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ORIGINAL ARTICLE

# Influence of preparation design on fit and ceramic thickness of CEREC 3 partial ceramic crowns after cementation

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**Abstract**

***Objective.*** This study investigated the influence of preparation design on the marginal and internal gap and ceramic thickness of partial ceramic crowns (PCCs) fabricated with the CEREC 3 system. ***Materials and methods.*** Sixteen extracted human mandibular molars were prepared according to two different preparation designs ($n = 8$): a retentive preparation design with traditional cusp capping (Group I) and a non-retentive preparation design with horizontal reduction of cusps (Group II). PCCs were fabricated from IPS Empress CAD with the CEREC 3 system. The parameters for luting space and minimum occlusal ceramic thickness were set to 30 μm and 1.5 mm, respectively. The fabricated PCCs were cemented to their corresponding teeth with self-adhesive resin cement and were then scanned by micro-computed tomography. The marginal and internal gaps were measured at pre-determined measuring points in five bucco-lingual and three mesio-distal cross-sectional images. The ceramic thicknesses of the PCCs were measured at the measuring points for cusp capping areas. ***Results.*** Group II ($167.4 \pm 76.4$ μm) had a smaller overall mean gap, which included the marginal and internal gap measurements, than that of Group I ($184.8 \pm 89.0$ μm). The internal gaps were larger than the marginal gaps, regardless of preparation design. Group I presented a thinner ceramic thickness in the cusp capping areas than the minimum occlusal ceramic thickness parameter of 1.5 mm. ***Conclusion.*** Preparation design had an influence on fit, particularly the internal gap of the PCCs. Ceramic thickness could be thinner than the minimum ceramic thickness parameter.

**Key Words:** *CAD/CAM, internal gap, luting space, marginal gap, micro CT*

## Introduction

Advanced technology of computer-aided design and manufacturing (CAD/CAM) systems has brought about changes in the production process for indirect dental restorations [1,2]. CAD/CAM-fabricated tooth-colored restorations have been substituted for metal restorations fabricated with the conventional lost wax technique. Dental CAD/CAM systems have a wide variety of clinical applications including anterior veneers, inlays and partial or full coverage crowns. As the demand for esthetics and awareness about the importance of conserving tooth tissues are increasing, extensively damaged teeth are frequently restored with adhesively luted partial ceramic crowns (PCCs), which restore one or more cusps as an alternative to full coverage crowns [3,4].

The fit of an indirect restoration with the tooth is crucial for clinical long-term success [3–9]. Poor marginal fit can exacerbate degradation of luting cements in the oral environment, resulting in micro-leakage, recurrent caries, periodontal disease and marginal discoloration [10,11]. Internal fit can also affect clinical performance of tooth-colored restorations that are supported by adhesive luting cement and the subjacent tooth [8,12,13].

Marginal fit of restorations has been investigated through various methods, including the modified US Public Health Service criteria [14], scanning electron microscopy [3,15] and dye penetration testing [4,16].

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For investigating internal fit, specimens are sectioned after cementing the restoration to the tooth [8,17,18] and the silicone replica technique has been frequently used as a non-destructive method [7,19–21]. The overall internal gap can be calculated from the volume of silicone materials and the area of the fitting surface [22,23]. Recently introduced micro-computed tomography (μCT) provides non-destructive and reproducible analyses for marginal and internal restoration fits [24–26].

The fit of indirect restorations depends on the type of restoration, tooth preparation design and materials used [4,14,15,19,27]. The cementing procedure can also affect the final gap between the restoration and the tooth [8,9,27,28]. In addition to fit, ceramic thickness is a crucial factor for fracture resistance and the clinical outcome of a ceramic restoration [16,29]. However, limited information on the actual ceramic thickness of CAD/CAM-fabricated PCCs is available. The purpose of this study was to investigate the influence of different preparation designs on the fit and ceramic thickness of PCCs fabricated with a dental CAD/CAM system.

## Materials and methods

### *Specimen preparation*

Sixteen sound, caries-free, human mandibular molars extracted due to periodontal disease were used for this study. The teeth were kept in normal saline until use and randomly assigned to two groups of eight teeth each according to the preparation designs (Figure 1):

- Group I: Retentive preparation design with traditional coverage of cusps that were reduced by ~ 1.5 mm.
- Group II: Non-retentive preparation design with simple coverage of cusps that were horizontally reduced by ~ 2.5 mm.

