Comparison between Occlusal Error of Single Posterior Crowns Adjusted using Patient Specific Motion or Conventional Methods

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Comparison between Occlusal Error of Single Posterior Crowns Adjusted using Patient Specific Motion or Conventional Methods

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감사의 글

먼저, 제가 이 자리에 있을 수 있기까지 제 삶을 인도해주신 하나님 아버지께 감사드립니다. 부족한 제가 치과의사의 꿈을 이루고 학위를 마무리하기까지 하나님께서 이끌어 주셨던 것을 잊지 않고, 믿는 치과의사로서 하나님이 원하시는 삶을 살기를 원합니다.

많은 분들이 저의 학위 논문을 위해 도움을 주셨던 것을 기억합니다. 먼저, 세심한 지도와 격려를 통해 이 논문이 잘 마무리될 수 있도록 지도해 주신, 김종은 지도교수님과 이근우 교수님께 감사드립니다. 두 분 교수님의 지도와 격려가 제게 큰 힘이 되었습니다. 또한 논문 심사를 맡아 주시고 귀중한 조언을 해주신, 심준성, 박지만, 신유석 교수님께 진심으로 감사드립니다.

아울러, 치과의사로서 바르게 설수 있도록 저를 지도해주시고 본보기가 되어주신 연세대학교 치과대학 보철과학교실의 정문규, 한동후, 문홍석, 김선재, 이재훈, 박영범, 김지환 교수님께 이 지면을 빌어 감사의 마음을 드립니다. 보철과 수련 과정 동안 사제의 연을 맺고 많은 것을 배울 수 있었던 것은 제 인생 최고의 행운 중 하나였습니다.

더불어, 보철 수련기간 동안 여러가지로 서로를 격려해주고 도와주었던 보철과 의국 동기 및 선후배들에게도 감사를 드립니다. 그리고, 연구가 원활히 진행되도록 도와준 김대환 기공사를 비롯한 원주 세브란스 기독병원 치과 보철과 식구들에게도 감사의 말씀을 전하고 싶습니다.

마지막으로, 제가 가장 존경하고 사랑하는 부모님께 깊이 감사드립니다. 아버지, 어머니의 헌신과 사랑이 있었기에 지금 제가 있을 수 있었습니다. 묵묵히 기도해 주시며 응원해 주셨던 것을 기억합니다. 또 하나밖에 없는 우리 여동생 예주에게도 특별히 감사의 말을 전하고 싶습니다.

2020 년 12 월

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ABSTRACT

Comparison between Occlusal Error of Single Posterior Crowns Adjusted using Patient Specific Motion or Conventional Methods

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(Directed by Professor Jong-Eun Kim, D.D.S., M.S.D., Ph.D.)

In recent years, digital workflows that could design restorations with anatomical and functional occlusal morphology have been developed to minimize clinical occlusal adjustment. The Patient Specific Motion (PSM) is a tool for reproducing the dynamic occlusal relationship in computer-aided design (CAD) software by tracking mandibular movement with an intraoral scanner (IOS). The purpose of this clinical study is to assess the amount of occlusal error in the occlusal surface of a single posterior crown adjusted with the PSM method compared to conventional methods. Fifteen individuals participated in this study. All participants had indications of a single crown restoration on the posterior area. After obtaining quadrant scan data of the treated area using IOS (Trios 3), the restoration design was performed on CAD software. The occlusal morphology was designed based on the static occlusion recorded using IOS. The single zirconia crown restorations were fabricated by a 5-axis milling machine. The clinical intraoral adjustment was performed to fabricated restorations. After clinical intraoral adjustment, quadrant scan data of the treated area were obtained as reference data using IOS. In the no adjustment (NA) group, CAD data of the crown with static occlusion were used for comparison data. In the Patient Specific Motion (PSM) group, the occlusal design of duplicated CAD data from NA was adjusted using the dynamic occlusion relationship recorded by IOS using the PSM tool. In the semi-adjustable articulator (SA) group, a zirconia crown based on duplicated CAD data was adjusted in a mechanical semi-adjustable articulator. In the surface analyzing software, superimposition between the comparison data of the three experimental groups and the reference data was performed by the best-fit algorithm. After a valid arrangement, models were trimmed, leaving only the occlusal surface. A 3D comparison was performed between the comparison data and reference data to calculate value of root mean square (RMS) value, +Average (AVG) deviation value, -AVG deviation value, and in tolerance (%) value in areas such as the entire occlusal surface, functional cusp area, non-functional cusp area, central groove area. In addition, The RMS and ±AVG values of areas limited into the out of tolerance area was obtained. Color-coded map representing a deviation of the occlusal surface was generated and analyzed. In the quantitative analysis, the points over tolerance regarded as occlusal errors. The results of one-way ANOVA show significant differences in the RMS and +AVG values of the out of tolerance area from the NA, PSM, and SA groups (p=0.028, 0.040). The RMS values calculated from the out of tolerance area were 257.0 ± 73.9μm in the NA group, 202.3 ± 39.3μm in the PSM group, and 222.9 ± 41.9μm in the SA group. The +AVG values calculated from the out of tolerance area were 210.9 ± 48.6μm in the NA group, 173.1 ± 31.3μm in the PSM group, and 194.7 ± 36.4μm in the SA group. In post-hoc analysis, the RMS and +AVG of PSM groups was statistically lower than the NA groups. In entire occlusal surface and subdivided area, there was no statistically difference between three experimental groups. In the qualitative analysis, the decrease of the occlusal error areas was mainly shown in the inclined plane of the cusp and triangular ridge on the occlusal surface in a single posterior crown adjusted with the PSM method. Within the limitations of this clinical study, the following conclusions were drawn. In the quantitative analysis, the extent of occlusal error in areas of the out of tolerance area was decreased in a single posterior crown adjusted with the PSM method as compared to other methods using a traditional mechanical semi-adjustable articulator or conventional CAD software. However, there was no significant difference in the amount of occlusal error in the entire occlusal surface or subdivided area level. In the qualitative analysis, the PSM group showed decreased areas of occlusal errors in the color-coded map. The PSM method might be a simple and effective alternative tool that shows clinically acceptable results in the occlusal adjustment of a single posterior crown.

Keywords: Articulator, CAD/CAM; dynamic occlusion; optical scanner; single crown

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I. INTRODUCTION

The prosthesis in the oral cavity should be functionally and anatomically compatible with the existing stomatognathic system (Thompson 1954; Turp, Greene, and Strub 2008; Parmar et al. 2016). The common consensus of occlusal design is that the dental restorations should correspond to the natural tooth anatomy and be in a harmonic relationship with the adjacent and antagonistic structures (Christensen 2004; Malaguti et al. 2017; Fiore et al. 2020). In addition, dental prosthesis should offer both functional stability in maximum intercuspation (MICP) and no interference during eccentric movements in articulation and mastication (Olthoff et al. 2007). However, reproduction of the anatomic and functional occlusal morphology of posterior teeth in definitive dental restoration is still a challenge in dentistry due to some errors occurring in clinical and laboratory procedures (Turp, Greene, and Strub 2008).

Conventional single posterior crown restorations are designed and adjusted in a dental laboratory using a mechanical articulator. Mechanical articulators are used to establish harmonious occlusal design (Fang and Kuo 2009). Mandibular functional movements can be simulated in different types of articulators, by using values obtained from interocclusal relationship records or default values for the determinants of occlusion (Romerowski and Bresson 1990; Schulte et al. 1985b; Schulte et al. 1985a). The conventional mechanical articulator can be broadly categorized into four types: hinge, fixed condylar path, semi-adjustable, and fully adjustable articulators (Gracis 2003b). While the hinge articulator can only hold instruments capable of accepting single static registration, the fully adjustable articulator can simulate functional mandibular movement by customized condylar pathways (Ak et al. 2014). However, current conventional methods with mechanical articulators focus on reproducing the maxilla–mandible relationship determined by the temporomandibular joint (TMJ) rather than directly reconstructing the actual functional movement of mandible (Kim et al. 2019). In addition, the articulator is a rigid device with movement patterns determined by solid pathways, whereas the actual movement of mandible is guided by various anatomic elements such as muscles, ligaments, , non-rigid joint surfaces, teeth, and the complex neuromuscular system (Monson 1920). Even the fully adjustable articulator cannot fully duplicate functional mandibular movement (Ak et al. 2014). An articulator does not provide an accurate reconstruction of mandibular movement but a simulation; a fully functional occlusion design through the conventional method using a mechanical articulator is not possible. The traditional solution to this problem is time-consuming clinical occlusal adjustment for functionally and anatomically harmonious occlusion among the individual's teeth, condyles, and associated facial muscles (Fang and Kuo 2009).

For more accurate reconstruction of the occlusal pathway, the functional generated pathway (FGP) technique was described by Myer et al. (Meyer 1959). The FGP technique involves practically recording the actual occlusal pathway of the teeth during movement directly in the patient's mouth by locating a recording medium between the arches. Many researchers have demonstrated the clinical usefulness of this technique for fixed partial dentures (Curtis 1999; Pankey and Mann 1960; Mehl 2012). However, this technique has a limitation in that the clinical procedure is complicated and requires much additional laboratory work. In addition, some controversy exists as to whether the recording material reduce the accuracy of the occlusal grid in which consecutive occlusal movement is accumulated (Mehl 2012).

In recent years, computer-aided design and computer-aided manufacturing (CAD/CAM) technology is adapted to digital dental workflow to increase accuracy and to reduce operative time (Di Fiore et al. 2019). With the development of scanning equipment and CAD software, the fabrication of restorations using digital dental technology has rapidly developed in the fixed partial denture area. For example, the advance of optical devices such as the intraoral scanner (IOS) has made it possible to generate a digital working model without conventional impression taking. In addition, various CAD software have been replaced the conventional wax-up procedure with a virtual design procedure (Bando et al. 2009). However, since the concept of designing occlusal morphology is still based on standard libraries and static occlusion, it requires considerable experience of technician and occlusal knowledge of clinician besides interaction between them (Ender, Mörmann, and Mehl 2011; Ender et al. 2016; Baroudi and Ibraheem 2015). Most CAD/CAM systems fabricate restorations of accurate fit but require that final anatomical shaping is performed clinically (Olthoff et al. 2007). Moreover, excessive clinical adjustments may result in remarkable alterations in morphology and esthetics and may affect the strength of restorative materials by altering the thickness of the restoration (Fiore et al.).

The accuracy of a CAD/CAM crown depends on accumulated errors and the precision and reproducibility of the scan-design-manufacturing process (Olthoff et al. 2007). For occlusal designs without interference during eccentric mandibular movements, values for determinants of mandibular movement must be considered (Olthoff et al. 2007).

To reduce clinical intraoral adjustments, a virtual articulator module in CAD software is commonly used in the digital workflow. However, because the mechanism of the virtual articulator is fundamentally similar to that of the conventional mechanical articulator, it is not easy to design fully functional occlusion in the digital workflow. In current CAD software, crown restorations are still designed mainly based on technicians' own know-how (Sornsuwan and Swain 2011).

