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Accuracy evaluation of CBCT scanning based digital model for interim crown fabrication

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Directed by Professor Sang-Sun Han, D.D.S., Ph.D.

The Doctoral Dissertation submitted to the Department of Dentistry, and the Graduate School of Yonsei University in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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February 2018

감사의 글

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존경하는 여러 선생님들과 함께 공부할 수 있던 최근의 시간은 그 어느 때보다 감사하는 마음으로 보낸 시간들이었습니다. 공부를 시작할 때에는 논문만 작성하고 나면 모두 끝나는 것이라고 생각했던 것도 사실입니다. 하지만 오랜 공부를 마치고 모든 과정을 마무리하는 지금에 오니 이제부터가 진짜 시작이라는, 너무도 상투적인 말이 진리임을 깨달습니다.

그동안 어려운 일도 많았지만 주변 여러분들의 도움을 받아 무사히 공부를 마칠 수 있었습니다. 그리고 이 논문을 위해 도움을 주신 분들을 일일이 찾아뵙고 인사를 드려야 하나, 이런 인사말로 대신함을 송구하게 생각합니다.

부족한 저를 지도해주신 한상선 과장님께 무한한 감사를 드립니다. 뒤에서 물심양면으로 도움을 주신 이정희, 김영현 박사과정 선생님, 나지연 수련의 선생님께도 진심으로 감사드립니다. 제가 공부하는 동안 각자의 자리에서 책임감을 가지고 최선의 노력을 보여준 병원 식구들에게도 감사의 인사를 전합니다. 그리고 그 누구보다도, 부족한 남편을 믿고 사랑해주는 저의 아내와 세상 무엇보다도 소중한 두 아이 준석과 민솔에게 함께 생활하며 어제보다 오늘 더 사랑할 수 있어 감사하다고 말하겠습니다.

2017 년 12 월 박재형

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Abstract

Accuracy evaluation of CBCT scanning based digital model for interim crown fabrication

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Objectives: The purpose of this study was to evaluate the accuracy of digital model obtained from cone-beam computed tomography (CBCT) data of rubber impression for fabricating interim crown using a 3-dimensional (3D) printer.

Materials and Methods: Rubber impressions were taken from 16 single prepared teeth of 16 patients. Each impression was scanned using CBCT with special image acquisition mode of a 90×50 mm^2 field of view and 100 μm voxel and scanning data were converted to positive stereolithography (STL) files with customized software. The fabricated plaster model was scanned with an intraoral optical scanner and the surface accuracy was compared with the STL data obtained using CBCT. Interim crowns were designed and then were printed with photopolymer using a digital light processing 3D printer. For analysis of accuracy, internal replica method is used. All interim crowns were filled with light rubber material under a load of 50 N, and embedded in putty. Each mold was sectioned buccolingually and mesiodistally along the midline. The marginal gap and internal gap were measured in replica specimen of each interim crown using an Image Analyzer microscope, and the mean values and standard deviations were calculated.

Results: The RMS values of the CBCT and intraoral optical scanners ranged from 0.041 to 0.126 and the mean was 0.06. The mean and standard deviation values for the marginal and internal gap were 132.96 (± 139.23 μm) and 137.86 (± 103.09 μm), respectively. There was no statistically significant difference in marginal and internal gap between the mesiodistal surface and buccolingual surface at all measurement points.

Conclusion: The marginal gap of the 3D-printed interim crowns was thought to be within the limits of clinical success and the values of marginal gap showed relative uniformly at the measurement sites. CBCT scans of rubber impression can be used as 3D digital models for Computer-aided design and computer-aided manufacturing interim crown.

Keywords: CAD/CAM, Cone-Beam Computed Tomography, Digital model, interim crown, three dimensional printer

Accuracy evaluation of CBCT scanning based digital model for interim crown fabrication

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I. INTRODUCTION

Computer-aided design and computer-aided manufacturing (CAD/CAM) method has been applied in areas of fabrication of dental prostheses.[1] In these digital prosthetic technique, the first step is to obtain three dimensional digital model that create a virtual impression of prepared teeth. This procedure can be acquired by various scanning methods such as intraoral optical scanning, extraoral scanning or cone-beam computed tomography (CBCT) scanning.

Making resin interim crowns until the final crowns are fabricated is an important part of the procedure, because they function to protect the tooth, to maintain the patient's masticatory function, to prevent the tooth from micro-shifting, and avoid contamination.[2,3] However, conventional methods of making an interim crown may take a substantial amount of time, cause the inhalation of resin powder, result in an allergic reaction in patient's oral mucosa, and cause the patient to experience discomfort from the awful flavor of the monomers.[4,5] These problems can be solved by making interim crowns through CAD/CAM.

Intraoral optical scanning can capture directly the oral cavity, however, it can be inaccurate in full dental arch and difficult to use.[6,7] Extraoral optical scanning is the most common method to obtain digital model. However, the additional step to make the plaster cast is need. Both scanning methods are required long scan time and have limitation of blocking light between adjacent teeth.[8]

CBCT is widely used for three dimensional diagnosis of oral and maxillofacial disease, because of low cost, low dose, effective resolution.[9] According to the 2016 statistics published by the National Health Insurance Service, some 48% of all dental clinics in South Korea have CBCT apparatus,[10] which is a higher rate than in many nations with advanced medical systems. Recently in addition to diagnosis of disease, CBCT is introduced as the alternative scanning method for virtual impression of oral cavity, which it has been studied for orthodontic models, surgical guides and fixed prosthodontics.[11-14] CBCT data is not affected by light and it can make digitized model in short scan time.

