The effect of preparation designs on the marginal and internal gaps in Cerec3 partial ceramic crowns

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ABSTRACT

The effect of preparation designs on the marginal and internal gaps in Cerec3 partial ceramic crowns

The purpose of this study was to evaluate the marginal and internal gaps in Cerec3 partial ceramic crowns (PCCs) of three different preparation designs in vitro using microcomputed tomography (μCT).

Cerec3 PCCs of three different preparation designs (n = 20) were fabricated according to the following: Group I-conventional functional cusp capping/shoulder preparation, Group II-horizontal reduction of cusps and Group III-complete reduction of cusps/shoulder preparation. After fixation of PCCs, the μCT scanning was performed. For obtaining the average internal gap (AIG), the μCT sections were reconstructed 3-dimensionally, and then the total volume of the internal gap was divided by the contact surface area. The 2-dimensional (2D) μCT views were used to investigate the gaps at predetermined key positions in seven bucco-lingual sections and three mesio-distal cross sections. The gaps were measured using the μCT at each reference point. Statistical analysis was performed using one-way ANOVA and Tukey′s test.

For the 3D reconstruction technique, the AIGs were as followed: Group I 197.3 ± 48.2 μm, Group II 171.2 ± 45.1 μm, and Group III 152.7 ± 27.1 μm. For the 2D μCT views, the gaps of each group were the smallest on the margins ranging from 35.4 ± 32.2 to 128.4 ± 69.5 μm, and the largest on the horizontal or angle walls ranging from 184.5 ± 41.2 to 406.5 ± 176.1 μm. According to the results, group I showed larger marginal and internal gaps compared with the other groups.

For the PCCs, the simplified designs (groups II and III) demonstrated superior results compared to the traditional cusp capping design (group I). The marginal gaps were smaller than the internal gaps in all groups.

Keywords: Cerec3; CAD/CAM; Microcomputed tomography; Marginal gap;

Internal gap; Preparation design; Partial ceramic crown

The effect of preparation designs on the marginal and internal gaps in Cerec3 partial ceramic crowns

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I. Introduction

The introduction of computer-aided design computer-aided manufactured (CAD/CAM) techniques has led to the shaping of high-performance materials. However, it is not easy to fabricate the shape of a dental restoration (Jedynakiewicz and Martin, 2001; Tsitrou *et al.*, 2007). The Cerec3 system is one of the CAD/CAM systems currently in use. Using this system inlays, onlays, veneers, and crowns may be fabricated at the chair-side during a single-visit procedure (Allen *et al.*, 2004; Fasbinder, 2006; Jedynakiewicz and Martin, 2001; Mou *et al.*, 2002). Using this system, procedures may be performed without intermediate appointments, thereby decreasing cost, time and the chance of contamination during the provisional phase (Jedynakiewicz and Martin, 2001; Mou et al., 2002; Sadowsky and Sadowsky, 2006). In addition, the machined ceramic restoration has the advantages of durability and improved esthetics due to the chameleon effect (Jedynakiewicz and Martin, 2001; Mou et al., 2002; Otto and De Nisco, 2002; Reiss, 2006; Sadowsky, 2006).

However, many investigators have criticized the marginal accuracy of these restorations (Hickel *et al.*, 1997; Siervo *et al.*, 1994). Poor marginal fit can lead to secondary caries, periodontal disease, endodontic inflammation due to microleakage from the oral cavity, and clinical failures of the fixed restoration (Beuer *et al.*, 2008; Kokubo *et al.*, 2005). Traditionally, a cementation width of 50 to 120 μm has been considered to be acceptable (Akbar *et al.*, 2006; Hickel *et al.*, 1997; McLean and von Fraunhofer, 1971; Mou *et al.*, 2002; Nakamura *et al.*, 2005). In recent studies, the marginal gap of Cerec3 crown has been reported to be in the range of 27 to 162 μm (Akbar *et al.*, 2006; Mou *et al.*, 2002; Nakamura *et al.*, 2003; Tsitrou *et al.*, 2007). These investigations have mainly concentrated on the marginal gap of the full veneer crown.

However, as the demand for conservative tooth treatment increases, there is a greater need for the use of partial ceramic crowns (PCCs)-i.e. more extended ceramic restoration with replacement of one or more cusps (Bindl and Mormann, 2003; Federlin *et al.*, 2004; Reiss and Walther, 2000). In these restorations, in addition to the traditional cusp capping preparation techniques, simplified preparation designs have been recommended (Federlin *et al.*, 2007; Federlin *et al.*, 2004). Because of the efficacy of adhesive luting procedures, it has been suggested that the preparation for partial coverage restoration can be made with less emphasis on retention form (Federlin *et al.*, 2004; Hansen, 2000; van Dijken *et al.*, 2001). In this case the internal gap may also directly influence the longevity since the restoration is supported by adhesive cement of the internal space (Molin *et al.*, 1996; Mou *et al.*, 2002). However, there have been only a few studies on the marginal and internal gaps of these designs. Many clinical long term research report favorable results for Cerec inlays, however, few studies have focused on partial crown designs (Bindl and Mormann, 2003; Hayashi *et al.*, 2003; Martin and Jedynakiewicz, 1999; Molin and Karlsson, 2000; Otto and De Nisco, 2002; Otto and Schneider, 2008; Reiss, 2006; Reiss and Walther, 2000; Sjögren *et al.*, 2004). With regard to the crown designs, there have been reports on direct (USPHS(Akbar et al., 2006), optical microscopy(Kokubo et al., 2005), SEM(Akbar *et al.*, 2006; Federlin *et al.*, 2005)) and indirect (dye penetration(Federlin et al., 2007; Federlin et al., 2004)) methods of investigating the marginal gaps. In addition, to date, the methods used for studying the internal gaps have been measurements of specific sections using luting cement (Bindl and Mormann, 2005; Kokubo et al., 2005), or calculations using the volume and density of silicone materials (Nakamura et al., 2003; Nakamura et al., 2005). More recently, with significant improvements in both the software and hardware of microcomputed tomography (μCT), the three dimensional (3D) structure of small objects can be obtained with high spatial resolution (Plotino *et al.*, 2006; Sun and Lin-Gibson, 2008). The μCT may be used to generate 3D rendering of a structure and investigate the marginal and internal gaps within the range of a few micrometers at multiple sites and directions, in high resolution by rapid, reproducible and non-destructive methods (Kakaboura *et al.*, 2007; Parkinson and Sasov, 2008; Plotino *et al.*, 2006; Sun and Lin-Gibson, 2008).