One investigator prepared all teeth using a tapered flat-end diamond bur (TF-S 22, MANI Inc. Tochigi, Japan). The prepared teeth of both groups had 1.0 mm-wide shoulder margins. After preparation, the teeth were coated with anti-reflection powder (VITA CEREC Powder, VITA Zahnfabrik, Bad Säckingen, Germany) for the optical impression using an intra-oral camera (CEREC Bluecam, Sirona Dental Systems GmbH, Bensheim, Germany). The images were transferred to CEREC software v.3.85 and used to design the PCCs. The parameters for spacer (luting space) and adhesive gap were set to 30 μm and 20 μm, respectively. The minimum occlusal ceramic thickness parameter was set to 1.5 mm. The ceramic thickness of the PPC was checked during the design phase, making sure that it was > 1.5 mm. Next, PCCs were milled from leucite-reinforced glass ceramic blocks (IPS Empress CAD, LT A3/C14, Lot No. M13138, Ivoclar Vivadent Inc., Schaan, Liechtenstein) using the CEREC MC milling unit with a Step Bur 12 and a Cylinder Pointed Bur 12S.

The fabricated PCCs were cemented to their corresponding teeth using self-adhesive resin cement (SmartCem 2, Lot No. 100225, Dentsply Caulk, Milford, DE). The cementing procedure was performed according to the manufacturers' instructions. The fitting surface of the PCC was etched with a 4.0% hydrofluoric acid gel (Porcelain etchant, Bisco Inc., Schaumburg, IL) for 60 s, thoroughly rinsed and dried with oil-free air. A silane agent (Monobond-S, Ivoclar Vivadent Inc.) was applied to the etched surface of the PCC and was completely air-dried after 60 s. Resin cement mixed through an auto-mixing tip was applied to the PCC, which was then seated on the corresponding tooth. Excess cement was removed and the resin cement was light-polymerized from buccal, lingual and occlusal directions for 20 s each with an LED curing unit (Elipar S10, 3M ESPE, St. Paul, MN). All cemented specimens were stored at 37°C under 100% humidity before μCT scanning.

### *μCT scanning*

The specimens were scanned with a desktop μCT (SkyScan 1172, Bruker Co., Kontich, Belgium). Scanning was performed at 65 kVp and 153 μA with an

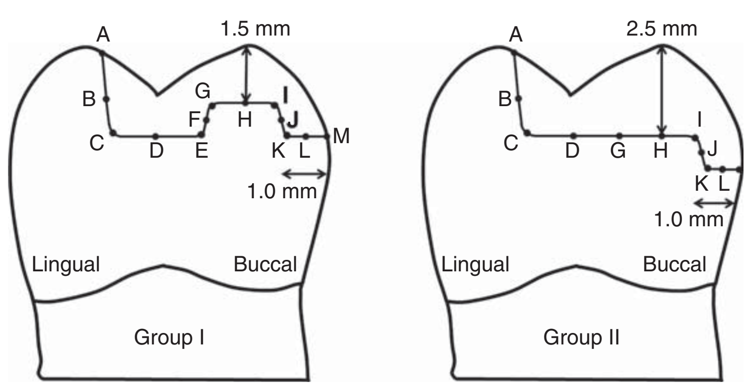


Figure 1. Schematic drawings of bucco-lingual cross-sections for each preparation design showing locations of the measuring points (A–M). Group I, retentive preparation design; Group II, non-retentive preparation design.