CBCT Digital Information and Communications in Medicine (DICOM) data is used for 3D printed prosthesis fabrication after it is converted into stereolithography (STL) file format with conversion program. Various conversion software such as open source and commercial software are introduced. The accuracy of CBCT based STL data must be evaluated according to its voxel size and capability of conversion software.

However, few of the papers on the conversion program from CBCT data to STL file have been studied. Thus, in this study, we introduce the special acquisition image mode of CBCT and customized conversion software, which can acquire digital model with rubber impression and evaluated the accuracy of marginal and internal gaps in 3D printed interim crown from CBCT data.

II. MATERIALS AND METHODS

1. Subjects

The subjects of the study were selected from patients who visited Yonsei University Dental Hospital between January and April 2017 for prosthodontic treatments. A total of 16 patients were selected as the final subjects from those who needed single crown restoration of a posterior tooth for endodontic treatment, dental caries, or tooth fracture, and did not have any tooth loss in the maxillary and mandibular dentition, orthodontic appliances, or crowding. This study received approval from the Institutional Review Board of Yonsei Dental Hospital (IRB No. 2-2016-0048).

2. Rubber impressions and CBCT scanning

A skilled dental practitioner prepared teeth following the standard protocol, with coolants, diamond rotary instruments and high speed handpiece. The impressions were taken after inserting a gingival enlargement cord to ensure accuracy, medium body monophase impression materials (3M EPSE Monophase; 3M Deutschland GmbH, Neuss, Germany) were used for a prepared tooth. Rubber impression of the prepared tooth was scanned with a CBCT apparatus (RAYSCAN α+; Ray Co., Ltd., Hwaseong-si, Korea) after fixating the impression on a special chin rest provided by the manufacturer to scan rubber impressions (Fig 1). The scanning was performed by a skilled radiographic technician at object scanning mode of 90 kVp and 6 mA and a voxel size of 100 μm with a field of view of $90×50\ mm^2$and a duration of 14 seconds. Immediately after CBCT scanning of the rubber impression, plaster models were fabricated by pouring high strength dental stone (MG Crystal Rock; Maruishi Gypsum Co., ltd, Osaka, Japan) in rubber impressions.

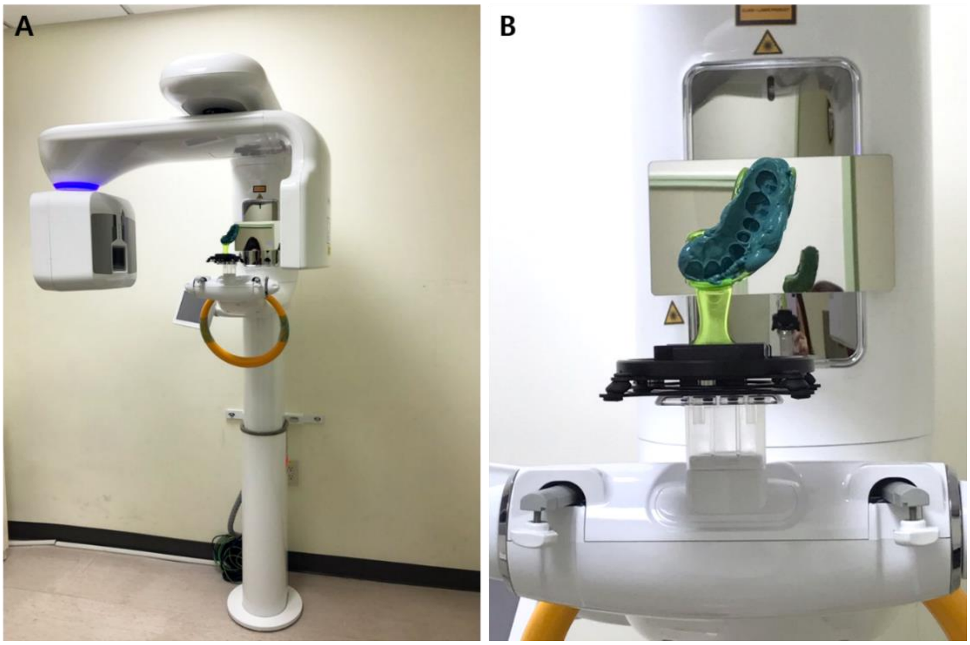

Figure 1. Cone-beam computed tomography scanning. A, CBCT apparatus (RAYSCAN α+); B, Fixating the impression on a special chin rest provided by the manufacturer to scan rubber impressions.

3. Development of customized conversion software

The CBCT data in the DICOM format of rubber impressions of the prepared teeth were transferred to a customized conversion software and converted into STL files (Fig 2). The conversion process is shown in figure 3. An effective method of histogram-based valley estimations was utilized for determining the number of clusters in an image.[15] To increase the effectiveness of auto thresholding, Expectation-maximization (EM) algorithm used the calculated values of rubber impression material (Fig 4).[16]