The purpose of this study was to investigate the effects of different PCC preparation designs on the marginal and internal gaps in Cerec3. In present study, μCT was used to assess the followings: ⅰ) the average internal gap (AIG; total volume of gap/total contact surface area) by investigating the 3D reconstruction,ⅱ) the marginal and internal gaps by the average values of multiple cross sections in the bucco-lingual view and mesio-distal view. The null hypothesis was that no statistically significant differences in the AIG, marginal gaps and internal gaps exist among the three different preparation designs.

II. Materials & Methods

Sixty human first and second molars without any caries or anatomical defects were kept in normal saline. These teeth, which were relatively comparable in size, were randomly allocated into three groups of 20 specimens each. Three different preparation designs were applied to each group: Group I-conventional functional cusp capping/shoulder margin, Group II-horizontal reduction of cusps and Group III-complete reduction of cusps/shoulder margin (Fig. 1-2.). One investigator prepared the teeth. All teeth were prepared according the protocol shown in Fig. 2. The margins were finished with 1.5 mm shoulder preparation using a TF-S 22 (Mani, Japan) tapered flat end diamond bur.

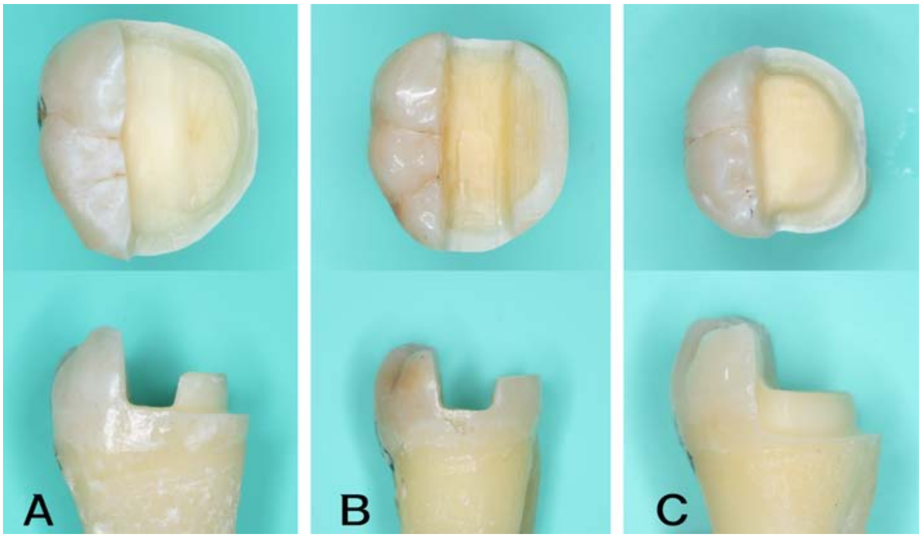

Fig. 1. Different tooth preparations suggested for partial ceramic crown: (A) Group I-conventional functional cusp capping/shoulder margin, (B) Group II-horizontal flat reduction of cusps, (C) Group III-complete reduction of cusps/ shoulder margin.

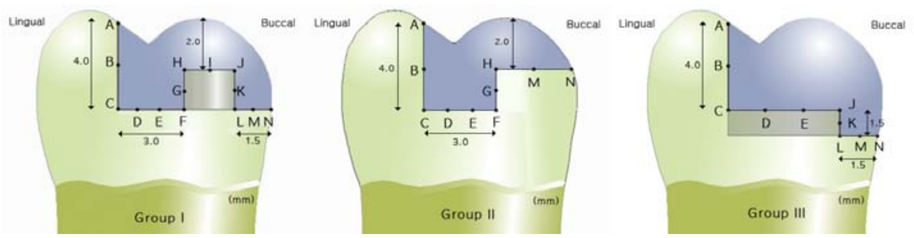

Fig. 2. Schematic drawings of preparations in groups I, II and III, representing bucco-lingual cross sections. Reference points in groups II and III were designated based on reference points in group I.

After completion of all preparations, the surfaces were evenly covered with antireflection powder (Vita Cerec Powder, Patterson Dental Company, St. Paul, MN. USA) to facilitate the scanning process. An optical impression was then taken using the intraoral camera of the Cerec3 system (Sirona Dental Systems, Benshei, Germany). After checking the clarity of the scan, the data was stored using the computer software (CEREC 3D, V3.05, Sirona Dental Systems, Benshei, Germany). The same computer software was used to design each PCC. The luting space and adhesive gap were set at 30 μm. After designing each crown the information was sent to the milling unit, which utilized two step and cylinder pointed diamond burs. The PCCs were fabricated using ProCAD milling blocks (lot number J03292, B3, E300/I12, Ivoclar Vivadent, Liechtenstein). The fabricated PCCs were evaluated for seating on the respective teeth, and utility wax was wrapped around each tooth for fixation. The hardware device used in this study was a desktop μCT scanner (SkyScan 1172, SkyScan, Aartselaar, Belgium). The settings for scanning of the samples were determined by a pilot study. The scanning was performed at 65 kVp, 153 μA and the exposure time of 474 ms per frame using a 0.5 mm aluminum filter. The rotation step (degree) was set at 0.700, and a 360 ° rotation scanning procedure was preformed. The x-ray beam was irradiated perpendicularly to the tooth's long axis. Using the zoom function, the crown portion, 10 mm in height, was focused and scanned. The images were 1024×512 pixels and had a resolution of 15.91 μm. After completion of the scans, the 600-800 slices were reconstructed using the manufacturer's complete imaging software.

