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CLINICAL RESEARCH

Accuracy of the evaluation of implant position using a completely digital registration method compared with a radiographic method

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ABSTRACT

Statement of problem. Conventional radiographic methods are widely used to evaluate the clinical accuracy of implant position. However, such methods require a second computerized tomography (CT) scan and manual registration between presurgical and postsurgical CT data. The alignment errors cannot be calculated.

Purpose. The purpose of this clinical study was to introduce a completely digital registration method to evaluate the clinical accuracy of implant position. The digital registration method was then compared with the radiographic method in evaluating accuracy. Some of the alignment errors produced in the digital registration procedures were recorded.

Material and methods. A total of 32 implants from 19 patients with sufficient bone volume were enrolled in the study, and all implant surgeries were conducted by one experienced practitioner. Before the surgery, a cone beam computerized tomography (CBCT) scan was made for each patient along with a diagnostic impression to design the ideal implant position using the Simplant software. After the surgery, the postsurgical implant position was determined using an optical scan of the dentition cast and a series of custom registration models (the digital registration method). A simulated cylinder was designed using the Geomagic Studio software to represent the implant, and the deviation of the ideal and postsurgical implant position was calculated. The accuracy evaluated by the 2 methods was also compared. The parameters of the entrance point, apical point, and axis were recorded for each implant. A part of the alignment errors in the digital registration was calculated automatically and recorded. One sample *t* test and paired *t* test were conducted by using a statistical software program.

Results. The mean deviation between the ideal and postsurgical implant positions evaluated using the digital registration method was 0.84 ±0.57 mm for the entrance point, 1.03 ±0.78 mm for the apical point, and 4.52 ±2.37 degrees for the angulation. No significant difference was found between the accuracy evaluated by the digital registration method and the radiographic method ($P>.05$). In the digital registration procedure, the alignment error was 0.03 mm for the registration model and 0.29 mm for the dentition. Significant differences were found in the alignment procedure of the impression cylinder ($P<.001$) and dentition ($P<.001$). The average positive and negative errors were +0.09 and −0.19 mm for the simulated cylinder of the ideal implant and +0.08 and −0.15 mm for the simulated cylinder of the postsurgical implant.

Conclusions. The precision of the digital registration method could be accepted in clinical applications. No significant difference was found between the digital registration method and the radiographic method in evaluating the clinical accuracy of the implant position. The digital registration method was able to control and minimize the alignment errors produced during data processing. (J Prosthet Dent 2019;122:537-42)

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Clinical Implications

The digital registration method appears to be a practical technique for evaluating the accuracy of the implant position. The new method avoids a second computerized tomography scan and provides advantages over the radiographic method.

Implant-supported restorations are established as a predictable approach to restoring the masticatory system in terms of function and esthetics.[1] The precise placement of the implants in an ideal position is of great importance, and studies have evaluated the accuracy of implant positioning.[2,3]

Radiographic methods have been widely used to evaluate clinical implant accuracy. Two computerized tomography (CT) scans must be carried out for each patient—one before and the other after the implant surgery. Then, a reconstruction software program is used to evaluate the deviations between the ideal and postsurgical implant positions.[4-7] However, the accuracy of the implant position is largely influenced by the quality of CT images.[8] Factors such as image artifacts (edge effect), patient movement, and scan parameter setting affect the quality of CT images.[9-11] In addition, a postsurgical CT scan to evaluate the implant position cannot be considered a clinical necessity and should be avoided.[12-14]

Nonradiographic methods have been introduced to overcome the disadvantages of the radiographic method, with optical scanning being introduced to evaluate the clinical accuracy of the implant position in 3 dimensions. Platzer et al[15] measured the deviation between presurgical and postsurgical casts using a laser scanner and reported a 3D displacement of 0.46 ±0.21 mm. Komiyama et al[16] made presurgical gypsum casts based on an individual surgical template and postsurgical gypsum casts by using an intraoral impression and then optically scanned the 2 casts to compare the deviations of the implant positions. The mean deviation in the maxilla was 0.59 mm at the neck and 0.59 mm at the apex. The mean deviation in the mandible was 0.39 mm at the neck and 0.40 mm at the apex.

