Evaluation of marginal and internal integrity of endo-crowns with different cavity depths using two chairside CAD/CAM systems

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D.D.S., M.S.D., Ph.D.)

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감사의 글

2002 년 보존과에 들어와 보존학에 입문한 후 박사를 끝마치기까지 11 년이라는 긴 시간이 지났습니다. 박사 논문을 준비하며 어려운 점도 많았지만, 저는 이 과정을 통해 보존학이 어떤 학문인지 이제야 겨우 알게 되었습니다. 그리고 이 시간은 제 자신의 부족한 부분이 어떤 무엇인지를 깨닫게 해 주는 소중한 시간이었습니다.

실험의 전 과정 동안 지도와 격려로 끝까지 저를 이끌어주시며 많은 것을 깨닫고 느끼게 해 주신 노병덕 교수님께 진심으로 감사드립니다. 또한 논문을 꼼꼼이 살펴주시고 많은 도움을 주신 박성호 교수님과 박정원 교수님, 논문 심사 과정에서 소중한 조언과 가르침을 주신 김광만 교수님, 실험에 대한 다양한 분석 방법을 가르쳐 주신 박영범 교수님께도 감사를 드립니다.

수련의와 스텝으로서의 전 과정 동안 항상 칭찬과 격려를 아끼지 않으시고 많은 가르침을 주신 이찬영 교수님, 이승종 교수님, 김의성 교수님, 정일영 교수님, 신수정 교수님께 감사드립니다. 실험에 많은 도움을 준 서덕규 교수님, 어려울 때마다 큰 도움을 준 이윤 교수님과 1 년 동안 같은 방을 쓰며 통계에 도움을 많이 준 조신연 선생님께도 감사의 마음을 전합니다. 실험을 지원해 주신 서우경 선배님과 회사 관계자들, 실험의 진행 및 연구에 같이 참여하여 팀보다 나은 개인은 없음을 보여 준 연세대학교 치과대학 김지혜, 노지영, 박연정, 강주현 학생들과도 논문의 기쁨을 함께 하고 싶습니다.

언제나 한결 같은 믿음으로 든든한 지원군이 되어주는 사랑하는 가족들에게도 감사의 마음을 전하고 싶습니다. 부족한 저를 묵묵히 지켜봐 주시고 항상 사랑으로 감싸주신 양가 부모님께 감사와 사랑의 마음을 전합니다. 그리고 제가 힘들어도 포기하지 않고 논문을 무사히 마칠 수 있도록, 늘 곁에서 저를 응원하며 저에게 힘이 되어준 사랑하는 부인 김형연과 하나뿐인 소중한 아들 신승표에게도 큰 감사와 기쁨을 전하며 이 논문을 나누고자 합니다.

2013 년 12 월 저자 씀

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ABSTRACT

Evaluation of marginal and internal integrity of endo-crowns with different cavity depths using two chairside CAD/CAM systems

Yooseok Shin D.D.S.,M.S.D

(Directed by Prof. Byoung-Duck Roh, D.D.S.,M.S.D.,Ph.D.)

The purpose of this study was to evaluate marginal and internal integrity of endo-crowns with different cavity depths using two different CAD/CAM systems (CEREC AC and E4D) by comparing micro-computed tomography (micro-CT).

Endo-crowns (n=48) of two different cavity depth (2mm and 4mm) were fabricated in two different CAD/CAM systems (CEREC AC and E4D). The micro-CT scan was taken before and after cementation. For analysis of the marginal and internal gap, reference points were selected in 2-dimensional (2D) views of three bucco-lingual cross sections and three mesio-distal cross sections. Cross sections were examined with a microscope, SEM and ss-OCT. For calculating the total gap volume, the micro-CT sections were reconstructed 3-dimensionally (3D), and changes of volume and surface area were examined. Statistical analysis was performed using two-way ANOVA with bonferroni correction.

Gap thickness increased depending on cavity depth. Gaps on the pulpal floor were largest among other sites. Gaps on the B, L margins were larger than gaps on the M, D margins. Cementation did not show significant differences in total gap thickness. Both chairside CAD/CAM systems showed similar integrities in endo-crown.

Based on the present study, cementation did not increase the dimension of gap between the restoration and cavity wall. Also Cerec AC and E4D in the fabrication of endo-crown fail to show the differences. The gap on the pulpal floor seemed to affect to these results.

Keywords: Endo-crown; CAD/CAM system; Marginal gap; Internal gap; Cavity depth; Cementation; Micro-computed tomography (micro-CT)

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I. Introduction

The ultimate goal of endodontic treatment is achieved by proper restoration of teeth after root canal filling (Chivian, 1984), which enables the recovery of masticatory function and esthetics. Thus, prior to endodontic treatment, the remaining coronal and root structure should be evaluated for feasibility, method and cost of restoration.

Restoring endodontically treated teeth with severely damaged crown has higher possibility of fracture compared to natural vital teeth in biomechanical aspect (Winter and Karl, 2012). The cause for decreased resistance against fracture is known to be due to extensive loss of teeth structure induced by caries or trauma (Trope and Ray, 1992), rather than dehydration of teeth (Huang et al., 1992). Therefore, the longevity of restoration of endodontically treated teeth depends on the amount of remaining teeth structure, the anatomic position of the tooth, occlusal forces on the tooth and the characteristics of restorative material (Dietschi et al., 2007).

Conventional method for restoring endodontically treated teeth used post-and-core followed by crown restoration provided with 1 - 2 mm ferrule effect (Stankiewicz and Wilson, 2002). However, several studies have proved that endodontically treated teeth are in the danger of root fracture, coronal-apical leakage, dislodgment of core/prosthesis, biological width invasion and perforation due to posts (Biacchi and Basting, 2012; Ona et al., 2013; Tinaz et al., 2004). Provided that there is enough remaining tooth structure for adhesion, cementation made the retentive designs non-essential (De Munck et al., 2005).

Pissis introduced endo-crown technique, which was named “mono-block porcelain technique” (Pissis, 1995). Endo-crown is a one-piece restoration used in endodontically treated teeth, developed with the advances in adhesive technique (Bindl and Mormann, 1999). It consists of a crown part and a cavity part inside the pulp chamber. This endo-crown uses the pulpal chamber surface to achieve the stability and retention of the restoration via adhesive procedures using cementation instead of a post and core system. Since then, Bindl and Mormann manufactured endo-crown with CAD/CAD system and evaluated the performance of 208 endo-crowns cemented to premolars and molars (Bindl et al., 2005). These endo-crown restorations in premolar showed higher fracture resistance than the classical crown configuration in maxillary premolars (Bindl and Mormann, 2005; Lin et al., 2010)

Endo-crown gains sufficient retention by adhesion with the wide dentin surface on the pulp cavity and cementation material inside the cavity (Biacchi and Basting, 2012). It is possible to restore endodontically treated teeth without the need of crown lengthening procedure in the short clinical crowns, which could not be restored by post-and-core crowns due to lack of retention. Furthermore, the use of single restoration material contributes in reducing the stress concentration that results from the differences in material property (Lin et al., 2010). Failure in adhesion can also be minimized since the interface exists only between the one-piece restoration and the tooth material (Zarone et al., 2006).

Composite resin, ceramic and gold materials can be used for endo-crown. Among them, ceramic materials can specially offer appropriate strength and aesthetics. Material with high rigidity such as IPS e.max CAD has advantages in enduring occlusal stress. Thus, IPS e.max CAD is reported to be a reliable material for single crown restoration (Fasbinder et al., 2010). Recently, chairside operation using CAD/CAM (Computer Aided Design/Computer Aided Manufacturing) proves to be convenient in simplifying the procedure, minimizing the chair time and providing esthetically excellent ceramic restoration.