An ideal functional occlusal morphology is difficult to design because it requires modeling the relationship between a crown and its antagonist during functional movement. Single crown restorations that are produced by digital workflow should be designed such that when they are used in clinical applications, they require only minor adaptation. Also, They show no interference during mandibular contact movements (Mehl 2012). Despite the enormous advances in both CAD/CAM technology and optical devices, the digital workflow still lacks a strategy for integrating the dynamic occlusion into the occlusal design with a precise and efficient method (Mehl 2012).

Recently, new methods based on mandibular motion tracking using optical device have been introduced. Among them, the method called Patient Specific Motion (PSM) (3Shape A/S, Copenhagen, Denmark) provides the patient's own dynamic occlusion recording in eccentric movement through IOS. A consecutive accumulated dataset of mandibular movement is recorded in the patient's mouth using IOS without marker attachment. The recorded digital dataset is used to not only visualize the mandibular movement but also adjust the occlusal errors of the occlusal design in CAD software. In this way, the PSM can reduce occlusal interference in the eccentric movement by reproducing the dynamic functional movement in CAD software. However, there are few clinical studies on this method except one clinical reports (Valenti and Schmitz 2020). In addition, clinically, it is unclear whether the PSM can minimize intraoral clinical adjustment better than the existing method using a conventional mechanical articulator or CAD software.

The purpose of this clinical comparative study is to compare the decrease of the occlusal errors in the occlusal surface of a single posterior crown adjusted with the PSM to that of one adjusted with the conventional method. The null hypothesis of this study is as follows: There is no difference in the amount of occlusal error on the occlusal surface between a single posterior crown adjusted with the PSM and one adjusted with the conventional methods.

II. MATERIALS AND METHODS

1. Participants

From June 2018 to December 2019, 15 individuals were selected to participate in the clinical study. There were ten male participants and five female participants. The average age of participants was 49.93 years (range of 29-67 years). Participants were informed about the clinical study, and they agreed to participate in the study. Inclusion criteria for this study were a need for a single crown restoration in the first or second molars, complete permanent dentition, anterior guidance with canine guidance or group function, intact crown morphology of the rest of the teeth, and no sign of temporomandibular dysfunction. Exclusion criteria were unwillingness to participate in the study, signs of malocclusion such as Angle class II or III, and unilateral/bilateral crossbite and presence of parafunctional habit. This clinical study was approved by the Institutional Review Board of Wonju Severance Christian Hospital (No. CR320028).

2. Clinical procedure

2.1. Tooth preparation and Optical impression acquisition

The overall study workflow is presented in Figure 1.

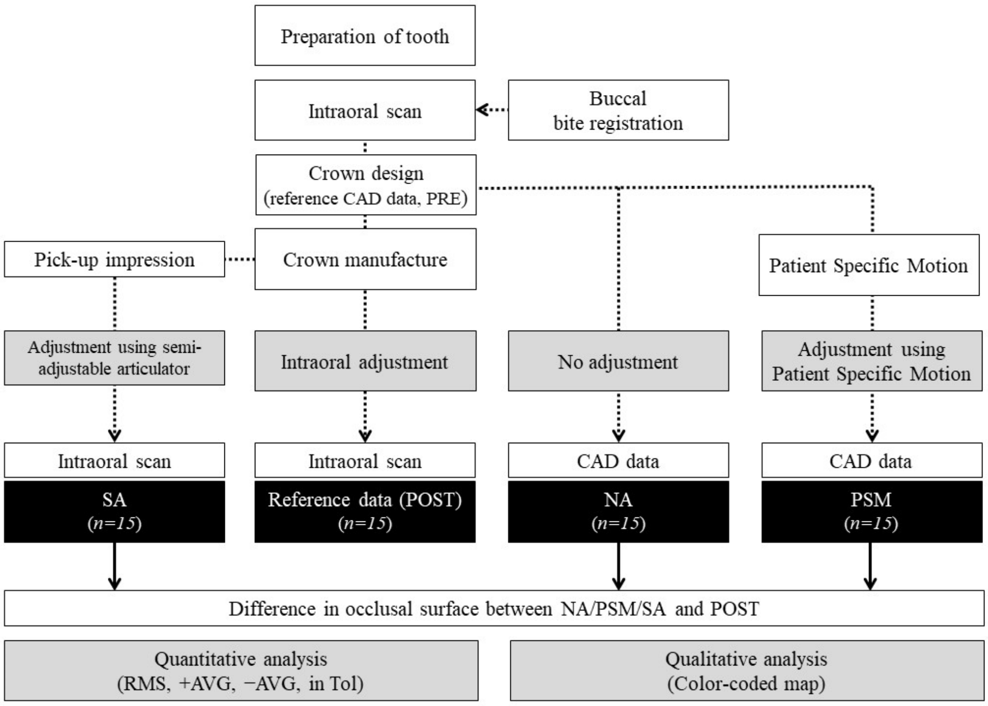

Figure 1. Workflow used to compare the amount of occlusal error among the experimental group. NA; no adjustment group, PSM; Patient Specific Motion group, SA; semi-adjustable articulator group.

All participants had indications of a single crown restoration supported by the tooth or implant. Single crown restoration treatments were performed on 10 maxillary molars (six first molars and four second molars) and five mandibular molars (four first molars and one second molars). All clinical procedures were performed by a professional dentist specialized in prosthodontics.

For a tooth-supported single crown, after a preliminary clinical examination, all of the tooth preparation was made in a standardized manner (Figure 2). The occlusal reduction was about 2mm, and the axial reduction was about 1.5mm. A 10-degree taper was tried to form along the scalloping of the free gingival margin. The subgingival margin of the preparation was avoided. For the digital impression, the quadrant scan image of the maxilla and mandible was obtained using IOS (Trios 3; 3Shape A/S, Copenhagen, Denmark) according to the manufacturer's instructions. The static interocclusal registration was recorded according to the manufacturer's instructions using the buccal bite registration method. The PSM was used to obtain the dynamic occlusion of the patients. The patients were instructed to practice two or three times of adequate mandibular movement which is ranged from centric occlusion position to canine tip to canine tip position before the recording procedure. For dynamic occlusion recording, The IOS scanner tips was located to the buccal side of prepared teeth similar to buccal bite registration. After the validation of the green scan area including prepared teeth and adjacent teeth, the patient functional mandibular movement with adequate speed was consecutively recorded.

For an implant-supported single crown, the implant stability quotient value was measured using Osstell ISQ (Osstell AB, Gothenburg, Sweden) to evaluate osseointegration for loading in the preliminary examination. More than 70 ISQ value is considered as adequate osseointegration. To acquire a digital impression, an emergence profile scan was first performed; then, a scan body (H-Scan body; Dio Implant Co., Busan, Korea) was connected in the oral cavity, and a scan of the scan body and an antagonist scan were performed. The rest of the process was the same as that for the tooth-supported restoration. A customized implant abutment was fabricated according to the principles outlined for ideal teeth.

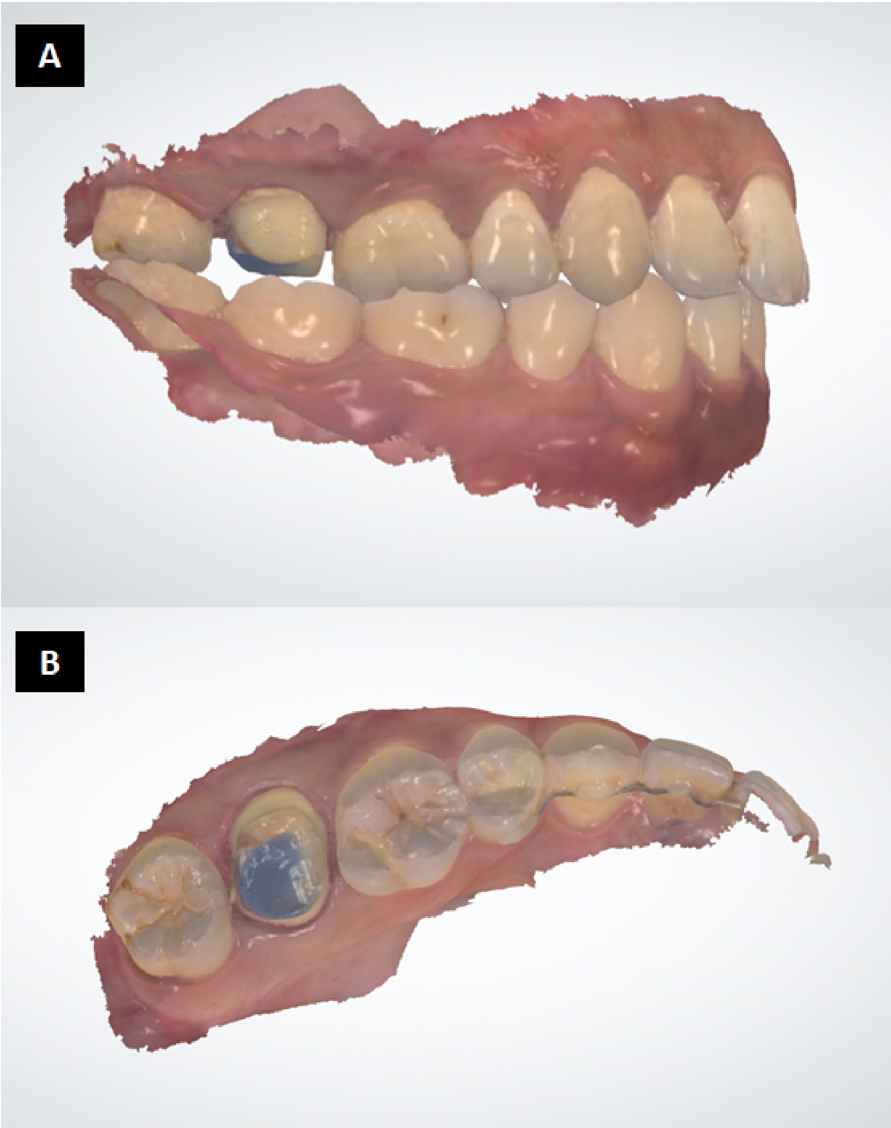

Figure 2. Quadrant scan data of prepared tooth. (A) Buccal view of quadrant scan. (B) Occlusal view of quadrant scan.

2.2. Design and fabrication of restoration

Crown design and fabrication were performed by an experienced professional dental laboratory technician. Intraoral scanning data were loaded in CAD software (3Shape Dental System; 3Shape A/S, Copenhagen, Denmark). After trimming the excess soft tissue in the scan image, the static occlusion of the model was verified.

