

The Effect of Different Fabrication Steps on the Marginal Adaptation of Two Types of Glass-Infiltrated Ceramic Crown Copings Fabricated by CAD/CAM Technology

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Keywords

Milling; CAD/CAM; zirconia; alumina; coping; glass infiltration; fracture strength.

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Source of funding: Ministry of Higher Education, Saudi Arabia.

Accepted April 29 2011

doi: 10.1111/j.1532-849X.2011.00803.x

Abstract

Purpose: Marginal adaptation is an important factor affecting the longevity of allceramic restorations, although the effects of different fabrication steps on marginal adaptation at various stages of fabrication are not fully understood. The purpose of this study was to assess with an in vitro model whether In-Ceram alumina (IA) or In-Ceram zirconia (IZ) copings produced by the CAD/CAM method would be clinically acceptable, and to evaluate the effect of each fabrication step (post-milling, post-trimming, and post-glass infiltration) on the marginal discrepancy of the coping. Materials and Methods: A melamine tooth was prepared, duplicated, poured with inlay wax, and then cast with metal to fabricate a master die. An InLab 3D system was used to scan the master die and to design and mill the copings. Thirty IA and IZ copings each were developed with thicknesses of 0.6 mm and a 30- μ m thick computer luting space. Epoxy resin replicas of the master die were fabricated, and the vertical and horizontal marginal discrepancies were measured using a Micro-Vu optical microscope at three stages of the fabrication (post-milling, post-trimming, post-infiltration). Oneway ANOVA was used to analyze the data between the three stages of fabrication for each marginal discrepancy, and a *t*-test was used to compare vertical and horizontal marginal discrepancies (after glass infiltration) between IZ and IA copings

Results: There were no significant differences (p > 0.05) in the vertical marginal discrepancies (μ m) between IA (36 ± 14) and IZ (40 ± 14) copings after glass infiltration. ANOVA (comparing three stages within horizontal marginal discrepancy for IZ copings) showed that post-milling (40 ± 26) > post-trimming (23 ± 11) = post-infiltration (19 ± 13). ANOVA (comparing three stages within vertical marginal discrepancy for IZ copings) showed that post-milling (53 ± 12) = post-trimming (47 ± 13) > post-infiltration (36 ± 14). ANOVA (comparing three stages within horizontal marginal discrepancy for IA copings) showed that post-milling (52 ± 28) > post-trimming (30 ± 16) > post-infiltration (30 ± 16). ANOVA (comparing three stages within vertical marginal discrepancy for IA copings) showed that post-milling (54 ± 13) = post-trimming (56 ± 26) > post-infiltration (40 ± 14).

Conclusion: There was no significant difference in the marginal adaptation of both material copings. After the trimming process, the glass infiltration firing cycle improved the vertical marginal discrepancy for both IZ and IA copings. *Clinical implications*. IA and IZ copings fabricated by CAD/CAM technology have an acceptable marginal fit as documented in the literature, and the glass infiltration process improves the marginal fit after machining.

Marginal adaptation is one of most important criteria for longterm clinical success of dental restorations.¹ The presence of marginal discrepancies exposes the luting agent to the oral environment. The larger the marginal discrepancy and the subsequent exposure of the dental luting agent to oral fluids, the more rapid the rate of cement dissolution and microleakage.² These marginal irregularities facilitate the adherence of oral bacteria along with percolation of food, oral debris, and other substances

to finally cause plaque retention, which in turn causes changes in the distribution of the subgingival microflora, thereby leading to periodontal disease³ and secondary caries.⁴

Several authors have attempted to determine what constitutes clinically acceptable marginal openings that are not visible to the naked eye and are undetectable with a sharp explorer. Various values have been proposed in the literature as the maximum acceptable marginal gap width, depending on the type of restoration and the study. For CAD/CAM-generated restorations, the approximate acceptable marginal gap discrepancies are less than 90 μ m.^{1,5-7}