1. Measuring the average internal gap

The raw files were converted into bmp files using NRecon software (Skyscan, Aartselaar, Belgium), and CTAn (Skyscan, Aartselaar, Belgium) was used for designing bmp CT files and reconstructing 3D images. The area of the internal gap, between the PCC and tooth, was designated on 600-800 bmp files (Fig. 3). The internal gap was reconstructed 3-dimensionally based on the designated areas. The total volume of the internal gap and the surface in contact with the tooth were obtained using Rapidform2006 (INUS, Seoul, Korea) which can be used in viewing 3D images and measuring their values. The average internal gap was calculated by dividing the total volume of the internal gap by the contact surface.

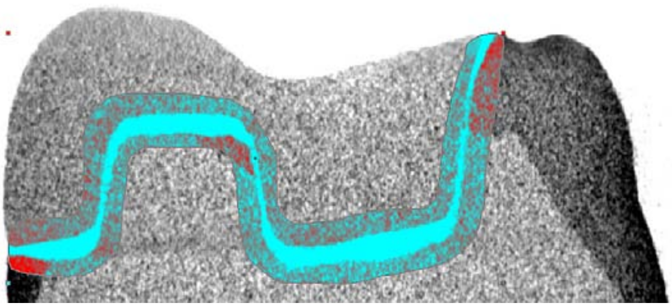

Fig. 3. The designated area for the three dimensional reconstruction of internal gap on a CT file.

2. Measuring the marginal and internal gaps

For each design, the reference points were set at the margin, axial, angle and horizontal areas. The points were labeled in the bucco-lingual and mesio-distal orientation, as shown in Fig. 2, 4-5. From the cross-sections through the center of the tooth (x axis in Fig. 6), additional cross-sections were obtained bilaterally at 1mm intervals for a total of seven bucco-lingual sections. Seven bucco-lingual sides were obtained by cross sections through 2, 3, 4, 5, 6, 7, and 8 of the mesio-distal reference points (Fig. 4). In the mesio-distal side (y axis in Fig. 6), three sections were obtained with D, E and M of the bucco-lingual reference points (Fig. 2) in the same manner. In group I, they were obtained from D, I and M. To maintain a consistent position during these measurements, the pixel level in the X and Y axes were recorded using DataViewer (Skyscan, Aartselaar, Belgium) software. The determined gap sizes were the average values of the bucco-lingual and mesio-distal multisections for each reference point.

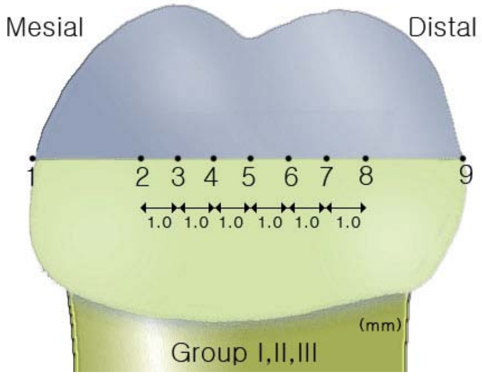

Fig. 4. Schematic drawing of preparations in groups I, II and III, representing mesio-distal cross sections.

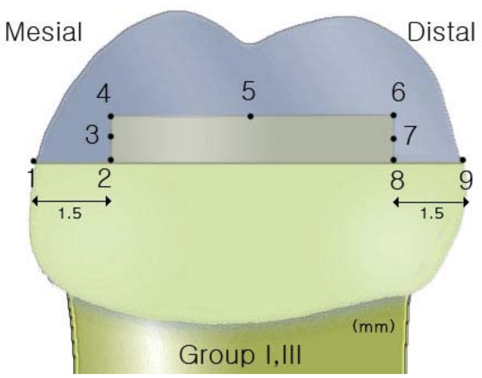

Fig. 5. Schematic drawing of preparations in groups I and III, representing mesio-distal cross sections.

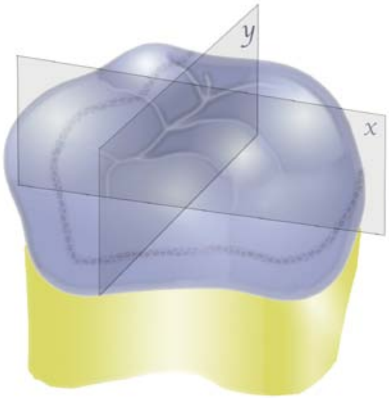

Fig. 6. Cutting planes, x for the bucco-lingual cross section and y for the mesio-distal cross section.

3. Statistical analysis

Statistical analysis of the results was performed using a one-way analysis of variance (ANOVA) to identify significant differences in the AIG among the three groups. For each reference point, a one-way ANOVA was performed to assess the differences among the groups. In addition, a one-way ANOVA was conducted within each group for comparison of the reference points. These analyses were performed separately for the bucco-lingual and mesio-distal sections. A confidence level of 95% was used, and Tukey's test was performed. All statistical analyses were carried ou t using SAS ver.9.1.2 (SAS institute, U.S.A.).

III. Result

The images of the internal gap for each group were reconstructed three dimensionally (Fig. 7). The mean values and standard deviations of the AIG for all groups are listed in Table 1 and shown graphically in Fig. 8. Group I (197.3 ± 48.2 μm) and groups II (171.2 ± 45.1 μm) and III (152.7 ± 27.1 μm) showed statistically significant differences ($p < 0.05$). However, there was no significant difference between group II and III ($p > 0.05$).