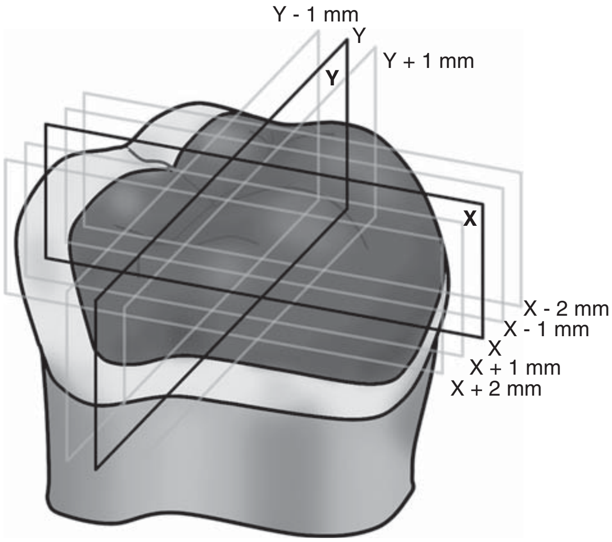


Figure 2. A bucco-lingual cross-section (x-axis) through the mesio-distal center of the tooth and four additional cross-sections were obtained at 1 mm intervals. A total of three mesio-distal cross-sections (y-axis) were obtained in the same manner.

exposure time of 474 ms per frame using a 0.5 mm aluminum filter. The rotation step (degree) was set to 0.700 and a 360° rotation scanning procedure was performed. The X-ray beam was irradiated perpendicularly to the tooth's long axis. The crown portion, 10 mm in height, was focused and scanned using the zoom function. The images had 1024 × 512 pixels and a resolution of 15.91 μm. After completing scanning, multiple cross-sectional images were obtained using Data Viewer software (Bruker Co.).

### *Gap and ceramic thickness measurements*

A bucco-lingual cross-sectional image (x-axis in Figure 2) through the mesio-distal center of the tooth was obtained and additional cross-sections were obtained bilaterally at 1 mm intervals, resulting in five bucco-lingual cross-sectional images. Additionally, three mesio-distal cross-sectional images (y-axis in Figure 2) were obtained from the tooth. Figures 1 and 3 show schematic drawings of the cross-sectional images and pre-determined points for measurements. The points were labeled in the bucco-lingual (A–M) and mesio-distal (a–i) directions. As a result, each Group I and II specimen had a total of 92 and 77 measuring points, respectively. Ceramic thickness in the cusp capping areas was measured at points G, H and I in the bucco-lingual sections.

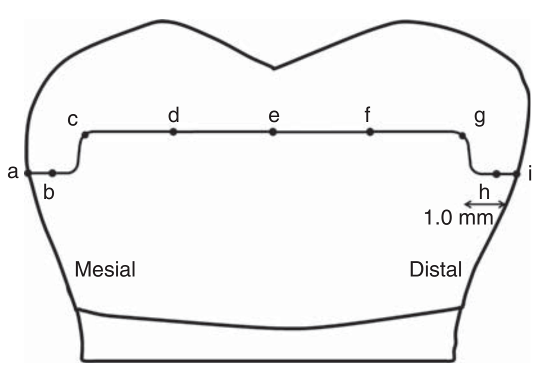


Figure 3. Representative schematic drawing of mesio-distal cross-section showing locations of the measuring points (a–i).

Table I. Mean gaps (standard deviation) in μm for the measuring points in the bucco-lingual cross-sections.

| Point | Group I | Group II |
|---|---|---|
| A | 102.7 (26.9)$^{ab}$ | 110.3 (34.0)$^{b}$ |
| B | 120.1 (31.9)$^{bc}$ | 143.7 (47.0)$^{bc}$ |
| C | 208.2 (50.5)$^{ef}$ | 243.4 (70.1)$^{d}$ |
| D | 287.9 (46.7)$^{g}$ | 225.2 (55.4)$^{d}$ |
| E | 213.6 (60.2)$^{ef}$ | n/a |
| F | 132.7 (66.4)$^{bc}$ | n/a |
| G | 177.9 (53.0)$^{de}$ | 223.1 (50.5)$^{d}$ |
| H | 293.0 (49.0)$^{g}$ | 222.8 (47.1)$^{d}$ |
| I | 192.7 (56.3)$^{ef}$ | 135.2 (40.0)$^{bc}$ |
| J | 143.1 (39.1)$^{cd}$ | 163.9 (50.8)$^{c}$ |
| K | 125.9 (42.2)$^{bc}$ | 172.4 (58.7)$^{c}$ |
| L | 93.6 (27.2)$^{a}$ | 113.0 (42.8)$^{b}$ |
| M | 82.6 (29.9)$^{a}$ | 81.5 (38.7)$^{a}$ |

Values with the same letter within the same column are not significantly different from each other.