Marginal gap measurement has been defined as vertical marginal discrepancy, horizontal marginal discrepancy, overextended margin, underextended margin, seating discrepancy, and absolute marginal discrepancy; however, the absolute marginal discrepancy has been considered the best method to measure the marginal gap because the error at the margin is the largest.⁸ Today, there is no standard method available for measuring the marginal fit. The most common method is to measure the distance directly under a microscope after sectioning the embedded specimens; however, it is impossible to use this method in vivo. The replica technique, described initially by McLean and von Fraunhofer, has been a reliable and valid noninvasive method to determine the adaptation of crowns to tooth structure.⁹

The internal fit is evaluated by the gap between the intaglio surface of the restoration and the prepared tooth. Variation in the internal fit can create stress concentrations, which may reduce the restoration strength. The gap size is affected by the thickness of the dental cement layer along the axial walls of the preparation, and this layer influences the seating of the restoration. Many factors affect film thickness, including preparation margin design, marginal configuration, surface roughness, cementation pressure, duration of cementation, powder/liquid ratio of the cement, type of cement, die spacers, and cementation technique.¹⁰

Coating the master die with a spacer material all but 0.5 mm from the finish line will compensate for the luting cement between the prepared tooth and the intaglio surface of the crown restoration, thus improving the fit of the crowns.¹¹ Grajower and Lewinstein¹² stated that "an optimum fit of the casting can be obtained only if the relief space allows for the cement film thickness and roughness of the tooth and casting surfaces," confirmed through the application of a die spacer with a thickness of 50 μ m.

The marginal discrepancy depends on the fabrication stage,¹³ type of CAM system,^{14,15} number of units in the substructure,¹⁶ location of the tooth, tooth preparation design,¹⁷ material stiffness,¹⁸ type and thickness of the luting cement,¹⁹ and presence of a luting cement.²⁰ To increase the marginal adaptation and decrease the wear of the luting cement, the marginal gap and the bulk of resin should be minimized. This hypothesis was consistent with Cho et al, who reported the shear bond strength was significantly improved and was greatest with a two-coat application of die spacer compared with four or six coats.²¹ In CAD/CAM systems, it is possible to program the software so additional space can be provided to accommodate for the cement, potentially influencing the internal and marginal fit values.

The milling of semisintered zirconia has the advantages of shorter milling times and less wear of the cutting burs, but this technique necessitates a final sintering after the milling process.²² This sintering procedure is associated with a certain amount of shrinkage. The drawbacks of this technique are the uncertainty of the correct enlarging factor, as well as a marginal fit that does not meet highest demands, whereas milling fully sintered zirconia, which is processed through hot isostatic pressing, had a better marginal fit. Kohorst et al reported a 23.8- μ m gap for a restoration milled from a fully sintered material using the Digident CAD/CAM system, due to no further sintering being necessary.²³

An examination of the marginal integrity of CAD/CAMgenerated restorations is evaluated by comparing the measurement values obtained at different stages of the manufacturing process as follows: after machining for glass-infiltrated ceramics, after sintering for pre-sintered blocks, after trimming the margin, after glass infiltration, after veneering (before cementation), and after cementation. This can provide information about the accuracy of different stages.^{7,24} An assessment of the effect of fatigue on the marginal accuracy may provide information on its long-term stability and, subsequently, on the long-term outcome of the restorations.

The marginal fit is affected by the type of CAD/CAM system used for scanning (different digitization system), software design (CAD-construction), milling (mechanized technique), and sintering (shrinkage effects), which can cause inaccuracies during the fabrication of the ceramic substructure. The difference of marginal gaps between copings fabricated with CAD/CAM technology compared to CAM technology might be the result of the long fabrication chain of the CAM process: (1) master cast preparation with spacer, (2) wax-up, and (3) wax pattern removal from the master cast. Manual wax-ups are associated with nonuniform layers, which may lead to distortion in the sintering process. Removal from the cast might have a negative effect on accuracy. Additionally, the scanner has to scan the concave inner surface of the wax pattern, which is much more difficult to scan than the convex definitive cast.