Fig. 9 shows the 2D cross sections of each group at the X, Y and Z axes from which the gaps from each reference point were measured. The mean gaps which were obtained from the multiple sections and results of ANOVA, at each measuring point are listed in Tables 2 and 3. The mean marginal gap value from the multiple sections of each reference point (A, N, 1, 9), ranged from 80.7 to 113.2 μm for group I, 45.5 to 128.4 μm for group II, and 35.4 to 78.4 μm for group III. The mean internal gap value from the multiple sections of each reference point (B-M, 2-8), ranged from 116.8 to

406.5 μm for group I, 72.5 to 320.2 μm for group II, and 119.5 to 305.1 μm for group III. The gaps of each group were the smallest at the margins, and the largest on the horizontal or angle walls. Statistical comparison of the mean marginal and internal gaps among the three groups demonstrated significant differences in the bucco-lingual and mesio-distal views ($p < 0.05$). For each group, there were significant differences in the mean values at the margins (A, N), axial walls (B, G, K) and, the angles and horizontal walls (C, D, E, F, H, I, J, L, M) in the bucco-lingual views ($p < 0.05$). In addition, for the mesio-distal views, there were significant differences within each group at the margins (1, 9) and internal reference points (2-8) ($p < 0.05$). Fig. 10 and 11 illustrates the change in the gaps at each reference point in the bucco-lingual and mesio-distal views from Tables 2 and 3.

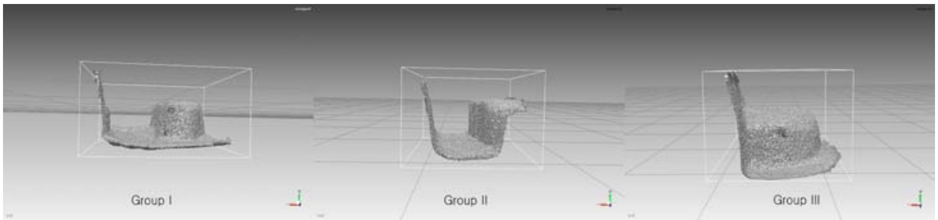

Fig. 7. The three dimensional rendering images of the internal gap for each group.

Table 1 - Measuring the average of internal gap (μm, mean ± S.D.)			
	Group I	Group II	Group III
The Average of Internal Gap	197.3 ± 48.2 a	171.2 ± 45.1 b	152.7 ± 27.1 b
The same letters indicate mean values with no statistically significant differences (p>0.05).			

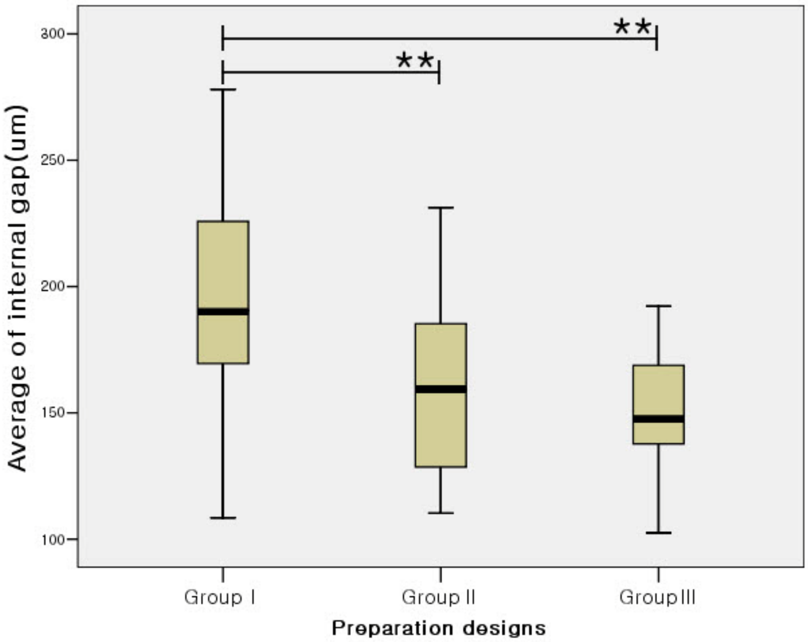

Fig. 8. A box-plot diagram of the average internal gap of partial ceramic crowns from groups I, II, and III. Tukey's test: $^{**}p < 0.05$.

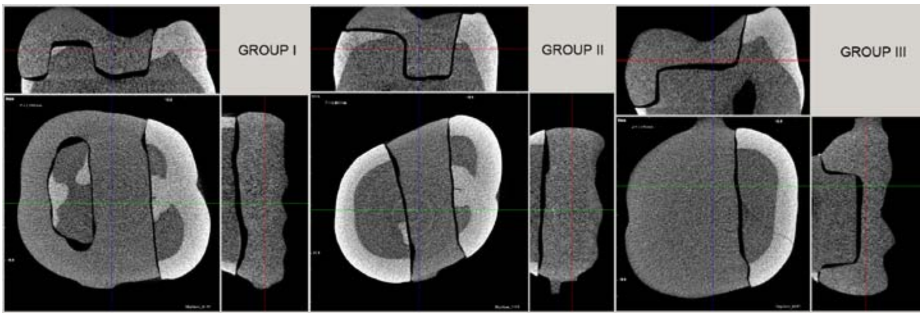

Fig. 9. The two dimensional images from each group for measuring the gap distance.

Table 2 - Marginal and internal gap measurements in the bucco-lingual section (µm, mean ± S.D.)