CAD/CAM represents automatic designing or manufacturing procedure by utilizing a computer. Dental CAD/CAM is a field of dentistry, which uses CAD/CAM technology to provide a range of dental restorations in conservative and restorative treatment including inlays, onlays, crowns, fixed bridges and removable restorations. Due to recent development in technologies, high-strength ceramic with increased esthetics and safety compared to conventional materials has been developed (Miranda et al., 2013). Since then, the use of CAD/CAM has risen due to its advantages in the ability to process new material, reduce manufacturers' effort and cost, and to easily assess qualities.

CEREC AC (Sirona, Bensheim, Germany) is one of the most well-known systems among dental CAD/CAM systems. It uses optical impression named Cerec AC *bluecam* for capture of prepared tooth with the short capture time. The Cerec AC *Bluecam* allows higher scanning resolution than the former CEREC cameras and has an scanning quality similar to the laboratory-scanners (Mehl et al., 2009). This system needs a thin contrast powder on the surface before the optical impression. However, a drawback is that a powder coating step is essential to keep oral cavity dry prior to the impression procedure. On the other hand, although E4D Sky ™ (D4D, Richardson, Tx, USA) is another complete chairside CAD/CAM system, similar to the CEREC, the E4D system uses a laser scan to capture the dental data. Images are captured when the borders are clear between the margin of prepared teeth and surrounding gingival structures. Its laser scanner is called an intraoral digitizer (IOD) which does not require pre-powdering step. But occasionally an opaquing powder might be necessary to opaque the translucency of the enamel. For a single tooth, generally eight to ten images need to be captured. It needs longer time to collect data for a virtual model than powder coating system but milling can be done at the same time.

According to research on the behavior of endo-crown manufactured by Cerec, under loading, the overall failure rate of endo-crown and classical single crown is similar, although the fracture resistance of the endo-crown is higher than that of the single crown in fatigue fracture testing (Biacchi and Basting, 2012). Finite element analysis revealed low stress values in endo-crowns compared to conventional crowns and endo-crowns are more resistant to stress than crowns with FRC post (Dejak and Mlotkowski, 2013; Lin et al., 2010). Thus, endo-crown is reported to be suitable for restoring endodontically treated teeth in the restorative, esthetic and clinical viewpoints.

However, when the restorations are adhesively fixed to a tooth cavity, these stresses will be affected the margins and they can negatively affect the marginal integrity (Ferracane and Mitchem, 2003). Several clinical problems may arise due to polymerization shrinkage. Microleakage can be induced which allows the inflow of saliva and bacteria. As a result, secondary caries, pathological changes of pulp tissue, loss of restoration due to adhesion failure of dentin-composite resin, etc. can occur (Hashimoto et al., 2003), and clinical symptoms such as masticatory pain can also arise (Eicker, 1986).

The marginal and internal fit of dental restorations, such as inlays and crowns, is crucial for the clinical outcome of dental restorations (Jacobs and Windeler, 1991). For investigating the overall degree of internal gap during the past few decades, marginal and internal fit has been determined using a variety of measuring techniques: dental probe

(Bindl and Mormann, 1999), mid-buccal cut of specimens with a diamond after embedding in acrylic resin (Belser et al., 1985; Bindl and Mormann, 2005; Grenade et al., 2011; Sjogren, 1995), direct measurement with a light microscope (Hickel and Kunzelmann, 1990), or replica technique with polyvinyl-siloxane impression materials (Brawek et al., 2013; Colpani et al., 2013; Kokubo et al., 2005; Nakamura et al., 2003). Most methods of measuring gap were indirect and invasive methods. Recently, Micro-CT was been introduced for non-invasive evaluations of the internal structure of teeth. This provides three-dimensional images of small samples with high resolution. It is used for measuring the amount of shrinkage and marginal and internal gaps in dentistry (Park and Kim, 2013; Rungruanganunt et al., 2010; Seo et al., 2009).

The purpose of this study was to evaluate marginal and internal integrity of endo-crowns with different cavity depths using two different CAD/CAM systems (CEREC AC and E4D) by comparing the micro-computed tomography (micro-CT) images.

II. Material & Methods

This study was approved by the Institutional Review Board of the Yonsei University Dental Hospital, Seoul, Korea. IRB number 12-0153(2-2012-0064)

1. Specimen preparation

Forty eight human mandibular first and second molars were selected and kept in normal saline. Coronal parts of teeth were checked with Quantitative Light-induced Fluorescence-Digital (QLF-D) Biluminator^{TM} (Inspektor Research Systems BV, Amsterdam, The Netherland) and Periapical X-ray images for detections of any dental caries or anatomical defects. Afterwards, twelve specimens were randomly allocated into two groups (2 mm, 4 mm) for two chairside dental CAD/CAM systems (Fig. 1) so that the tooth size distributions of both groups were similar.

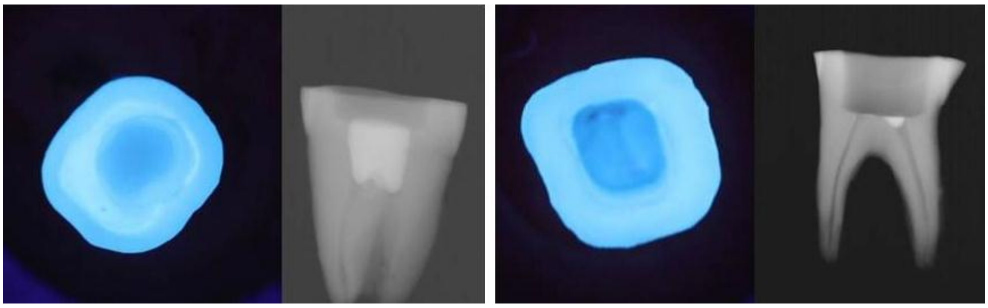

Fig. 1. Quantitative Light-induced Fluorescence-Digital (QLF-D) images and periapical X-ray images, 2 mm (left), 4 mm (right). Every specimen was confirmed that there were no caries or anatomical defects on the coronal portions by QLF-D and Periapical X-ray

2. Endo-crown preparation

Two different preparation designs were applied, and each group was divided as 2 mm and 4 mm sub-groups according to cavity depth. After reduction of the coronal portion, occlusal margin was prepared at 1.5 mm from cementoenamel junction (CEJ). Cavity depth was prepared as either 2 mm or 4 mm (Fig. 2). After preparation, depth was checked with a digital caliper (Mitutory Corp, Kawasaki, Japan) and adjusted to within 0.1 mm precision. The margins were finished with a 1.5 mm shoulder preparation and total occlusal convergence (TOC) was set at an angle of 10 degrees with a tapered flat end diamond bur (845R 016, Diatech, Diamant AG, Heerbrugg, Switzerland). Preparations were finalized after checking a path without interferences. One trained practitioner prepared the teeth by manual method. Orifices and undercuts of mesial and distal canals were protected using a resin adhesive system (One-step™, Bisco Inc, Schaumburg, IL, USA) and cavities were covered with a flowable resin (ÆLITEFLO™, Bisco Inc). All teeth were stored under saline during storage. Prepared teeth were put into the position of a mandibular first molar on a dentiform because occlusal morphologies were intended for a similar form of clinical crown. They were fixed on a 1 mm supragingival margin with utility wax and clearance was checked on the bucco-lingual and mesio-distal sides on the dentiform.