A combination of viewing the impression with and without colors was used with carefully set exact margins. After setting the initial direction through the automatic insertion direction, the final insertion direction was manually adjusted. Production parameters such as cement gap were set in the die interface step. In the design stage, the anatomic crown design (RAINBOW 20 Orange) was selected from the library and then auto placed to determine the crown position. Contour and occlusal morphology were adjusted to achieve anatomic harmony with adjacent teeth. After positioning the proximal contact area to the adjacent teeth using the tools in the sculpt tab, anatomic properties such as occlusal fit, occlusal cusp, central groove, and marginal ridge were adjusted. By setting the parameters in the contacts and smoothing tab, the minimum thickness of the crown, the contact point area, and the occlusal contact were refined. The technician tried to position ideal occlusal contact on the central fossa and functional cusp. Using single tooth tools such as the wax knife tool, anatomic properties such as occlusal contact and anatomical ridge and groove were additionally adjusted and controlled by referring to the antagonist and distance map in the static occlusion state (Figure 3).

Finished crown design was considered to reference CAD data (PRE). Two zirconia crowns for reference data (POST) and semi-articulator (SA) group were fabricated by a 5-axis milling machine (Arum 5X-300, Doowon, Daejeon, Korea) using 0.6mm, 1.2mm and 2.0mm diameter bur, and post-processing such as sintering of the crowns was performed.

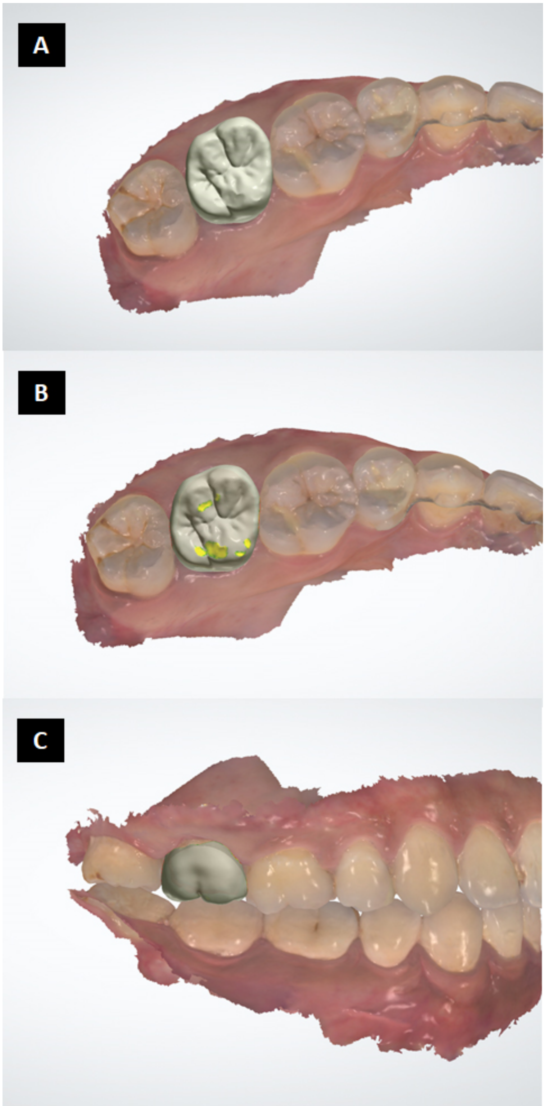

Figure 3. Design of occlusal morphology of single posterior crown. Crown was designed on static occlusal relationship using CAD. (A) Occlusal view of crown design. (B) Crown design with occlusal contact. (C) Buccal view of crown design.

2.3. Delivery of restorations

The margin adaptation and proximal contact of the first zirconia crown for reference data (POST) were verified (Figure 4). All crown restorations showed clinically acceptable margin adaptation when checked by dental explorer tip. Interproximal contact was verified by double checking process. Firstly, the interproximal contact was assessed with dental floss. Secondly, the patient`s identical sensation with/without a crown was verified. The tight contact was adjusted by zirconia polishing burs (Eve Diacera HP 321 kit, EVE Ernst Vetter GmbH, Keltern, Germany), whereas the loose contact was repaired by adding porcelain. Occlusal contact was evaluated using two types of articulating paper (Arti-Check Articulating Paper 40μm, Dr. Jean Bausch Gmbh & Co. KG, Koln, Germany; Hanel Shimstock foil, Coltene, OH, USA) (Brizuela-Velasco et al. 2015). Any occlusal interferences in MICP and eccentric movement were eliminated. To avoid over-correction, the amount of posterior disocclusion was achieved by referring to the standard amount of disocclusion by Hobo (Hobo and Takayama 1997). After the occlusal adjustment was completed, the clinician evaluated the occlusion and examined that there was no patient discomfort. The adjusted crown was temporarily cemented (Temp-bond; Kerr Dental, CA, USA).

The second zirconia crown for SA group was tried in the patient's oral cavity. Margin adaptation and proximal contact adjustment were performed like first zirconia crown. Full-arch pick-up impressions were taken with addition silicone impression material (Aquasil Ultra; Dentsply De Trey, Konstanz, Germany) without occlusal adjustment. The impression of the antagonist was taken using alginate (GC Aroma Fine Plus; GC Corporation, Tokyo, Japan). The cranio-maxilla relationship was recorded using a facebow (Hanau Springbow; Whip Mix, Louisville, KY, USA), and the interocclusal relationship without occlusal interference was recorded using silicone bite registration material (Blu-Mousse; Parkell, NY, USA). A protrusive check-bite record was obtained using baseplate wax (Keystone Industries, Gibbstown, NJ, USA).

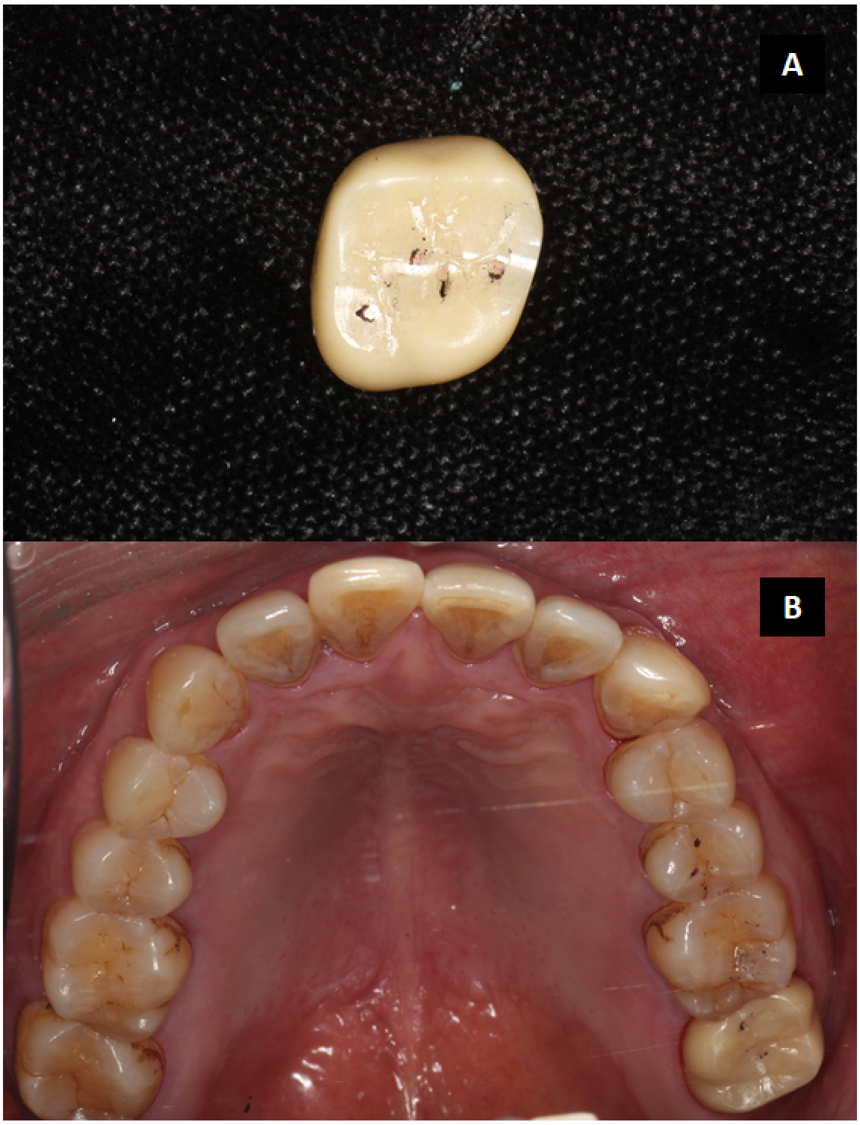

Figure 4. Clinical intraoral adjustment of fabricated restorations. (A) Occlusal surface of crown for which anatomic and functional occlusal adjustment was completed. (B) Intraoral photo of single crown restoration on upper second molar after final cementation.

3. Preparation of experimental data

3.1. Reference data (POST)

One month after temporary cementation, participants visited for final cementation. Any necessary additional adjustments were performed. The occlusal surface of single zirconia crown restoration after clinical adjustment was considered to reference data (POST) in this study. reference data (POST) were obtained by scanning the quadrant of the treated area using IOS (Trios 3, 3Shape A/S, Copenhagen, Denmark). After intraoral scanning, final cementation was performed (Figure 4B). The intraoral scan dataset was exported as a Standard Tessellation Language (STL) file. This dataset was belonged to reference data (POST) that had completed anatomic and functional occlusal adjustment.

3.2. No adjustment (NA) group

The duplicated reference CAD data (PRE) which was used to fabricate definitive restorations were exported to STL files. The duplicated reference CAD data (PRE) belonged to the NA group. The NA group represents conventional CAD workflow for occlusal design on static occlusion. Therefore, the duplicated reference CAD data (PRE) was intact used for the NA group.

3.3. Patient Specific Motion (PSM) group

In the PSM group, occlusal adjustment was performed by dynamic occlusion records obtained using the PSM. The reference CAD data (PRE) was duplicated and then loaded into the CAD software (3Shape Dental System; 3Shape A/S). While maintaining the established occlusal morphology and design of the single crown, the PSM function in smart tools was executed at the anatomic design stage for occlusal adjustment by dynamic occlusion (Figure 5). Running recorded articulation mode was performed, dynamic occlusion records were evaluated, and occlusal contact status was examined. The adapt designs button was clicked to remove occlusal interferences marked with red and yellow colors. In this way, the only additional adjustment on reference CAD data (PRE) was made by PSM function of the CAD software. The altered design was exported as an STL file and belonged to PSM group.

