Effect of artifact area on cone beam computed tomography scans when integrated with intraoral scans

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Objective. The aim of this study was to examine whether integration accuracy increases upon removing artifacts from the registration area when integrating maxillofacial cone beam computed tomography (CBCT) scans and intraoral scans.

Study Design. Three methods were implemented according to the region of interest (ROI): R0, all teeth included as the registration area (artifacts included); R1, anterior teeth included as the registration area (artifacts in premolars and molars not included); and R2, anterior teeth and second molars included as the registration area (artifacts in premolars and first molars not included). Discrepancies between the 2 images were evaluated by using color-mapping methods. The average surface distance was calculated by measuring the shell/shell deviations for overall discrepancies and 3-dimensional distances between the surface points on the 2 images for registration discrepancies.

Results. The R1 method showed more discrepancies between the CBCT and intraoral scans compared with the other 2 methods. The R2 method showed smaller overall discrepancy values compared with the R1 method. Most CBCT artifacts were located in the posterior area. Registration discrepancies were greatest in the x-dimension.

Conclusions. The results suggest that intraoral and CBCT scans might be integrated by using a registration method that involves exclusion of artifacts and inclusion of the second molar on both sides. (Oral Surg Oral Med Oral Pathol Oral Radiol 2021;131:468−474)

For accurate diagnosis and treatment planning of a maxillofacial deformity, precision analysis of the maxillofacial relationship and occlusion is required. A precision 3-dimensional (3-D) craniofacial model can be fabricated by integrating a digital dental model into a maxillofacial 3-D image. Cone beam computed tomography (CBCT) is superior at reconstructing maxillofacial images. However, its limitation is an inability to represent occlusion accurately, in particular, the occlusal dental surfaces, on the images.[1] For this reason, many attempts have been made to replace the dental part of the maxillofacial computed tomography (CT) image with an image that represents teeth in more detail.[2-9] Methods based on fiducial markers have been used for integrating intraoral images with CBCT images at an accurate location; however, processing is complicated, and clinical application is difficult.[2] The surface registration method for simple registration using the iterative closest point algorithm has also been proposed.[10-12] Noh et al.[6] and Sun et al.[7] conducted comparative studies of accuracy based on the area of registration during the integration of a laser-scanned dental image with a CBCT image. They found that a larger area increased the accuracy and that surface registration can be used for the integrated image.[6,7]

When integrating two images by replacing the dental part of a CBCT image with an intact dental image, an accurate registration of the two images is essential. However, CBCT contains artifacts because of beam hardening.[10,13] This type of artifact appears in the presence of metals, such as amalgams or titanium.[11,12] Enamel also creates an artifact,[10] which can be caused by differences in the radiation attenuation coefficient of the natural dentition without metal restorations. These artifacts may influence the accuracy of integration when superimposing CBCT scans on intraoral scans. However, research on this issue is insufficient.[14] It is believed that a higher number of registration points results in better registration quality, but this is based on the premise that all of the points on an image are in the correct positions. If the molar area shows an artifact and the resulting rendered image is blurred, the points in that area can cause registration errors. The objective of this study was to compare the accuracy of registration in the integration of intraoral-scanned dental images with CBCT scan volumes with the use of different protocols of beam hardening artifact removal and

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Statement of Clinical Relevance

The accuracy of integration of intraoral scans into cone beam computed tomography data may be increased by excluding areas highly affected by artifacts, but including the second molars.

registration areas. The null hypothesis stated that there would be no differences in registration accuracy as a result of removal of artifact and registration areas.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board of Chonnam National University, Gwangju, Korea, and was in compliance with the tenets of the Helsinki Declaration. Thirty patients were enrolled in this study, and each patient signed a detailed informed consent form. The CBCT scans used in this study were acquired in the process of screening the patients for orthodontic treatment and were not taken only for research purposes. The inclusion criteria were as follows: (1) fully erupted permanent dentition in both jaws and (2) absence of prosthetic restorations, such as crowns and fixed bridges on the molars.