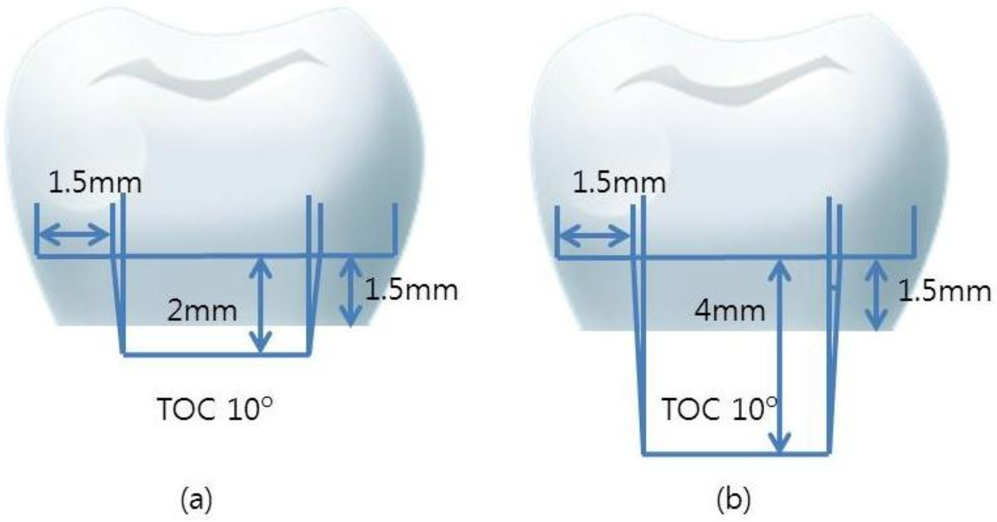

Fig.2. Schematic drawings of endo-crown models with (a) 2 mm, (b) 4 mm cavity depth. Clinical crown margin was set at 1.5 mm from CEJ and the total of convergence (TOC) was set at an angle of 10 degrees

3. CAD/CAM procedures

For the manufacture of endo-crowns, two chairside CAD/CAM systems were used according to the manufacturer’s direction (Table 1). One system was Cerec AC (CEREC AC, V4.2, Sirona Dental Systems, Benshei, Germany) and the other was E4D Sky ™ (E4D Sky ™ software V2.0, Richardson, TX, USA). For Cerec AC group after preparations, a thin contrast powder (Vita Cerec Powder, Patterson Dental Company, St. Paul, MN. USA) was applied on the dry surface before the optical impression. Cerec *bluecam* (Sirona Dental Systems, Benshei, Germany) was used for *a*n optical impression. After obtaining the images, designing of the endo-crown was performed with computer software.

For the E4D Sky ™ group, optical impressions of under of all prepared surfaces were taken under dry conditions. Endo-crown was designed using computer software. The luting space and adhesive gap were set at 30 μm. After designing each crown, the information was sent to the milling unit (E4D milling unit, Richardson, TX, USA) which utilized two step and cylinder pointed diamond burs.

The Endo-crowns were fabricated using lithium disilicate ceramic (IPS e.max CAD; Ivoclar Vivadent, Schaan, Liechtenstein). Ceramic blocks of e.max were different holder of milling machine according to CAD/CAM system, but had the same composition and protocol. e.max blocks were milled first in the bluish grey pre-crystallized metasilicate phase, and then followed by a subsequent crystallization process in Programat P300 (Ivoclar vivadent AG, Schaan, Liechtenstein) furnace under a crystallization temperature of 820~840℃ (Program no.81) to precipitate the crystal.

Table 1. Two chairside CAD/CAM systems, instrument, material, hardware, software

System	Instrument/material	Hardware	Software
Cerec AC	CAD/CAM	Cerec AC - Acquisition unit serial no. 15321 - Milling unit serial no. 124779 Bensheim, Germany	Cerec AC version 4.2 design mode: “replication” Sirona
	Burs/parameters/settings	- Step bur ø 1.0 mm, D64 μm diamond coating, no. 54 66 193 - Pointed bur ø 1.6 mm, D64 μm diamond coating no. 58 55 734	- Margin width parameter set to: 30 μm - Spacer width parameter set to: 100 μm
	Ceramic	Esthetic-ceramic CAD/CAM blocks, IPS e.max CAD; Ivoclar Vivadent, Schaan, Liechtenstein. LotR80247	Standard milling mode
	Grinding agent	Dentatec, Sirona	-
E4D	CAD/CAM	E4D Sky ™ - Acquisition unit serial no. 300325 - Milling unit serial no. 107449 Richardson, Tx, USA.	E4D version 2.0 design mode: “replication” Sirona
	Burs/parameters/settings	- White Tapered bur diamond coating, - Yellow Ellipsoidal bur diamond coating	- Margin width parameter set to: 30 μm - Spacer width parameter set to: 100 μm
	Ceramic	Esthetic-ceramic CAD/CAM blocks, IPS e.max CAD; Ivoclar Vivadent, Schaan, Liechtenstein. Lot R82800	Standard milling mode
	Grinding agent	Milling coolant concentrate, Empowering Dentistry ™	-

4. Micro-CT scanning

The fabricated endo-crowns were placed on each prepared tooth and it was fixed with a parafilm at a just fit state. The desktop micro-CT scanner (SkyScan 1172, SkyScan, Aartselaar, Belgium) was used in this study. The micro-CT settings of the objects were adjusted according to Seo's study (Seo et al., 2009). The X-ray beam was exposed for 474 ms per frame with a 0.5 mm aluminum filter. Electric source was at 65 kVp voltage and 153 μA current. Specimens were rotated 180° with a 0.7°step during X-ray irradiation. The image pixel size was 15.91 μm. Micro-CT scanning was performed twice, before and after cementation. Reconstruction Program (NRecon software, Skyscan, Aartselaar, Belgium) was used for converting raw data into bmp files.

5. Cementation

After the optical impression, each tooth was etched with 37% phosphoric acid. And then an adhesive system was applied and light-cured according to the manufacturer's instructions. For the restoration, the endo-crowns were prepared with 9.5% hydrofluoric acid, a silane agent, and an adhesive agent. The description of the cementation procedure and commercial brand are given in Table 2. This was followed by light curing for a total of three minutes (one minute per surface). After applying the adhesive system, dual-cured resin cement was used at room temperature with finger pressure (10N) on the occlusal surface of the endo-crown. Specimens were kept in saline before and after taking micro-CT.

Table 2. Type of cement, tooth conditioning, ceramic conditioning, and light curing during cementation

Cement type	Tooth conditioning	Ceramic conditioning	Light curing during cementation
Duo link™ dual-cured resin cement (lot 1300003015b)	Uni-Etch™ phosphoric acid$_b$ 30-sec. application, (lot 1000011578) One-step™, (lot 1200000313b) 20-sec. application 20-sec. dry 40-sec. light cured $_a$	Porcelain Etchant™ Ceramics etch 9.5% hydrofluoric acid gel, 2 min. (lot 1300003017$_b$) Bis-silane™, Silane agent, (lot 1300002786$_b$) 60 sec. All-Bond Universal™, light-Cured Adhesive, (lot 1200012015$_b$)	3 x 1 min. occlusal, buccal and lingual side

$_a$ LED light-curing unit 1000 mW/cm2 (Bisco). $_b$ Bisco.

6. Analysis

The area of the marginal and internal gap between the endo-crown and tooth was analyzed with DataViewer (Skyscan) software. Gap thickness was measured on six cross sections. From the cross-sections through the center of the tooth (x, y axis), additional cross-sections were obtained bilaterally at 1 mm intervals for a total of six sections: three bucco-lingual sections and three mesio-distal sections (Fig. 3). Eleven reference points were selected on cross sections in mesio-distal (a, b, c, d, e, f, g, h, i, j, k) and bucco-lingual (A, B, C, D, E, F, G, H, I, J, K) sides. In this study, reference points were set on four sites, such as the cavosurface (a, k, A, K), the line angle (b, j, B, J), the cavity wall (c, i, C, I) and the pulpal floor (d, e, f, g, h, D, E, F, G, H). For margin analysis, marginal points (a, k, A, K) were classified by tooth direction such as the mesial (M), the distal (D), the lingual (L) and the buccal (B).

The total gap volume of endo-crown was calculated using Rapidform2006 (INUS, Seoul, Korea). This program can reconstruct 3-dimensional images and measure the changes in the cavity volume and cavity surface area according to the cavity depth.