In the evaluation procedure, errors may occur during data acquisition and processing.[17] While constructing 3D models by using cone beam computerized tomography (CBCT) and multislice computed tomography (MSCT), a mean error of 0.252 mm and 0.137 mm, respectively, were detected on the 3D model.[18,19] However, the optical scan data had a higher accuracy (about 0.01 mm) than dental CT images.[20] During data processing, one of the main errors was caused by manual operation. To minimize such errors, studies reported that the measurement procedure should be repeated several times.[21]

Geomagic Studio software (3D Systems) is a reverse engineering software program that can automatically generate accurate digital casts based on scanned point clouds. Its "Best Fit Alignment" function can align 2 similar 3D models by the size of the point cloud (sample size) and calculate the alignment error automatically. The "Feature Best Fit" function can optimally simulate geometric shapes according to certain areas, and the simulation errors can also be calculated based on point clouds. With the help of the functions of the reverse engineering software, the registration process can be performed digitally. Moreover, the measurement process only needs to be conducted once. Furthermore, the alignment and simulation errors can be minimized and calculated automatically.

The purpose of this clinical study was to introduce a digital registration method to evaluate the clinical accuracy of the implant position. The digital registration method was compared with the radiographic method in evaluating the accuracy. A part of the alignment errors produced in the digital registration method were recorded. The first null hypothesis was that there was no difference in the implant position accuracy evaluated by the digital registration method and the radiographic method. The second null hypothesis was that there were no alignment errors during the digital registration procedure.

MATERIAL AND METHODS

The protocol was approved by the Ethics Committee of Shanghai Ninth People's Hospital, Shanghai Jiao Tong University School of Medicine ([2015]84). Participants were recruited from a group of partially edentulous patients, from September 2015 to March 2017. All participants were aged above 18 years and systematically healthy without contraindication of implant surgery. The number of adjacent missing teeth was no more than 3, and the edentulous area had to have sufficient bone volume to allow implants (SPRN Loxim; Institut Straumann AG) placed in the proper position without an augmentation procedure. Patients who had received a previous fixed dental restoration were excluded. During the implant surgery, the rough surface of the implant was completely inserted into the alveolar bone, whereas the smooth surface was left above the bone. All implant surgeries were conducted by one of the authors (X.Z.). Nineteen participants with a total of 32 implants were included in the study.

Before the implant surgery, a CBCT scan (FLX V10 [voxel size, 0.25 mm; layer thickness, 0.25 mm]; I-CAT) was made for each participant along with diagnostic impression. The diagnostic impression was scanned by using a 3D optical scan machine. The CBCT data (Digital Imaging and Communication in Medicine [DICOM]) and

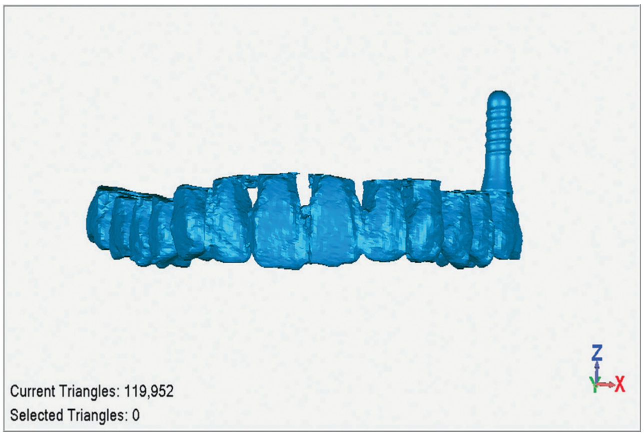

Figure 1. Cone beam computed tomography of implant in ideal position.

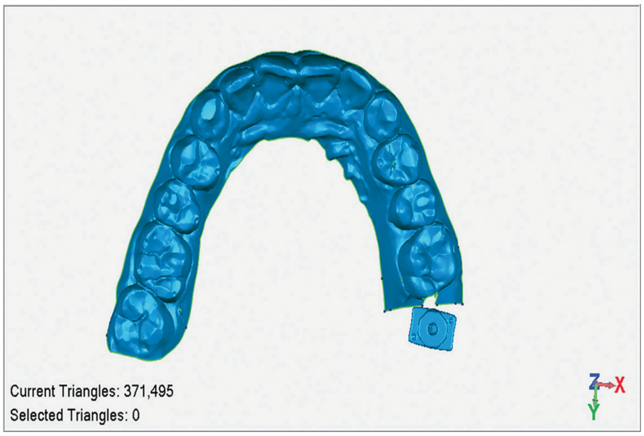

Figure 2. Optical scan of dentition and impression cylinder.

optical data (standard tessellation language [STL]) were imported into the 3D reconstruction software to determine the ideal implant position (Fig. 1) according to the following steps: the optical data were aligned with the CBCT data; the virtual tooth was designed based on occlusal relationships; and the implant position was determined according to the virtual tooth and anatomic structures.[22]

To determine the postsurgical implant position with the digital registration method, a gypsum cast with an implant analog was made for each participant before restoring the superstructure. To acquire the implant position data in optical scanning, an impression cylinder was inserted on the implant analog. Because the relationship between the impression cylinder and implant was fixed, the position of the postsurgical implant could be represented by the impression cylinder. Then, the gypsum cast was optically scanned, and the optical scan of the dentition cast was obtained (Fig. 2).

