Fit of zirconia all-ceramic crowns with different cervical margin designs, before and after porcelain firing and glazing

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The purpose of this study is to investigate the fit of zirconia cores and all-ceramic crowns prepared with different cervical margin designs. The radius of curvature between the axial wall and the occlusal surface was set to 1 mm in an abutment using the cervical shoulder marginal design (S) and to 0.2 and 0.5 mm in abutments with round shoulders (0.2RS and 0.5RS, respectively). The internal gaps of the cores were 45–138 µm (S), 41–141 µm (0.2RS), and 43–133 µm (0.5RS). The internal gaps of the all-ceramic crowns were 40–115 µm (S), 45–113 µm (0.2RS), and 42–126 µm (0.5RS). There were no significant differences in one-way ANOVA for any region in any marginal design before and after firing the porcelain. The marginal gaps between the all-ceramic crowns and dies were 27±25 (S), 30±29 (0.2RS), and 24±27 µm (0.5RS), again with no significant differences in one-way ANOVA.

Keywords: Zirconia all-ceramic restoration, Y-TZP, CAD/CAM, Adaptation, Margin design

INTRODUCTION

Owing to their esthetics, biocompatibility, and high strength, zirconia-based restorations have become commonly used. Zirconia ceramics are superior to other ceramics in bending strength and fracture toughness, and yttrium oxide partially stabilized zirconia (Y-TZP) is currently used clinically. This material has the specific property of strengthening under stress-induced phase transformation in which crystal transition accompanied by volume expansion occurs when stress is loaded on the zirconia with the compressive stress acting on the tip of the crack and preventing its progression. This metal-like behavior of a ceramic material is unique to zirconia among the ceramics used for dental restoration.

Recent advances in dental computer-aided design/computer-aided manufacturing (CAD/CAM) systems have allowed the development of all-ceramic systems using zirconia and have enabled all-ceramic restorations of the molar region. The Cercon® Smart Ceramics System includes a core of zirconia on which a layering of porcelain material is built up to complete the prosthesis for crown restoration. This system is supplied as a CAM type, which scans the wax pattern of the core, and as a CAD/CAM type, which scans the die and designs and prepares the core.

Several studies on the fit of crown prostheses prepared using other CAD/CAM systems have been documented. Akbar et al. found that the marginal gap of crowns prepared using the Cerec 3 system was about 65.9 µm for the chamfer group and about 46.0 µm for the shoulder group, and Kunii et al. measured a marginal gap of about 3.6 µm in shoulder-type crowns prepared using the Katana system. Reportedly, the marginal gap of Vita In-Ceram YZ is 75±39 µm and that of Vita In-Ceram Zirconia is 99±60 µm, and the mean marginal and internal gaps after processing of In-Ceram YZ Cubes were 102.4±24.3 and 73.0±21.8 µm, respectively. In Vita in-Ceram YZ molar crowns prepared using Cerec inLab, the marginal gap was about 25.8 µm, and the internal gap was about 31.8 µm. The mean marginal gaps of the premolar and molar In-Ceram crowns prepared using GN-I were about 65.3 µm and 72.9 µm, respectively, and those of premolar and molar crowns prepared using Proceras were about 56.0 µm and 63.0 µm, respectively.

In our previous study, the mean marginal fit of the zirconia all-ceramic crown made using the CAD/CAM system under three types of finish line curvature (1 mm, 3 mm, and 5 mm) and prepared for the maxillary left central incisor was about 34 µm for 1 mm curvature, 29 µm for 3 mm curvature, and 32 µm for 5 mm curvature; no significant difference was indicated between these three types of marginal shapes. Furthermore, in the other similar study, the abutment finish line curvature had no significant effect on the marginal fit of all-ceramic crowns. Also, because of influence of the CAM system versus the CAD/CAM system in the vertical misfit of zirconia FPDs, vertical discrepancy of the CAM system was significantly higher than that of the CAD/CAM system. In the different cervical margin designs, the marginal fit of zirconia crowns made by a CAD/CAM system was influenced by the finish line design; preparations with a 90° round shoulder finish line showed a better marginal seal than did preparations with a 45° chamfer finish line. This means that there is not enough evidence to decide which cervical margin design offers a better marginal fit. Different cervical margin designs and ceramic manufacturing technique are factors that have been investigated for all-ceramic crowns. In addition, the ceramic firing cycles and glaze
firing cycles have shown effects on the marginal fit of all-ceramic restorations. Balkaya et al. reported the effects of the porcelain and glazing cycles on the fit of three types of all-ceramic crowns and concluded that porcelain firing cycles affect the marginal fit of all-ceramic crowns\textsuperscript{16}. On the other hand, Vigolo and Fonzi found that porcelain firing cycles and glazing cycles did not affect the marginal fit of the zirconium-oxide-based ceramic with three different CAD/CAM systems\textsuperscript{17}. Marginal fit is one of the most important criteria for the long-term success of all-ceramic crowns\textsuperscript{18}. Thus, we prepared all-ceramic crowns for the molar region with the shoulder region rising from the axial surface at various angles and investigated the fit of these crowns. The objective of the current study was to investigate the fit of zirconia cores (before the firing of the porcelain) and zirconia all-ceramic crowns (after the firing of the porcelain and glaze) prepared with various marginal designs of the abutment tooth cervical region and to clarify the influence of the cervical marginal design on the fit.