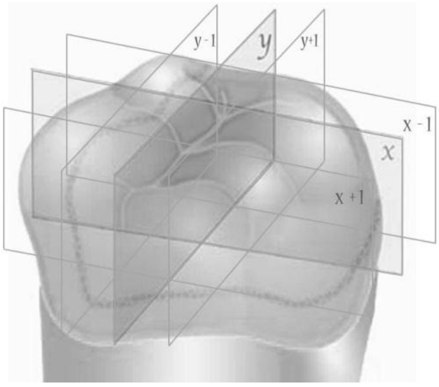

Fig. 3. Cutting planes, x for the bucco-lingual cross section and y for the mesio-distal cross section (x-1 mm, x, x+1 mm, y-1 mm, y, y+1 mm)

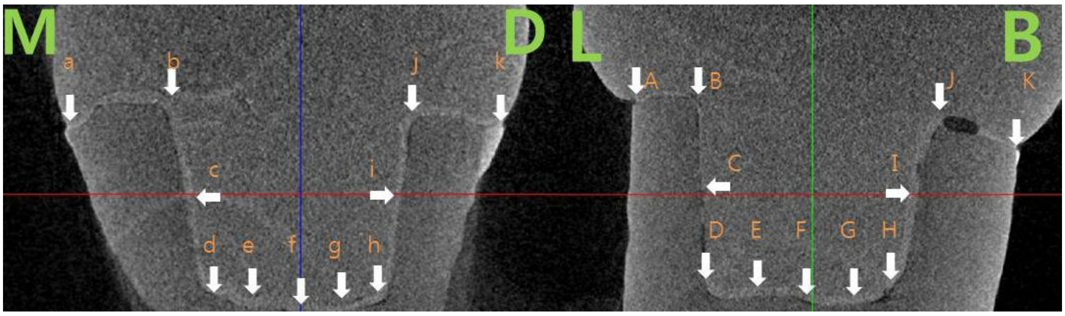

Fig. 4. Eleven reference points on the mesio-distal section (a to k) and the bucco-lingual section (K to A). They were sorted by the cavosurface (a,k,A,K), line angle (b,j,B,J), cavity wall (c, i,C,I) and pulpal floor (d, e, f, g, h, D, E, F, G, H)

7. Scanning electron microscope (SEM) and Swept source - optical coherence tomography (SS-OCT).

Through microscopic examination, specimens which had irregular interfaces were selected. For analysis of cross sections, specimens were cut with a microtome. After gold coating, the preparations were observed under a scanning electron microscope (SEM; ×20 and ×100 magnifications; JEOL JSEM-820, JEOL, Tokyo, Japan). And Swept source OCT (SS-OCT prototype, LG electronics, Korea) was performed. SS-OCT was set at centered wavelength 1310 nm, bandwidth 100 nm, sweep rate 50-kHz.

8. Statistical analysis

Statistical analysis of the results was performed using two-way analysis of variance (ANOVA) to identify significant differences of the gap thickness (μm) according to each cavity depth and two chairside dental CAD/CAM systems after stratified samplings. Two-way analysis of variance (ANOVA) was applied using gap volume (mm^3) in each cavity depth and two chairside dental CAD/CAM systems. Bonferroni tests were used in the post hoc comparisons. A confidence level of 95% was used. All statistical analyses were carried out using SPSS 20 for Windows (SPSS Inc., Chicago, IL, USA).

III. Results

1. Gap analysis before cementation

System and cavity depth were analyzed by 2-way ANOVA after stratifying the population regardless of sites. There were significant differences in gap thickness between cavity depth ($p<0.05$) and there were no differences between systems ($p>0.05$). There was no interaction between cavity depth and systems ($p>0.05$). Site and cavity depth were analyzed by 2-way ANOVA after stratifying the population regardless of systems. There were significant differences in gap thickness between site ($p<0.05$) and cavity depth ($p<0.05$). There was interaction between marginal site and cavity depth ($p<0.05$). Post-hoc test revealed that gap thickness at the pulpal floor were largest compared to other sites ($p<0.05$). Results for gap thickness on different sites are summarized in Table 3.

Table 3. Gap measurements before cementation according to site (㎛, mean ±S.D.)

System	Depth	Site	Gap
Cerec AC	2mm	Cavosurface	137.06 ± 78.23
		Line angle	176.59 ± 111.64
		Cavity wall	214.81 ± 109.37
		Pulpal floor	303.89 ± 125.21
	4mm	Cavosurface	241.21 ± 110.85
		Line angle	186.53 ± 117.09
		Cavity wall	204.90 ± 114.54
		Pulpal floor	331.99 ± 250.57
E4D	2mm	Cavosurface	168.43 ± 89.70
		Line angle	153.05 ± 73.48
		Cavity wall	228.66 ± 108.90
		Pulpal floor	306.18 ± 75.37
	4mm	Cavosurface	198.46 ± 120.62
		Line angle	147.33 ± 72.83
		Cavity wall	173.85 ± 77.01
		Pulpal floor	382.97 ± 94.54

Gaps on the pulpal floor were largest among other sites ($p<0.05$).

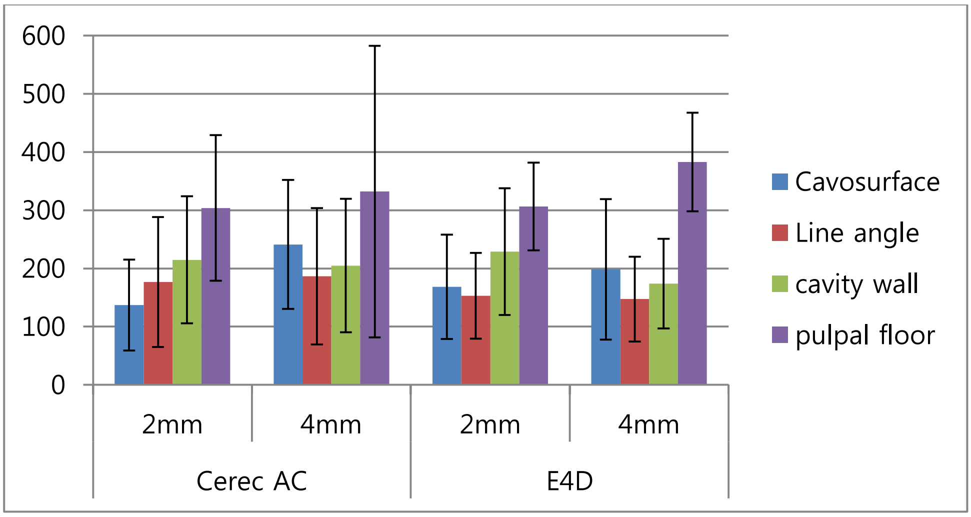

Fig. 5. Gap thickness (㎛) on different sites before cementation

2. Comparison of change before and after cementation

The effects of site and cementation were separately analyzed by 2-way ANOVA in both CAD/CAM systems. There were significant differences in gap thickness among site ($p<0.05$) and there were no differences between before and after cementation ($p>0.05$). There was an interaction between marginal site and cementation ($p<0.05$). Post-hoc test revealed that the pulpal floor sites showed significant differences with other sites ($p<0.05$) before and after cementation. Gap thickness of pulpal floor site significantly decreased in value before and after cementation. The representative dimensional images on two chairside dental CAD/CAM systems were shown in Fig.6 and Fig.7

