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Accuracy of the Point-Based Image Registration Method in Integrating Radiographic and Optical Scan Images: A Pilot Study

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Purpose: The purpose of this study was to investigate the influence of different implant computer software on the accuracy of image registration between radiographic and optical scan data.

Materials and Methods: Cone-beam computed tomography and optical scan data of a partially edentulous jaw were collected and transferred to three different computer softwares: Blue Sky Plan (Blue Sky Bio), Implant Studio (3M Shape), and Geomagic DesignX (3D systems). In each software, the two image sets were aligned using a point-based automatic image registration algorithm. Image matching error was evaluated by measuring the linear discrepancies between the two images at the anterior and posterior area in the direction of the x-, y-, and z-axes. Kruskal–Wallis test and a post hoc Mann–Whitney U-test with Bonferroni correction were used for statistical analyses. The significance level was set at 0.05.

Result: Overall discrepancy values ranged from 0.08 to 0.30 μm. The image registration accuracy among the software was significantly different in the x- and z-axes ($P=0.009$ and <0.001, respectively), but not different in the y-axis ($P=0.064$).

Conclusion: The image registration accuracy performed by a point-based automatic image matching could be different depending on the computer software used.

Key Words: Accuracy; Cone-beam computed tomography; Digital scan; Image registration

Introduction

Dental implant treatments have provided an alternative to conventional fixed dental prosthesis that requires preparation of the adjacent teeth[1]. The implant surgery was essentially based on two-dimen-

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sional periapical or panoramic radiographs[2,3]. With the introduction of the cone-beam computed tomography (CBCT) to the dental field, three-dimensional (3D) images of critical anatomical structures such as the inferior alveolar nerve, maxillary sinus, and roots of neighboring teeth were started and evaluated accurately in the diagnostic modalities and treatment planning[4,5].

Implant guide templates are the physical tools that transfer the implant position planning to the surgical site inside the oral cavity[6]. With the widespread use of CBCT, the development of dental computer-aided design and computer-assisted manufacturing (CAD/CAM) helped to realize the restoratively driven implant placement concept[7]. The CAD/CAM technologies enhanced the accuracy of implant placement and the convenience of the fabrication of surgical guides by reducing the manual work[8]. Accordingly, these 3D imaging and computerized works have contributed to optimize implant treatments to be more evidence based, safer, and quicker from both a prosthodontic and a surgical point of view[9].

Implant guide systems can be classified as bone, tooth, or mucosa-supported types according to the structure on which the guides are supported[10]. A systematic review compared the accuracy of different implant guide support types and showed that the accuracy of the implant placement is not consistent among studies[11]. The total error of implant placement depends on the summation of the possible errors that are involved in all the clinical treatment and fabrication steps of the implant protocol[11]. The error sources could be the 3D radiographic image taking, intraoral optical scanning, image registration process, guide sleeve design, 3D printing process, guide positioning, and unskilled guided surgery performance[11,12].

Image registration in the computer-assisted guide fabrication is the process of aligning the optical scan image of the oral cavity surface to the corresponding CBCT data[13]. However, because the gingival structure cannot be shown in the CBCT images, the merging of the 3D optical scan image of the oral cavity to the CBCT images is a prerequisite for accurate diagnosis and guide designing, especially for tissue-supported guide templates[14]. For the alignment of the two data sets, implant planning software are used. First, anatomical landmarks shown in both CBCT and optical scan images are selected by operators and then, further alignment is processed using the automatic best-fit algorithm[15].

The image registration is an important process that replicates the relation of soft tissue and hard tissue. When the alignment of optical scan images to CBCT is not accurate, critical errors in implant position can occur[16]. The purpose of this study was to assess the effects of implant planning software on the accuracy of image registration of optical scan to CBCT data. The proposed null hypothesis was that the difference in implant software would not result in different image matching accuracy between the optical scan and CBCT data for computer-guided implant surgery.

Materials and Methods

The workflow of this study is described in Fig. 1. Within the patients who required implant surgery, a patient was selected as per the following inclusion criteria: partial edentulous dental arch, no metallic restoration, no large tooth structure defect. Patients who had edentulous dental arch and were not planned to undergo guided surgery were excluded. Based on the criteria, a partially edentulous maxilla case with missing of teeth 15 and 16 was selected for this study. Implant-supported fixed dental prosthesis was planned in the edentulous area to restore the chewing function and esthetics. To prepare the computer-guided implant placement, radiographic data of computer tomography were obtained using a CBCT device (Pax-i3D Smart; Vatech, Hwaseong, Korea) with 89 kVp, 8 mA, 24 seconds pulsed scan, field of view of 120×85 mm, and slice thickness of

0.3 mm. The radiographic data was saved in digital imaging and communications in medicine (DICOM) format. An optical scan image of the surface of the oral cavity was obtained by scanning the stone cast that had been made by silicone impression using a lab-based scanner (IDC S1; Amann Girrbach, Koblach, Austria). The scan image was saved in the format of standard tessellation language (STL).