To regain the implant position data, several registration models were designed. The implant with an inserted impression cylinder was optically scanned, and the data were reconstructed using a software program (Geomagic Studio, v2012; 3D Systems) and defined as the registration models. The impression cylinder part was used to align the registration model with the optical scan of the dentition cast. As the impression cylinder part of the optically scanned dentition was not complete because of undercut areas, only the top part of the impression cylinder was used to produce the alignment. In this study, 6 types of standard plus Straumann implants were used (2 width types: wide neck and regular neck; 3 length types: 8 mm, 10 mm, and 12 mm), and 6 registration models were established.

The alignment procedure was conducted by using the reverse engineering software, and the alignment error was automatically calculated by the software and then recorded. Then, the postsurgical implant position was obtained using the digital registration method and saved in the STL format (Fig. 3).

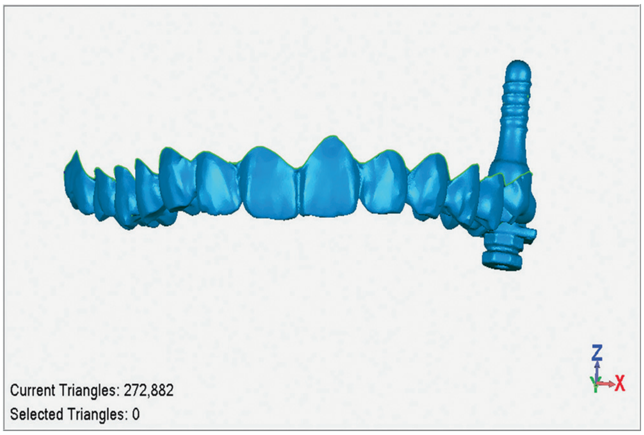

Figure 3. Implant position after surgery from digital registration method.

To determine the postsurgical implant position with the radiographic method, a second CBCT scan was made for each participant before restoring the superstructure. The CBCT parameter settings were the same as the presurgical settings. The data from the second CBCT scan were imported into the implant planning software (Simplant, v11.04; Dentsply Sirona). The postsurgical implant position and dentition were constructed in terms of their corresponding Hounsfield unit values. Using the radiographic method, the postsurgical implant position was obtained and saved in the STL format.

To make the measurements, the ideal implant position data and postsurgical implant position data determined by the digital registration method were imported into the reverse engineering software, and the alignment was made according to the corresponding dentition part. The alignment error of the dentition was calculated and recorded.

To minimize the artificial error caused by choosing the measurement points, a simulated cylinder was designed

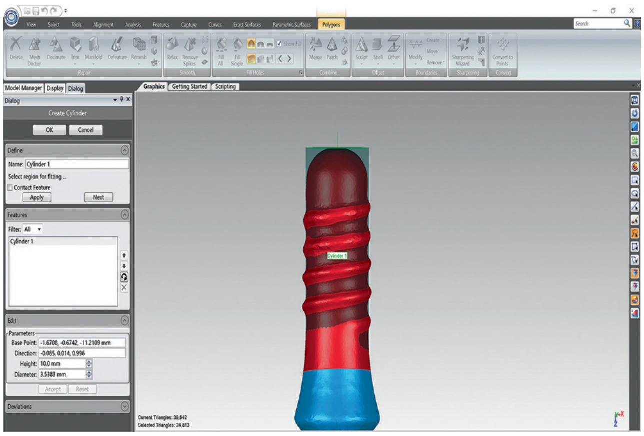

Figure 4. Simulated implant cylinder positioning.