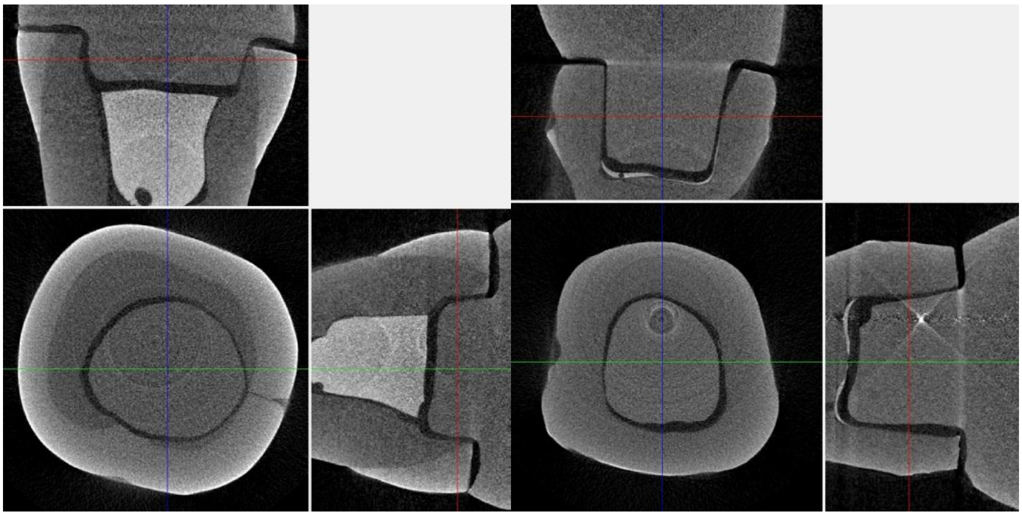

Fig. 6. The two representative dimensional images before cementation pictures on E4D, 2mm. (left) and Cerec, 4mm (right)

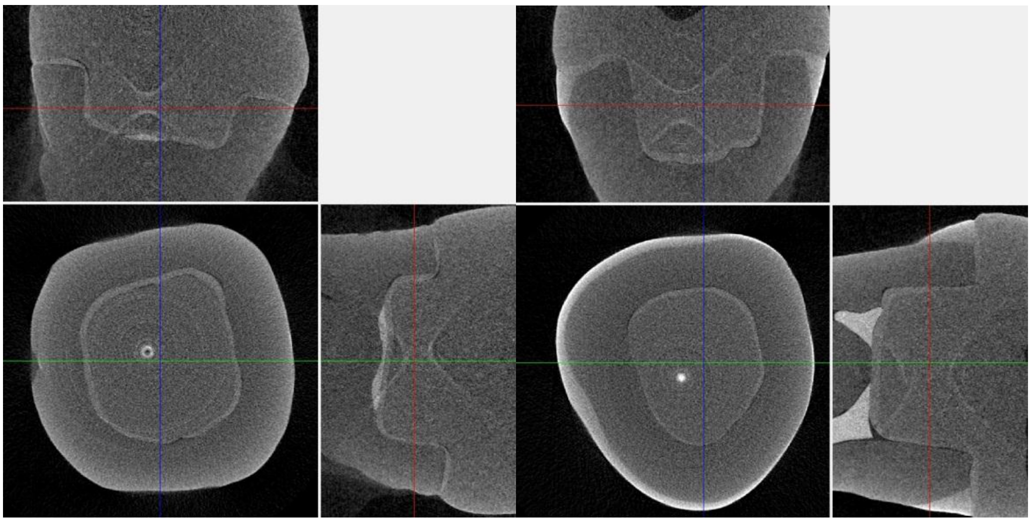

Fig. 7. The two representative dimensional images after cementation pictures on Cerec, 2mm. (left) and E4D, 4mm (right)

3. Gap analysis after cementation

System and cavity depth were analyzed by 2-way ANOVA after stratifying the population regardless of sites. There were significant differences in gap thickness between cavity depths ($p<0.05$) and there were no differences between systems ($p>0.05$). There was an interaction between cavity depths and systems ($p<0.05$).

i. Gap thickness on different sites (cavosurface, line angle, cavity wall, pulpal floor site)

Results for gap thickness on different sites are summarized in Table 4. Site and cavity depth were separately analyzed by 2-way ANOVA after stratifying the population regardless of systems. There were significant differences in gap thickness between sites ($p<0.05$) and there were no differences between cavity depths ($p>0.05$). There was no interaction between marginal site and cavity depth ($p>0.05$). Post-hoc test revealed that length-order was as the following: Pulpal floor ($p<0.05$) > cavity wall > cavosurface > line angle.

Table 4. Gap measurements after cementation according to site (㎛, mean ±S.D.)

System	Depth	Site	Gap
Cerec AC	2mm	Cavosurface	212.76 ± 90.69
		Line angle	185.49 ± 70.35
		Cavity wall	232.48 ± 93.71
		Pulpal floor	298.75 ± 98.93
	4mm	Cavosurface	201.85 ± 93.14
		Line angle	185.92 ± 81.86
		Cavity wall	202.49 ± 117.50
		Pulpal floor	279.58 ± 118.74
E4D	2mm	Cavosurface	185.89 ± 68.32
		Line angle	155.94 ± 75.87
		Cavity wall	209.41 ± 78.29
		Pulpal floor	281.23 ± 90.30
	4mm	Cavosurface	197.74 ± 66.85
		Line angle	199.68 ± 95.96
		Cavity wall	186.72 ± 76.00
		Pulpal floor	363.34 ± 89.91

Gaps on the pulpal floor were largest among other sites ($p<0.05$).

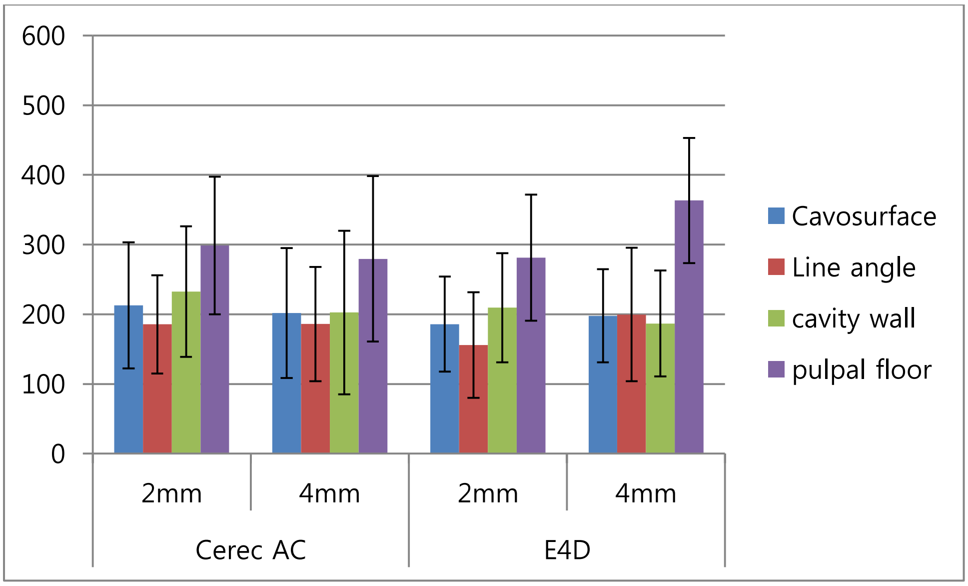

Fig. 8. Gap thickness (㎛) on different sites after cementation. There were significant differences in cavity depth and site ($p<0.05$) but no differences between Cerec AC and E4D

ii. Differences of gap thickness on marginal site

Results for gap thickness on marginal site are summarized in Table 4. The effects of marginal site and cavity depth were separately analyzed by 2-way ANOVA regardless of systems. There were significant differences in gap thickness between marginal sites ($p<0.05$) and there were no differences between cavity depths ($p>0.05$). There was no interaction between marginal site and cavity depth ($p>0.05$).

In E4D system, the buccal site showed significant differences from the mesial and distal sites. In Cerec AC system, the buccal site showed significant differences with the mesial site (Fig. 9). When marginal sites were combined, the B, L margins, showed significantly larger values than the M, D margins in both systems ($p<0.05$) (Fig.10).

Table 5. Gap measurements after cementation according to marginal site (㎛, mean ±S.D.)