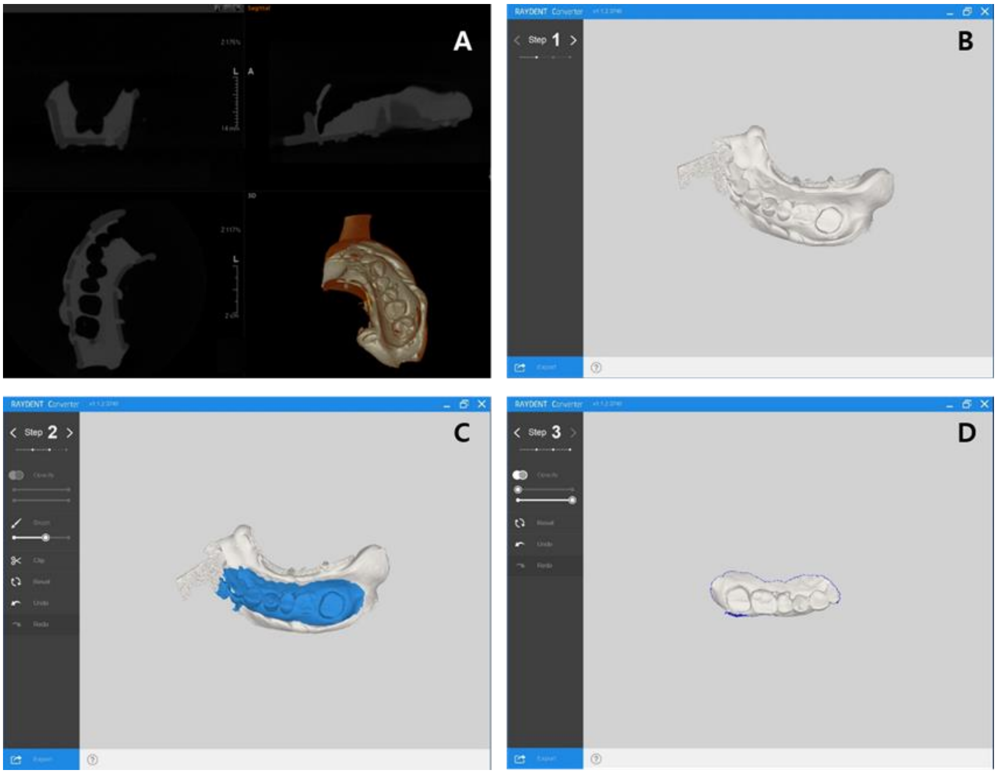

Figure 2. Conversion from the Digital Imaging and Communications in Medicine (DICOM) format to stereolithography (STL) files using customized conversion software. A, DICOM file loading; B, Negative data; C, Selection of the positive range; D, Conversion to a positive format.

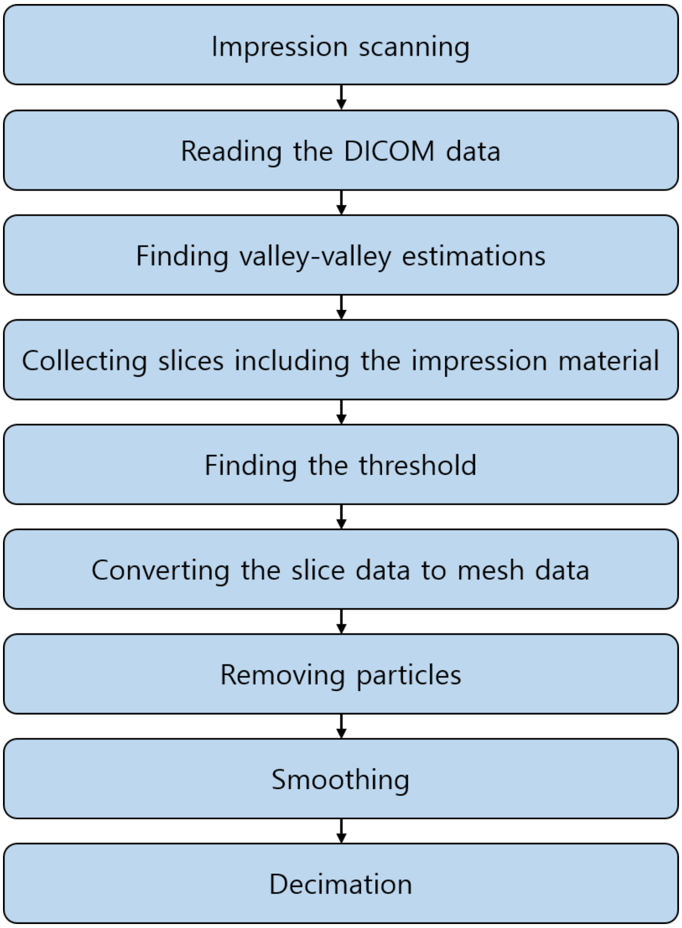

Figure 3. Flow chart of the conversion process.