The objectives of this study were to assess with an in vitro model whether zirconia or alumina copings produced by the CAD/CAM method would be clinically acceptable, and to evaluate the effect of each fabrication step (post-milling, posttrimming, and post-glass infiltration) on the marginal discrepancy of the coping. The hypotheses were: (1) the marginal adaptation of In-Ceram Alumina (IA) and In-Ceram Zirconia (IZ) copings would be within the acceptable range as documented in the literature, and IZ copings would have a better marginal adaptation than IA copings and (2) after milling, the trimming process would decrease the marginal thickness (horizontal marginal discrepancy), and glass infiltration would increase the marginal discrepancy for IZ and IA copings.

Material and methods

The materials tested were IA (Vita Zahnfabrik, Bad Sackingen, Germany), an interpenetrating composite of 30% glass and 70% alumina, and IZ (Vita Zahnfabrik), an interpenetrating composite of 30% glass and 70% polycrystalline ceramic consisting of Al_2O_3 :ZrO₂ in a vol% ratio of approximately 70:30.



Figure 1 Steps for fabrication of the epoxy resin solid block.

These materials will be noted in this manuscript as alumina and zirconia, respectively, although the zirconia material is actually composed of a higher percentage of alumina than zirconia.

A maxillary left first molar (melamine tooth, Columbia Dentoform Corporation, Long Island, NY) was prepared for placement of all-ceramic posterior crowns using a parallelometer (Parrallel-A-Prep, Weissman Technology International, New York, NY) to ensure accurate replication of the preparation parameters. The preparation design included a 1.0-mm wide shoulder around the entire circumference, an occlusogingival height of 4 mm, and a 12° convergence angle, as recommended by the CEREC manufacturer. An occlusal reduction of 1.5 mm was prepared in the center of the occlusal surface. The melamine tooth preparation was duplicated with an addition-type silicone material (light and medium bodies, Aquasil, Dentsply/Caulk Milford, DE), and then the impression was poured using inlay wax. The inlay wax pattern was cast with a metal alloy (Lodestar, Ivoclar Vivadent Amherst, NY), finished, and polished as a metal master die. An impression was made with medium viscosity Aquasil.

To fabricate the crown copings, an inLab 3D system was used (software version 3.6X, Sirona Dental Systems, Charlotte, NC), which contained a scanner for optical measurement of the preparation with the following features: ~ 2 mm/min measuring speed, active triangulation measuring technique, and a 670-nm wavelength laser light source. The CEREC powder (titanium dioxide) was sprayed with a uniform, even layer on the master die surface while being able to visualize both the internal line



Figure 2 Solid block sectioned into four segments

angles of the preparation and a well-defined cavosurface margin with an optimal thickness of 32 μ m.²⁵ An optical impression of the sprayed master die was made with a laser scanner and then designed according to the manufacturer's instructions. The crown coping was designed using the framework design technique. Thirty IA and IZ copings each were developed with 0.6 mm thicknesses and a 30- μ m thick computer luting space. The copings were finished to be even and align with the master die margin to simulate the clinical situation. Subsequently, all the copings were infiltrated with lanthanum glass.

Each coping was placed on the metal die and stabilized with two drops of molten sticky wax at two corners only (mesiobuccal and distolingual points) (Fig 1). An impression was taken for each coping with the master metal die using a silicone material (light body Aquasil) at three stages: post-milling, posttrimming, and post-infiltration. Each impression was used as a mold that was poured with epoxy resin material (American Dental Supply, Inc. Allentown, PA) according to the manufacturer's instructions to fabricate epoxy resin dies. These dies were placed in the center of prefabricated plastic molds and then invested with a clear orthodontic resin material to cover the occlusal surface to fabricate solid blocks. Each block was sectioned buccolingually and mesiodistally into four segments (Fig 2) at the center of each surface (buccal, lingual, mesial, distal) using a diamond saw (low-speed saw, Isomet Buehler Ltd., Lake Bluff, IL). Eight measurements were made for each epoxy resin die to measure marginal discrepancy (vertical and horizontal marginal discrepancies). The marginal discrepancy was measured using a Micro-Vu optical microscope (Micro-Vu Corporation, Windsor, CA) at $70 \times$ magnification at three stages: post-milling, post-trimming, and post-infiltration.