System	Depth	Site	Gap
Cerec AC	2mm	Buccal	248.26 ± 93.37
		Lingual	203.70 ± 95.94
		Mesial	189.15 ± 71.66
		Distal	217.48 ± 97.03
	4mm	Buccal	228.11 ± 117.02
		Lingual	212.86 ± 109.85
		Mesial	191.86 ± 86.65
		Distal	186.99 ± 64.61
E4D	2mm	Buccal	211.34 ± 88.20
		Lingual	217.46 ± 77.15
		Mesial	164.19 ± 48.04
		Distal	166.87 ± 47.64
	4mm	Buccal	219.62 ± 73.22
		Lingual	199.24 ± 63.84
		Mesial	188.25 ± 66.80
		Distal	190.52 ± 47.64

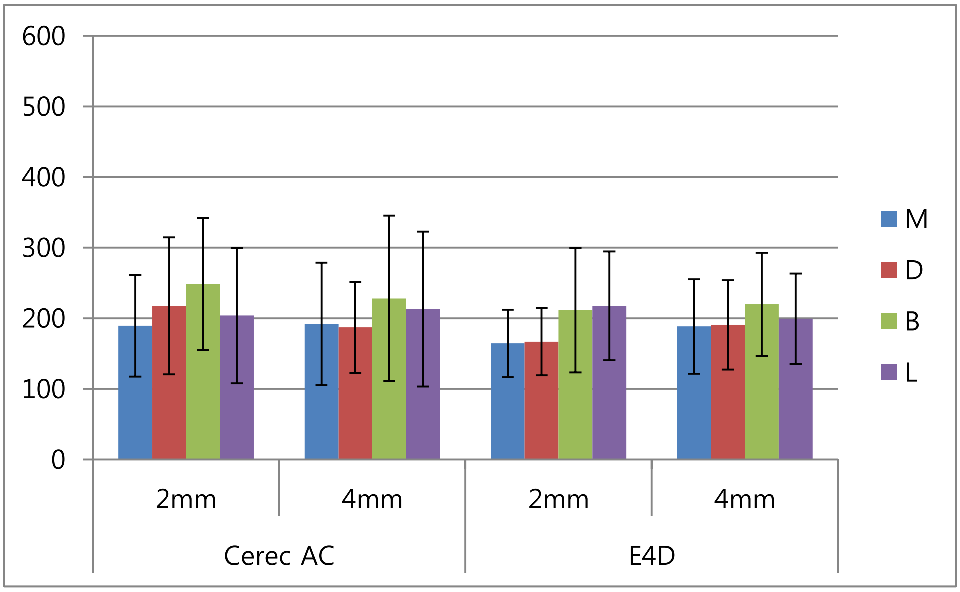

Fig. 9. Gap thickness (㎛) on each margin after cementation. There were no differences in system and cavity depth

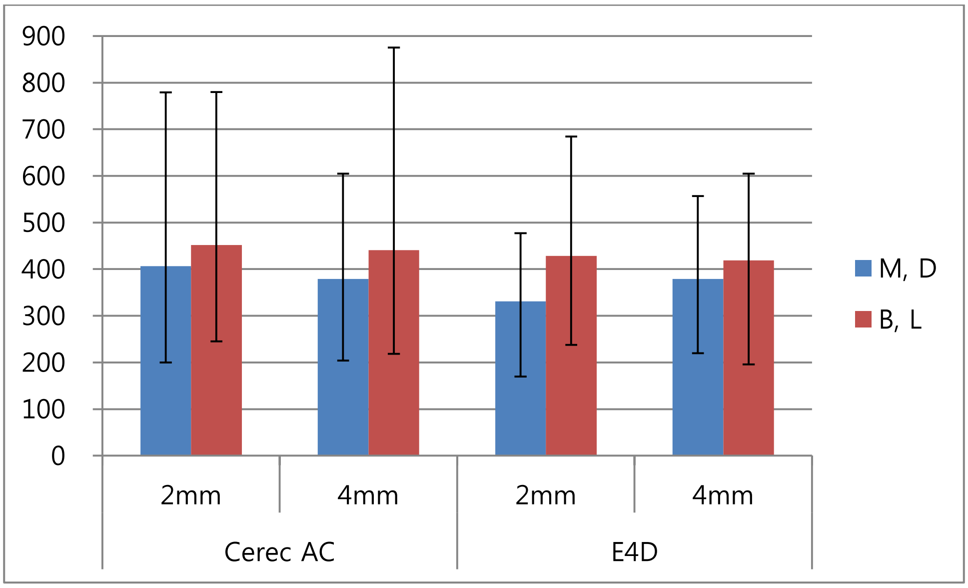

Fig. 10. Gap thickness (㎛) on combined margins (M, D and B, L) B,L showed differences with M,D margins in both systems ($p<0.05$)

4. Three dimensional analysis

i. Gap volume

Results for gap volume are summarized in Table 5. On the mean gap volume according to cavity depth and systems, 2-way ANOVA analysis showed no differences between Cerec AC and E4D systems (*p>0.05*), but there was significant difference in gap volume according to cavity depth (*p<0.05*).

Table 6. Gap volume in 3D analysis (mm^3 mean ±S.D.)

System	Cavity depth	Gap volume
Cerec AC	2mm	$22.57 \pm 5.47_a$
	4mm	$29.77 \pm 4.29_b$
E4D	2mm	$24.56 \pm 4.80_a$
	4mm	$28.42 \pm 4.80_b$

The same letters indicate mean values with no statistically significant differences ($p > 0.05$).

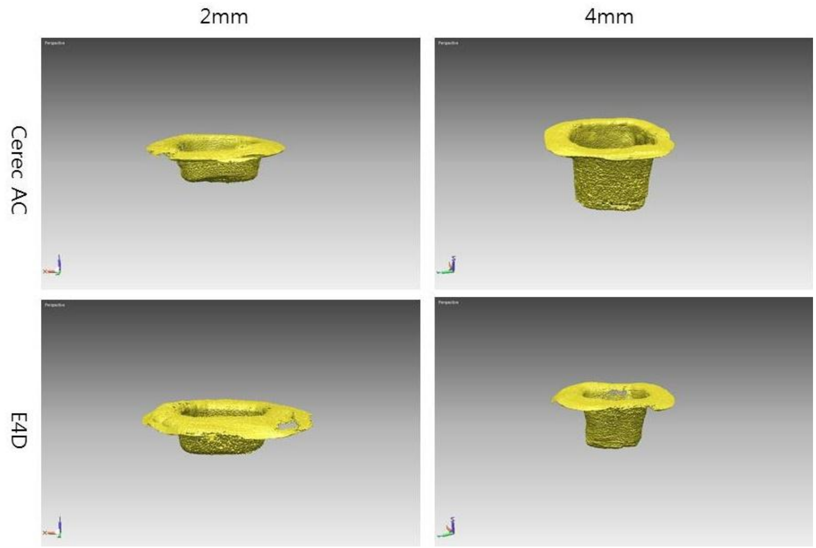

Fig. 11. The designated area for the three dimensional reconstruction of gap volume on a CT file

ii. Cavity volume and cavity surface area according to cavity depth

Results for cavity volume and cavity surface are summarized in Table 7. The cavity volume and the cavity surface area were 1.62 times and 1.23 times higher, respectively, in the 4mm group compared to the 2mm group.

Table 7. Cavity volume and cavity surface area measurements in 3D analysis

Cavity depth	Cavity volume (mm^3 mean ±S.D.).	Cavity surface area (mm^2 mean ± S.D.).
2mm	49.03 ± 8.49	92.78 ± 18.04
4mm	79.36 ± 14.53	113.93 ± 21.16

5. SEM and ss-OCT observations

On the cross section of the endo-crown specimen, homogenous resin cement was shown. But some of SEM images showed irregular surface and voids on the endo-crown - tooth interface. Small voids could be examined on ss-OCT images.