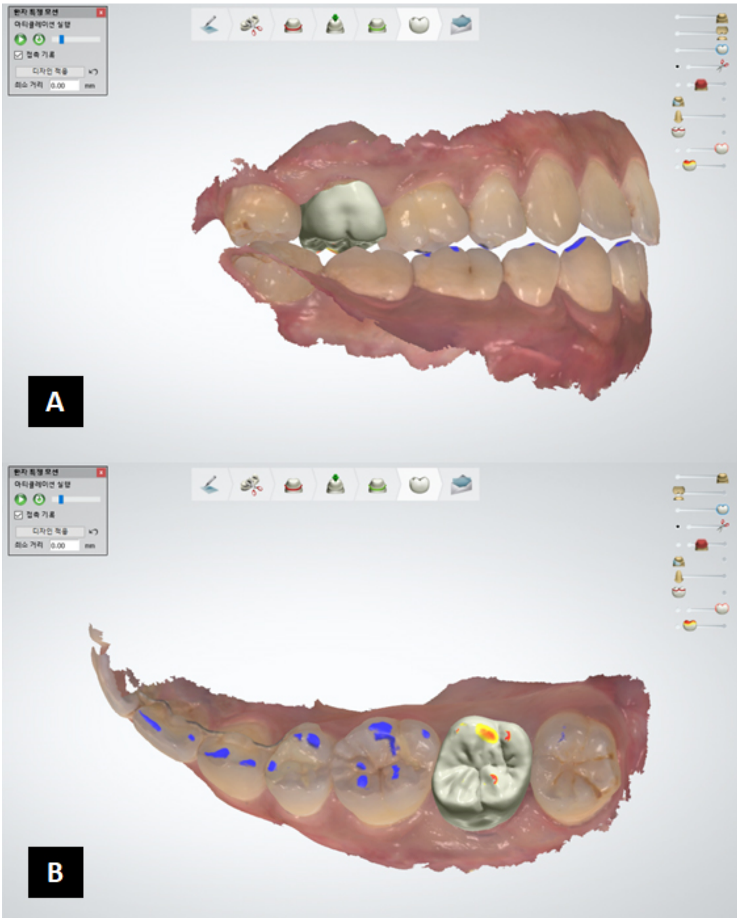

Figure 5. Occlusal adjustment using Patient Specific Motion tool. (A) In running recorded articulation mode, the recorded dynamic occlusion was visually reproduced in CAD software. (B) After running recorded articulation, the red and yellow colors meaning occlusal errors were marked in the crown design, and the marked areas were removed in CAD software. The blue colors mean the occlusal contact of adjacent teeth.

3.4. Semi-adjustable articulator (SA) group

Occlusal adjustment of the SA group was performed by a conventional mechanical semi-adjustable articulator (Hanau modular 190, Whip Mix, Louisville, KY, USA). To place the cast derived from the pick-up impression on the articulator, the cranio-maxilla relationship record by a facebow obtained at the try-in appointment was transferred to a semi-adjustable articulator. The maxilla-mandibular relationship was adjusted using an interocclusal record. After the cast was clinically remounted, the horizontal condylar angle was adjusted in the articulator using a protrusive check-bite. According to Weinberg et al (Weinberg 1963), Hanau's formula can be used for the calculation of lateral condylar guidance in the Hanau modular articulator system. The lateral condylar angle value was obtained using Hanau's formula.

$$L = \frac{H}{8} + 12$$

where L is the lateral condylar angle and H is the horizontal condylar angle.

After the adjustments of the articulator, the occlusal adjustment of the single crown was performed. Occlusal errors in MICP and eccentric movement were removed using articulating paper (Arti-Check Articulating Paper 40μm, Dr. Jean Bausch Gmbh & Co. KG; Koln, Germany; Hanel Shimstock; Coltene, OH, USA) (Brizuela-Velasco et al. 2015; Boyarsky, Loos, and Leknius 1999; Meng et al. 2010).

After the occlusion adjustment was completed, the occlusion was evaluated. The quadrant scan data were obtained using IOS (Trios 3; 3Shape A/S, Copenhagen, Denmark) and exported as an STL file. In this way, the adjustment using articulator was performed to the occlusal surface of zirconia crown fabricated from reference CAD data (PRE). The STL files of quadrant scan data was belonged to SA group.

4. Data processing

A dataset of four groups (POST, NA, PSM, SA) was obtained from 15 participants (n=15). All datasets of STL files were loaded into surface analyzing software (Geomagic Control X; 3D Systems, SC, USA). After importing data of four groups into the input data, the excess soft tissue area was trimmed. The STL files of the three experimental groups (NA, PSM, SA) were superimposed to reference data (POST) using the Align Between Measured Data function. The best-fit algorithm was used in the arrangement. The best-fit alignment is performed by the iterative closest point (ICP) algorithm for arrangement among mesh data (O'Toole et al. 2019). The alignment of scan data is processed by the minimization of the mesh distance error between each corresponding point. In order to avoid using the occlusal surface of the crown on the treated tooth for arrangement, the field of interest was limited to the occlusal, buccal, and lingual surfaces of the two premolars and one molar except treated tooth (Figure 6A). The tolerance level for model arrangement was set to 100μm (Al Hamad et al. 2020; Bosch, Ender, and Mehl 2014; Mangano et al. 2019 ; Wang et al. 2019 ; Yang et al. 2015).

In case of the valid alignment of the experimental model to the reference model, all areas of the teeth except the treated tooth were coded green (Figure 6B). After the valid arrangement was confirmed, the data were trimmed for leaving only the same occlusal surface of the four groups (Figure 7). The field of interest for 3D comparison was limited

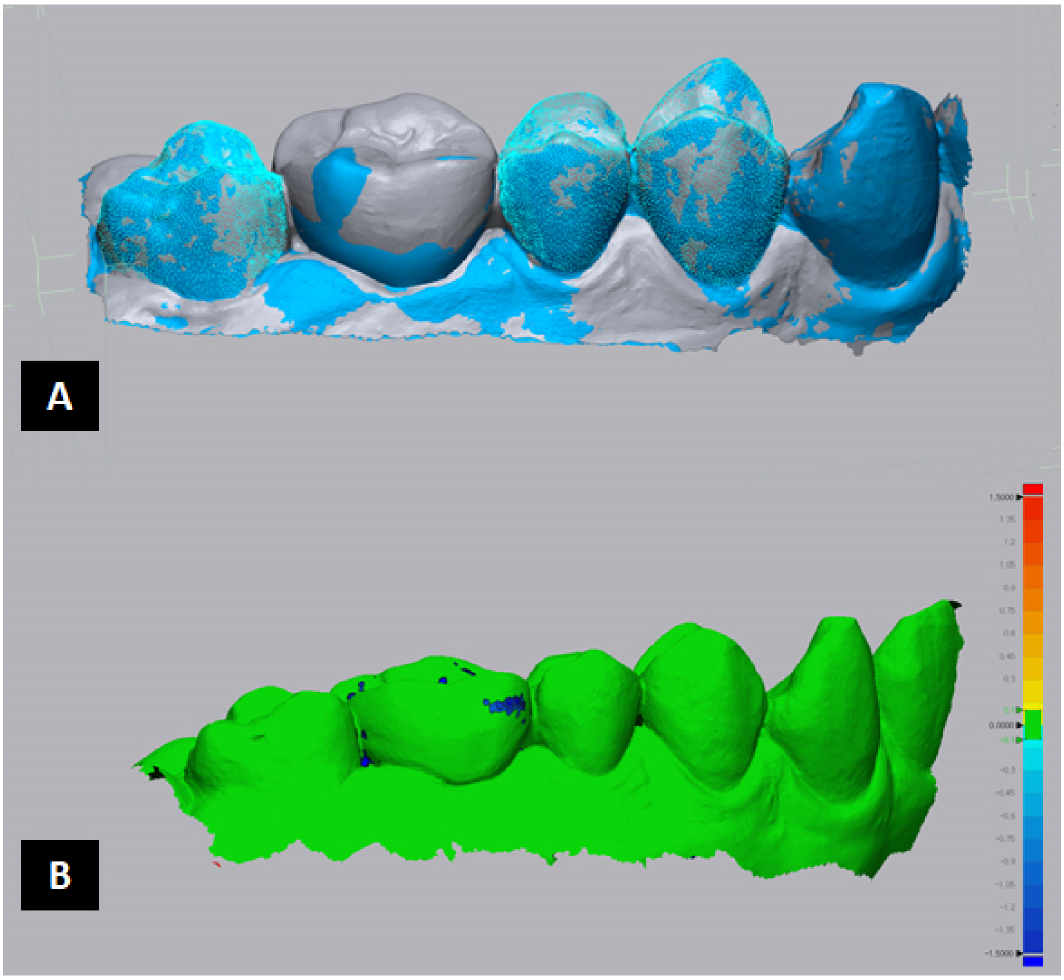

Figure 6. Superimposition of comparison data to reference data. (A) The field of interest for superimposition was limited to the occlusal, buccal, and lingual surfaces of the teeth except the treated tooth. (B) Validation of superimposition. The surfaces of all the teeth except that of the treated tooth were in tolerance range. The best-fit algorithm was used in the arrangement.

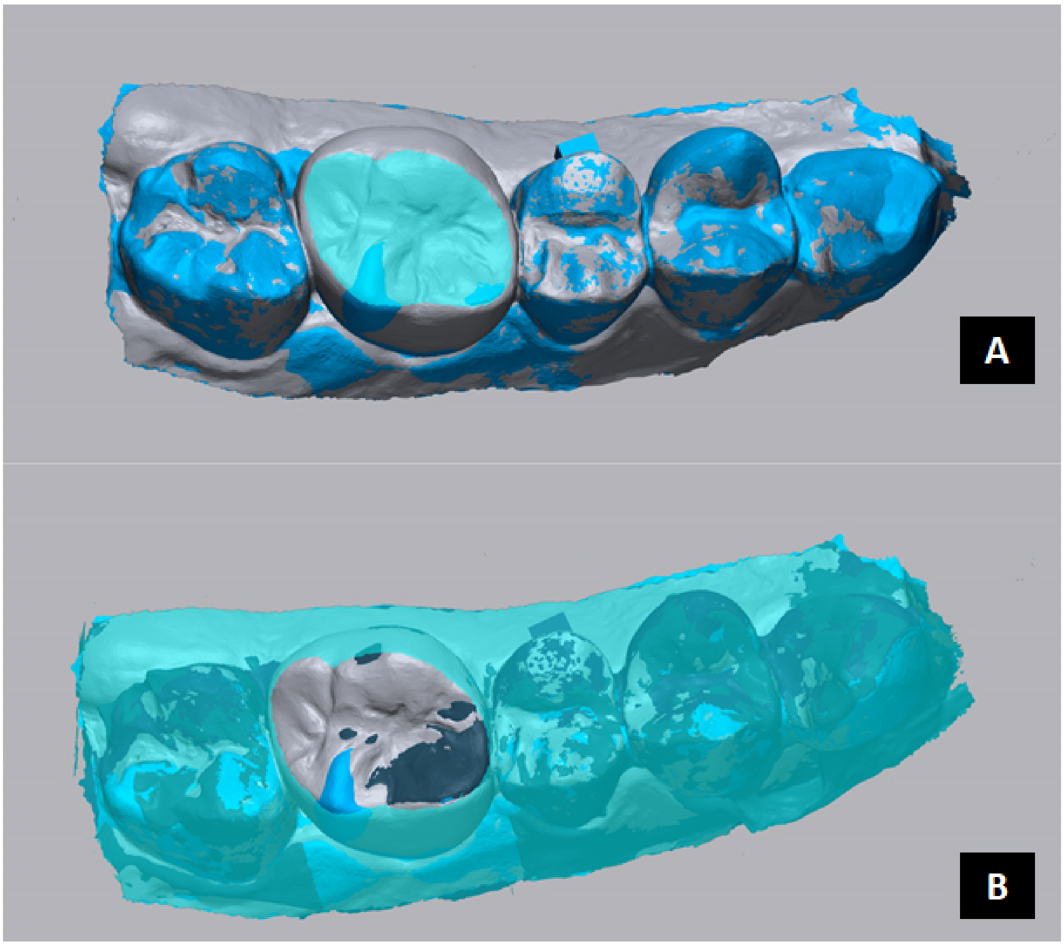

Figure 7. Trimming of model except occlusal surface. (A) Selection of occlusal surface. (B) Using the invert function of the selected area, the area not belonging to the occlusal surface was removed without residue.