The image registration of optical scan to radiographic data was performed in three different computer software: Blue Sky Plan (BSP) (Blue Sky Bio LLC, Grayslake, IL, USA), Implant Studio (IS) (3Shape, Copenhagen, Denmark), and Geomagic DesignX (GD) (3D Systems, Rock Hill, SC, USA). The DICOM and STL files were transferred to each software, where the two 3D images were matched by a point-based automatic alignment method (Fig. 2). As fiducial points for the image matching, the incisal line angle of tooth 11 and mesio-buccal cusp tip of tooth 17 and 27 were used. After the point designation, the automatic image matching with best-fit algorithm was followed.

After the image registration, the accuracy of the image matching was assessed by measuring linear discrepancies between the images at the anterior and posterior areas (tooth 11 and 17) in the direction of the x-, y-, and z-axes (Fig. 3). The measurements were conducted in the cross-sectional view of teeth at the frontal, sagittal and transverse planes using the measurement function of each implant planning software (Fig. 4). All the image registration and

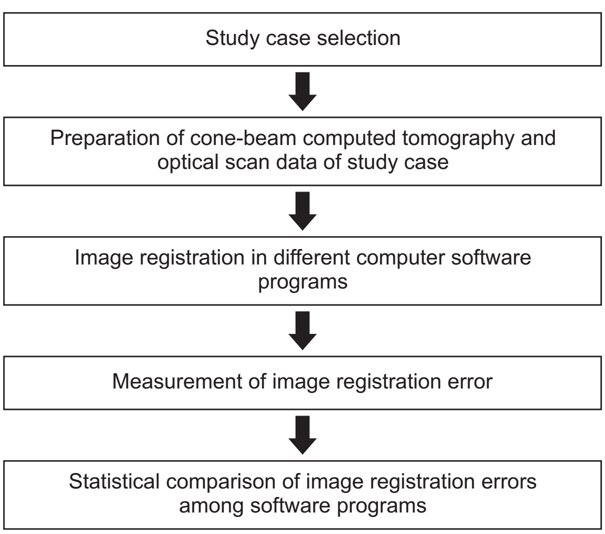

Fig. 1. Workflow of this study.

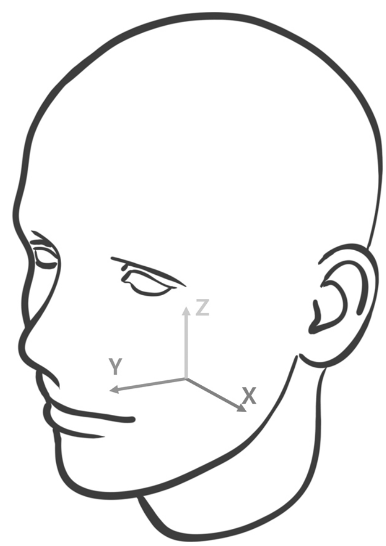

Fig. 3. Three-dimensional coordinates for matching discrepancy measurement.

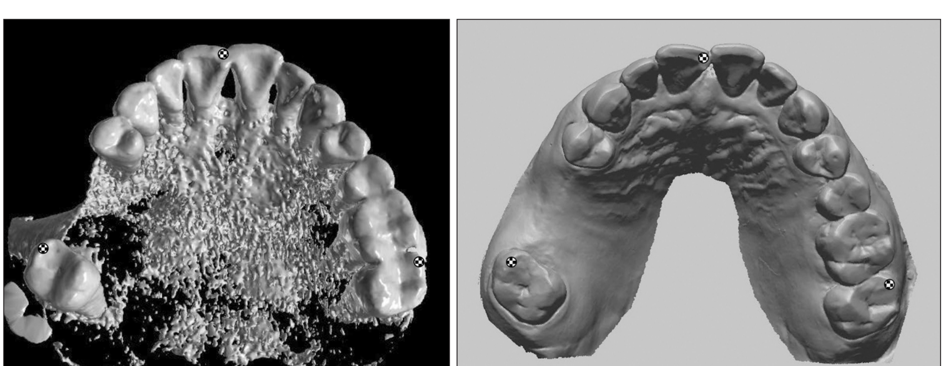

Fig. 2. Image registration process between radiographic and optical scan data using point-based automatic image matching.

measurement processes were carried out 5 times at 1-week intervals by a single investigator who was blinded to the purpose of this study to avoid inter-examiner related bias.

The mean accuracy of image registration in each software program was calculated by averaging the discrepancy values collected in the anterior and posterior areas, and compared between the different software. Kruskal–Wallis test and a post hoc Mann–Whitney U-test with Bonferroni correction were used for statistical analyses. The significance level was set at 0.05.

Result

The linear discrepancies of image registration in each software program are presented in Table 1. The IS software showed significantly higher discrepancy values than the BSP and GD software in the x- and z-axes (P=0.009 and <0.001, respectively). In the y-axis, no difference was found between the software (P=0.064). With regards to the measurement axis, even though the discrepancy values were different between the axes in all the software (P<0.001), there was no trend in the results. Generally, discrepancy values ranged from 0.08 to 0.30 μm (Fig. 5).