MATERIALS AND METHODS

Cores and crowns
Three brass abutment models were prepared for all-ceramic crowns for molar abutment teeth with height, cervical diameter, and shoulder width of 6, 8, and 1 mm, respectively, and a taper of 6 degrees (Fig. 1). The radius of curvature between the axial wall and the occlusal surface was set to 1 mm in an abutment using the cervical shoulder marginal design (S) and to 0.2 and 0.5 mm in abutments with round shoulders (0.2RS and 0.5RS, respectively) (Fig. 2). Impressions of these 3 metal abutment models were made using a silicone rubber impression material (Exafine Regular Type, GC, Tokyo, Japan), and the dies were completed by infusing Type IV dental stone (New Fujirock, GC, Tokyo, Japan). Five dies were prepared for each model, giving a total of 15 dies. For the core to return to its original position, it was given a semi-circular depression in the margin of the die. Each die was measured using the Cercon\textsuperscript{®} eye laser scanner of the CAD/CAM system, and the core was designed using Cercon\textsuperscript{®} art CAD software following the standard set by the manufacturer (wall thickness: 0.5 mm, cement gap: 30 μm, spacer coverage: 90%). Zirconia blocks were cut using the Cercon\textsuperscript{®} brain CAM device and sintered using the Cercon\textsuperscript{®} heat furnace to complete preparation of the zirconia cores. The cores were sandblasted, washed with a steam cleaner, and dried well. A porcelain layering material (Vintage ZR, Shofu, Kyoto, Japan) was built up on the zirconia cores according to the manufacturer’s recommendations (Table 1) and followed by firing to complete preparation of the all-ceramic crowns (Fig. 3). The powder-water ratio was 0.35% and the crowns were veneered with about 1.0 mm layer occlusally with a gradual decrease in thickness toward the cervical margin.

Table 1  Schedule of porcelain firing

<table>
<thead>
<tr>
<th></th>
<th>Start temperature (°C)</th>
<th>Drying time (min)</th>
<th>Heating rate (°C/min)</th>
<th>Firing temperature (°C)</th>
<th>Holding time (s)</th>
<th>Vacuum (hPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opaque</td>
<td>500</td>
<td>8</td>
<td>45</td>
<td>940</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>Body</td>
<td>650</td>
<td>6</td>
<td>45</td>
<td>920</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>Enamel</td>
<td>650</td>
<td>6</td>
<td>45</td>
<td>920</td>
<td>60</td>
<td>80</td>
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<tr>
<td>Glaze</td>
<td>650</td>
<td>6</td>
<td>45</td>
<td>920</td>
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Internal and marginal fitness
The internal gap was measured in the cores before firing of the porcelain material (0 firing) and in the all-ceramic crowns after firing and glazing (5 firings). A black silicone impression material (Bite Checker, GC, Tokyo, Japan) was infused into the cores and internal crowns and then removed from the die after pressure welding and solidifying; the internal and external surfaces of the black material were embedded with a white silicone impression material (Fit Checker, GC, Tokyo, Japan). The replica sample was cut bucconeogally, and the thickness of the cross-sectioned black silicone was measured at 50-times magnification under a universal projector (V16-D, Nikon, Tokyo, Japan). The replica sample was then cut mesiodistally, and the black silicone thickness was measured similarly to the buccolingual section. Measurements were made at 2 points in the shoulder region (A and B), at 5 points on the axial surface (C, D, E, F, and G), and at 2 points on the occlusal surface (H and I) for a total of 9 points (Fig. 4). The mean value for each region was defined as the internal gap for that region. The vertical gap between the margin and the die was measured at 8 points on the circumference under a universal projector in the all-ceramic crown, and the mean value was defined as the marginal gap. The significance of differences (α=0.05) in these results was analyzed by one-way ANOVA followed by Tukey’s HSD.