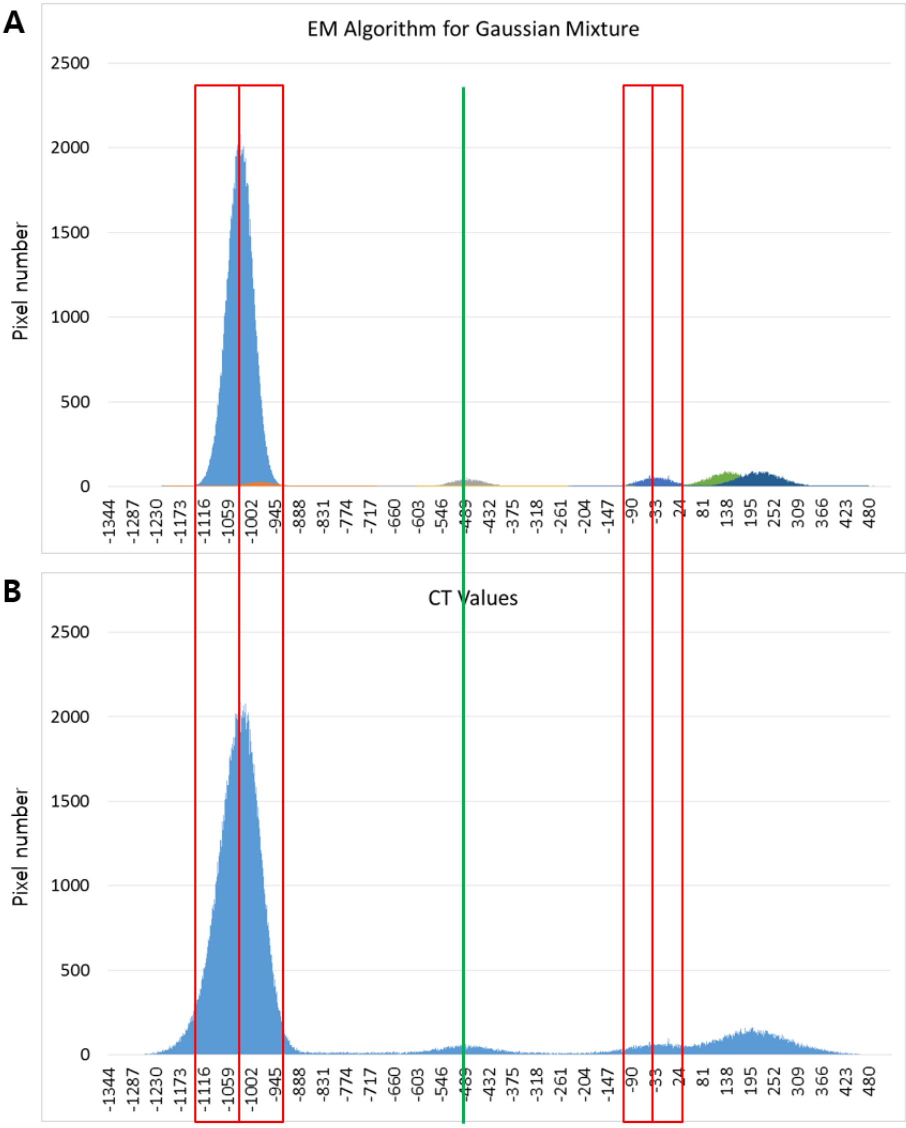

Figure 4. Expectation-maximization (EM) algorithm using Gaussian mixtures used for auto thresholding of rubber impression. A, The threshold of rubber impression after using EM algorithm; B, The raw data of CT value before using the EM algorithm.

4. Comparison of accuracy between CBCT and intraoral scans with master model

The fabricated plaster models were scanned with an intraoral optical scanner (CS 3600; Carestream, Rochester, NY, USA) and saved as STL format (Fig 5). GeoMagic software (GeoMagic Control X; Braunschweig, Germany) was used to compare the surface accuracy of the STL data taken by the intraoral optical scanner with those obtained using the CBCT. The STL obtained by the intraoral optical scanner was set as the reference data, and the STL generated from the CBCT was set as the comparison data in the software. To compare two data, the auto-segmentation function was used to separate the prepared area, which is the regarded as the reference area for superimposition of the two data, from the other segments. In order to reduce the human error in superimposing two data and to ensure the reliability, 'initial alignment' and 'best fit' functions were used and the software was set to automatically recognize the figures to improve the accuracy. Finally, the 3D deviations of the prepared tooth area between the comparison and reference STL data were calculated by measurements with a color-coded scale based on the root-mean-square (RMS) values (Fig 6).

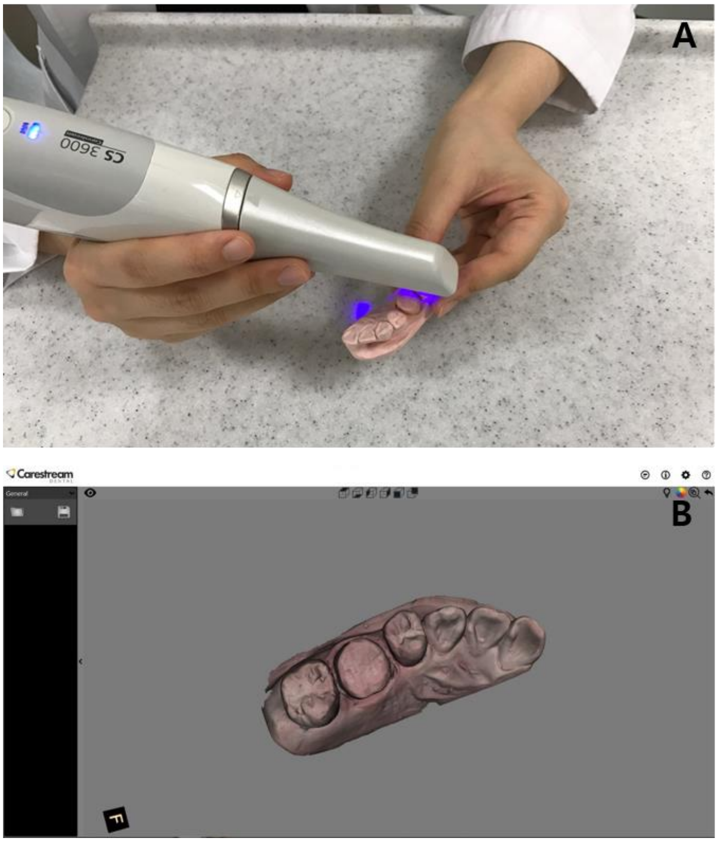

Figure 5. Intraoral optical scanning process. A, Intraoral optical scanner (CS 3600); B, Saved as STL format.