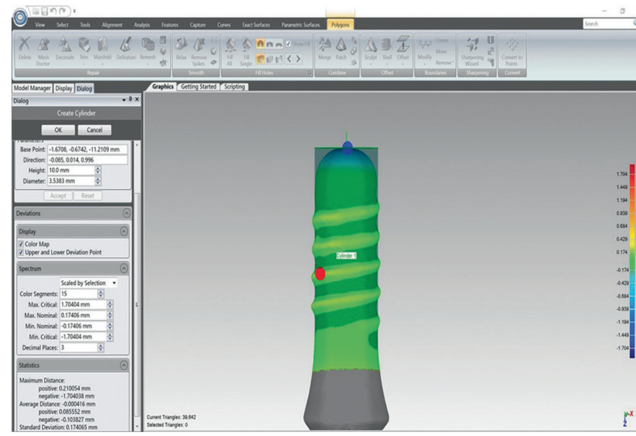

Figure 5. Mean errors of simulated cylinder. *Red* circle represents positive errors caused by screw thread, and *blue* circle represents negative errors caused by apical part.

to represent the implant. The simulated cylinder had the same height as the implant and substituted for the rough part of the implant (Fig. 4). The positive and negative errors of the simulated cylinder were calculated and recorded (Fig. 5). The deviations between the ideal and postsurgical implant positions at the entrance point (d1), apical point (d2), and axis (α) (Fig. 6) were calculated from the following formula:

$$d=\sqrt{(x1-x2)^2+(y1-y2)^2+(z1-z2)^2}$$

$$\arccos \alpha=\left|\frac{x1x2+y1y2+z1z2}{\sqrt{x1^2+y1^2+z1^2}\sqrt{x2^2+y2^2+z2^2}}\right|$$

The postsurgical implant position data derived from the digital registration method and the radiographic method were also imported into the reverse engineering software, and the alignment was made according to the corresponding dentition part. The parameters of the entrance point, apical point, and axis of the 2 methods were recorded. Then, the difference between the 2 methods in evaluating the accuracy of the implant position was calculated.

The accuracy of the implant position using the digital registration method was calculated. Differences in the implant position accuracy evaluated by the digital registration and radiographic methods at the entrance point, apical point, and axis of the implant were analyzed using the paired *t* test. The average alignment errors of the impression cylinder and dentition were calculated using a 1-sample *t* test. The error of the simulation cylinder was divided into positive and negative deviations and then calculated. All statistical analyses were conducted using a statistical software program (IBM SPSS Statistics, v19.0; IBM Corp) (α=.05).

RESULTS

The mean deviation between the ideal and postsurgical implant positions identified using the digital registration method was 0.84 ±0.57 mm for the entrance point, 1.03 ±0.78 mm for the apical point, and 4.52 ±2.37 degrees for the angle (Table 1). The mean deviation between the digital registration method and the radiographic method was −0.03 ±0.38 mm at the entrance point, −0.03 ±0.57 mm at the apical point, and 0.60 ±2.94 degrees at the angulation. No significant differences (P>.05) were found between the 2 methods (Table 2).

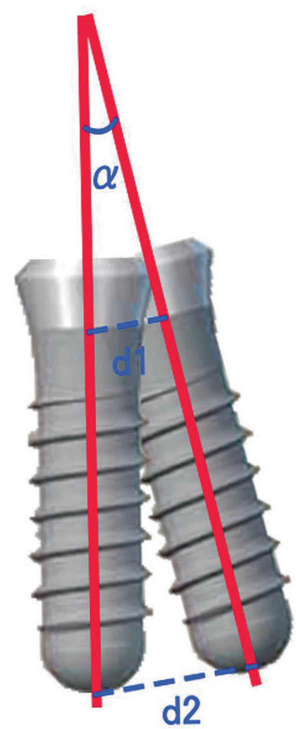

Figure 6. Measurement parameters. Deviations at entrance points (d1), apical points (d2), and angles (α).

Table 1. Accuracy of implant position using digital registration method

Metric	Entrance Point (mm)	Apical Point (mm)	Angle (Degree)
Mean	0.84	1.03	4.52
SD	0.57	0.78	2.37
95% CI	0.64-1.05	0.75-1.31	3.66-5.37

CI, confidence interval; SD, standard deviation.

Table 2. Three-dimensional deviation between digital registration method and radiographic method

Metric	Entrance Point (mm)	Apical Point (mm)	Angle (Degree)
Mean	-0.03	-0.03	0.60
SD	0.38	0.57	2.94
T	-0.50	-0.26	1.15
P	.62	.79	.26

SD, standard deviation.

Table 3. Alignment errors of impression cylinder, dentition, and simulated implant

Metric	Impression Cylinder (mm)	Dentition (mm)	Ideal Implant (mm)		Postsurgical Implant (mm)	
			Positive	Negative	Positive	Negative
Mean	0.03	0.29	0.09	-0.19	0.84	-0.15
SD	0.01	0.15	0.01	0.08	0.01	0.04
95% CI	0.02～0.03	0.22～0.36	0.08～0.09	-0.21～-0.16	0.08～0.09	-0.16～-0.13

CI, confidence interval; SD, standard deviation.