### *Statistical analysis*

Data were analyzed using SPSS 18.0 statistical software (SPSS Inc., Chicago, IL). All gap measurements obtained from the bucco-lingual and mesio-distal sections were pooled for each group to evaluate the influence of preparation design on overall mean gap. The overall mean gaps for the groups were compared using the two-sample t-test. One-way analysis of

Table II. Mean gaps (standard deviation) in μm for the measuring points in the mesio-distal cross-sections.

| Point | Group I | Group II |
|---|---|---|
| a | 113.8 (31.7)$^{a}$ | 93.3 (37.1)$^{ab}$ |
| b | 160.0 (37.8)$^{b}$ | 135.4 (56.2)$^{b}$ |
| c | 275.0 (55.0)$^{c}$ | 234.3 (70.4)$^{c}$ |
| d | 281.3 (62.1)$^{c}$ | 229.5 (49.4)$^{c}$ |
| e | 306.8 (52.7)$^{c}$ | 229.7 (50.6)$^{c}$ |
| f | 294.4 (67.1)$^{c}$ | 235.9 (53.2)$^{c}$ |
| g | 306.7 (82.5)$^{c}$ | 227.8 (65.9)$^{c}$ |
| h | 164.9 (51.9)$^{b}$ | 135.0 (80.5)$^{ab}$ |
| i | 142.6 (54.2)$^{ab}$ | 81.0 (39.7)$^{a}$ |

Values with the same letter within the same column are not significantly different from each other.

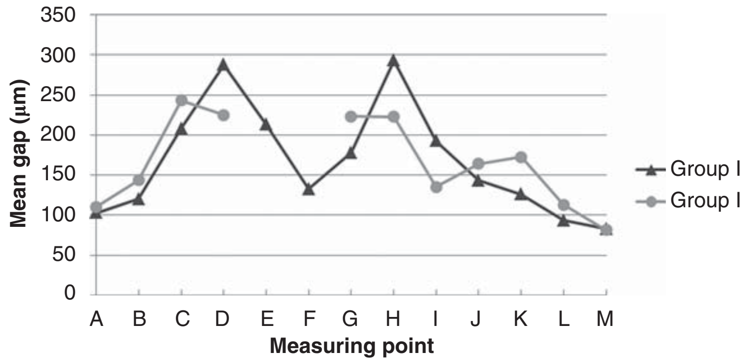


Figure 4. Change of mean gaps in the bucco-lingual cross-sections. Group I, retentive preparation design; Group II, non-retentive preparation design.

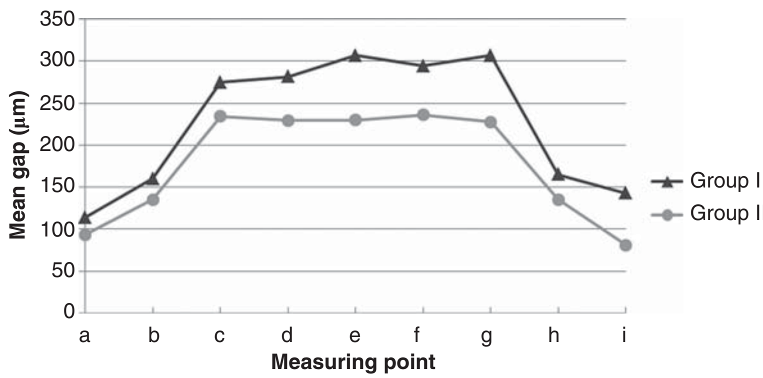


Figure 5. Change of mean gaps in the mesio-distal cross-sections. Group I, retentive preparation design; Group II, non-retentive preparation design.

variance was performed for the bucco-lingual and mesio-distal sections, respectively, to assess differences among the measuring points within each group. The Dunnett T3 test was selected for post hoc pairwise comparisons. Ceramic thickness for each point was compared to the minimum occlusal ceramic thickness parameter using the one-sample t-test. Analyses were performed at a significance level of $\alpha = 0.05$.

