



Comparison of accuracy between digital and conventional implant impressions: two and three dimensional evaluations

Chuang Bi¹, Xingyu Wang², Fangfang Tian², Zhe Qu¹, Jiaming Zhao^{1*}

¹Dalian Stomatological Hospital, Dalian, Liaoning Province, China

²Dalian Medical University, Dalian, Liaoning Province, China

ORCID

Chuang Bi

<https://orcid.org/0000-0001-9840-4166>

Xingyu Wang

<https://orcid.org/0000-0003-0788-3419>

Fangfang Tian

<https://orcid.org/0000-0001-8107-2564>

Zhe Qu

<https://orcid.org/0000-0002-2822-0879>

Jiaming Zhao

<https://orcid.org/0000-0003-3545-905X>

PURPOSE. The present study compared the accuracy between digital and conventional implant impressions. **MATERIALS AND METHODS.** The experimental models were divided into six groups depending on the implant location and the scanning span. Digital impressions were captured using the intraoral optical scanner TRIOS (3Shape, Copenhagen, Denmark). Conventional impressions were taken with the monophase impression material based on addition-cured silicones, Honigum-Mono (DMG, Hamburg, Germany). A high-precision laboratory scanner D900 (3Shape, Copenhagen, Denmark) was used to obtain digital data of resin models and stone casts. Surface tessellation language (STL) datasets from scanner were imported into the analysis software Geomagic Qualify 14 (3D Systems, Rock Hill, SC, USA), and scan body deviations were determined through two-dimensional and three-dimensional analyses. Each scan body was measured five times. The Sidak t test was used to analyze the experimental data. **RESULTS.** Implant position and scanning distance affected the impression accuracy. For a unilateral arch implant and the mandible models with two implants, no significant difference was observed in the accuracy between the digital and conventional implant impressions on scan bodies; however, the corresponding differences for trans-arch implants and mandible with six implants were extremely significant ($P < .001$). **CONCLUSION.** For short-span scanning, the accuracy of digital and conventional implant impressions did not differ significantly. For long-span scanning, the precision of digital impressions was significantly inferior to that of the traditional impressions. [J Adv Prosthodont 2022;14:236-49]

Corresponding author

Jiaming Zhao

Dalian Stomatological Hospital,
No. 935 Changjiang Road,
Shahekou District, 116021, Dalian,
Liaoning Province, China

Tel +8615942808079

E-mail

dlkq_zhaojiaming@126.com

Received April 6, 2022 /

Last Revision June 15, 2022 /

Accepted July 29, 2022

This study was supported by the Medical Science Research Projects of Dalian (No. 1911082).

KEYWORDS

Accuracy; Dental implant; Digital impression; Conventional impression; Impression technique

© 2022 The Korean Academy of Prosthodontics

© This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/4.0>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

INTRODUCTION

Dental implants, which have recently been introduced for patients with tooth loss, can remarkably improve the masticatory efficiency of patients compared with conventional dentures.^{1,2} Dental implantation involves two steps, namely inserting the implant into the bone and attaching the prosthesis 4 - 6 months after healing. Stable osseointegration and passive fit for restorations are critical for successful dental implantations.³⁻⁵ The causes of non-passive adjustment include deviation of the implant's position and deformation of the impression and plaster model.⁶ In addition, accurate reproduction of the patients' oral condition is critical for achieving a correct impression. Although different impression techniques are available,⁷ open-tray impressions have been demonstrated to be superior to closed-tray impressions.⁸ Currently, the splinted open-tray technique is the mainstream method for completely edentulous jaws⁹ and this impression provided acceptable clinical results. With the development of dental impression techniques in recent years, digital technology has gained popularity because digital impressions do not require the use of trays and reduce patients' oral sensation. Furthermore, the method is highly efficient, and it facilitates communication among doctors, dental technicians, and patients. Conventional impressions can cause some discomfort to patients during operation, including breathing difficulties, difficulty in mouth opening, and tooth sensitivity.¹⁰ Conventional impressions are difficult to reproduce accurately under some circumstances, especially when the angle between implants is large or in case of long-span implant scanning.¹¹ Digital impression techniques eliminate the complex steps required in conventional impression techniques such as pouring, disinfecting, and shipping molds to the laboratory.¹² Intraoral scanner systems can help acquire the 3D positions of implants easily and allow dentists to quickly understand patients' oral conditions.