Points	Group I	Group II	Group III
A	96.8 ± 44.7 a	45.5 ± 37.8 b	78.4 ± 38.9 a
B	116.8 ± 43.1 a	72.9 ± 40.0 b	119.5 ± 51.5 a
C	254.9 ± 41.6 a	212.2 ± 53.1 b	305.1 ± 54.3 c
D	356.3 ± 57.7 a	272.5 ± 59.4 b	299.1 ± 38.8 b
E	391.6 ± 137.3 a	275.5 ± 48.8 b	299.4 ± 43.0 b
F	344.9 ± 79.5 a	288.1 ± 85.7 a	
G	253.5 ± 79.5 a	301.7 ± 192.1 b	
H	252.1 ± 79.1 a	320.2 ± 205.7 b	
I	401.2 ± 92.4		
J	252.1 ± 109.3 a		217.8 ± 44.3 b
K	207.0 ± 119.3 a		178.7 ± 56.0 b
L	257.9 ± 82.1 a		265.1 ± 50.9 b
M	233.4 ± 94.8 ab	258.0 ± 61.1 a	184.5 ± 41.2 b
N	113.2 ± 102.9 a	128.4 ± 69.5 a	54.4 ± 40.4 b
Mean	252.3 ± 98.2	217.5 ± 99.5	200.2 ± 93.4

The same letters indicate mean values with no statistically significant differences among the three groups (p>0.05).

Table 3 - Marginal and internal gap measurements in the mesio-distal section (µm, mean ± S.D.)

Points	Group I	Group II	Group III
1	102.1 ± 43.8 a	72.5 ± 74.5 ab	35.4 ± 32.2 b
2	364.1 ± 164.5 a	268.8 ± 81.1 b	232.5 ± 53.0 b
3	321.0 ± 76.1 a	281.6 ± 71.8 ab	249.7 ± 52.9 b
4	339.6 ± 55.1 a	283.7 ± 65.6 b	257.9 ± 42.0 b
5	339.4 ± 48.6 a	281.8 ± 45.0 b	257.6 ± 40.4 b
6	330.8 ± 64.2 a	280.7 ± 51.1 b	263.2 ± 32.4 b
7	306.7 ± 66.7 a	265.8 ± 43.3 ab	250.5 ± 49.0 b
8	406.5 ± 176.1 a	246.1 ± 53.9 b	252.3 ± 82.5 b
9	80.7 ± 54.3 a	67.6 ± 47.0 a	50.5 ± 46.5 a
Mean	287.9 ± 115.1	227.6 ± 90.1	205.5 ± 92.6

The same letters indicate mean values with no statistically significant differences among the three groups (p>0.05).

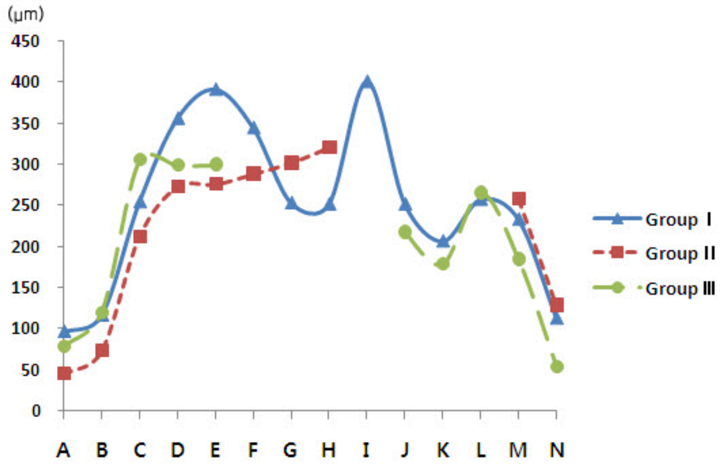

Fig. 10. Change of marginal and internal gaps at the reference points in the bucco-lingual section.

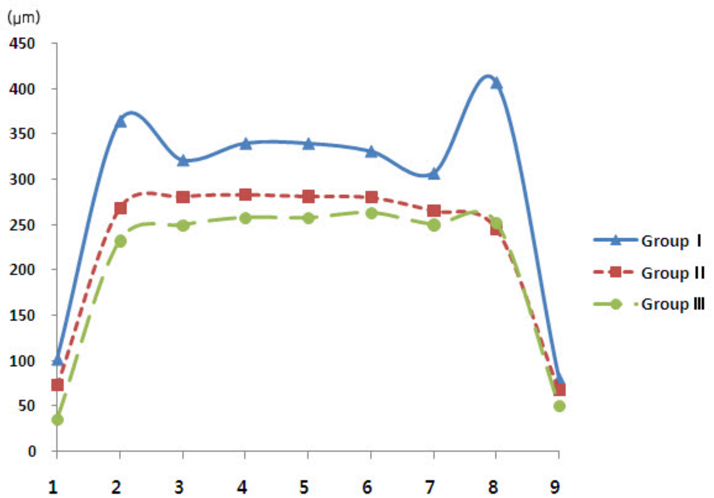

Fig. 11. Change of marginal and internal gaps at the reference points in the mesio-distal section.

IV. Discussion

The μCT method, which was used to evaluate the marginal and internal gaps between the tooth and the PCC in this study, provides an advantage over other methods. The three dimensionally reconstructed image obtained through nondestructive methods allows quantitative analysis and investigation of the internal space, which cannot be visualized (Sun and Lin-Gibson, 2008). In addition, such images allow measurement in any angle or position, and reference values in X, Y, and Z axes can be consistently maintained (Kakaboura et al., 2007). Moreover, the 2D and 3D measurements and analysis may be performed simultaneously, and additional and repeated testing is also possible. Previously, the use of the μCT has been limited by low resolution and a long scanning time. However, recent technological improvements have increased the resolution to nanometers (Parkinson and Sasov, 2008), and the use of this technology in research is expanding. In this study skyscan1172 was used at a resolution of 15.91 μm. The scanning time was about 10 minutes per tooth and this equipment allows a resolution of up to 2 μm.

For μCT, the accuracy and precision are dependent on the experimental design and subsequent image analysis. The selection of appropriate segmentation values is critical in the image analysis. An optical threshold value must be used (Sun and Lin-Gibson, 2008), and we obtained this value according to a pilot study. The μCT cannot be applied in situations where insufficient or inappropriate radiographic contrast exist (Kakaboura et al., 2007; Sun and Lin-Gibson, 2008). Accurate image analyses require sufficient contrast between the cavity and the restoration (Sun and Lin-Gibson, 2008). In this study, the interfacial space was analyzed. However, if a material with similar density to dentin or ceramic was used, it would be difficult to analyze the gap.