## Results

The mean values for each measuring point of the bucco-lingual and mesio-distal sections are summarized in Tables I and II and are also shown graphically in Figures 4 and 5. The mean gaps ranged from 82.6–306.8 μm for Group I and from 81.0–243.4 μm for Group II. All gap measurements were pooled for each group and, as a result, Group I had a significantly larger overall mean gap than that of Group II ($p < 0.05$) (Table III).

Table III. Overall mean gaps (standard deviation) in μm including the marginal and internal measurements for the preparation designs.

| | Group I | Group II | |
|---|---|---|---|
| Overall mean gap | 184.8 (89.0) | 167.4 (76.4) | $p < 0.05$ |

Significant differences among the measuring points within the bucco-lingual and mesio-distal sections were observed in each group ($p < 0.05$) (Tables I and II). The internal points (points B–L and b–h) showed higher mean values than those of the marginal points (points A, M, a and i). The marginal point (point M for Group I and i for Group II) presented the lowest mean value, whereas the internal point (point e for Group I and C for Group II) presented the highest mean value. As shown in Figure 4, the measuring points for the horizontal wall (points D and H) showed higher mean values than those of the other internal measuring points.

Mean ceramic thicknesses in the cusp capping areas ranged from 1.36–1.58 mm for Group I and from 1.80–2.13 mm for Group II (Table IV). Group I had a mean ceramic thickness of 1.36 mm at point G, which

Table IV. Mean ceramic thicknesses (standard deviation) in mm for the cusp capping areas

| Point | Group I | Group II |
|---|---|---|
| G | 1.36 (0.31)* | 1.80 (0.68) |
| H | 1.56 (0.32) | 2.09 (0.73) |
| I | 1.48 (0.28) | 2.13 (0.67) |

*The mean was statistically lower than 1.50 mm of the minimum occlusal ceramic thickness parameter ($p < 0.05$).

was significantly lower than 1.50 mm of the minimum occlusal ceramic thickness parameter ($p < 0.05$).

## Discussion

We investigated the influence of tooth preparation design on the gap of CEREC 3 PCCs using μCT. The retentive preparation design for the PCC presented a significantly larger overall mean gap than that of the non-retentive preparation design. This finding is in accordance with the results of a previous study [24], in which overall mean gaps were calculated from the volume of the luting space and the area of the fitting surface. The overall mean gap included the internal gap as well as the marginal gap. The internal gap is a crucial factor for performance of ceramic restorations supported by adhesive luting cement and the tooth [8,12,13]. The marginal fit has become better with improvements in the CEREC system [30,31], but the adequacy of the internal fit is still in doubt [6,13,27]. The internal gap of CAD/CAM restorations has been reported to be in the range of 85.0–406.5 μm [7,13,17,24]. In the present study, the maximum mean values for the internal measuring points were 306.8 μm and 243.4 μm with the retentive preparation design and the non-retentive preparation design, respectively. The discrepancy in the internal gaps between the preparation designs can be attributed to the three-dimensional (3D) optical impression and the milling processes. The optical impression process presents a so-called 'overshooters' phenomenon that simulates virtual peaks near the edges [13,32]. The point clouds obtained through the optical impression are transformed into a smooth and continuous surface by the software [33]. Although this physical phenomenon contributes to preventing premature contacts and improving feasibility of milling, it may result in an increase of the internal gap, especially in cases where the fitting surface of a prepared tooth has complicated geometry. Milling precision also has an influence on the internal fit and is limited by the shape and diameter of the milling instruments [31]. The fitting surface of a restoration is milled with a Step Bur positioned on the left side of the CEREC milling unit. The Step Bur 12 used in the present study has a flat end of 1 mm in diameter, which determines the smallest millable intaglio of the restoration. The retentive preparation produces more complicated fitting surfaces of the prepared tooth and the PCC, which could increase errors in the optical impression and the milling processes.

Regardless of preparation design, the internal gap was greater than the spacer parameter, which was set to 30 μm. Although there is no consensus on the optimal internal gap for adhesively luted ceramic restorations, an internal gap of 50–100 μm has been advocated for good performance of luting cements [12,13,34]. An excess internal space can cause high polymerization shrinkage of luting cement and poor support for a ceramic restoration [8,29,35]. The internal gap is still considered to be a weak point of restorations fabricated with the CEREC system. Thus, it is necessary to use adhesive luting materials to support and strengthen the restorations [8,12,13,36,37].