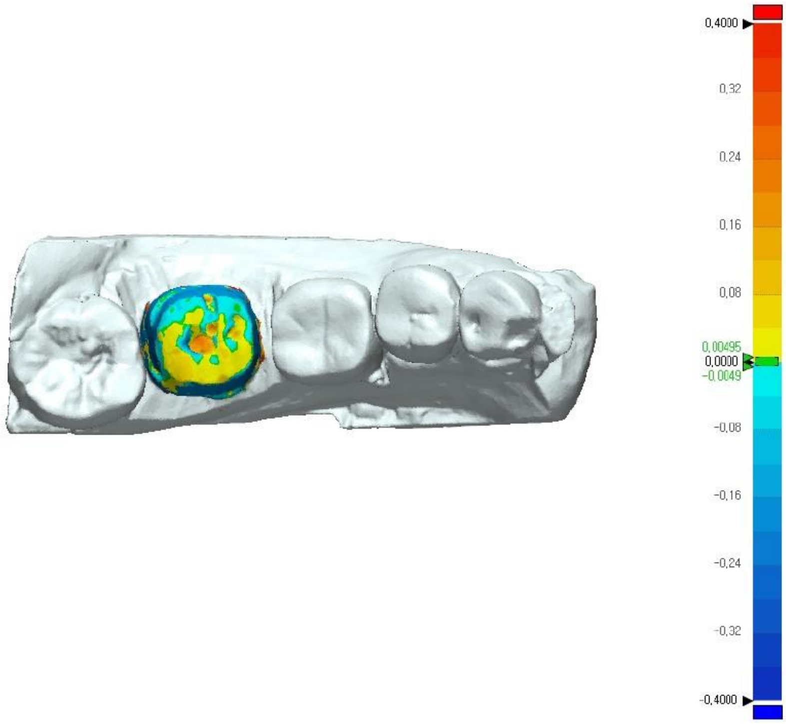

Figure 6. 3-dimensional deviations between the comparison and reference stereolithography (STL) files using GeoMagic software.

4. Design of interim crown and 3D printing

Interim crowns were designed by a skilled dental technician based on the STL files using CAD/CAM software (Exocad GmbH, Darmstadt, Germany). The method of Mai et al.[1] was modified so that the cementing space was set at 50 μm near the margins of the crowns and 100 μm for the rest of the internal space (Fig 7). The interim crowns were printed with photopolymer (RAYDent C&B; Ray Co., Ltd., Hwaseong-si, Korea) (Table 1) using a digital light processing 3D printer (RAYDent Studio; Ray Co., Ltd., Hwaseong-si, Korea) from the completed CAD designs (Fig 8).

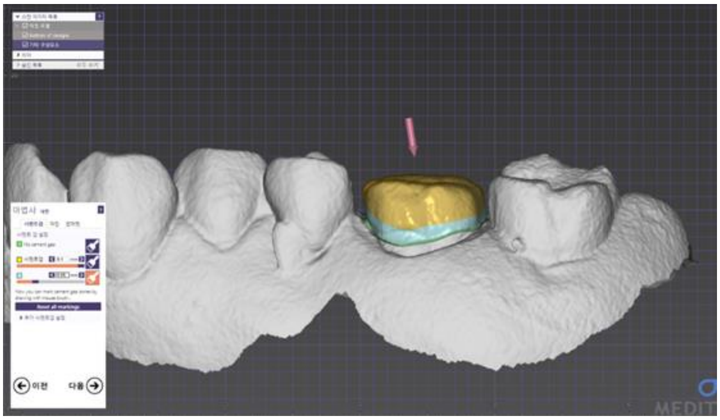

Figure 7. Computer-aided design for interim crowns.

Table 1. Composition and Ingredients of manufactured interim crown.

Component	Content (%)
α,α`-[(1-Methylethylidene)di-4,1-phenylene]bis[ω-[(2-methyl-1-oxo-2-propenyl)oxy]poly(oxy-1,2-ethanediyl)	20~35
7,7,9(or 7,9,9)-Trimethyl-4,13-dioxo-3,14-dioxa-5,12-diazahexadecane-1,16-diyl 2-methyl-2-propenoate	20~28
2-Methyl-2-propenoic acid 1,2-ethanediylbis(oxy-2,1-ethanediyl)ester	20~25
Phenylbis(2,4,6-trimethylbenzoyl)phosphine oxide	1~10
Rutile(TiO2)	0.1~5

Figure 8. Fabricated interim crown with photopolymer using a digital light processing 3D printer.

6. Measurement of the marginal gap and internal gap

The internal replica technique was used to measure the accuracy of the 16 interim crowns. This technique involves measuring the thickness of the cross section of the silicon replica obtained after filling the gap between the crown and prepared tooth with silicon material. The manufactured interim crowns were filled with light body polyvinylsiloxane impression materials (Aquasil Ultra XLV, Dentsply DeTrey GmbH, Konstanz, Germany) and seated together with the master cast models of the prepared tooth. They were then put under 50 N of pressure for 5 minutes,[14] using static load equipment. Cotton rolls were placed onto every specimen before applying pressure to deliver a consistent force across every spot and to reproduce the actual clinical environment in which single fixed partial denture is inserted during cementation procedures. Cylinder-shaped molds filled with putty (Aquasil Soft Putty; Dentsply DeTrey GmbH, Konstanz, Germany) were used to create the specimens and to support the shape. The replica specimens were removed from the mold after polymerization of the putty, and each replica specimens was sectioned buccolingually and mesiodistally at the midline (Fig 9). The thickness of light body was measured in 4 directions using buccolingual and mesiodistal sections. Four measurement points were investigated: (1) the marginal area, (2) the axial area, (3) the axio-occlusal angle, and (4) the occlusal area (Fig 10). Each specimen was examined for its marginal and internal gap with ×100 magnification using a light microscopy (Hirox KH-1000 Hi-scope 3D Power, Hirox-USA, Inc., Hackensack, NJ, USA) (Fig 11).