CBCT scans were obtained by using an Alphard Vega scanner (Asahi Roentgen, Kyoto, Japan) with the following parameters: 80 kVp; 5 mA; voxel size 0.39 mm^3; and field of view 200 mm × 179 mm. The scan data were imported into Invivo 5 software (Anatomage, San Jose, CA) and were exported to a stereolithography (.STL) file format.

A TRIOS scanner (3 Shape, Copenhagen, Denmark) was used for the maxillary arch scan (Figure 1). The patient's dentition was dried with an air syringe, and intraoral scanning was started from the left side. The occlusal surfaces were scanned first, followed by the lingual and buccal surfaces. The image could be continuously viewed on a computer screen during scanning, which allowed for direct visual feedback to ensure that no areas were missed. The scans were sent to the OrthoAnalyzer (3 Shape, Copenhagen, Denmark) program, where they were reprocessed as .STL files. Because the soft tissues of the gingiva and palatal mucosa can increase the error range, scanning of these tissues along the gingival margin was omitted to superimpose the clinical crowns alone. Each intraoral scan was incorporated into the dental part of the corresponding CBCT scan by using a software program (Rapidform 2006, Inus Technology, Seoul, Korea). Initial (global) registration was achieved by the selection of 3 points corresponding to the CBCT and intraoral scans. Regional (fine) registration was subsequently used to finalize the registration. For the regional registration process, it was necessary to define the registration area. The labial or buccal surfaces were included as ROI, and the incisal edges and marginal ridges were included as much as possible. However, the gingival margin was not included because of potential errors associated with the adjacent soft tissue. On the basis of our experience, we assumed that artifacts, including metal or streak artifacts resulting from beam hardening on the CBCT images, would tend to occur in the premolar and first molar areas. Therefore, 3 types of methods, based on the ROI, were implemented: (1) R0, all teeth included as the registration area (including artifacts); (2) R1, only anterior teeth included as the registration area (artifacts in premolars and molars not included); and (3) R2, anterior teeth and second molars included as the registration area (artifacts in premolars and first molars not included) (Figure 2). Inclusion of the registration area was achieved by using the function of coloring (painting) the area provided in the software.

Fig 1. The TRIOS intraoral scanner (3 shape, Copenhagen, Denmark) was used in this study.

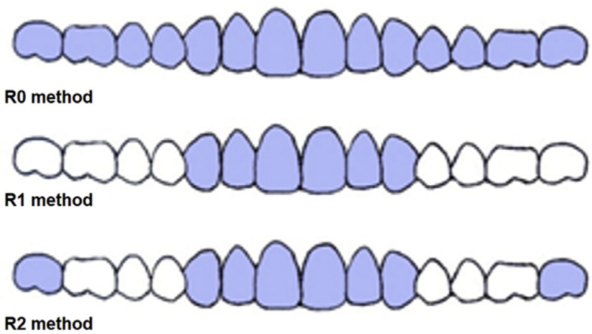

Fig 2. The blue-colored areas represent the registration area used in each method. *R0,* registration area including all teeth; *R1,* registration area including only anterior teeth; *R2,* registration area including anterior teeth and second molars.

Registration errors were evaluated by measuring the 3-D Euclidean distances between the surface points on the 2 images through the use of the *shell/shell deviation* function in the program. Shell/shell deviation is defined as the average surface difference between the 2 models when the registration is performed using the surface information. The shell/shell deviation function of this software calculates the closest distance between the thousands of points on the 2 registered models by using an iterative closest point algorithm.[15] The value of shell/shell deviation is the overall discrepancy (Figure 3).

To determine which direction of discrepancy contributed to the degree of overall discrepancy, the registration discrepancy was determined at 4 points—2 points for the first molars and 2 points for the central incisors—for each registration. The discrepancies in the x-direction (mediolateral), y-direction (superoinferior), and z-direction (anteroposterior) were then assessed. A cross-sectional plane was constructed by selecting 3 points on the incisal third of the interproximal area of the central incisors and on the occlusal half of the right and left first molars. By using the *section view option* function in the software, a point on the outline of the CBCT image was selected. The x-, y-, z-coordinates of the point represented "point 1," and the corresponding point on the intraoral scan was automatically "point 2." In the program, the actual distance in the 3-D space between the 2 points was expressed as *Distance*, whereas the difference in the x-, y-, and z-directions was expressed as *Displacement* (Figure 4). All of these processes were performed by the same experienced researcher (B.Y.), with a master's degree in orthodontics and over 2 years of experience in this field.