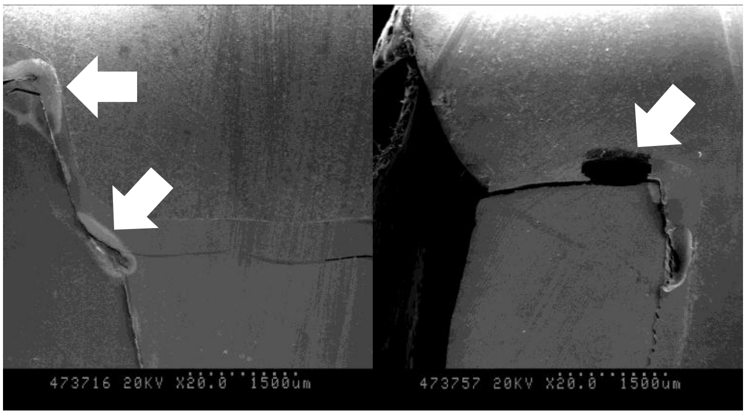

Fig. 12. Scanning electron micrograph of cross section in endo-crown (magnification: × 20). Arrow indicates irregular surface (left) and a void (right) on the endo-crown - tooth interface

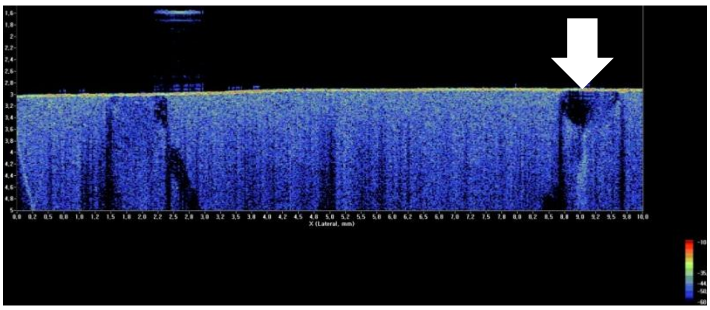

Fig. 13. Optical coherence tomography of cross section in endo-crown. Arrow indicates a small void on the endo-crown - tooth interface

IV. Discussion

With the development of CAD/CAM technology, endo-crown allowed complex restorative procedures to become a simpler process. The integration of CAD/CAM technology and endo-crown made a chairside restorative procedure with reduced chair time a possibility.

Digital impression has reported to be as accurate as the convention method (Tidehag et al., 2013). In this study, the precision of endo-crowns was analyzed when manufactured in actual teeth using CAD/CAM systems. The endo-crown models were scanned using the Cerec AC blue cam and E4D IntraOral Digitizer Wand (IOD) to capture the image of the preparation.

The more accurate the preparation scanning is guaranteed, the more precise the restoration can be made (Galhano et al., 2012). But for CAD/CAM work, a learning curve which is time and patience needed for a new user to gain a predictable level of competence should be allowed (Birnbaum and Aaronson, 2008). Good optical scanning requires proper placement and movement of scanner, and a sufficient number of scans to ensure adequate digitalization of the restoration site.

In this study, the operator achieved an acceptable optical impression after making 20-30 preliminary restorations on each CAD/CAM system. On comparing the scanning time, CEREC AC Bluecam was able to obtain acceptable results of one quadrant within one minute because Cerec AC needed only two images for CAD. But E4D IOD needed more time to capture images on automatic mode because E4D needed overlapped images for the next scan.

Cerec AC system needs a nonreflective surface for precise scanning. Because the contrast powder has to be thin and homogeneous to avoid distortions in scanning, it was not an easy work. Although the powder was carefully applied, it could be one of affecting factors for increasing the marginal and internal gaps.

Endo-crowns fabricated using CAD/CAM were chosen in mandibular molars because previous studies showed that molars had higher success rates, comparable to conventional methods, than premolars (Bindl et al., 2005). To select teeth with sound coronal portions, Quantitative Light-induced Fluorescence (QLF) and periapical X-ray were used. QLF device (Inspektor Research Systems BV, Amsterdam, The Netherlands) was used as it can detect subtle changes in plaque, which cannot be detected with a naked eye (Lee et al., 2013).

In order to reproduce a true clinical situation, root canal treatment should be done before endo-crown fabrication. However, in the present study, related factors were eliminated as much as possible by using a flowable resin base.

In the dentiform, the right mandibular first molar was removed to simulate the clinical situation as much as possible, and the prepared natural teeth were positioned on the removed mandibular first molar site. They were placed at 1.5mm above the cemento-enamel junction. The occlusal clearance was set at 3-4mm to allow for ceramic thickness because fracture load values of ceramics were influenced by thickness (Bindl et al., 2006).

In terms of cavity depth, 2mm group represented teeth with severe attrition on crown portion, while 4mm group represented teeth with sound coronal structure and deep cavity depth. The changes in cavity volume, cavity surface area, marginal and internal integrity were analyzed according to the changes in cavity depth. The volume and surface area increased 1. 62 times and 1.23 times respectively in the 4mm group compared to the 2mm group. These changes influenced the margins and internal integrity and led to the significant increase in the gap thickness and total volume.

Although both of the shoulder and chamfer margin have a strong fracture resistance during biting (Jalalian and Aletaha, 2011), shoulder margin is more suitable for ceramic blocks of CAD/CAM. In this study, shoulder margin design was used for the endo-crown.

Resin cement has good effects in ceramic restorations. Adhesive restorations can reduce the penetration of micro-organisms and resin cementation gives a reliable clinical retention of restorations. The procedure of resin cementation is especially important in endo-crown because the retention forms of endo-crown does not provide enough macro mechanical retention, as would be required for conventionally placed crowns (Kent et al., 1988).

In this experiment, all the tooth specimens and crowns were pre-treated as shown in table 2 before the cementation procedure. All efforts were made to uniformly apply the adhesives, but according to the micro-CT analysis, radiolucent spots were found. When the cross sections were analyzed using SEM and ss-OCT, large radiolucent spots were seen as voids, and small spots represented areas where the adhesives were applied in a thicker layer. However, one disadvantage of SEM analysis was that the specimens were dehydrated and separations within the tooth along crack interface occurred during direct observation. These needed to be differentiated. OCT allowed for observation of void or adhesives on the internal surfaces, but generalized surface analysis was impossible.

In future experiments, if self-adhesives cements are used without the separate adhesive layer, the effect of cement can be analyzed. In addition, if cements containing higher radiopaque filler content were used, 2D analysis would have been more feasible.

The main concern around CAD/CAM restorations is the marginal and internal gaps on clinical adaptation. The initial CAD/CAM restorations had poor adaptation with gaps greater than 270 μm (Samet et al., 1995). But more recently marginal fit has become more clinically acceptable (Ender and Mehl, 2011; Lee et al., 2008; Nakamura et al., 2003).

There is no one absolutely accurate method to measure the gap. In this study, non-invasive micro-CT was used to determine the gap volume and thickness before and after resin cementation in endo-crown models. Ultra-high-resolution micro-CT has become a popular instrument for analysis of internal adaptation on polymerization shrinkage, (Park and Kim, 2013), CAD/CAM crown (Rungruanganunt et al., 2010) and Cerec 3 Partial ceramic crowns (Seo et al., 2009).

For analysis on before cementation state, endo-crown restorations were fixed on a passive fit state. Parafilm was used for preventing separation between the tooth and the restoration. This method was easy and effective for fixation. It provided stronger retention than other methods like utility wax. But Parafilm’s method also cannot exclude the influence of loading during setting.

Most studies have used micro-CT for analyzing the marginal and internal gaps before cementation because the difference of radiographic contrast was not large between the dentin and the cement (Seo et al., 2009; Sun and Lin-Gibson, 2008). But in this study, Micro-CT was also applied for detection of the marginal and internal gaps after cementation. As shown in Fig. 6, 7 cement spaces were detectable with a naked eye. Measuring the cement space after cementation was difficult and 3D analysis of gap volume was impossible because the computer software could not automatically distinguish between the real cement space and the restoration. In this study, the analysis was done manually, and since the gaps after cementation reflect the clinical situation more closely, the results of this study are more meaningful clinically.

One of the limitations of this study is that during Micro-CT scanning, a zig was not used for horizontal and vertical fixation. If a zig was used, images before and after cementation could be superimposed, and it would have been possible to evaluate the changes of gap thickness and volume.