The marginal discrepancy of the sectioned die was oriented until the upper part of the marginal discrepancy was parallel to the horizontal plane. The horizontal plane was located by drawing a red line through the upper part of the marginal discrepancy, point A, which was located at the most protuberant aspect of the lower part of the marginal discrepancy, and then extended vertically to intersect with the red line at point B, such that the distance from point A to point B was designated as the vertical marginal discrepancy. The extension from point B to the most protuberant location on the upper part of the gap was recorded as the horizontal marginal discrepancy (Fig 3). The



Figure 3 Measurement of the vertical and horizontal marginal discrepancies.

vertical and horizontal marginal discrepancies were measured for 60 copings (30 IZ, 30 IA copings) at each fabrication step.

The eight measurements from each epoxy resin die were averaged (mean \pm SD), and the means of 30 epoxy resin dies were then averaged (mean \pm SD) for each fabrication stage. A *t*-test was used to compare vertical and horizontal marginal discrepancies (after glass infiltration) between IZ and IA copings. Analyses were done using the data (three stages of fabrication) for each marginal discrepancy using one-way ANOVA. If the ANOVA was significant (p < 0.05), Tukey's HSD test was used to determine which groups were significantly different.

Results

There were no significant differences (p > 0.05) in the vertical marginal discrepancies between IA and IZ copings after glass infiltration (Table 1). ANOVA (comparing three stages within horizontal marginal discrepancy for IZ copings) showed that post-milling > post-trimming = post-infiltration. ANOVA (comparing three stages within vertical marginal discrepancy for IZ copings) showed that post-milling = post-trimming > post-infiltration. ANOVA (comparing three stages within horizontal marginal discrepancy for IA copings) showed that postmilling > post-trimming > post-infiltration. ANOVA (comparing three stages within vertical marginal discrepancy for IA copings) showed that post-milling = post-trimming > postinfiltration.

The trimming stage significantly reduced the horizontal marginal discrepancy for both IZ and IA copings after the milling stage. The horizontal marginal discrepancy of IA copings was improved by glass infiltration. The glass infiltration improved the vertical marginal discrepancy for both IZ and IA copings. The vertical marginal discrepancy at the post-milling stage was not affected by the trimming for both IA and IZ copings.

Discussion

There was no significant difference in the marginal adaptation between IA and IZ copings, so the null hypothesis was rejected.

	IZ copings		IA copings	
	Horizontal marginal discrepancy $^{\rm a}$ (mean \pm SD)	Vertical marginal discrepancy $^{\rm a}$ (mean \pm SD)	Horizontal marginal discrepancy ^a (mean \pm SD)	Vertical marginal discrepancy $^{ m b}$ (mean \pm SD)
Post-milling	40 ± 26	53 ± 12	52 ± 28	54 ± 13
	(n = 30)	(n = 30)	(n = 30)	(n = 30)
Post-trimming	23 ± 11	47 ± 13	30 ± 16	56 ± 26
	(n = 30)	(n = 30)	(n = 30)	(n = 30)
Post-infiltration	19 ± 13°	36 ± 14^{d}	$16 \pm 16^{\circ}$	40 ± 14^{d}
	(n = 30)	(n = 30)	(n = 30)	(n = 30)

Table 1 Effect of laboratory stages on the horizontal and vertical marginal discrepancies (μ m) between In-Ceram zirconia (IZ) and In-Ceram alumina (IA) copings

F-test was used to compare three stages of fabrication for each marginal discrepancy [a (p < 0.001), b (p = 0.003)].