The main reason for failure of ceramic inlays and onlays is ceramic fracture [38,39]. Ceramic thickness is a crucial factor for fracture resistance [16,29]. A ceramic thickness of 1.5–2.0 mm for stress-bearing areas is recommended. In this study, the amount of cusp reduction was ~ 1.5 mm for the retentive preparation design and 2.5 mm for the non-retentive preparation design, assuming a clinical situation. The ceramic thicknesses of the fabricated PCCs were generally coincident with the amount of cusp reduction, which verified the accuracy of the CAD/CAM process. However, the mean ceramic thickness for the G point of the cusp capping area in the retentive preparation design was < 1.5 mm, despite that all PCCs were designed to have an occlusal ceramic thickness > 1.5 mm. Even if a tooth is prepared adequately, the presence of an internal gap combined with occlusal adjustment of the restoration can result in thin ceramic thickness. Therefore, the practitioner should consider possible processing errors as well as the recommended ceramic thickness according to the materials used when the amount of tooth reduction is determined.

Marginal gap is associated with microleakage, recurrent caries, periodontal disease and marginal discoloration [10,11]. In both preparation designs in this study, the marginal gaps were close to 100 μm and smaller than the internal gaps. A previous study showed that a marginal gap up to 100 μm has little influence on marginal integrity, regardless of the type of luting cement used [40]. On the other hand, Federlin et al. [4,15] investigated the effect of luting cement and preparation design on microleakage and marginal integrity of PCCs using dye penetration and scanning electron microscopy. They revealed that the type of luting cement was more relevant to microleakage and marginal integrity than the preparation design. In the present study, the gap was measured after the PCCs were cemented with self-adhesive resin cement. Because the cementing procedure could increase the gap [23,27], measurement after cementing is more clinically relevant. The cementing procedure seemed to have little influence on the gap of PCCs when compared with the results of a previous study [24] in which gaps were measured without cementation. This may be attributed to greater marginal and internal gaps compared to the low film thickness of the luting cement (19 μm according to the manufacturer).

In contrast to the conventional method in which a specimen is sectioned to produce a certain

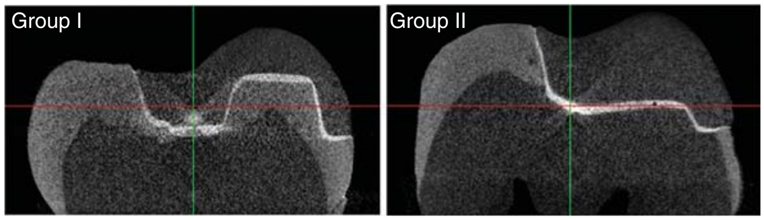


Figure 6. Typical µCT images of bucco-lingual cross-sections showing the marginal and internal gap between the restorations and the tooth substrates. Group I, retentive preparation design; Group II, non-retentive preparation design.

cross-section using a diamond saw [8,17,18], µCT provides many cross-sectional images and multiple point measurements [24–26]. The present results were obtained from more than 70 measurements for a single specimen and similar to those of a previous study [24] using µCT 3D reconstruction. Although 3D reconstruction is useful to analyze the overall gap between the restoration and the tooth, it is time-consuming and complicated when compared to the two-dimensional (2D) method. The reliability of the µCT image analysis is dependent on the experimental design and subsequent image analysis [41,42]. The appropriate setting of segmentation values is critical for the image analysis, and we optimized the values through our pilot studies. The µCT images provided sufficient radiographic contrast to differentiate between ceramic, resin cement and tooth substrates (Figure 6). The 2D µCT image analysis, which is conducted by controlling frontal, sagittal and horizontal views, is suitable for evaluating the fit of restorations and can provide comparable results before and after additional experiments due to its non-destructive property [41–43].

With the limitations of this study, the non-retentive preparation design presented a smaller overall mean gap than that of the retentive preparation design. The internal gap was larger than the marginal gap, regardless of preparation design. The cusp capping area in the retentive preparation design had a point where the ceramic thickness was thinner than the minimum occlusal ceramic thickness parameter of 1.5 mm.

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