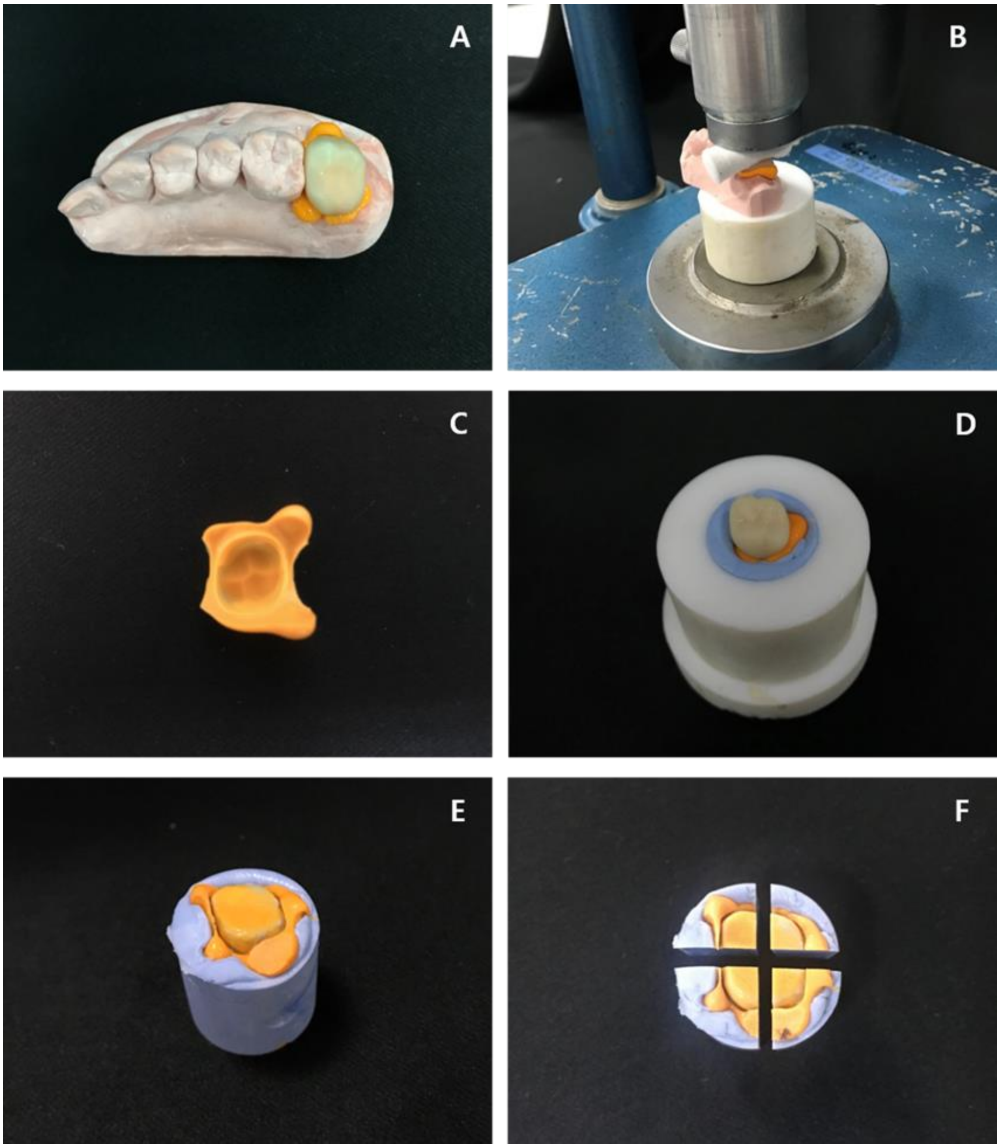

Figure 9. Internal replica method. A, Filled with light-body polyvinylsiloxane impression materials and seated together with the plaster models; B, Put under 50 N of pressure for 5 minutes, using static load equipment; C, Removed from the plaster models after polymerization of the light-body; D, Cylinder-shaped molds filled with putty; E, Create the specimen; F, Sectioned buccolingually and mesiodistally at the midline.

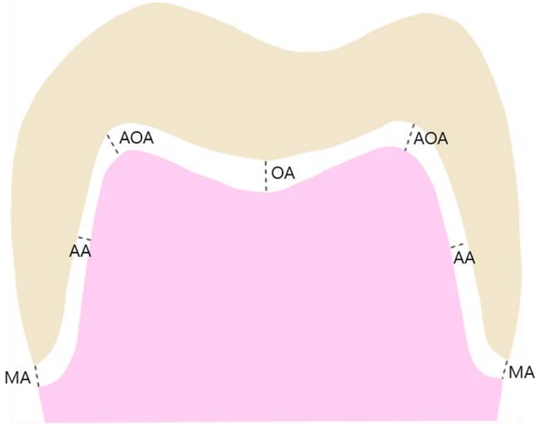

Figure 10. Schematic representation of the measurement points in a cross-section of a specimen. MA: marginal area; AA: axial area; AOA: axio-occlusal angle; OA: occlusal area.

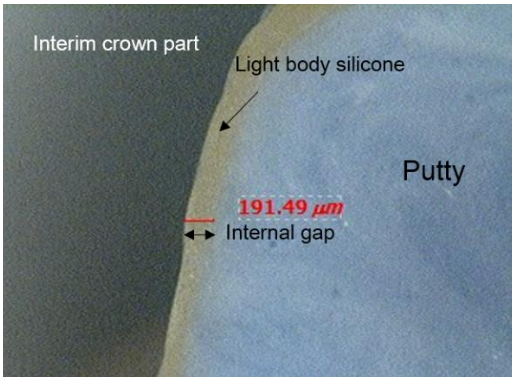

Figure 11. Measurement of marginal and internal gaps using a digital microscope (magnification ×100).

6. Statistical analysis

Statistical analyses of the marginal and internal gaps were performed using the mean values and standard deviations of the measurements; the normality of the data was assessed, and normality was not confirmed for the data ($P < 0.01$). The Mann-Whitney U test was conducted to determine whether the measurement points of the marginal and internal gaps were significantly different between the mesiodistal and buccolingual surfaces. Statistical analysis was performed using SPSS Statistics for Windows, version 23.0 (IBM Corp., Armonk, NY, USA). Statistical significance was defined at $P < 0.05$.