RESULTS
The internal gaps of the core in the S design before the firing of the porcelain were 70±30, 45±17, and 138±19 μm for the shoulder, axial surface, and occlusal surface, respectively. These gaps were 80±30, 41±12, and 141±34 μm, respectively, in the 0.2RS design and 80±40, 43±17, and 133±29 μm, respectively, in the 0.5RS design (Fig. 5). The internal gaps of the all-ceramic crowns after the
firing of the porcelain were 40±10, 49±17, and 115±28 μm for the shoulder, axial surface, and occlusal surface, respectively, in the S design; 70±40, 45±18, and 113±26 μm, respectively, in the 0.2RS design; and 60±40, 42±18, and 126±28 μm, respectively, in the 0.5RS design (Fig. 6). There were no significant differences in one-way layout ANOVA for any region in any marginal design before and after firing of the porcelain. The marginal gaps between the all-ceramic crowns and dies were 27±25, 30±29, and 24±27 μm in the S, 0.2RS, and 0.5RS designs, respectively, again with no significant differences in the one-way layout ANOVA (Fig. 7).

**DISCUSSION**

The dies were prepared by taking impressions of model metal abutments with a silicone rubber impression material followed by infusion of a Type IV dental stone. Abrasion of the plaster model by friction when returning the crown to the die and solidification-induced size changes were matters of concern. However, this method was used since only plaster models can be scanned and to ensure that the experiment was performed under conditions close to those of clinical practice. The vertical gap between the restoration prosthesis and the die has been measured in previous evaluations of the fit of crown prostheses. Therefore, we measured gaps between the crown prostheses and dies to permit comparison with other reports.1,10,19-23.

Fitness tests were performed for three abutment teeth with different cervical margin designs. The marginal gap in the 3 types of all-ceramic crowns was 24–30 μm, showing a favorable fit; there was no significant difference in this gap among the 3 abutment teeth, suggesting that the differences in the marginal design did not affect the fit. The internal fit was measured before and after the firing of the porcelain layering material and showed no significant change after the firing, indicating that sintering at 1350°C converted the semi-sintered cores to completely stabilized tetragonal polycrystals, and that subsequent firing of the porcelain at 830°C did not affect the fit. The crown and abutment tooth were in contact only at the marginal region for all 3 types of margin designs with no internal contact noted. Generally, loosening in the horizontal direction occurs when the crown is in contact only at the marginal region, and horizontal gaps may be produced on the buccolingual and mesiodistal sides. However, the gaps of the crowns were close to the spacers set for the axial surface (C, D, E, F, and G) and guided the direction of fitting of the crown, suggesting that the crown returns to the appropriate position without deviation toward the buccolingual or mesiodistal side. When the spacer was set to 30 μm, the gaps in the shoulder region (A) and at the axial surface (C, D, E, F, and G) tended to be similar. In the shoulder region rising from the margin to the axial surface (B), the gap tended to be greater than that at the axial surface (C, D, E, F, and G). The gap was marked at the occlusal surface (H and I). Spacers were set for these regions, but the value was 3–4 times greater than the spacers, suggesting that the CAD program automatically increases the size of a region, which may affect the fit. Since the internal gaps were large in some regions, frictional fit, such as that of full cast crowns, could not be obtained, and the crowns felt loose on fitting. The manufacturer explains that the system is intended to prepare loose crowns to avoid failure or instability of crown attachments prepared by dentists and dental technicians worldwide. Wettstein et al. stated that in clinical comparisons of the internal gaps of zirconia (Cercon) and cast gold-alloy FPD frameworks, zirconia frameworks exhibited larger internal gaps, with significantly higher values at cervical, axial, and occlusal measurement locations. However, the latest updates of the software have been made available and have improved framework precision. Hence, acquisition of a frictional fit similar to that of full cast crowns would be possible.

The gaps showed a tendency to increase at the occlusal surface, which is similar to the findings in the current study. The results show that the marginal gap of all-ceramic crowns varies depending on the CAD/CAM system and the measurement method, but the mean marginal gap of 24–30 μm in our study showed a favorable fit as compared to those obtained with other systems.