For this reason, the study design did not employ any treatment between the dentin and the ceramic to maximize the differences in the density of the dentin, ceramic, and the gap. Consequently, it was more efficient in analyzing the gap. This also excludes the influence of the cement thickness, which depends on the kind of cement, and the variable setting pressure. Fixation using utility wax allowed investigation of the original interface of the restoration through passive fitness. The result of this method was not different from the pilot study in which cyanoacrylate was used. Conventional sectioning techniques have the drawbacks such as movement, artifacts and fracture of the material, while the μCT is more effective for evaluating the marginal and internal gaps of non-bonded restorations.

Through improvements of the Cerec machine, marginal fit has become more acceptable. Internal fit is now the main concern since the 3D optical impression taking of the prepared tooth and the milling accuracy of Cerec may not always be reliable (Hickel et al., 1997; Mou et al., 2002). The AIG results obtained using the 3D reconstruction of μCT rejected the null hypothesis. The traditional cusp capping method (group I) and the new simple designs (groups II and III) showed statistically significant differences. However, there was no significant difference between the two new designs. As shown in Fig. 8, group I showed a greater AIG and standard deviation compared to groups II and III. It was shown that simple designs lead to closely fitting restorations in PCC fabricated by the Cerec3 system. It has been reported that the average internal gap, which is calculated by the weight and density of the silicone material, is 116-162μm for Cerec3 crowns (Nakamura et al., 2003). Our results were larger since it is presumed that PCC designs are more complicated than those of crowns. Although group I requires more effort to prepare, the hardware milling system, using two diamond burs, and the software program seem to be relatively less accurate. Previous studies have been limited by the fact that the internal gap may be evaluated only through certain cross sections (Bindl and Mormann, 2005; Kokubo et al., 2005), and there have been no studies on the internal gap for PCC designs. Therefore, the fact that the total internal gap can be obtained with μCT has significance. The average gap per area obtained through such methods better represents the entire restoration rather than a random portion of it. However, since this is not easy and additional effort is required, there rarely have been such studies. One study reported that the internal gap was obtained using the weight and density of silicone material (Nakamura et al., 2003). However, the results from such methods may be influenced by the variation in finger pressure, flow of the material and the base/catalyst ratio (Kokubo et al., 2005; Nakamura et al., 2003; Nakamura et al., 2005). In this study, using the 3D rendering without additional experiments the shape of the total internal gap was obtained. Both 3D and 2D analysis showed similar results. However, the 3D AIG had relatively smaller values compared to the mean gaps of the 2D reference points. This was probably due to the fact that the 2D reference points included more areas where there were large gaps. In addition, this method is limited by the fact that the x-rays are represented by pixels of diverse density (Kakaboura et al., 2007; Parkinson and Sasov, 2008; Sun and Lin-Gibson, 2008). As a result, the ceramic, gap and the dentin are represented as pixels of various density, therefore the observer may misinterpret the darker gray pixels as gaps upon 2D analysis, thereby increasing the values for the gap size.

The 2D analysis represented in Tables 2 and 3 showed statistically significant difference for each reference point among groups and rejected the null hypothesis. Mostly, group II and III had significantly superior results than group I. Rapid changes of the gaps at the reference points in each group are shown in Fig. 10 and 11. These results demonstrate that for the Cerec3, the margin and the axial walls are the areas where the fabrication is affected the least by preparation designs. The marginal gap was the smallest, but, the internal adaptation was relatively inaccurate in all groups. For a good long term prognosis, the clinically acceptable marginal gap limit is considered to be in the range of 120 μm to 200 μm (Bjorn *et al.*, 1970; McLean and von Fraunhofer, 1971). It was reported that marginal gap of conventionally fabricated all-ceramic crowns is within range of 1-161 μm (Davis, 1988; Schaerer *et al.*, 1988; Sulaiman *et al.*, 1997), Cerec3 crowns were reported to be between 27 and 162 μm (Akbar *et al.*, 2006; Mou *et al.*, 2002; Nakamura *et al.*, 2003; Tsitrou *et al.*, 2007). The marginal gap results of this study were consistent with the results of previous studies, and the gaps were clinically acceptable. In this study, the marginal gap of PCC was measured without luting cement. It has been reported that the marginal gap increased by 13 to 22μm when the crown was luted with cement (Beschnidt and Strub, 1999; Wolfart *et al.*, 2003). Nonetheless, even with the additional gap due to cementation, the results of this study seem to achieve a clinically acceptable marginal gap.

The results of this study suggest that the μCT has enough resolution to measure the internal gaps. The above results showed that there were differences in the internal gaps of the different preparation designs, when using the Cerec 3 system. It has been reported that the internal gap of conventional all ceramic crown is 123-154 μm (Grey *et al.*, 1993) and CAD/CAM crowns fabricated by Cerec3 or Procera are 85-247 μm (Bindl and Mormann, 2005; Kokubo et al., 2005; Mou et al., 2002). However, the mean internal gaps of 2D analysis were considerably larger in the present study. This finding may be attributed to more complex PCC designs and different reference points when compared with all ceramic crowns. In addition, the fact that the gaps were measured from only one cross section in previous studies may also be the cause of such difference (Bindl and Mormann, 2005; Kokubo et al., 2005). At each of the reference points, internal gaps of group II and III were significantly smaller than group I, but the internal gaps of group II and III showed wide variation at a range of 73-320 μm. The gaps of the horizontal and angle reference points were larger towards the center, and those of the axial and margin reference points were smaller. In vivo, the distal shadow problem still remains and may influence the internal fit of Cerec3 especially on the distal surface (Mou et al., 2002). However, it had no effect on this in vitro study. Nevertheless, although Cerec3 has improved impression and milling accuracy, they may cause the large internal gaps on PCCs of relatively complex designs. The internal gaps at horizontal or angle walls were the largest. These areas showed wider differences of the gap sizes among three groups, and they seemed to be more affected by the preparation designs. Interfacial gaps of 200 to 300 μm can be considered acceptable (Hickel et al., 1997; Mou et al., 2002). From the results of our experiment, the internal gaps were not acceptable. Indeed, some reference points of the horizontal and angle walls (C, D, E, F, H, I in Fig. 2) had internal gaps of 300-400 μm, which means that even with an accurate preparation design, the restoration may be too thin in those areas. This may cause additional problems. Longevity may be affected due to polymerization shrinkage during the setting of resin cement (Kakaboura et al., 2007). Because the cement thickness is increased, retention may be decreased (Wiskott *et al.*, 1999). Since the restoration is supported by adhesive cement of the internal space (Molin *et al.*, 1996; Mou *et al.*, 2002), ceramic restoration may fracture in areas where it is too thin (Federlin *et al.*, 2007; Nakamura *et al.*, 2003; Tuntiprawon and Wilson, 1995; Wiskott *et al.*, 1999). Therefore this needs to be considered clinically during tooth preparation, and improvement of accuracy is needed in the Cerec3 system.