III. RESULTS

The RMS values of 16 single prepared teeth ranged from 0.041 to 0.126 mm and the mean was 0.06 (± 0.057) mm (no table).

The mean values of the marginal, internal and total gaps were 132.96 (± 139.23) µm, 137.86 (± 103.09) µm and 135.68 (± 120.30) µm, respectively (Table 2). The mean and standard deviation of the marginal and internal gaps between the mesiodistal and buccolingual surfaces were not statistically significant in any measurement area (Table 3). The overall mean (average of the marginal and internal gap) and standard deviation values for all measurement points at the mesiodistal and buccolingual surfaces were 143.51 (± 127.51) µm and 127.86 (± 112.52) µm, respectively, with no statistically significant difference.

Table 2. Mean and standard deviation values of marginal and internal gaps.

Measurements (μm)	Samples	Mean (± SD)
Marginal gap	64	132.96 (± 139.23)
Internal gap	160	137.86 (± 103.09)
Total gap	224	135.68 (± 120.30)

Table 3. Comparison of marginal and internal gap between mesiodistal and buccolingual surfaces.

Measurement point (μm)	MD Mean (± SD)	BL Mean (± SD)	*P*
MA	148.97 (±149.42)	116.95 (±127.41)	0.156
AA	97.50 (±73.28)	108.39 (±88.09)	0.914
AOA	109.25 (±56.37)	118.28 (±77.09)	0.883
OA	282.15 (±126.19)	229.60 (±107.98)	0.346
Total	143.51 (±127.51)	127.86 (±112.52)	0.292

Abbreviations: SD, standard deviation; MD, mesiodistal; BL, buccolingual; MA: marginal area; AA: axial area; AOA: axio-occlusal angle; OA: occlusal surface area. *P*-values were obtained using the Mann-Whitney U test.

IV. DISCUSSION

In this study, the feasibility of interim crown fabrication on a prepared tooth through the STL images obtained from CBCT data was evaluated.

Prior to the fabrication of an interim crown using a CBCT based digital model, the accuracy of the digital model obtained by CBCT scan of the rubber impression was compared with the digital model of the intraoral optical scanner. Optical scanners are known to be within clinical acceptable range by previous studies and have been used in dental field.[17] The surface accuracy was compared by superimposing the STL files obtained from the optical scanner and the CBCT. The RMS values ranged from 0.041 to 0.126 and the average was 0.06. These results were within the range of 0.04 to 0.2 mm reported in the previous study as the clinically acceptable discrepancy between the plaster model and the digital model.[18-22]

Although it may be easier to perform a direct CBCT taking like the intraoral scanner without making a rubber impression of the prepared tooth. However, it is impossible to obtain accurate digital models due to additional radiation exposure to the patient, patient's motion artifact, and beam hardening artifact.

The conventional direct method of interim crown fabrication involves a polymerization process in which monomers and resin polymers are mixed extraorally, which produces chemical reactions, and then repetitive intraoral fitting is performed.[23] The bitter flavor of non-polymerized monomers may also cause patients to experience discomfort when the process takes place intraorally, and the heat generated during the process may stimulate the dental pulp tissue.[24] Previous literature suggested that monomers may cause allergic reactions in the oral mucosa.[4] The indirect method is fabricating an interim crown extraorally by polymerizing resins and monomers after impression-taking and cast model fabrication, but completing the setting of the model may take so long that the patient may not be able to receive the interim crown on the same day that the tooth is prepared.[23]

Marginal fit is considered one of the most important criteria for evaluating the quality of interim crown. The smaller between the marginal gap of the preparation and the prosthetic margins, the more successful the treatment is considered to be. Many researchers reported marginal gap for long-term maintenance of the prosthesis is from the 100 to 200 μm range.[25-28] Furthermore, the average marginal gap of the conventional method to fabricate interim crown was 177-400 μm.[29,30] In this study, the marginal gap of the interim crown fabricated by CBCT scan was 132.96 (± 139.23) μm, which is within the clinical acceptance reported by previous researchers. The discrepancy in this study was sufficiently close to the threshold for fixed prosthesis, implying the in vitro feasibility of fabricating interim crowns using CBCT scanning. The internal and marginal fit of an interim crown is less essential than that of a permanent crown. This support the proposal that the marginal gap of 3D printed interim crowns designed using CBCT technology is generally lower than that of crowns those fabricated using the conventional method.

The marginal gaps between the mesiodistal and buccolingual surfaces of the CBCT digitalized, 3D printed interim crowns did not show statistical significance in any measurement areas. This suggests that CBCT scanning produces consistent results regardless of the conditions of the surface, whether they are small areas, such as the mesiodistal surfaces, or more open areas, such as the buccolingual surfaces. Our findings also demonstrated that CBCT scanning is sufficient at small interdental spaces.

In previous studies, there are conflicting results about the accuracy of digital models obtained through CBCT scans. According to Seker et al., the marginal gap of PMMA crowns, when a CBCT were used, was significantly larger than the marginal gap of crowns fabricated using extraoral scanner.[11] Reyes et al. reported that the accuracy of CBCT scanned surgical guides is less than the accuracy of surgical guides fabricated with conventional methods and extraoral optical scanning.[12] On the other hand, as shown in Chung et al.'s studies there is no statistical difference and accuracy in orthodontic digital model produced by CBCT compared with optical scanning.[31] Lippold et al. found that the measurements of a digital model obtained by a CBCT scan of conventional casts were reliable as a diagnostic measurement tool compared to the actual measurements of a plaster model.[32] The difference in result between these studies is that there are several factors that affect the accuracy until the scanned digital model become 3D printing.[33] When evaluating models fabricated with CBCT scanners, the most important thing is to consider the voxel size and accuracy of segmentation in conversion software.[34] Data conversion software is necessary to convert the CBCT DICOM data of rubber impressions into STL files, and an accurate digital model can be generated when the segmentation of the rubber impressions is accurate and the conversion does not distort any information.