to the occlusal surface by trimming off the rest. The 3D comparison was performed to obtain the root mean square (RMS) value, +Average (AVG) deviation value, -AVG deviation value, and in tolerance (%) value of the three experimental groups. These values were used in the quantitative analysis. The RMS was calculated by applying the formula (Schaefer et al. 2012; Kim et al. 2016; Wang et al. 2019).

$$RMS = \sqrt{\frac{\sum_{i=1}^{n}\left(X_{1,i} - X_{2,i}\right)^2}{n}}$$

where n is the total number of measuring points, $X_{1,i}$ is the measuring point i on the reference data, and $X_{2,i}$ is the measuring point i on the comparison data of the experimental group.

RMS can serve as a measure of how far deviations between the two different datasets vary from zero. In this study, assuming all systematic errors have been removed, the only possible deviation between the reference data (POST) and the comparison data (NA, PSM and SA) was the sum of points in which occlusal adjustment was required. Based on this, the RMS value represented the average amount of occlusal error of the comparison area.

To analyze the amount of occlusal error according to functional properties of the occlusal surface, the trimmed occlusal surface of reference data (POST) was split into three areas: functional cusp area, non-functional cusp area, central groove area. The reference line was determined by dividing the buccolingual dimension into three. The 3D comparison of each subdivided areas was performed using surface analyzing software (Figure 8)

For the assessment of area out of tolerance, a dataset including all points of deviation was exported to Comma-Separated Values (CSV) files. About total 2000 vertices from point clouds of occlusal surface mesh in STL data were exported to the CSV files. After Filter out vertices in tolerance from the dataset (Spreadsheet software, Excel 2016; Microsoft Co, Redmond, WA, USA), the RMS value of valid point belonged to the out of tolerance area was calculated.

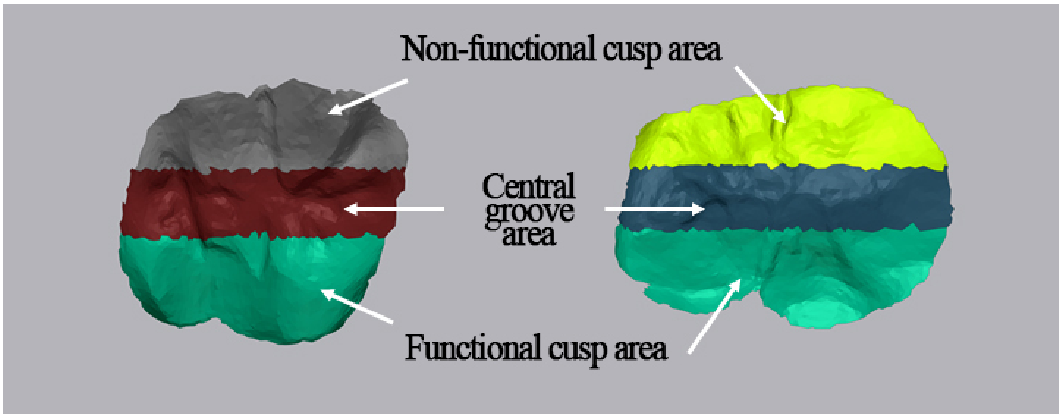

Figure 8. The representative images of subdivided areas according functional properties. To analyze the amount of occlusal error according to functional properties of the occlusal surface, the trimmed reference data was split into three areas. The reference line was determined by dividing the buccolingual dimension into three.

A color-coded map of the occlusal surface was generated for the qualitative analysis (Figure 9). The color-coded map represented the 3D deviation between the two datasets (POST versus PA, SA and PSM). The tolerance level in the color-coded map was 100μm. An area coded with green represented an area in tolerance, while an area with red or blue represented an area in positive deviation out of tolerance or in negative deviation out of tolerance, respectively.

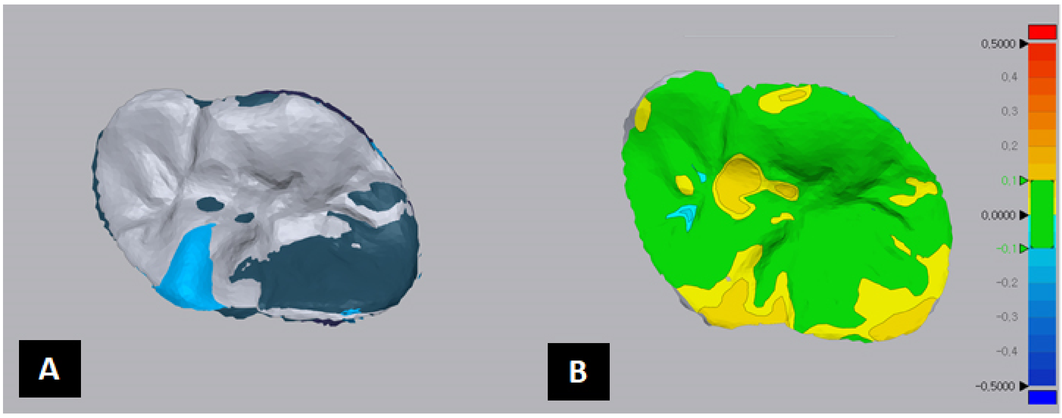

Figure 9. 3D comparison using surface analyzing software. (A) The field of interest was limited to the occlusal surface by trimming the rest of the model. (B) A color-coded map was generated to represent the deviation from the reference data (POST). The area coded in green represents in tolerance. The areas coded in yellow to red represent positive deviation out of tolerance. The areas coded in blue represent negative deviation out of tolerance. RMS, +AVG, -AVG, and in tolerance (%) values were calculated by the 3D comparison.

5. Statistical analysis

Normality test (Kolmogorov-Smirnov test) were performed for the RMS, +AVG deviation, -AVG deviation, and in tolerance (%) values of the NA, PSM, and SA groups.

The heterogeneity of variances between groups was measured by Levene's test (α = 0.05). An analysis of variance (one-way ANOVA) for the obtained values was used to compare the amount of occlusal error in single posterior crowns according to adjustment methods (NA, PSM and SA). Tukey`s honestly significant difference (HSD) tests was performed for post-hoc analysis. A value of α = 0.05 was considered significantly different. SPSS 23.0 (SPSS Inc., Chicago, IL, USA) was used for all statistical analyses.

III. RESULTS

1. Quantitative analysis

Table **1**-Table 4 shows the RMS ± standard deviation (SD) (μm), +AVG deviation ± SD (μm), -AVG deviation ± SD (μm), and in tolerance (%) ± SD analyzed of the three groups according to the entire occlusal surface, functional cusp area, central groove area, non-functional cusp area, respectively.

In the occlusal surface, The RMS values of the NA, PSM and SA groups were 168.2 ± 43.3μm, 152.1 ± 54.2μm, and 160.6 ± 84.6μm, respectively (

Table **1**). The RMS value of the PSM group was lower than those of the other groups, but there was no significant difference in the one-way ANOVA (p=0.797). The +AVG deviation values of the NA, PSM, and SA groups were 124.5 ± 45.3μm, 112.3 ± 46.3μm, and 135.8 ± 52.7μm, respectively. The -AVG deviation values of the NA, PSM and SA groups were -87.7 ± 73.1μm, -93.1 ± 61.5μm, and 91.5 ± 83.8μm, respectively. The in tolerance (%) values of the NA, PSM and SA groups were 90.5 ± 6.7%, 92.9 ± 5.9%, and 91.5 ± 8.3%, respectively. The one-way ANOVA showed no statistically significant difference in RMS value, +AVG deviation, -AVG deviation, or in tolerance (%) between the three groups (p=0.797, 0.443, 0.980, 0.658, respectively). The analogous tendency was indicated in the subdivided area (Figure 10, Figure 11).

Table 1. Analysis of deviation of entire occlusal surface among three groups.

	NA	PSM	SA
RMS (μm)	168.2 ± 43.3	152.1 ± 54.2	160.6 ± 84.6
+AVG (μm)	124.5 ± 45.3	112.3 ± 46.3	135.8 ± 52.7
-AVG (μm)	-87.7 ± 73.1	-93.1 ± 61.5	-91.5 ± 83.8
In Tol (%)	90.5 ± 6.7	92.9 ± 5.9	91.5 ± 8.3

		Sum of Squares	df	Mean Square	F	Sig.
RMS	Between Groups	.002	2	.001	.228	.797
	Within Groups	.180	42	.004		
	Total	.182	44			
+AVG	Between Groups	.004	2	.002	.831	.443
	Within Groups	.105	42	.002		
	Total	.109	44			
-AVG	Between Groups	.000	2	.000	.020	.980
	Within Groups	.242	42	.006		
	Total	.242	44			
In Tol	Between Groups	45.225	2	22.613	.423	.658
	Within Groups	2243.780	42	53.423		
	Total	2289.005	44			

The RMS value represents the amount of deviation from reference data. Data are presented as means ± standard deviation. RMS, root mean square. +AVG, positive average deviation. -AVG, negative average deviation.

NA, the group with no adjustment. PSM, the group adjusted using Patient Specific Motion. SA, the group adjusted with a semi-adjustable articulator.

Table 2. Analysis of deviation of functional cusp area among three groups.

