at the milling/grinding level of production: partially sintered stage (green stage or presintered stage) *versus* completely sintered stage²⁶. At partially sintered stage, ceramic blanks are usually machined or pressed to an enlarged size, so as to compensate for material shrinkage during final sintering. In contrast, completely sintered ZrO_2 ceramics are milled to the exact size and shape of the final copings, as no shrinkage occurs during final sintering. Therefore, there is a concern that the shrinkage of partially sintered ZrO_2 ceramics during the post-sintering process affects the adaptation of restorations. Pertaining to this concern, Coli and Karlsson^{22,27} reported that the marginal and internal fit of completely sintered ZrO_2 ceramics displayed high precision and were within the range of clinical acceptability. However, little information is available on the marginal and internal adaptation of copings or crowns made of partially sintered ZrO_2 ceramics.

Therefore, the aim of the present study was to evaluate *in vitro* the marginal and internal adaptation of copings and crowns manufactured from partially sintered ZrO_2 ceramics using CAD/CAM technology with three different finish line designs. The hypotheses to be tested were: (1) the finish line design affects the adaptation of ZrO_2 ceramic restorations; and (2) the adaptation of copings is better than that of completed crowns.

MATERIALS AND METHODS

Copings and crowns

Twenty-four machined steel dies (SUS303) were prepared for full coverage maxillary central incisor crowns. Tooth preparations were standardized with a height of 8 mm and a total convergence angle of 6 degrees (Fig. 1). Three finish line designs were prepared: shoulder with sharp axiokingival internal line angle (S), shoulder with rounded axiokingival internal line angle (RS), and chamfer (C) preparation (Fig. 2). Impressions were made of each abutment with vinyl polysiloxane impression material (Take 1, Kerr USA, Romulus, MI, USA) in a custom-fabricated impression tray (Tray Resin, Shofu, Kyoto, Japan). Impressions were poured with vacuum-mixed Type IV dental stone (New Fujirock, GC, Tokyo, Japan).

Twenty-four copings were made of a partially sintered ZrO_2 ceramic material using CAD/CAM technology (Cercon Smart Ceramics, DeguDent, Hanau, Germany). Stone dies were scanned by laser, and the copings were designed using Cercon Art CAD software (DeguDent). Data were transferred to the CAM unit (Cercon Brain, DeguDent), whereby 0.5-mm-thick copings with 30 μm cement space were milled out. Copings were then post-sintered in a special furnace (Cercon Heat, DeguDent). To finalize the crowns, a feldspathic ceramic veneer (Cercon Ceram S, DeguDent) was applied to the copings according to the manufacturer's recommendations. To standardize the shape of the maxillary central incisor crowns, a steel template was used.

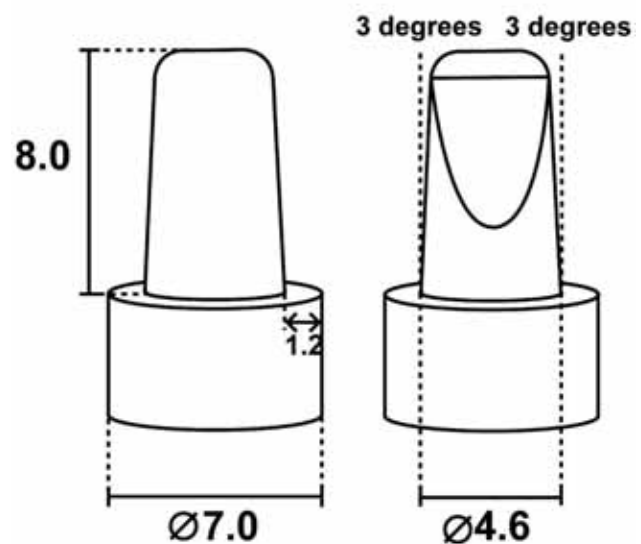


Fig. 1 Diagram of steel die (mm).