In the Cerec3 system, marginal and internal gaps can be affected by the following parameters: the occlusal convergence angle, occlusal-cervical height of the prepared tooth, the computer′s luting space setting and different margin designs (Mou et al., 2002; Nakamura et al., 2003; Nakamura et al., 2005). In a recent study, Nakamura et al. investigated the effects of the occlusal convergence angle and luting space on marginal and internal gaps (Nakamura et al., 2003). It was reported that when the luting space was 30μm, the marginal and internal gaps could attain optimal fit without the influence of occlusal convergence (Nakamura et al., 2003). In an experiment by Mou et al, the internal gaps were not influenced by the convergence angle when the occlusal height was less than 6mm (Mou et al., 2002). Based on these results, the adhesive gap and luting space in this study were set at 30μm, and the convergence angle was maintained at 14%, the taper of TF-S 22 (Mani, Japan) diamond bur. Occlusal height was kept under 6mm in all groups, and because this study was performed in vitro, the distal shadow effect caused by optical impression based on the active triangulation principle could be eliminated. However, previous studies present data from crown designs; therefore, additional research with various changes in parameter settings for PCC designs will have significant meaning. In recent studies, the marginal gaps of Cerec3 crowns showed no statistically significant differences among bevel, chamfer and shoulder margins, although it showed relative lower value for the shoulder margin group (Akbar *et al.*, 2006; Tsitrou *et al.*, 2007). Based on the data from these reports, and in order to provide a similar environment as the horizontal flat design of the new simple design groups, the shoulder margin design was chosen. Minimal finishing and rounding was conducted for accuracy and similarity of the designs within each group.

In spite of the large marginal gap, favorable results have been reported on long term clinical studies of ceramic inlays and onlays (Bindl and Mormann, 2003). According to reports by Kramer and Frankenberger, the 4, 6 and 8 year survival rates of IPS Empress ceramic inlays and onlays were 96, 93 and 92-90% (Frankenberger *et al.*, 2000; Krämer *et al.*, 2006; Krämer and Frankenberger, 2005; Krämer *et al.*, 2008). In a 10 and 18 year long term clinical study by Reiss et al., the survival rates of Cerec1 inlays were reported to be 90 and 84% (Reiss, 2006; Reiss and Walther, 2000). Moreover Otto et al. reported 90 and 89% survival rates for Cerec1 inlays and onlays in a 10 and 17 year study (Otto and De Nisco, 2002; Otto and Schneider, 2008). The main reason for failure of these restorations was ceramic fracture (Frankenberger *et al.*, 2000; Krämer *et al.*, 2006; Krämer and Frankenberger, 2005; Krämer *et al.*, 2008; Martin and Jedynakiewicz, 1999; Molin and Karlsson, 2000; Otto and De Nisco, 2002; Otto and Schneider, 2008; Reiss, 2006; Reiss and Walther, 2000; Sjögren *et al.*, 2004). If small internal gaps can be restored, and made more even, stress distribution will occur more evenly in long term occlusal loading, making it more resistant to fatigue fracture. If dual cured resin composites are applied, rather than chemically cured resin composites to large internal gaps, long term success rates may decline (Sjögren *et al.*, 2004) and decrease of retention may be the result of increased adhesive thickness (Wiskott *et al.*, 1999). Long term clinical success also depends on well controlled adhesive procedures (Frankenberger *et al.*, 2007; Krämer and Frankenberger, 2005; Krämer *et al.*, 2008; Otto and Schneider, 2008; Reiss, 2006). Many dentists prefer simplified procedures and as a result, recently one step luting agents are increasing. However, luting the restoration using these simplified procedures may cause failure in retention or fracture. Therefore, in spite successful long term clinical reports, continuous research on various factors for improved results are needed. Previous studies have focused on inlays, therefore, controlled prospective clinical research on partial crown designs will have significant meaning (Hayashi *et al.*, 2003; Krämer *et al.*, 2006; Martin and Jedynakiewicz, 1999; Molin and Karlsson, 2000; Reiss, 2006; Reiss and Walther, 2000; Sjögren *et al.*, 2004). Research comparing in vitro and in vivo studies, such as Frankenberger′s study (Frankenberger et al., 2007), provides to be a good example. In the clinical studies, it is difficult to evaluate internal gap, however, internal gap can be measured by using a non-destructive μCT method on the impression model before adhesive procedures. Through this method, it will be useful to perform prospective clinical evaluation with already identified internal gaps.