	NA	PSM	SA
RMS (µm)	170.6± 55.6	153.3 ± 60.8	168.3 ± 16.4
+AVG (µm)	125.0 ± 57.8	120.9 ± 58.2	138.0 ± 60.6
-AVG (µm)	-74.5 ± 65.3	-73.7 ± 53.3	-77.7 ± 75.3
In Tol (%)	88. 2 ± 11.9	90.7 ± 11.5	89.0 ± 10.8

		Sum of Squares	df	Mean Square	F	Sig.
RMS	Between Groups	.003	2	.001	.315	.732
	Within Groups	.172	41	.004		
	Total	.174	43			
+AVG	Between Groups	.002	2	.001	.320	.728
	Within Groups	.156	42	.004		
	Total	.159	44			
-AVG	Between Groups	.000	2	.000	.014	.986
	Within Groups	.201	42	.005		
	Total	.201	44			
In Tol	Between Groups	47.943	2	23.971	.171	.843
	Within Groups	5884.113	42	140.098		
	Total	5932.056	44			

The RMS value represents the amount of deviation from reference data. Data are presented as means ± standard deviation. RMS, root mean square. +AVG, positive average deviation. -AVG, negative average deviation.

NA, the group with no adjustment. PSM, the group adjusted using Patient Specific Motion. SA, the group adjusted with a semi-adjustable articulator.

Table 3. Analysis of deviation of central groove area among three groups.

	NA	PSM	SA
RMS (μm)	154.9 ± 47.9	140.2 ± 45.8	121.9 ± 68.5
+AVG (μm)	103.3 ± 45.0	89.2 ± 45.7	106.5 ± 57.5
-AVG (μm)	-93.8 ± 74.1	-95.9 ± 67.3	-76.8 ± 74.2
In Tol (%)	91.9 ± 9.0	94.3 ± 5.8	94.6 ± 8.0

		Sum of Squares	df	Mean Square	F	Sig.
RMS	Between Groups	.008	2	.004	1.264	.293
	Within Groups	.136	42	.003		
	Total	.144	44			
+AVG	Between Groups	.003	2	.001	.478	.623
	Within Groups	.111	42	.003		
	Total	.114	44			
-AVG	Between Groups	.003	2	.002	.297	.744
	Within Groups	.233	42	.006		
	Total	.236	44			
In Tol	Between Groups	64.641	2	32.320	.505	.607
	Within Groups	2686.996	42	63.976		
	Total	2751.637	44			

The RMS value represents the amount of deviation from reference data. Data are presented as means ± standard deviation. RMS, root mean square. +AVG, positive average deviation. -AVG, negative average deviation. In Tol, in tolerance.

NA, the group with no adjustment. PSM, the group adjusted using Patient Specific Motion. SA, the group adjusted with a semi-adjustable articulator.

Table 4. Analysis of deviation of non-functional cusp area among three groups.

	NA	PSM	SA
RMS (μm)	162.2 ± 53.1	131.8 ± 45.4	146.3 ± 74.5
+AVG (μm)	122.4 ± 58.9	99.9 ± 41.4	126.4 ± 51.5
-AVG (μm)	-89.6 ± 71.3	-88.5 ± 54.2	-81.4 ± 82.5
In Tol (%)	91.1 ± 8.8	95.2 ± 5.1	91.8 ± 11.9

		Sum of Squares	df	Mean Square	F	Sig.
RMS	Between Groups	.007	2	.003	.934	.401
	Within Groups	.156	42	.004		
	Total	.163	44			
+AVG	Between Groups	.006	2	.003	1.092	.345
	Within Groups	.118	42	.003		
	Total	.124	44			
-AVG	Between Groups	.001	2	.000	.055	.946
	Within Groups	.222	42	.005		
	Total	.223	44			
In Tol	Between Groups	139.970	2	69.985	.794	.459
	Within Groups	3702.266	42	88.149		
	Total	3842.236	44			

The RMS value represents the amount of deviation from reference data. Data are presented as means ± standard deviation. RMS, root mean square. +AVG, positive average deviation. -AVG, negative average deviation. In Tol, in tolerance.

NA, the group with no adjustment. PSM, the group adjusted using Patient Specific Motion. SA, the group adjusted with a semi-adjustable articulator.

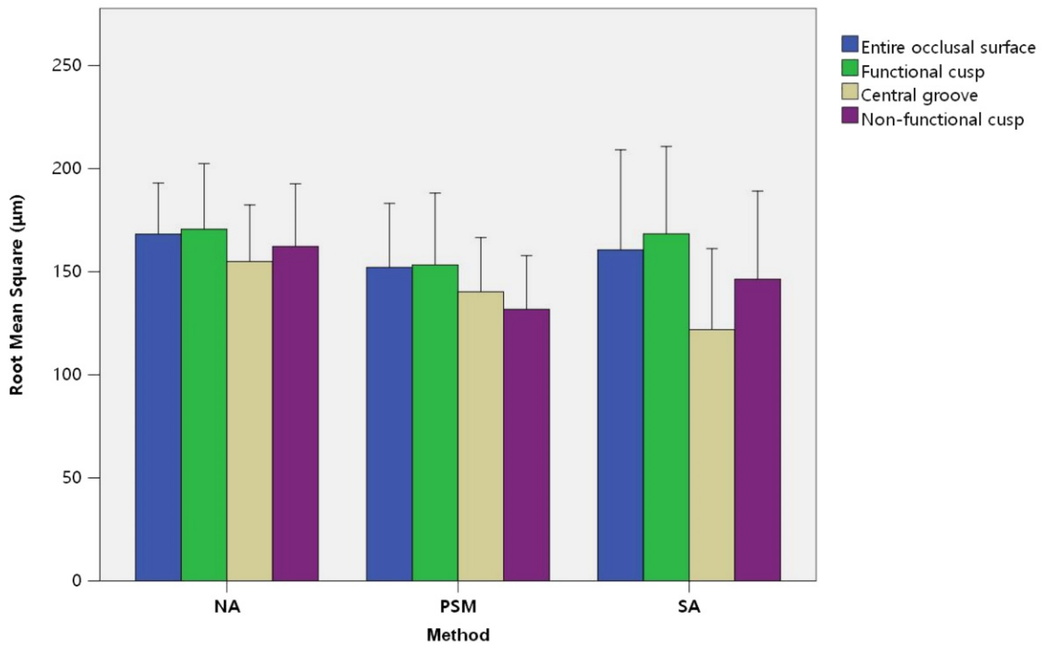

Figure 10. Amount of deviation in four types of occlusal surface compared to reference data. The mean of RMS of the PSM group was lower than those in the other groups. However, there was no significant difference in the one-way ANOVA between the three groups.

NA; the group with no adjustment. PSM; the group adjusted using Patient Specific Motion. SA; the group adjusted with a semi-adjustable articulator. RMS, root mean square.

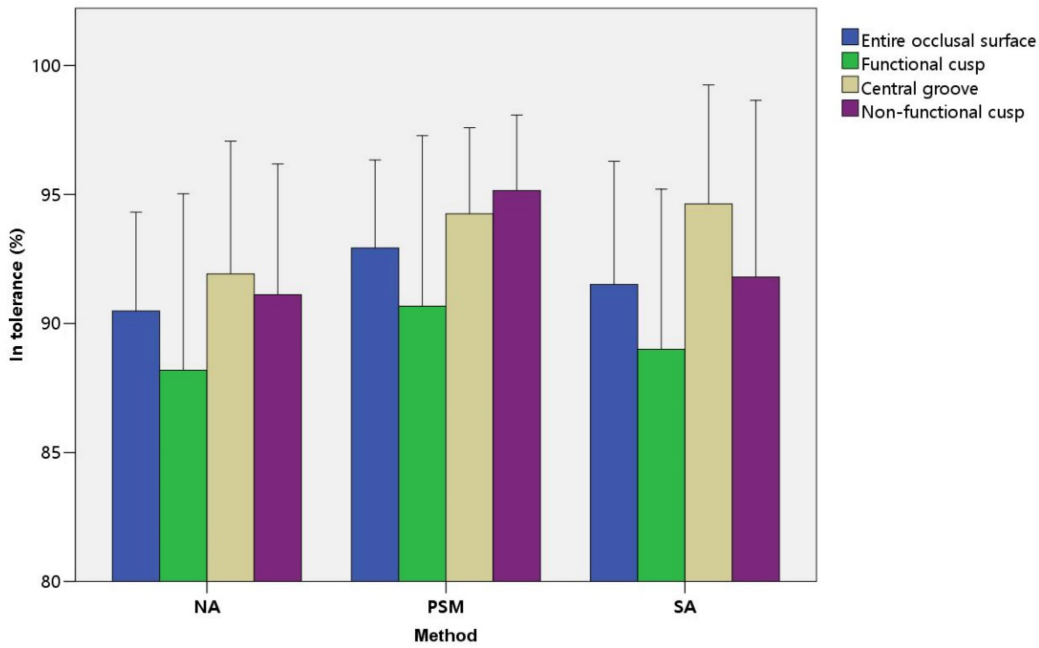

Figure 11. Amount of in tolerance (%) in four types of occlusal surface area. The mean of in tolerance (%) of the PSM group was higher than those in the other groups. However, there was no significant difference in the one-way ANOVA between the three groups.

NA; the group with no adjustment. PSM; the group adjusted using Patient Specific Motion. SA; the group adjusted with a semi-adjustable articulator.

For the area out of tolerance regarded as occlusal errors in this study, The results were described in Table 5 and Figure 12. There were significant differences in the RMS and +AVG values of the NA, PSM and SA groups (p=0.028, p=0.040). The RMS values calculated from the points of the out of tolerance area were 257.0 ± 73.9μm in the NA group, 202.3 ± 39.3μm in the PSM group, and 222.9 ± 41.9μm in the SA group. In post-hoc analysis, the RMS of PSM groups was statistically lower than the NA groups. The +AVG values calculated from the out of tolerance area were 210.9 ± 48.6 μm in the NA group, 173.1 ± 31.3μm in the PSM group, and 194.7 ± 36.4μm in the SA group. In post-hoc analysis, the +AVG of PSM groups was statistically lower than the NA groups.

Table 5. Analysis of deviation of the out of tolerance area among three groups.

	NA	PSM	SA	P-value
RMS (μm)	257.0 ± 73.9 [a]	202.3 ± 39.8 [b]	222.9 ± 41.9 [ab]	0.028
+AVG (μm)	210.9 ± 48.6 [a]	173.1 ± 31.3 [b]	194.7 ± 36.4 [ab]	0.040
-AVG (μm)	-228.9 ± 79.7	-189.8 ± 40.5	-190.6 ± 38.6	0.106

		Sum of Squares	df	Mean Square	F	Sig.
RMS	Between Groups	.023	2	.011	3.901	.028
	Within Groups	.123	42	.003		
	Total	.146	44			
+AVG	Between Groups	.011	2	.005	3.482	.040
	Within Groups	.065	42	.002		
	Total	.076	44			
-AVG	Between Groups	.015	2	.007	2.371	.106
	Within Groups	.133	42	.003		
	Total	.148	44			

The RMS value represents the amount of deviation from reference data. Data are presented as means ± standard deviation. +AVG, positive deviation average, -AVG, negative deviation average, RMS, root mean square. Superscript lowercase letters indicate significant differences of RMS between three groups.