In this study, we have developed a program that automatically segmentation is optimized especially for rubber impression materials. This customized software combines the valley estimation method with the EM algorithm. To estimate the parameters required for the EM algorithm, the histogram-based valley estimation method is used to find the valley and determine the number of clusters.[5] The EM algorithm can effectively determine thresholds by presetting a range of intensity values for the rubber impression material.[16] The algorithm found the internal and external boundary of the DICOM data and precisely separated the desired and the surrounding areas of the impression from the CBCT DICOM data by auto-thresholding the histograms of each pixel value of the image. The dual-marching cubes algorithm was implemented to obtain accurate mesh data.[8] Then, fair surface design algorithm is used to compensate for the error that occurs when smoothing.[35] Therefore, this customized software get more accurate results than using manual segmentation of existing open source or commercial software. This enabled the conversion of the rubber impressions into positive STL files within a short period of time.

Intraoral scanning is the only way to directly digitize intraoral information. Intraoral scanners can directly produce oral images without impression-taking and/or cast model fabrication.[6] However, the scanning head of an intraoral scanner may not fit for patients with limited mouth openings or be suitable for the molars, and the scan data may show higher deviations when the light is not beamed evenly, producing distorted.[8]

Meanwhile, impression-taking and extraoral desktop scanning of model casts is preferred by some dental practitioners, as these methods produce higher-resolution images.[7] Because the angle of the scanner head is limited, light cannot scan the space between adjacent teeth and optical scanning can produce incomplete oral information. There is a possibility of error due to additional steps of cast model making and expansion and contraction of plaster.[7] CBCT has no process of fabricating the cast model to obtain digital data, has a short scan time, and is not influenced by the angle of light.

In addition to diagnostic purposes, CBCT is actively exploring the possibilities of digital model acquisition for another uses. A variety of methods have been used to fabricate devices for implant guide surgery,[12,36,37] reduces model storage space by digitizing orthodontic models,[14,32] and fabricate prosthesis.[11] In this case, if the resolution of CBCT is better, it will get much more accurate results. It is therefore necessary to study the resolution, and it is possible to correctly convert the DICOM file obtained by using the software to the STL file.

V. CONCLUSION

1. The digital information of the prepared teeth obtained with customized software after CBCT scanning at 100 μm did not show statistically significant deviation from the STL data of the cast models made from intraoral scanning.
2. The marginal, internal, and total gaps of the interim crowns measured in this study were 132.96 (± 139.23) μm, 137.86 (± 103.09) μm, and 135.68 (± 120.30) μm, respectively, indicating that consistency was maintained in the internal gaps as well as in the marginal gaps.
3. The digital model of the prepared tooth obtained with CBCT special acquisition mode and optimized software show the potential of clinical use for fabricating 3D printed interim crown.

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Abstract (Korean)

임시치아 제작을 위한 콘빔시티 기반 디지털 모델의 정확도 평가

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목적: 이 연구의 목적은 3D프린팅 임시치아 제작을 위해서 고무인상체의 CBCT 촬영으로부터 얻은 디지털 모델의 정확성을 평가하는 것이다.

재료 및 방법: 16명의 금관 치료가 필요한 치과 환자로부터 지대치 형성 후 고무인상 채득을 시행하였다. 각 고무인상체는 100 μm, 90×50 mm^2 조사범위의 콘빔시티를 사용하여 촬영하였다. 다이콤 형식의 콘빔시티 데이터를 auto-thresholding 알고리즘을 적용하여 개발한 소프트웨어를 이용하여 양각의 스테레오리소그래피 (STL) 파일로 변환하였다. 고무인상의 석고모델을 제작하여 구내 광학스캐닝 후 콘빔시티 데이터와 표면정확도를 비교하였다. STL 파일을 캐드 소프트웨어로 전송하여 임시치아를 디자인하고 포토폴리머 소재를 사용하여 디지털 광처리 방식의 3D프린터에서 임시치아를 출력하였다. 임시치아의 정확도 측정을 위해 인터널 레프리카 방법을 사용하였다. 모든 임시치아 내면에 라이트바디 고무인상재를 채운 후 50뉴턴의 압력을 가하고, 퍼티를 이용해 시편을 제작하였다. 각 시편의 중심을 협설면, 근원심 방향으로 절단하고 이미지 분석 현미경을 이용하여 각 임시치아 시편의 변연 및 내부 적합도를 측정하여 평균과 표준편차를 산출하였다.

결과: CBCT와 구내 광학 스캐너를 비교한 RMS값은 0.041~0.126의

범위를 보였고 평균은 0.06이었다. 변연과 내부 오차는 각각 132.96 (± 139.23) μm 와 137.86 (± 103.09) μm로 나타났다. 근원심면과 협설면 사이의 변연 및 내부 오차는 모든 측정점에서 통계적으로 유의한 차이를 보이지 않았다

결론: 3D 프린트된 임시 치아의 변연과 내부 오차는 임상적 성공을 위한 허용 범위 내에 있었고, 오차 값은 모든 측정 부위에서 일관성을 보였다. 고무인상체의 콘빔시티 기반 디지털 모델을 이용한 임시치아의 제작은 유용성이 높음을 시사하였다.

중심단어: 캐드캠, 콘빔시티, 디지털모델, 임시치아, 3D프린터