In current clinical practice, crown restoration prostheses are attached in the mouth by luting with cement or through adhering to the abutment tooth. The gap between the prosthesis and the abutment tooth is space required for the cement, but there is no clear criterion for the gap width. Thus, it may be appropriate to refer to the gap for full cast crowns that have been used for crown restoration. Christensen defined two categories for the marginal fit of restorations: (1) supragingival finish lines, where discrepancies ranging from 2–51 μm were considered satisfactory; and (2) subgingival finish lines, where marginal discrepancies ranging from 34–119 μm were deemed acceptable; furthermore, he states that the marginal discrepancy of 30–40 μm is clinically acceptable for visually accessible margins. Boening et al. reported that marginal gaps of 100 μm are considered clinically acceptable with regard to...
to longevity and Christensen states that theoretical requirements of marginal gaps should be lower than 40 μm. McLean and Von Fraunhofer reported on their clinical study of 1,000 restorations over a 5-year period, concluding that 120 μm represented the maximum clinically acceptable marginal opening. Pera et al. indicated that the thickness of cement in every examined situation was well below the clinical acceptability of 50 μm. Tuntiprawn and Wilson found that increasing the cement thickness to 70 μm reduced the fracture strength. The above findings show variations in the clinically acceptable range of the marginal gaps reported. Poor marginal adaptation can cause increased plaque retention, resulting in damage to the tooth, to the periodontal tissues, and to the restoration. Large marginal discrepancies result in the dissolution of the luting agent and favor microleakage of bacteria and their byproducts.

However, the fitness of crown restoration prostheses in all-ceramic restoration, particularly the marginal fitness, markedly affects the postoperative course of fixed prosthodontics, including the occurrence of secondary caries and periodontal disease. Both general full cast crowns and all-ceramic crowns should be prepared within the clinically acceptable range to prevent secondary problems in crown restorations. The results of previous studies suggest that the marginal gap for crown restoration prostheses should be 100 μm or less, and that luting with less soluble cement may also be important. All-ceramic crowns with a simplified molar shape do not seem to cause clinical problems due to their marginal fit.

In the present study, there were no significant differences for any region in any marginal design before and after firing and glazing of the porcelain. These results are consistent with those found by Komine et al. After firing and glazing, the internal gaps tended to be smaller; however, it was not believed that there was a shrinkage of the zirconia core with firing. The distortion that occurred during the porcelain firing cycle might be due to nonuniform porcelain mass. Because the firing shrinkage is a function of porcelain bulk, it is possible that the larger marginal discrepancy seen at the labial and palatal margins is related to the greater bulk of the porcelain at these surfaces. The distortion of the copings during the porcelain firing affects the success of the restoration as it may cause an increase in the marginal opening. However, the crowns were fabricated to create a uniform contour for each specimen in this study. Thus, there were no significant differences for before and after firing and glazing on internal fitness of crowns.

Subasi reported that the adaptation of zirconia copings may be affected by the milling process and the size of the milling burrs. Since CAD/CAM systems use computer-assisted mechanical processing, the durability of the cutting bur affects the fitness and surface properties, and the frequency of bur replacement affects the cost, which is important in clinical practice. Hotta et al. investigated the durability of tungsten carbide burs for the fabrication of titanium crowns using a CAD/CAM system and found that it is desirable to limit the number of molar crowns to at least 51 for preparation with continuous cutting using the same bur. The CAD/CAM system used in our study cuts chalk-like semi-sintered zirconia blocks, which reduces the wear on the cutting bur. One cutting bur can be used to prepare 100 units, showing the superiority of this system with regard to processing and cost.

CONCLUSION
The following results were obtained by measuring the fit of all-ceramic crowns with different marginal designs prepared using the Cercon CAD/CAM system:

1. The mean internal gap between the all-ceramic crown and the die was 70–80 μm in the shoulder region, 41–45 μm at the axial surface, and 133–141 μm at the occlusal surface.
2. The mean marginal gap of the all-ceramic crowns was 24–30 μm.
3. Differences in the cervical marginal design do not affect the fit.
4. There were no significant differences in any region in any marginal design before and after firing of the porcelain.
5. The fit of the all-ceramic crowns prepared using this CAD/CAM system is suitable for clinical application.

REFERENCES