A t-test was used to compare the marginal discrepancy between IZ and IA copings [c (p = 0.464), d (p = 0.212)].

Since the particle size of zirconia is smaller than alumina, theoretically the IZ block would fracture less at the margins during machining than would IA. This did not occur in this study because the IZ block contained a high percentage of alumina, reinforced with 33 vol% of 12 mol% ceria-stabilized zirconia (12 Ce-TZP).²⁶ This small reinforcement did not affect the marginal fit compared with IA blocks.

For both IA and IZ copings, trimming to reduce the thickness resulted in an improved alignment with the cavosurface margin and a contour with less horizontal marginal discrepancy. It should be noted that the vertical marginal discrepancy was not significantly affected by trimming procedures and was not chipped as a function of the finish line design.²⁷ Glass infiltration did not affect the horizontal marginal discrepancy for IZ copings, but it reduced the horizontal marginal discrepancy for IA copings. Furthermore, it improved the vertical marginal discrepancy for both IZ and IA copings after the machining stage because the glass particles melted and fused to fill intramolecular voids of the copings. Therefore, IZ and IA copings have less vertical marginal discrepancy, so the null hypothesis is accepted. The IA and IZ copings were not cemented on the composite resin dies in this study because the luting cement would cover the margins for coping and die finish line, thereby masking the reference points, making them difficult to read and get an accurate measurement.

The vertical marginal discrepancy was measured as a distance between the most protuberant point of the finish line of the composite resin die with the intersection of the horizontal part of the coping margin. This method has the advantage of avoiding the errors caused by chipping at the die finish line. A different number of points at the crown/die interface were selected in the literature to measure the marginal gap, and the number of specimens was increased to compensate for imprecise measurement at the coping/die interface. In this study, eight points were selected for measurement of each specimen, so the value of mean marginal discrepancy obtained from measurement points could provide reasonable data for each specimen.

Replica technology was used in this study to evaluate the marginal discrepancy at different fabrication stages and to compare the values between different groups. This method is less costly and time consuming than other techniques for creating test specimens, such as the cross-section preparation technique. In addition, the evaluations can be performed at different stages of the fabrication process, as the original abutment tooth is conserved. It should be noted that the replica technique does not provide any information about internal fit of the restorations, microleakage, and disintegration of the cement layer. In addition, it should be considered that different procedures required for the fabrication of the copings for this technique (impression making, pouring replicas) and the measurement of the marginal discrepancy itself may involve some errors and, therefore, may affect the results.

The results in this study were different from what is documented in the literature because of the measurement method, location²⁸ and number of measurements, die material, and procedure type (before cementation or after cementation). Within the examined limits, this study confirmed that it is possible to use CAD/CAM systems to achieve good in vitro marginal fit with the advantages of homogeneous standardized materials.¹ Further research should be conducted on the effect of the marginal discrepancy after cementation and to evaluate the influence of the scanning and milling processes on the accuracy of a CAD/CAM restoration along with the influence of an artificial aging process (thermocycling and mechanical loading) on the marginal and internal fit of zirconia restorations and tooth preparation design. The following limitations apply to this study: (1) artificial teeth were prepared ideally, which does not represent clinical practice and (2) only one cementation technique was performed.

Conclusions

Within the limitation of this study design, the following conclusions can be drawn:

- 1. IA and IZ copings demonstrated a comparable and acceptable marginal fit, and there was no significant difference in the final marginal adaptation of both material copings.
- The trimming process reduced the marginal discrepancy for IZ and IA copings after the milling process.
- 3. After the trimming process, the glass infiltration firing cycle improved the vertical marginal discrepancy for both IZ

and IA copings and the horizontal marginal discrepancy for IA copings.

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