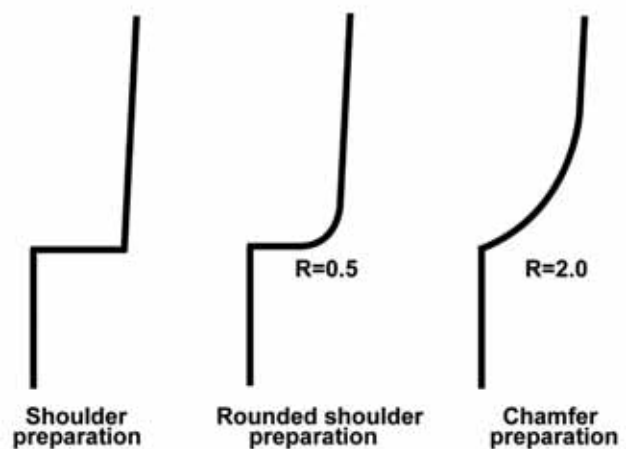


Fig. 2 Finish line designs. Shoulder preparation had axiokingival internal line angle of 90 degrees. For rounded shoulder preparation, curvature radius (R) of axiokingival internal line angle was 0.5 mm. For chamfer preparation, curvature radius (R) of axiokingival internal line angle was 2.0 mm.

Marginal and internal adaptation evaluations

Marginal and internal adaptation evaluations were performed at two stages: the sintered copings and completed crowns. A single examiner performed and recorded all the measurements. Marginal adaptation was assessed by measuring the vertical discrepancy, which measured the distance between the outer restoration margin and the preparation line parallel to the abutment axis¹⁾. The marginal discrepancy values of copings or crowns were recorded without cementation. Restorations were fixed on the master steel die with a small amount of temporary dental cement (Temporary Pack, GC) with finger pressure. Each specimen was placed in a jig to prevent parallax error. Measurements were performed at 60 different points³⁾ across the entire circumference of each restoration, using a laser microscope (1LM21W, Lasertec Inc, Kanagawa, Japan) at a magnification of $\times 250$.

Internal adaptation of the copings and crowns was evaluated by measuring the internal space width using a cement space replica technique^{2,4,5)}. The inner surface of each restoration was filled with a test-fit silicone paste (Fit Checker, GC), then seated on the master die with finger pressure. After polymerization of the paste, the restoration was removed from the master die. A second black silicone paste (Bite Checker, GC) was injected into the internal surface of the copings or crowns, such that the two silicone pastes bonded firmly to each other. After the paste had set, the eventual replica consisting of the cement space and master die replicas was carefully removed from the restoration. No adjustments were made for either the master die or restoration before replication.

The replicas were cross-sectioned in the labiolabial direction using a scalpel (Stainless Surgical Blade No. 11, Feather Safety Razor, Osaka, Japan). Internal adaptation was defined as the width of the cement space replica. Measurements were taken of the perpendicular distance from the internal surface of restoration to the die from seven sliced surfaces of a replica. The following seven landmarks were defined for internal space width measurement: P1, labial marginal area (300 μm internal from restoration margin); P2, labial line angle of chamfer or shoulder; P3, labial axial area which was of the same level as palatal basal ridge; P4, incisal area; P5, palatal axial area (500 μm internal from basal ridge); P6, palatal line angle of chamfer or shoulder; P7, palatal marginal area (300 μm internal from restoration margin). Five measurements were recorded for each section in all three groups, giving a total of 1680 measurements. In addition, discrepancies in the margin of cement space replicas were measured to compare with the marginal discrepancy values obtained from the marginal adaptation measurements in the present study.

Measurements were conducted by viewing the specimens at $\times 250$ magnification using Salt software (Mitani Corp., Fukui, Japan), a high-resolution image processing and analysis system. This software was able to detect the internal space width perpendicular to the internal surface of the restorations.

Statistical analysis

Mean value of the 60 marginal discrepancy measurements or 35 internal space measurements was used for statistical analysis. Statistical analyses of the test groups were done using the Kruskal - Wallis test and Mann - Whitney U test with Bonferroni correction for comparison of two groups. The Wilcoxon signed-ranks test was performed for pairwise comparison between coping and crown for marginal and internal discrepancy values. All hypothesis testing was conducted at a 95% level of confidence.

RESULTS

The following median marginal discrepancy values were obtained for ZrO₂ copings/crowns: S, 73 μm /69 μm ; RS, 61 μm /60 μm ; C, 64 μm /55 μm (Fig. 3). No significant differences in marginal discrepancy value for either copings ($P = 0.59$) or crowns ($P = 0.07$) were observed.