The clinically acceptable range of marginal discrepancy is less than 120 ㎛ in terms of longevity of the restoration (McLean and von Fraunhofer, 1971). But the ranges of marginal fit before cementation on CAD/CAM restorations were 85-247 ㎛ (Bindl and Mormann, 2005; Kokubo et al., 2005; Mou et al., 2002).

In this study, the range of marginal gaps before cementation were 137-241 ㎛ regardless of the CAD/CAM systems. Distances of measuring vertical marginal gaps in various types of cavosurface were measured between the outermost part of the crown margin and the outside shoulder corner according to the Nakamura's method (Nakamura et al., 2003).

These results are similar to previous studies. Similar trends were seen in the study by Seo et al (Seo et al., 2009), which used the same method, and in other studies the internal gap, especially at pulpal floor site, was similar ranging from 200 to 300 ㎛ (Hickel et al., 1997; Mou et al., 2002). This is probably due to the difference in measuring methods of marginal gaps.

In terms of experimental method, since each endo-crown specimen was analyzed in 3 vertical planes and 3 horizontal planes, there were many measurements for each specimen, and generalized analysis on marginal and internal gaps were possible. For more detailed analysis, gap thickness at margin sites and internal sites were measured.

When compared according to sites, while there was not any statistical difference between systems, the difference was the lowest at line angle sites, and, the difference at pulpal floor site was significantly larger than other sites ($p<0.05$). This is consistent with the results of Seo et al. (Seo et al., 2009) . This may be due to the fact that areas farther from the scanner is less accurate or the software may be designed by the CAD/CAM company to eliminate undercuts, which may interfere with restoration setting. The 4mm, Cerec AC group showed the largest gap. Since Cerec AC bluecam was taken in a relatively short time, the error may have increased as the cavity depth increased in Cerec AC due to the small amount of data.

When comparing before and after resin cementation, generally there is a gap increase after cementation (Beschnidt and Strub, 1999; Wolfart et al., 2003), Vertical marginal discrepancy of ceramic crowns had differences of almost two times before and after cementation (Quintas et al., 2004). But in this study the gap decreased or didn’t change.

It is important to note that gap thickness of pulpal floor site significantly decreased after cementation in all systems. This is clinically significant. First, this may be due to the fact that horizontal sites were affected by the stress on the crown by polymerization shrinkage during resin cementation. This is consistent with the study of Kakaboura et al. which reported that composite resin shrinkage affected the internal gap (Kakaboura et al., 2007). Second, this may been due to the fact loading was not applied before cementation. Third, since the gap thickness at horizontal site may have decreased and the gap thickness at the marginal gap decreased, there may have been a minute distortion of the restoration itself. The gap on the pulpal floor seemed to affect results of this study.

When comparing differences of gap thickness on marginal sites, there were significant differences in gap thickness between marginal sites regardless of systems and cavity depth. Except for the E4D 2mm group, the buccal margin showed the largest gap. Since buccal marginal gaps of greater than 200 ㎛ can be detected clinically, efforts should be made to reduce this. When comparing the proximal marginal with adjacent teeth and buccal and lingual margins without adjacent teeth, the margins with adjacent teeth showed significantly less gaps.

Optical impression has limitation on distal side at a specific angle due to access direction of scanner. It is called the distal shadow phenomenon which creates a shadow distally to the scanned object (Mou et al., 2002). This shadow on tooth preparation increases when the clinical crown length of the prepared tooth is increased. However, in endo-crown, the tooth structure is positioned in reverse, and this shadow only appears in the mesial cavity surface. Theoretically, this may cause a mesial shadow phenomenon. But in this study, the mesial gap was similar to the distal gap without statistic differences regardless of Cerec AC and E4D systems. This suggests that this phenomenon did not affect the margin even with 4mm cavity depth. In the two CAD/CAM systems there was a significant difference in gap volume according to cavity depth. This gap volume was calculated by computer software, and it can be used only when there is a very large radiographic contrast. As a result, it could be applied only before cementation. Same method after cementation was tried but it could not give an exact distinction between cement and restoration. Using the same method, the cement void after cementation was measured, and the void formed when loading was applied during cementation could be obtained.

In this study, using a natural tooth, marginal and internal gaps before and after cementation of endo-crowns fabricated with CAD/CAM systems were analyzed. However, whether these marginal gaps and internal gaps are clinically acceptable is still questionable. Thus in future studies, in order to accurately simulate clinical situations, thermocycling and fracture resistance analysis are necessary. In addition, although there was not any statistically difference in the two CAD/CAM systems, but further investigation using different restoration designs are needed.

V. Conclusion

In this study, using a natural tooth, marginal and internal gaps before and after cementation of endo-crowns fabricated with chairside CAD/CAM systems were analyzed.

1. 4mm cavity showed the larger marginal and internal gap than 2mm cavity ($p<0.05$).
2. Gaps on the pulpal floor were largest among other sites ($p<0.05$). Gaps on the B, L margins showed larger than gaps on the M, D margins ($p<0.05$).
3. There were no significant differences in total gap thickness before and after cementation ($p>0.05$).
4. Both chairside CAD/CAM systems showed similar integrities in endo-crown.

Based on the present study, cementation did not increase the dimension of gap between the restoration and cavity wall. Also Cerec AC and E4D in the fabrication of endo-crown fail to show the differences. The gap on the pulpal floor seemed to affect to these results.

VI. References

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국문요약

두 개의 chairside CAD/CAM 시스템을 이용하여

다른 와동 깊이를 가진 endo-crown의 변연 및 내면 접합성의 평가

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신 유 석

이 연구의 목적은 두 개의 치과용 CAD/CAM 시스템들 (CEREC AC와 E4D)을 이용하여 다른 와동 깊이를 가진 Endo-crown의 변연 및 내면 접합성을 미세 전산화 단층 촬영법을 이용하여 평가하는 것이었다.

Endo-crown을 위해 치관부에 치아우식증이나 결손이 없는 48개의 하악 제1,2 대구치가 선정되었다. 각각 2mm, 4mm의 와동 깊이로 두 개의 다른 CAD/CAM systems (CEREC AC와 E4D)를 이용하여 제작되었다. 비파괴 검사인 미세 전산화 단층 촬영술이 크라운의 접착 전후에 시행되었다. 변연 및 내면의 적합성을 분석하기 위해 전체를 협설측 3개, 근원심측 3개의 단면으로 나누었으며, 재구성된 2차원 평면에서 11개의 참조점들이 선정되었다. 이 참조점들은 부위별과 변연 위치별로 나누어 분석되었다. 실제와 비교하기 위해 수복물과 자연치의 단면을 형성한 후 현미경, 주사전자현미경, ss-OCT을

이용하여 다시 관찰하였다. 총 공간 부피를 측정하기 위해 미세전산화 단층면들이 3차원적으로 재구성되었으며, 시스템과 와동 깊이간의 차이를 분석하였다. 통계 분석은 95% 신뢰수준의 two-way ANOVA과 사후 분석으로 bonferroni test을 이용하였다.

분석결과 와동 깊이가 깊을수록 변연 및 내면의 간극 두께는 커졌다. 부위별 차이와 변연 별 차이가 적합성에 영향을 주었는데 치수저의 간극이 다른 간극들보다 통계적으로 유의차 있게 컸고, 협설 변연이 근원심 변연과 유의차가 있었다. 접착 전후 의 간극 비교시 간극 두께 간에 차이가 나타나지 않았다. 전체적으로 평가 시 간극 두께와 부피에서 Chairside CAD/CAM 시스템들은 특별한 차이를 보이지 않았다.

이번 연구를 토대로 치수저의 큰 간극이 변연 및 내면의 접합성에 영향을 주었고, 이로 인해 접착에 의한 차이와 두 개의 Chairside CAD/CAM 시스템들간의 차이가 나타나지 않았던 것으로 추정할 수 있다.

핵심이 되는 말: Endo-crown, CAD/CAM 시스템, 변연 간극, 내면 간극, 와동 깊이, 접착, 미세 전산화 단층 촬영