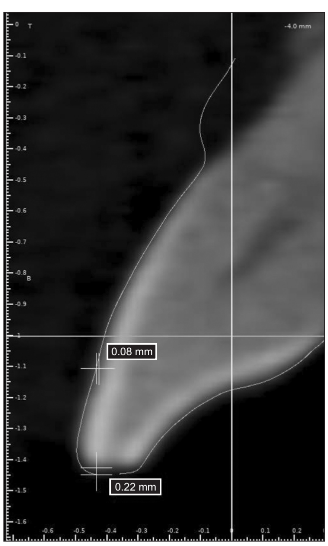

Fig. 4. Representative view for linear discrepancy measurement.

Discussion

This study was designed to investigate the accuracy of image registration of optical scan to CBCT data in different implant planning software. The results showed that all image registration errors were lower than 0.30 μm in every axis and that the accuracy of image matching was statistically different between the tested software. These findings imply that the

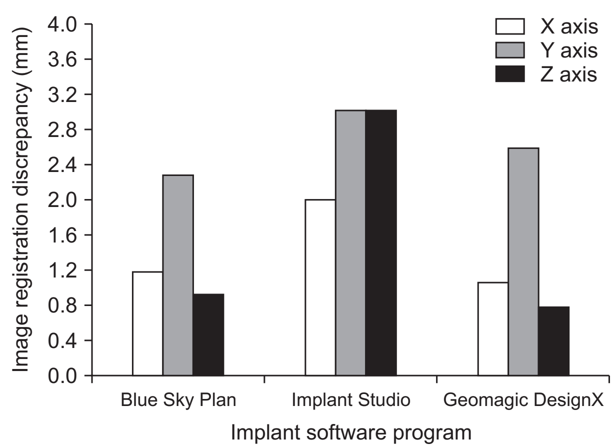

Fig. 5. Linear discrepancy of image registration in different computer software.

Table 1. Linear discrepancy of image registration between radiographic and optical scan images in different computer software

Coordinate	Blue Sky Plan	Implant Studio	Geomagic DesignX	P-value
x	$0.12\pm0.06^{1,a}$	$0.20\pm0.04^{2,a}$	$0.11\pm0.01^{1,a}$	0.009
y	$0.23\pm0.06^{1,b}$	$0.30\pm0.04^{1,b}$	$0.26\pm0.01^{1,b}$	0.064
z	$0.09\pm0.02^{1,a}$	$0.30\pm0.04^{2,b}$	$0.08\pm0.02^{1,c}$	<0.001
P-value	<0.001	<0.001	<0.001	

Values are presented as mean±standard deviation.

^{a,b}Significant differences within a row are represented by the different alphabetical letters.

^{1,2}Significant differences within a column are represented by the different numbers.

computer programs had different image matching performances, even though they used the same image alignment method. Thus, the null hypothesis stating that the difference in implant software would not result in different image matching accuracy between the optical scan and CBCT data was rejected.

Surface-based image registration is the basic method described for 3D image superimposition[17,18]. In the contemporary point-based automatic image matching techniques, the registration of 3D scanner models to CBCT data requires manual selection of the matching points[19,20]. Accordingly, the principle involves approximating two surfaces by selecting corresponding landmarks on the two images. Setting the appropriate reference points is the first step in obtaining reliable data for comparing the accuracy. The clinicians choose arbitrarily at least three pair of points in common between the radiographic and scan data. An increase in the number of registration points had no significant effect on the accuracy of the prosthetic treatment plan incorporation[21,22]. This image registration protocol is applicable when enough number of points could be used and were largely distributed in the oral cavity, because this condition is important to have favorable matching situations[13,23]. To reliably serve for registration, the reference areas should be clearly discernible in the respective images to be registered[24]. The use of point-based image matching workflow for guided implant surgery is known to be advantageous because this method is clinically feasible and time-efficient.

After the manual designation of the matching points, automatic image alignment is processed. Namely, based on the reference points, best-fit image registration is performed by means of software functions[15]. In this study, the three software used iterative closest point (ICP) algorithm that minimized the surface distance between the two surfaces. The ICP algorithm is graphic processing and can facilitate the alignment of the 3D polygon mesh data sets of the digital models[25]. Although the established registration framework ICP is currently used for dental applications, the present study identified that the quality of ICP could be different depending on the software used.

Several clinical concerns should be included in further studies. When a patient has prostheses made of metal alloys, image artifacts can occur due to the cone-beam hardening effect, which causes distortion and deformation of the images[26]. The difference in shape between the 3D radiographic image with artifacts and optical scan image can cause inaccurate automatic alignment results. Image registration is also affected by the number of missing teeth and length of edentulous ridges. Moreover, human error in selecting the matching is considered because the point designation depends on the decision making and proficiency of the operators.

Conclusion

Within the limitation of this *in vitro* study, accuracy of image registration performed by point-based automatic image matching could be different depending on the computer software used for guided implant surgery. Further studies are needed to confirm the findings of this study in various clinical setting and using other software.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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