Finish line design was shown to significantly affect the internal space values of ZrO₂ copings ($P < 0.001$) and crowns ($P < 0.001$) (Fig. 4). However, there were no significant differences between RS and C preparations ($P = 0.02$) for the internal space values of ZrO₂ crowns.

Intra-group comparisons of marginal discrepancy and internal space values for all groups were not significant. The following median discrepancy values

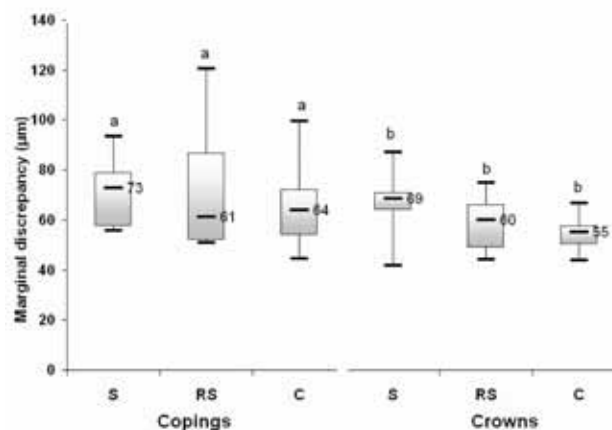


Fig. 3 Box plots of marginal discrepancy values of shoulder (S), rounded shoulder (RS), and chamfer (C) preparation copings and crowns. Horizontal line in each box represents median value. Identical alphabetical letters indicate that the values were not statistically different ($P > 0.05$).

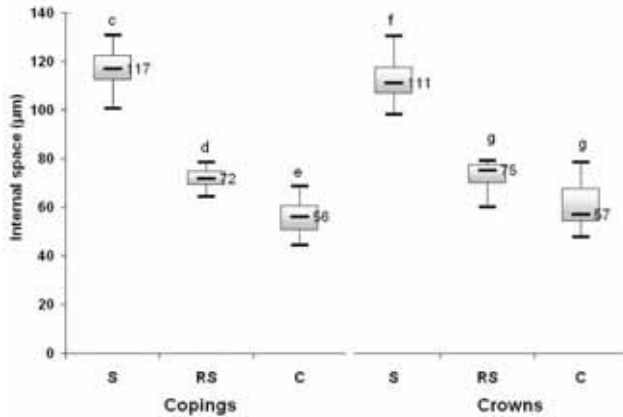


Fig. 4 Box plots of internal space values of shoulder (S), rounded shoulder (RS) and chamfer (C) preparation copings and crowns. Horizontal line in each box represents median value. Identical alphabetical letters indicate that the values were not statistically different ($P > 0.05$).

in the margin of cement space replicas for ZrO_2 copings/crowns were obtained: S, 62 μm /60 μm ; RS, 50 μm /43 μm ; C, 55 μm /59 μm . No significant differences between the discrepancy values in the margin of cement space replicas and marginal discrepancies for all groups were revealed (S, $P = 0.88/0.38$; RS, $P = 0.13/0.08$; C, $P = 0.72/0.51$).

DISCUSSION

In the present study, no statistically significant differences in the marginal discrepancy value of either ZrO_2 copings or crowns were observed among the three finish line designs tested. These results agreed with the findings of previous studies, which reported that the type of finish line design did not influence the marginal adaptation of all-ceramic restorations^{7,9}. The median marginal discrepancy values of ZrO_2 copings and crowns obtained in the current study were 61 - 73 μm and 55 - 69 μm respectively. In other words, the marginal quality of ZrO_2 restorations were considered clinically acceptable^{14,15}. These values were comparable to the 65- μm clinical median marginal gap in machine-milled, green stage ZrO_2 three-unit FPDs reported by Reich *et al.*⁵, but were much larger than the 23 - 33 μm marginal gaps of completely sintered ZrO_2 crown copings reported by Bindl and Mörmann²³. A possible explanation for this difference might be that no adjustment of copings was performed in the present study.