Statistical analysis

The shell/shell deviations (overall discrepancies) were calculated for each registration method and 1-way analysis of variance (ANOVA) was used to analyze the differences in shell/shell deviations based on the registration area. Tukey's test was used for post hoc comparisons. The registration discrepancies between the first molar and central incisor areas were compared by using the paired *t* test for each registration. They were also calculated as the difference in the x-, y-, and z-directions. The relative displacement of each registration compared with the R0 method (registration including all teeth without removal of artifacts) was computed.

RESULTS

Most artifacts occurred in the premolar and first molar areas on the CBCT scans.Table I shows the mean and standard deviation of the shell/shell deviations (overall discrepancies) with use of the 3 registration methods. The mean shell/shell deviation overall discrepancy values were 0.30 mm for the R0 method, 0.35 mm for the R1 method, and 0.28 mm for the R2 method. The ANOVA revealed a statistically significant difference among the methods based on the registration area ($P < .001$). The R0 method and the R2 method had significantly smaller errors compared with the R1 method. These findings indicated that registration accuracy may be increased by not including the artifact in the premolars and first molars and by including the anterior teeth and the second molars as the registration areas.

Table II shows the registration discrepancies in the central incisors and first molarsg in each of the 3 registration methods. The discrepancies were greater in the first molars (0.30−0.44 mm) than in the central incisors (0.12−0.19 mm). The mean registration discrepancies between the first molars and the central incisors were 0.13 mm in the R0 method, 0.26 mm in the R1 method, and 0.15 mm in the R2 method. These errors were significantly greater in the first molars than in the central incisors with all 3 registration methods ($P \leq .041$).

In the 3-D evaluation of the registration discrepancies, no significant differences in the incisors among the 3 directions were discovered in any of the registration methods ($P \geq .097$). However, x-directional discrepancies in the molars were significantly greater than the y- or z-directional discrepancies with all 3 registration methods ($P < .001$). This finding indicated that the x-directional discrepancies in the molars contributed significantly to the overall registration error (Table III).

DISCUSSION

The aim of this study was to identify more accurate registration methods for CBCT and intraoral imaging. The effect of removing CBCT artifacts, in part or entirely, from the registration area was examined. We assumed that artifacts, including metal or streak artifacts, tended to occur in the premolar and first molar areas. Thus, the 3 methods were designed on the basis of this assumption.