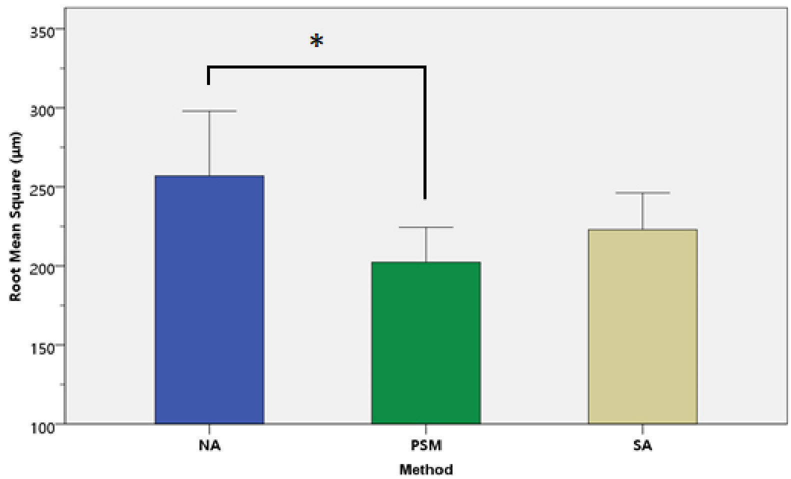

Figure 12. Amount of deviation of the out of tolerance area among three groups. The RMS value represents the amount of deviation from reference data (POST). Asterisk (*) indicate significant differences of RMS between groups in post hoc analysis.

NA; the group with no adjustment. PSM; the group adjusted using Patient Specific Motion. SA; the group adjusted with a semi-adjustable articulator. RMS, root mean square.

2. Qualitative analysis

The color-coded map represents the occlusal surface deviation between the comparison data of the three experimental groups (NA, PSM and SA) and the reference data (POST). The representative results of the qualitative analysis are presented in Figure 13.

In the three groups, most of the occlusal surface was coded green. The red-coded areas meaning occlusal error were mainly on the cusp tip and inclined plane of the cusp. In some cases of the NA and PSM groups, the central groove was coded blue. The PSM group showed decreased extent of occlusal error compared to the NA groups (Figure 13). The areas of occlusal error were reduced mainly in the triangular ridge, the lingual inclined plane of the buccal cusp, and the buccal inclined plane of the lingual cusp. However, in the cusp tip and central fossa, the areas of occlusal error remained. The SA group also showed a decrease in the red-coded area compared to the NA group. The position of reduced areas was similar to those in the PSM group. However, there were some cases in which an extensive negative deviation area appeared, meaning overcorrection (Figure 13B). Also, in some cases, reduced red-coded areas are observed in different positions between the PSM and SA groups (Figure 13C). The NA group showed the remained areas of occlusal errors. These areas were mainly on the cusp tip, triangular ridge, and inclined plane of the cusp.

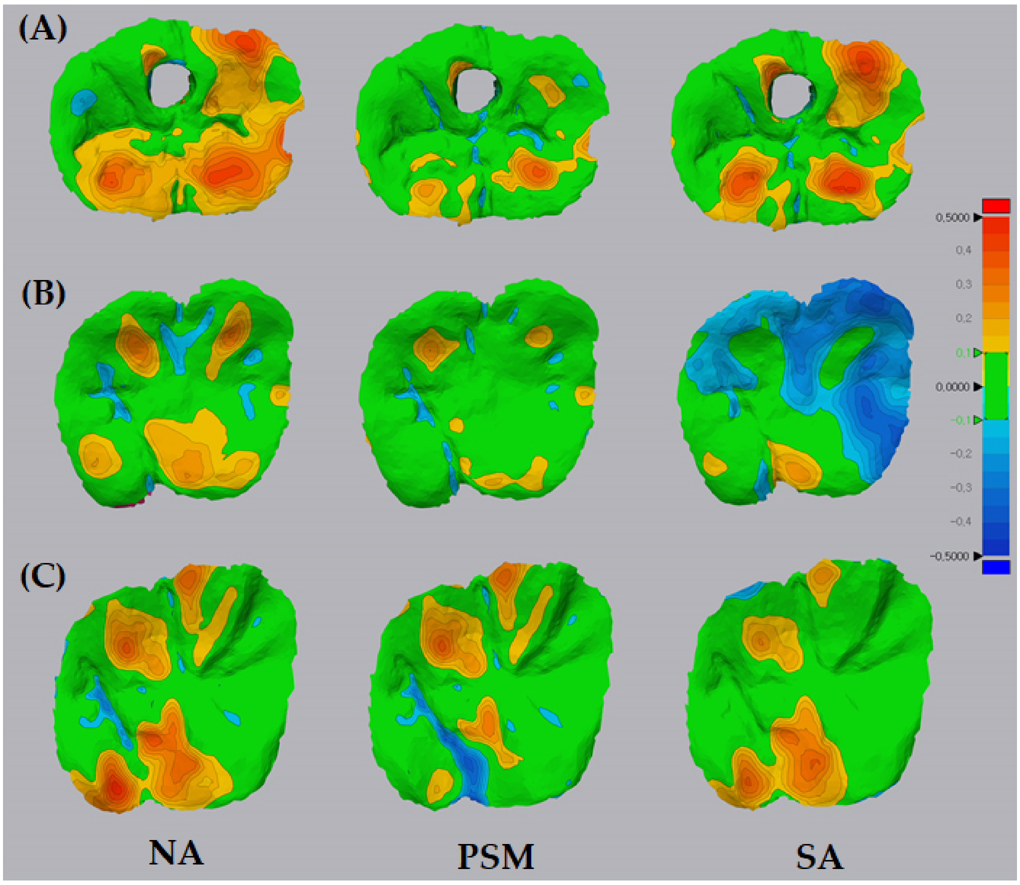

Figure 13. Representative images of color-coded maps showing deviation among comparison data (NA, PSM, and SA) and reference data (POST). Red-coded areas (i.e., positive deviation out of tolerance) suggest occlusal error requiring clinical occlusal adjustment. (A) PSM and SA groups show less red-coded areas than the NA group. (B) In some cases, there were extensively blue-coded areas in the SA group indicating over-correction. (C) Reduced red-coded areas are observed in different positions between the PSM and SA groups.

IV. DISCUSSION

The purpose of this study was to assess the amount of occlusal error in the occlusal surface adjusted with the PSM method compared to other methods using the traditional mechanical semi-adjustable articulator or current CAD software. The traditional method depended on the occlusal knowledge of the clinician and the skill of the technician using the mechanical articulator to decrease occlusal error (Sornsuwan and Swain 2011). For more accurate fabrication, the patient's condylar and anterior guidance and cranio-maxilla-mandibular relationship were adjusted to a semi-adjustable articulator or fully adjustable articulator (Hobo, Shillingburg, and Whitsett 1976; Ak et al. 2014). In this manner, simulated mandibular movement contributes to reduced occlusal errors in the occlusal design (Hobo, Shillingburg, and Whitsett 1976).

With the development of digital technology, digital workflow is adapted to many areas of dentistry including single crown restorations (Beuer, Schweiger, and Edelhoff 2008; Strub, Rekow, and Witkowski 2006). Recently, dynamic occlusion has been used in CAD software by tracking and reproducing the mandibular movement (Fang and Kuo 2009; Mehl 2012). The PSM is one such method. Since this method uses only IOS, it reproduces the mandibular movement simply and quickly. However, there are few research studies on whether digital workflows using the digitally reproduced dynamic occlusion are clinically superior to the conventional method (Mehl 2012).

In this study, the possible deviation between the reference data (POST) and the comparison data (NA, PSM and SA) is the sum of points in which occlusal adjustment was required. In other words, the RMS value represents the average amount of occlusal error in the comparison area of experimental groups. The RMS values of entire occlusal surface in the PSM, NA, and SA groups were 168.2 ± 43.3μm, 152.1 ± 54.2μm, and 160.6 ± 84.6μm, respectively. However, The RMS values from the out of tolerance area were 257.0 ± 73.9μm, 202.3 ± 39.8μm, and 222.9 ± 41.9μm, respectively. In case of the latter, there was a statistically significant difference among the three groups. The null hypothesis was partially rejected. The result of the quantitative analysis suggests that the overall occlusal surface did not differ among the three groups in single posterior crown restorations. It also suggests that all groups had occlusal errors to some extent and required clinical intraoral adjustment. However, in level of the out of tolerance area regarded as occlusal error, the extent of error was decreased in the group with adjusted PSM. The RMS value does not measure the clinical quality but only the difference between experimental data and reference data. Therefore, clinical quality such as clinical adjustment time was need to be evaluated for dynamic occlusion recorded by PSM (Wang et al. 2020).

To the author's knowledge, there are few studies comparing occlusal morphology designed in dynamic occlusion recorded using optical devices to that designed in static occlusion. In a qualitative analysis by Olthoff et al. (Olthoff et al. 2000), an occlusal morphology of a single crown using the FGP technique with the CAD/CAM system was compared to a crown with static occlusion. The difference was mainly on the distobuccal part on the occlusal surface. However, the number of occlusal contacts was enough to functional occlusion in all groups. No statistical analysis was performed in this study. Lin et al. (Lin et al. 2017) reported that a single crown designed by the FGP technique showed more significant changes in occlusion time and disocclusion time than those from conventional single crowns. The occlusion and disocclusion time were measured using a computerized occlusal analysis system (T-scan). The result indicated easier occlusal adjustment in the FGP single crown. However, the differences were clinically relevant small. In another study, Saini et al. studied the occlusal surface designed using a virtual mastication simulator. (Saini et al. 2009) Comparing the obtained results with the actual tooth, these subject-specific functional occlusal surfaces showed that errors in functional and static occlusion ranged between 90μm and 200μm. The result of this study is similar to that of our study.

In the color-coded map analysis, the areas of occlusal errors among the three groups were coded green. Occlusal interference mainly occurred in the lingual inclined plane of the buccal cusp and in the buccal inclined plane of the lingual cusp (Figure 13). If this occlusal interference was not eliminated even in the clinical occlusal adjustment procedure, various signs, such as local tooth pain, loosening of the tooth, excessive wear, and a change in chewing stroke patterns, could appear (Clark et al. 1999; Dawson 1983; Watamoto et al. 2008; Fang and Kuo 2009). In addition, it is hard to identify occlusal errors in the patient's mouth directly due to factors such as the presence of saliva, limitation of visualization, and incomplete marking ability of articulating paper (Davies, Gray, and Smith 2001; Altarakemah et al. 2020). In this aspect, any possible occlusal errors should be minimized in the occlusal design procedure. Considering the significant difference of the RMS in the out of tolerance area, the adjustment using dynamic occlusion such as the PSM might be helpful to eliminate the errors in advance.