It was also shown in the present study that the internal adaptation of ZrO_2 restorations in most groups was significantly affected by the finish line design. The only exceptions were the RS and C preparations of ZrO_2 crowns. These results could be attributed to the accuracy of laser scanning for the

finish line angle. An additional plausible explanation could be found in the curvature radius of the axiokingival internal line angle. This was because the differing curvature radius of each finish line design might affect the scanned results of the axial wall of the abutments. The S preparation had a sharp axiokingival internal line angle (*i.e.*, no curvature radius). As such, laser might not have completely irradiated the area of the axiokingival internal line angle. The above statements were based on the results that there were no significant differences between the discrepancy values in the margin of cement space replicas and marginal discrepancies. In a previous report on sealing by cementation, it was claimed that a 90-degree shoulder preparation exerted a negative influence²⁶. However, in the present study, no such negative influences were noted in all groups when silicone paste was filled into the inner surface of the ZrO_2 restorations to fabricate the cement space replicas. To date, few studies have investigated the influence of finish line design on the internal space width of all-ceramic crowns. Shearer *et al.*⁸ reported no significant differences in the internal fit of chamfer and shoulder finish line designs with In-Ceram crowns manufactured using the slip casting technique. This result contrasted with our present findings, which could be explained by the different materials or fabrication procedures used in the two studies. With the slip casting technique for In-Ceram restorations, the ceramic slurry was directly applied to the die and sintered almost without shrinkage. On the other hand, the ZrO_2 copings used in the present study were laser-scanned, computationally designed, machine-milled, and then post-sintered. Most importantly, the internal space values of ZrO_2 copings and crowns were well within the 50 - 100 μm range shown by Molin *et al.*²⁰ to achieve a strong bond between the ceramic and resin composite.

Comparisons between the ZrO_2 copings and crowns in the present study demonstrated that ceramic firing did not significantly affect either the marginal or internal adaptation. This finding was not consistent with the results of previous studies that reported on the influence of ceramic firing on marginal adaptation^{6,10}. This disagreement might again reflect the differences arising from the different types of ceramic materials used in each study. Balkaya *et al.*¹⁰ evaluated conventional In-Ceram, copy-milled In-Ceram, and copy-milled feldspathic ceramics, and reported that all-ceramic copings were unstable during the ceramic firing cycle. The ZrO_2 ceramics used in the present study were much stronger than the ceramics used in a previous study²⁹, and this might explain why they were unaffected by the ceramic firing procedure. Moreover, by comparing measurement values obtained at different

stages of the ceramic firing process, ceramic contamination on the margin might lead to misleading results. If the outermost point of margin were contaminated with ceramic, faulty measurement values might be obtained after ceramic firing. To prevent ceramic contamination, therefore, ceramic was not applied to an area of approximately 0.5 mm at the cervical area of the restorations in the present study.

Several methods are available for analyzing the marginal and internal adaptation of crowns. In the present study, marginal adaptation was evaluated using a direct view of the non-cemented specimen on a die. This non-destructive method thus measured a restoration's distortion arising strictly from the manufacturing process. As for internal adaptation, it was previously measured using either the cross-section view or the replica technique. In the present study, a non-destructive replica measurement technique was employed, despite the minor limitation of evaluating specimens in a non-cemented condition. It should be mentioned that this technique requires the specimen and die be repositioned in predefined locations during measurement and seating of the silicone. In addition, the flow property of the luting agent used in the replica technique was not identical to that of the silicone paste used in the present study. Some studies noted that differences in the flow of cement used affected the sealing discrepancy after cementation³⁰. Therefore, the different flow between the luting agent and silicone paste could likewise affect the adaptation of restorations.

In the current study, measurements were performed with a laser microscope at a magnification of $\times 250$. A restoration margin that appears sharp at a relatively low magnification ($\times 20$ or $\times 30$) would typically appear more rounded at a higher magnification (>200). When a restoration margin appeared rounded, a point would be chosen on that margin along a line bisecting the angle between the outer contour and inner contour of a restoration using the computer¹⁵.

From the results of the present study, it could be concluded that the marginal adaptation of partially sintered ZrO₂ ceramic copings and crowns was not affected by the finish line design. Conversely, there were significant differences in internal space value of partially sintered ZrO₂ ceramic copings and crowns among the three finish line designs ($P < 0.05$), except for RS and C preparations. Moreover, the marginal and internal adaptation values observed in the present study were all within the clinically acceptable range. Factors that affect the marginal and internal adaptation of partially sintered ZrO₂ crown restorations require further investigation and substantiation. In addition, there is a critical need for clinical trials to

validate these results.

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