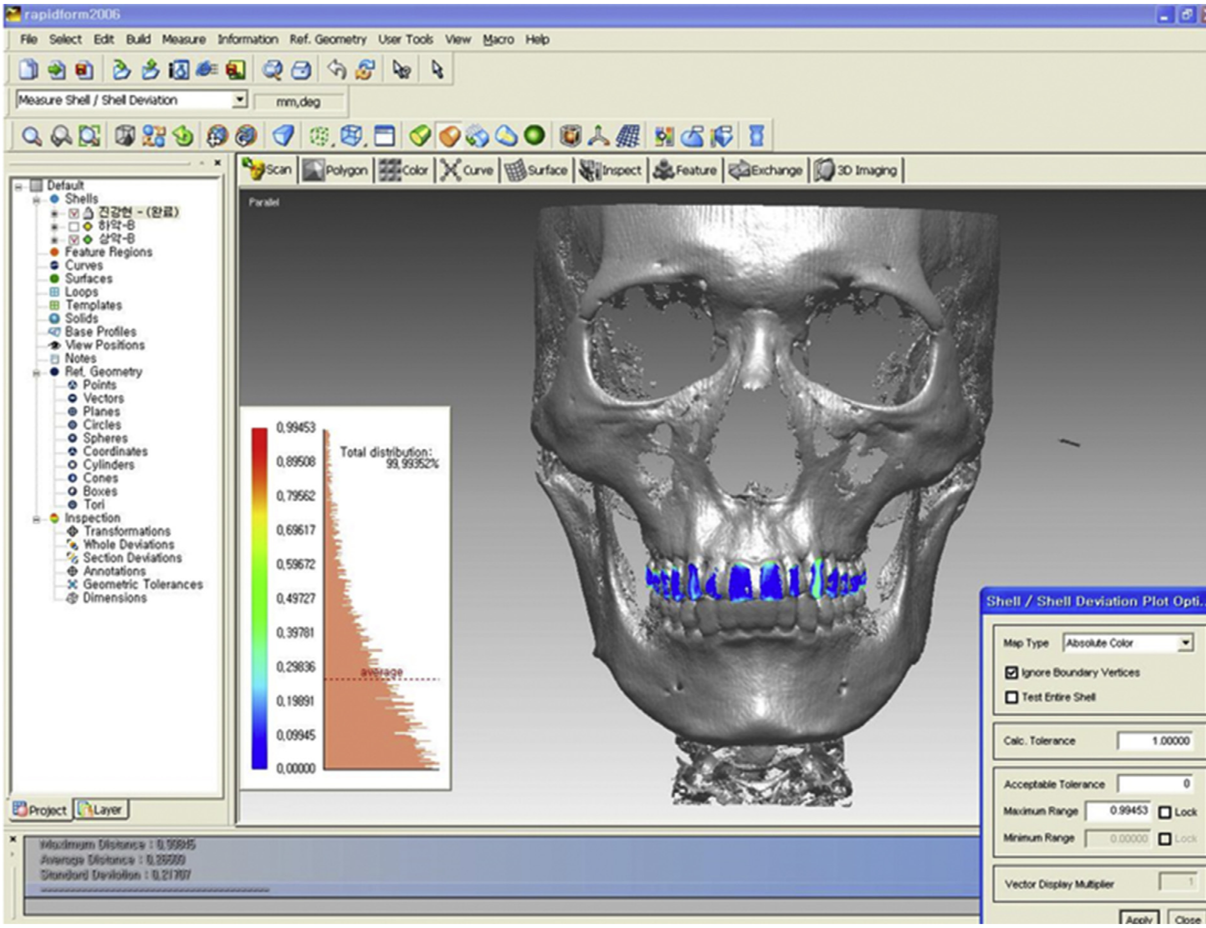

Fig 3. An assessment of the overall discrepancy between the cone beam computed tomography (CBCT) and intraoral scans. Shell/shell deviation is the average surface difference between 2 models when the registration is performed by using the surface information. The software calculates the closest distance between the thousands of points on the registered 2 models by using an iterative closest point algorithm.[15] The color-coded spectrum shows the differences between the scans after registration. The blue colors in the spectrum signify no differences in registration. Differences become greater closer to the red portion of the spectrum. The shell/shell deviation is the overall discrepancy.

The results showed that most artifacts tend to occur in the posterior region, particularly the premolar and first molar areas. Nagarajappa et al. reported that artifacts can also appear on images of the natural dentition without metal restorations because tooth enamel has a high degree of radiation absorption.[10]

Compared with R0, the R1 registration had the largest error, which included all teeth as the registration area. This result was consistent with a previous study by Nkenke et al.,[3] who reported that the presence of artifacts reduced registration accuracy. A larger number of registration points should result in better registration quality; however, this is based on the premise that all of the points on the images are in the correct positions. If artifacts are produced in the molar region, the points in that area could be incorrectly registered.

However, even if artifacts existed on images of the posterior teeth, exclusion of the entire posterior dentition in the registration area could reduce registration accuracy. Improved registration accuracy was found with use of the R2 method, so inclusion of the second molar in the registration area yielded better results than exclusion of it. This could be explained by 2 factors: (1) the broad anatomic area in the molar region and (2) the orientation of the registration. Sun et al. evaluated registration accuracy according to the registration areas.[7] In that study, the method of including the anterior incisal edge and the buccal surface yielded greater accuracy compared with the techniques wherein only the incisal edges or only the buccal surfaces were included.[7] This means that registration accuracy can increase when a broad area is used for registration. In addition, inclusion of the second molar can affect the orientation of registration. In the present study, registration using only the anterior teeth (R1) caused the greatest error in the orientation of registration. By including the second molar in the registration