In this study, the average values for multiple sections in the bucco-lingual and mesio-distal views were used for the analysis. This was due to the fact that there were statistically significant differences between the sections of the same reference point. If a single section had been used, it would only reflect a randomly selected section. This could change the experimental results, especially in studies where the results are in the range of μm. As shown in Fig. 10 and 11, as one moves internally from the external margin, the gap distance changes continuously. This also shows that previous studies focusing on the marginal fit of only certain sections have been insufficient in evaluating the restoration fitness. Therefore, in order to minimize the error of using a single section, maximize the advantages of the μCT and to accurately reflect the specimen studied the average values from multiple sections were used. For these reasons, the μCT can be recommended as a new useful method of evaluating the marginal and internal gaps. Despite some of the limitations, the results of this study suggest that the μCT has enough resolution to measure the marginal and internal gap.

The results showed that in the PCC preparation, using the Cerec3 system, the preparation design and internal gap size need to be considered. Since the restoration was not cemented during the study, additional experiments regarding gap changes after cementation and polymerization shrinkage during setting are possible. In addition, since the nondestructive μCT method was used, fracture resistance and leakage testing after cementation, and SEM or microscopic studies after sectioning are possible. Such additional experiments may provide new insights into CAD/CAM preparation designs, and maximize the efficiency of study methods using the μCT.

V. Conclusion

Within the limits of this study, PCCs fabricated using the Cerec3 system showed significant differences in the mean marginal and internal gaps depending on the preparation designs. Simple designs provided superior results when compared to traditional cusp capping design. In all groups, the marginal gaps were smaller than the internal gaps. The gaps of each group were the smallest at the margins, and the largest on the horizontal or angle walls. The μCT used in this study was very efficient for measuring the marginal and internal gaps. Further studies of internal gaps are needed.

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국문요약

Cerec3의 partial ceramic crowns에서 변연 및 내면 간극에 대한 치아 삭제 디자인의 효과

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서 덕 규

이 연구의 목적은 세가지 다른 치아 삭제 디자인에 따라 제작된 Cerec3의 partial ceramic crowns을 미세 전산화 단층 촬영하여 변연 및 내면 간극을 비교 평가하는 것이었다.

Cerec3 partial ceramic crowns의 제작을 위해 다음의 제시된 방법에 따라 각 군당 20개의 시편을 준비 하였다. 제1군-기능 교두를

포함하는 전통적 방식의 교두 capping과 shoulder margin, 제2군-교두를 수평으로 평평하게 삭제하는 단순화된 디자인, 제3군-교두의 완전한 삭제와 shoulder margin을 갖는 단순화된 디자인으로 세 군의 시편을 제작하였다. 비파괴적인 이미지 기술인 미세 전산화 단층 촬영법을 사용하여 15.91㎛의 해상도에서 시적된 시편과 치아 사이의 변연 및 내면 간극을 촬영하였다. 촬영된 600-800장의 bmp파일로부터 시편과 치아 사이 전 부분의 내면 간극을 3차원 입체로 재구성하였다. 이로부터 전체 내면 간극의 총 부피를 측정하였으며, 치아와 접촉되는 부분의 총 면적도 구하였다. 전체 내면 간극의 총 부피를 접촉면의 총 면적으로 나누어 각 시편당 평균 내면 간극을 얻었으며, 이를 one-way ANOVA를 사용하여 세 군 사이의 통계적 유의 차 검정을 하였다. 다음으로 2차원 영상에서 변연 간극과 내면 간극을 측정하기 위해 촬영된 영상을 bucco-lingual방향에서 치아의 중심과 그로부터 1mm간격 양쪽으로 각각 3번씩 총 7개의 단면을 구하였다. 그리고 mesio-distal방향으로는 중심 단면을

포함하여 일정하게 미리 정해진 주요 지점에서 총 3개의 단면을 구하였다. 이렇게 구해진 bucco-lingual과 mesio-distal단면은 미리 정해놓은 marginal, axial, angle, horizontal reference points에서 수복물과 치아 사이의 거리를 측정하여 변연 및 내면 간극을 구하였다. 하나의 시편에서 여러 단면으로부터 구해진 측정치의 평균을 bucco-lingual및 mesio-distal에서 각 지점의 변연 및 내면 간극으로 사용하였다. one-way ANOVA를 사용하여 같은 기준 지점에서 세 그룹 사이의 차이를 분석하였으며, 각 군 안에서 여러 지점 사이의 차이 또한 알아보았다.

3차원의 입체 재구성을 통해 알아본 평균 내면 간극의 평균 및 표준편차는 제1군 197.3 ± 48.2 μm, 제2군 171.2 ± 45.1 μm, 제3군 152.7 ± 27.1 μm로 나타났다. 촬영 영상의 2차원적인 변연 및 내면 간극의 측정에서는 bucco-lingual과 mesio-distal방향 모두에서 수복물 양쪽 끝의 marginal points (35.4 ± 32.2 ~ 128.4 ± 69.5 μm)가 각각의 그룹에서 최소로 나타났다. 내면 간극은 변연 간극에

비해 두 배 전후로 큰 수치를 보였다. 내면 간극의 여러 기준 지점 중 horizontal 또는 angle points (184.5 ± 41.2 ~ 406.5 ± 176.1 ㎛)에서 세 군 모두 가장 큰 값을 나타냈다. 3차원과 2차원을 통한 두 가지 방법 모두에서 변연 및 내면 간극은 세 그룹 사이에 통계학적인 유의차를 나타냈다.

새롭게 제안된 두 가지의 단순화된 디자인은 변연 및 내면 간극에 있어서 전통적인 치아 삭제 디자인보다 우수한 결과를 보였다. Cerec3 시스템을 사용한 partial ceramic crown의 제작에 있어 변연 간극은 임상적 사용에 적합한 수준이었지만 내면 간극은 그렇지 않았다. 또한 미세 전산화 단층 촬영은 본 실험을 통해 변연 및 내면 간극의 연구에 있어서 성공적으로 사용될 수 있음을 보여주었다.

핵심이 되는 말: Cerec3, CAD/CAM, 미세 전산화 단층 촬영, 변연 간극, 내면 간극, 치아 삭제 디자인, partial ceramic crown