In the digital registration procedure, the average alignment error was 0.03 ±0.01 mm for the impression cylinder and 0.29 ±0.15 mm for dentition. Significant differences were found in the alignment procedure of the impression cylinder ($P<.001$) and dentition ($P<.001$). The average positive and negative errors were 0.09 ±0.01 mm and −0.19 ±0.08 mm, respectively, for the simulated ideal implant. The average positive and negative deviations were 0.08 ±0.01 mm and −0.15 ±0.04 mm, respectively, for the simulated postsurgical implant (Table 3).

DISCUSSION

The first null hypothesis was accepted. The digital registration method and radiographic method showed no significant difference in evaluating the accuracy of the implant position. The results of the study indicated that the digital registration method could be accepted in clinical applications.

The radiographic method has been used to evaluate the accuracy of an implant position.[10,15,21] The deviation in single implant placement using freehand has been reported to be 0.79 ±0.78 mm in the mesiodistal position and 4.79 ±3.56 degrees in angulation.[23] Previously, Schnutenhaus et al[24] used the Geomagic software to evaluate the accuracy of the implant position. They scanned the impressions with the implant analogs to represent the postsurgical implants and evaluated implant accuracy. The mean deviation was 0.9 to 1.0 mm, 1.5 to 1.6 mm, and 4 to 5 degrees at the implant neck, apex, and angle, respectively. These results were similar to those in the present study.

Schnutenhaus et al[24] reported the accuracy of the optical scan to be better than that of the CBCT scan in contrast with the results of the present study. The reverse engineering software used the interactive closest point (ICP) algorithm which could quickly register 2 similar 3D models. Although the precision of the ICP algorithm was limited by the system error, it was still better than a freehand calculation. The alignment error could be minimized but not eliminated.[25,26] Thus, the errors produced during the registration procedure, especially the occlusal registration, might be the main factor.

The second null hypothesis was rejected. The alignment error could be produced in each step. The errors of data processing were mainly caused by dentition registration and implant reconstruction. The CBCT and optical scan of the dentition have been aligned with manual registration. Tabea Flügge et al[27] reported that the deviation between the CBCT and intraoral scan models was 0.54 mm using manual registration. The digital registration method used the ICP algorithm of the reverse engineering software for the dentition alignment, and the average alignment of the dentition error was 0.29 mm.

In previous studies using radiographic methods, the Hounsfield unit value of the implant has been defined manually. Wang et al[28] reported that implants reconstructed by CBCT lacked accuracy of 0.5 mm of the peri-implant bone thickness.[28] In the present study, a postsurgical implant was reconstructed by using an optical scan, and the implant position was determined by using an impression cylinder with reverse engineering software. The precision of the optical scan was better than that of the CBCT scan, and the average alignment error of the impression cylinder was 0.03 mm.

In addition, the implant parameter measurement was calculated automatically by using the reverse engineering software. The average errors of the simulated implant cylinders were +0.09 and −0.19 mm and +0.08 and −0.15 mm. Such deviations were mainly caused by the screw thread part (positive deviation) and apical part (negative deviation) of the implants and registration models, as shown in Figure 5. The error was small and had little impact on the measurement.

Because the impression cylinders were variable in different implant systems, corresponding registration models should be established, and preliminary experiments should be conducted to verify the accuracy of the method. Although the connection type between the impression cylinder and the implant was variable, there was no difference in the accuracy of the different impression cylinder types.[29,30] The impression cylinders used in the present study were all inserted completely on the implant to ensure the stability of the impression.

To ensure the integrity of the scanned impression cylinder, further studies should focus on the size or shape. Because natural dentition can be regarded as a radiographic marker, as well as an optical marker, alignment was conducted based on natural teeth; thus, the digital registration method could only be used for partially edentulous patients. For edentulous patients, another marker with both radiographic and optical properties should be established to render the alignment, which still needs further investigation.

CONCLUSIONS

Based on the findings of this clinical study, the following conclusions were drawn:

1. The precision of the digital registration method was acceptable for clinical applications.
2. No significant difference was found between the digital registration method and the radiographic method in evaluating the clinical accuracy of the implant position.
3. The digital registration method was able to control and minimize the alignment errors produced during data processing.

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