Both in the PSM and SA groups, the area of occlusal error decreased in the color-coded map. However, in the SA group, there were cases in which excessive occlusal adjustment occurred. If the ipsilateral laterotrusion or incisal guide angle is not adjusted correctly in the articulator, overcorrection may result (Olthoff et al. 2007). Most semi-adjustable articulators have straight rather than convex condylar pathways (Gracis 2003b). This feature, called the “safety factor,” could contribute to excessive occlusal adjustment (Dawson 2006). The semi-adjustable articulator simply reproduces the static jaw position by reproducing determinants of occlusion, such as condylar guidance and anterior guidance (Dawson 1983). Because it does not directly reconstruct actual mandibular movement, there is a limitation in eliminating occlusal interference during eccentric movement on mechanical articulator in advance (Kim et al. 2019). On the contrary, technical errors that occur in laboratory procedures, such as cast mounting, and clinical procedures, such as bite registration, might contribute to increased occlusal errors (Gracis 2003b, 2003a).

In the NA group, the amount of occlusal error remained because the occlusal surface was designed using only static occlusion. In this case, the skill and experience of the technician are the main concerns when designing the occlusal morphology (Fang and Kuo 2009). The complete elimination of occlusal error area was not easy due to the lack of mandibular movement information.

Also, In the PSM method which is using marker-less mandibular motion tracking system, not all occlusal errors can be reduced because of inaccuracy caused by various factors. Some studies have reported that the accuracy of tracking mandibular motion system is 0.2–0.3mm (Fang and Kuo 2009; Saini et al. 2009). In addition, movement in loaded teeth and adjacent teeth is hard to be recorded and estimated with an optical tracking device (Bando et al. 2009). The deformative movement of the mandible and teeth which may be caused by the muscle forces exerted during functional movement is not recorded in tracking mandibular motion (van Essen et al. 2005). These limitations may contribute to decreased accuracy of motion records, which leads to the occlusal error. In addition, limitations during intraoral scanning procedure due to tip size, scanning speed, sample frequency might affect the accuracy of recording (Mangano et al. 2017; Tanaka et al. 2016). The dynamic mandibular movement is recorded on the buccal side of the teeth without a marker attachment in the PSM. As other marker-less systems, excessive movement over the sampling frequency in opening or horizontal movement makes the defective frame in records called "judder effect" (Tanaka et al. 2016). However, PSM method is meaningful as a simple alternative tool as compared to conventional methods (Fang and Kuo 2009). Current mandibular motion tracking based on optical tracking devices has some disadvantages, such as increased cost, time consumed for preparing devices, and existence of a learning curve (Fang and Kuo 2009). In addition, the existence of the marker makes clinical procedures time-consuming and technique sensitive (Zoss et al. 2019). The marker attached to the teeth might interfere with the movement of mandible (Tanaka et al. 2016).

However, like the buccal bite registration, the PSM method make it possible to simply record the eccentric movements in the buccal surface of the posterior tooth using only IOS without additional marker attachment.

In our study, qualitative analysis and quantitative analysis were performed by evaluating three-dimensional discrepancy between two aligned surfaces. Occlusal surface scan data was obtained using an intraoral scanner, which is currently known to be valid for the measurement of single teeth or quadrants (Lancellotta et al. 2019; Nedelcu et al. 2018). The commercial software used for our study, Geomagic control X, process best-fit alignment based on the ICP algorithm. Standard best-fit alignment minimizes mesh distance errors for all vertices of a dataset (O'Toole et al. 2019). However, if there is a large defect or difference (i.e. occlusal surface of treatment tooth in case of our study) between the dataset, this can cause an erroneous result during the metrological alignment process (O'Toole et al. 2019). To avoid this, a reference best-fit alignment has been proposed in recent research (Wulfman, Koenig, and Mainjot 2018). In a reference best-fit alignment, the alignment process of dataset is restricted to operator-identified areas of the dataset where the least change is expected (Stober et al. 2014). In our study, the occlusal surface of treatment tooth was excluded from the field of interest for an arrangement based on a reference best-fit alignment. Furthermore, recent study suggests that volumetric analysis based on custom ICP algorithms has high reliability of analysis in addition to linear analysis by commercial software (Pagano et al. 2019).

When calculating the deviation from the reference data, the precision of IOS and control of the milling process and sintering shrinkage can influence the accuracy of deviation. The tolerance range of 100μm was determined in consideration of these factors (Al Hamad et al. 2020; Bosch, Ender, and Mehl 2014; Mangano et al. 2019; Wang et al. 2019; Yang et al. 2015). In previous studies, the precision of the quadrant scan using Trios 3 was about 50μm (Mangano et al. 2019; Wang et al. 2019; Yang et al. 2015). The accuracy of the manufacturing and post-processing of a milled single zirconia crown was about 50μm (Al Hamad et al. 2020; Bosch, Ender, and Mehl 2014; Mangano et al. 2019). Because STL files from CAD were used in the PSM and NA groups, negative deviation occurred in the occlusal groove, but the effect of systemic error might have been minimized in the rest of the area. However, the relatively broad range of tolerance level was a limitation of this study, in addition to the heterogeneity of occlusal surface data among the three groups.

This study is limited to compare the amount of occlusal error in single posterior crown restoration. Future research should clinically investigate the effect of PSM recording by different positions and spans of restoration such as single anterior restoration or long-span fixed partial denture. Moreover, a randomized controlled clinical trial is required to reduce the dataset heterogeneity between the experimental groups and enhance the evidence level.

V. CONCLUSION

Within the limitations of this clinical study, the following conclusions were drawn:

In the quantitative analysis, there was a statistically reduced occlusal error in the group with adjustments using PSM on the out of tolerance area as compared to the NA group designed based on static occlusion. However, no significant difference in the amount of occlusal error was revealed in the entire and subdivided occlusal surface level between the PSM and conventional methods (NA, SA).

In the qualitative analysis, the decrease of the occlusal error areas was mainly displayed in the inclined plane of the cusp and triangular ridge on the occlusal surface in a single posterior crown adjusted with the PSM.

The PSM may be a simple and effective alternative tool that shows clinically acceptable results in the occlusal morphology of a single posterior crown.

VI. REFERENCE

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Abstract (Korean)

환자 특이 모션과 기존의 방법을 적용하여 조정한 후방 단일 크라운의 교합조정량의 비교

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이 예 찬

최근 들어, 구강 내 교합 조정을 최소화하기 위해 기능적이고 해부학적인 교합면 형태를 가진 보철물을 디자인할 수 있는 디지털 워크플로우의 개발이 이루어지고 있다. 환자 특이 모션은 구강 스캐너를 이용하여 하악의 움직임을 추적함으로써 캐드 소프트웨어 상에서 동적인 교합 관계를 재현하는 도구이다. 본 임상연구의 목적은 기존의 방법과 비교하였을 때, 환자 특이 모션을 사용하여 조정한 후방 구치부 단일 크라운 교합면에서 교합 오차를 비교하기 위한 것이다. 총 열다섯명이 이 실험에 참여하였으며 모든 참여자는 구치부 단일 크라운 수복을 필요로 하였다. 구강

스캐너를 이용하여 치료할 영역의 사분악을 스캔하고, 캐드 소프트웨어 상에서 보철물의 설계를 하였다. 교합면 형태는 구강스캐너를 통해 기록한 정적 교합을 기초로 설계하였고, 5 축 밀링 머신을 사용하여 크라운을 제작하였다. 제작된 크라운을 임상 교합조정 하였으며, 구강내 교합조정을 마친 후, 치료받은 부위의 사분악 스캔 데이터를 구강 스캐너를 이용하여 채득하고 이를 참조 데이터로 삼았다. No adjustment (NA) 군에서는, 정적 교합을 기초로 설계한 크라운의 캐드 디자인을 비교 데이터로 삼았다. Patient Specific Motion (PSM) 군에서는, NA 군의 캐드 디자인을 복제한 후, 환자 특이 모션 도구를 이용하여 기록한 동적인 교합 관계를 사용하여 교합면의 형태를 조정하고 이를 비교 데이터로 하였다. Semi-articulator (SA) 군에서는, NA 군의 캐드 데이터를 바탕으로 제작된 보철물을 반조절성 교합기 상에서 교합 조정하고 이를 비교 데이터로 하였다. 표면 분석 소프트웨어를 사용하여 참조데이터와 세 그룹의 비교 데이터를 Best-fit 알고리즘을 이용하여 중첩하였다. 중첩의 유효성을 확인한 후, 중첩된 모형을 동일한 영역의 교합면만 남기기 위하여 다듬었다. 참조 데이터와 비교데이터 간의 삼차원 비교를 전체교합면과 기능 교두 영역, 비기능 교두 영역, 중심구 영역에서 시행하여 RMS, +AVG, -AVG, In tolerance 값을 계산하였다. 더불어 공차를 벗어난 영역으로 제한하여 RMS, +AVG, -AVG 값을 계산하였다. 교합면의 변위를 나타내는 컬러 코드 맵을 생성하여 분석하였다. 정성분석시, 공차를 벗어난 영역은 교합 오차로 간주하였다. 공차를 벗어난 영역에서 one-way ANOVA 시험결과는 세 그룹 간에 RMS 와 +AVG 값이 통계적으로 유의한 차이가 있음을 나타내었다 (p=0.028, 0.040). NA, PSM, SA 군의 RMS 평균과 표준편차는 각각 257.0 ± 73.9μm, 202.3 ± 39.3μm, 222.9 ± 41.9μm 였다. NA, PSM, SA 군의 +AVG 평균과 표준편차는 각각 210.9 ± 48.6μm, 173.1 ± 31.3μm, 194.7 ± 36.4μm 였다. 사후 분석에서, PSM 군의 RMS 및 +AVG 는 NA 군보다 낮았다. 전체 교합면 영역과 삼등분한 영역에서는 통계적인 유의성이 나타나지 않았다. 정성분석시, PSM 을 이용하여 조정한 후방 구치부 단일 크라운의 경우 컬러 코드 맵상에서 교합 오차 영역의 감소를 교두의 경사면과 교합면의 삼각 융선에서 관찰 할 수 있었다. 본 임상 연구의 결과에 기초하여, 다음과 같이 결론 내릴 수 있다. 정량분석시, 기존의 캐드 소프트웨어나 전통적인 반 조절성 교합기를 사용한 방법과 비교하였을 때, 환자 특이 모션으로 조정된 후방 단일 구치부 크라운은 공차를 벗어난 영역에서 교합 오차가 유의하게 감소하였다. 하지만 전체 교합면이나 삼등분한 영역에서 교합 오차량은 유의한 차이가 없었다. 정성 분석에서, PSM 군은 컬러 코드 맵상에서 교합 조정량의 감소를 나타내었다. 이상의 결과를 토대로 환자 특이 모션은 단일 후방 구치부 크라운의 교합 조정에 있어 임상적으로 허용가능한 결과를 보여주는 효과적이고 간단한 대안의 하나로 사료된다.

핵심되는 말: 광학스캐너; 교합기; 동적교합; 캐드캠; 크라운