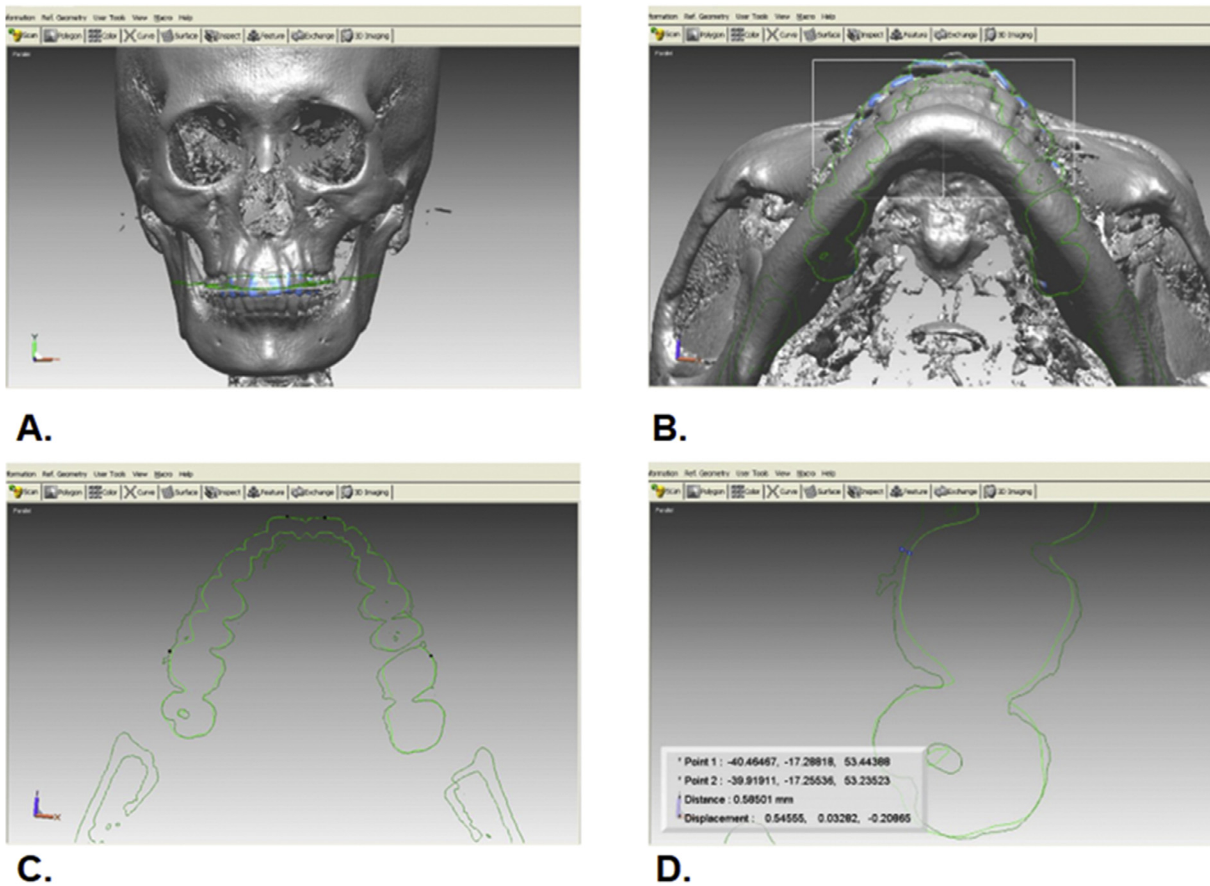

Fig 4. Measurement of the discrepancy between the CBCT and the intraoral images on the cross-sectional plane. **A**, Construction of the cross-sectional plane using 3 points: The incisal one-third of the maxillary central incisors' interproximal area and the occlusal half of the right and left first molars. This plane also crosses the superimposed intraoral scans. **B**, Rotation of the superimposed images to see the cross-sectional view. **C**, The green line indicates the cross-section of the CBCT image, and the light green line indicates the cross-section of the intraoral scan image. **D**, The discrepancy between the CBCT and intraoral images was calculated by selecting a point on the CBCT image. Once a point is selected on the CBCT image, the corresponding point on the intraoral image is automatically represented. The actual distance between these 2 points is expressed as "Distance," whereas the difference in the x-, y-, and z-directions is expressed as "Displacement" in the program.

Table I. Shell/shell deviations (overall discrepancies) and results of ANOVA among the 3 groups according to the registration area (in millimeters)

	R0	*R1*	*R2*	*Significance (P value)*
	Mean ± SD	*Mean ± SD*	*Mean ± SD*	
Shell/shell deviation	0.30 ± 0.05^{a}	0.35 ± 0.05^{b}	0.28 ± 0.04^{c}	< .001

Different superscript letters indicate a statistically significant difference among the groups.
ANOVA, analysis of variance; *R0,* all teeth included as the registration area (artifacts included); *R1,* only anterior teeth included as the registration area (artifacts in premolars and molars not included); *R2,* anterior teeth and second molars included as the registration area (artifacts in premolars and first molars not included); *SD*, standard deviation.

area (R2), the overall discrepancy was significantly reduced. These results suggest that exclusion of premolars and molars from the registration area reduces registration accuracy when superimposing the CBCT images of teeth on intraoral scans. Given these results, when registration of 2 images has to be done clinically, the left and right posterior teeth should be included with the anterior teeth in the registration area.

Registration discrepancies were significantly greater in the first molars than in the central incisors with all 2 registration methods. This indicates that the differences in error, based on the registration area, primarily resulted from a posterior error. When the intraoral scan was superimposed on the CBCT image of the dentition, the anterior area was positioned relatively accurately, whereas registration in the posterior area was slightly distorted. This could be explained by the finding that

Table II. Comparison of registration discrepancies in the central incisors and first molars (in millimeters)

	R0	*R1*	*R2*
	Mean ± *SD*	*Mean* ± *SD*	*Mean* ± *SD*
Central incisor			
Right side	0.19 ± 0.39	0.16 ± 0.37	0.19 ± 0.41
Left side	0.16 ± 0.14	0.12 ± 0.10	0.14 ± 0.12
Combined	0.17 ± 0.24	0.14 ± 0.22	0.17 ± 0.24
First molar			
Right side	0.31 ± 0.30	0.36 ± 0.35	0.30 ± 0.30
Left side	0.31 ± 0.28	0.44 ± 0.31	0.33 ± 0.25
Combined	0.31 ± 0.27	0.40 ± 0.30	0.31 ± 0.25
Difference*	0.13 ± 0.35	0.26 ± 0.32	0.15 ± 0.34
Significance† **(P value)**	.041	< .001	.026

R0, all teeth included as the registration area (artifacts included); *R1,* only anterior teeth included as the registration area (artifacts in premolars and molars not included); *R2,* anterior teeth and second molars included as the registration area (artifacts in premolars and first molars not included); *SD*, standard deviation.
*Difference of combined value of registration discrepancy between the central incisors and first molars.
†The results of paired *t* test of the registration discrepancy between central incisors and first molars in each method.

most artifacts occurred in the posterior region, particularly in the premolar and first molar areas.

In the 3-D evaluation of the registration errors, the x-directional discrepancy in the molar region was greater than the y- or z-directional discrepancies, and it contributed significantly more to the overall discrepancies. This indicated that registration errors were determined mostly by right-/left-side discrepancies in the posterior area. Because most artifacts occurred in the posterior region, particularly in the premolar and first molar areas, the CBCT images were larger than the intraoral scans. As the difference in points was calculated by subtracting intraoral scans from CBCT scans, a positive value in the x-direction on the right side and a negative value in the x-direction on the left side meant that the CBCT scan was positioned more laterally compared with the intraoral image. We did not include the occlusal surfaces as registration areas; thus, y- and z-directional discrepancies did not significantly affect registration accuracy. Considering these results, it seems that the buccal and lingual surfaces should be included as registration sites. Noh et al.[6] showed that

Table III. Registration discrepancy in 3-dimensional direction in the central incisors and first molars (in millimeters)

	R0	*R1*	*R2*
	Mean ± *SD*	*Mean* ± *SD*	*Mean* ± *SD*
Central incisor, right			
x-directional discrepancy	0.00 ± 0.05	0.00 ± 0.05	0.01 ± 0.05
y-directional discrepancy	0.00 ± 0.03	0.00 ± 0.02	0.01 ± 0.03
z-directional discrepancy	0.05 ± 0.42	−0.06 ± 0.39	−0.01 ± 0.44
Central incisor, left			
x-directional discrepancy	0.00 ± 0.04	0.00 ± 0.04	0.00 ± 0.04
y-directional discrepancy	−0.01 ± 0.04	0.00 ± 0.03	0.00 ± 0.03
z-directional discrepancy	0.03 ± 0.20	−0.30 ± 0.15	0.00 ± 0.18
Significance* (P value)			
x-directional	.686	.832	.618
y-directional	.176	.961	.097
z-directional	.204	.577	.150
First molar, right			
x-directional discrepancy	0.23 ± 0.31	0.21 ± 0.41	0.23 ± 0.31
y-directional discrepancy	0.01 ± 0.04	0.01 ± 0.04	0.01 ± 0.04
z-directional discrepancy	−0.07 ± 0.16	−0.06 ± 0.19	−0.06 ± 0.16
First molar, left			
x-directional discrepancy	−0.25 ± 0.22	−0.38 ± 0.33	−0.29 ± 0.24
y-directional discrepancy	0.02 ± 0.03	0.02 ± 0.04	0.01 ± 0.03
z-directional discrepancy	−0.12 ± 0.22	−0.12 ± 0.16	−0.10 ± 0.13
Significance* (P value)			
x-directional	< .001	<.001	<.001
y-directional	.433	.257	.559
z-directional	.261	.171	.335

The numbers indicate the relative position in 3 dimensions of a point on the intraoral scan for the corresponding point on the cone beam computed tomography (CBCT) scan. The difference in points was calculated by subtracting the intraoral scan from the CBCT scan. The x-, y-, and z-directions indicate mediolateral, superoinferior, and anteroposterior directions, respectively. A negative value in the x-direction on the left side means that the CBCT scan was positioned more laterally compared with the intraoral scan; a negative value in the y-direction means that the CBCT scan was positioned more laterally compared with the intraoral scan; and a negative value in the z-direction means that the CBCT scan was positioned more anteriorly compared with the intraoral scan.
R0, all teeth included as the registration area (artifacts included); *R1,* only anterior teeth included as the registration area (artifacts in premolars and molars not included); *R2,* anterior teeth and second molars included as the registration area (artifacts in premolars and first molars not included); *SD*, standard deviation.
*The results of paired *t* tests of the right/left discrepancies in each x-, y-, and z-directions.

accuracy of registration with use of the buccal surfaces as registration areas was not significantly different from that with use of both the buccal and lingual surfaces. However, if all of the posterior teeth on one side are clinically missing, then only using the buccal side as the registration area results in a deviation toward the side with the posterior teeth. In that situation, it is understood that the buccal and lingual surfaces should be included in the registration process.

On the basis of the results of this study, when intraoral scans are integrated into CBCT scans, the R2 registration method, which includes the anterior teeth and the second molars as registration areas, could be the best choice for achieving accuracy of registration. Even if there were artifacts on the premolars and the molars, it was found that excluding all of the premolars and molars decreased the accuracy of registration compared with the situation where all teeth are present.

In the present study, only patients who did not have prosthetic restorations, such as crowns and bridges, on the molars were included. In the case of a patient who has multiple restorations on the molars, the registration methods suggested in this study might cause registration errors. Considering that the exclusion of all artifacts, as in method R0, can cause registration inaccuracy, further studies on the registration technique in the presence of metal artifacts are needed. Moreover, the development of a CBCT scanner and algorithm to prevent artifacts on images of the premolars and molars should be established as a standard procedure for registration.

CONCLUSIONS

On CBCT images, artifacts appeared more often in the posterior area. When the intraoral scans were integrated into the maxillofacial CBCT scans, the registration error increased when all artifacts were excluded from the registration area, compared with the situation in which the second molar was included in the registration area.

The accuracy of registration in the integration of intraoral scans into the CBCT images may be increased by excluding areas highly affected by artifacts, but including the anterior teeth and the posterior-most tooth.

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