The direct oral scanning technique has been utilized in short-span implant scanning, and the digital workflow is applicable in clinical settings.¹³ The passive fit of a fixed restoration has been reported for single implants.¹⁴ Lee *et al.* compared the accuracy

of 30 gypsum models from conventional implant impression and 30 digitally milled models from directly scanning; all test models were fitted to a reference model in the software, 10 reference points were selected on the scanning rod of the implants, and the deviations of the reference points were used to compare the two models.¹⁵ A review comparing the digital impressions with traditional impressions in terms of accuracy in fixed restorations indicated that short, fixed dental prostheses from digital impressions could be clinically acceptable.¹⁶ Syrek *et al.* concluded that the zirconia single crown derived from digital impressions was not only suitable for clinical application but also exhibited higher accuracy than traditional impressions.¹⁷ However, there is a lack of consensus regarding the accuracy of edentulous jaw implant impressions. Vandeweghe *et al.* evaluated the accuracy of four intraoral scanners for complete-arch implant models with multiple implants and concluded that one of those scanners was not suitable for edentulous jaws.¹⁸ Some *in vitro* studies have assessed the clinical applicability of digital impressions for edentulous jaws.¹⁹⁻²² However, most of these studies were conducted under a single clinical condition and mainly determined the overall accuracy of the model. The present study measured the scanning deviation for each implant site by simulating all clinical conditions, thereby providing a reliable theoretical basis for clinicians. The null hypothesis was that the accuracy would not differ significantly between the digital impressions and the conventional impressions derived from the reference model for a unilateral implant, whereas for cross-arch implants, the comparison between the two impression techniques and reference models might yield inconsistent results.

MATERIALS AND METHODS

Resin models from four partially edentulous and two completely edentulous models were used in this study (Fig. 1). In the resin model experiment, all experimental models were divided into six groups: A, B, C, D, E, and F. The resin models of groups A, B, C, and D were the same partially dentate maxilla, with missing right first molar and left first and second molars. The edentulous model was assigned to groups E and

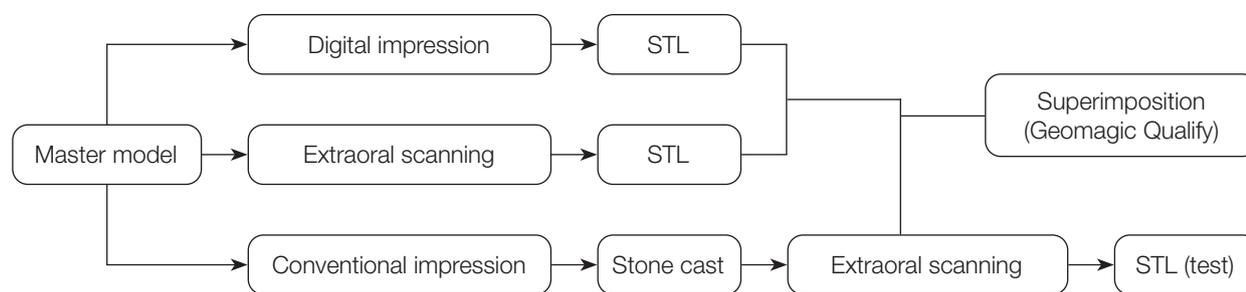


Fig. 1. Schematic diagram: Six master models were prepared and used in three ways for intraoral scanner scanning, extraoral scanner scanning, and conventional material impression. All data were converted to the STL format and superimposed in inspection software.

F. In groups A to E, implant analogs (RN, Straumann, Switzerland) were used. In group F, different implant analogs were used (RN, WN; Straumann, Switzerland). Groups A, B, D, and E constituted the non-trans-arch group, whereas the remaining groups constituted the trans-arch group. The implantation standards were implemented strictly according to the requirements of the manufacturer. The impact of implantation depth was not considered in this experiment because it does not affect the final accuracy of the digital impression, as reported by Arcuri *et al.*,²³ who used digital impressions to examine the effect of implantation depth on the digital precision.

The six sets of models are as follows:

Group A: an implant was drilled into site 16

Group B: implants were drilled into sites 26 and 28

Group C: implants were drilled into sites 16, 26, and 28

Group D: implants were drilled into sites 26 and 27, and implant at site 27 had an angulation of 15°

Group E: implants were drilled into sites 32 and 42

Group F: implants were drilled into sites 32, 42, 34, 44, 36, and 46

In this study, extraoral scan data of resin models served as the control group, whereas intraoral scan data of digital impressions and extraoral scan data of conventional impressions served as the experimental group.

Digital and conventional impressions were made by the same dentist (Fig. 2 and Fig. 3). Custom trays were fabricated for each resin model group, except for group A. The holes were drilled on the trays as the im-

pression copings (RN, WN; Straumann, Switzerland). All adjacent copings were splinted with autopolymerized acrylic resins (GC pattern resin; GC Corp., Tokyo, Japan) to avoid scan body shifting. Then, the resin bars were cut for releasing internal stress and connected before taking impressions.

The procedure was standardized by controlling the temperature at 25°C and the humidity at 50%. Impression copings were attached to the implants and the monophasic impression material was used addition-cured silicones Honigum-Mono (DMG, Hamburg, Germany). Open-tray impressions were prepared by applying light finger pressure on the top of the copings, and the resins were visible from the tray's holes. After obtaining the impressions, the custom trays were removed, and the implant analogs were screwed into the impressions. Thereafter, the impressions were forwarded to a laboratory for the preparation of type IV plaster (Silky Rock; Whipmix Corp., Louisville, KY, USA) casts. The plaster, which had a low expansion ratio (0.09%), was set for 40 min and then retrieved from impressions. To ensure the complete expansion of casts, all models were left at room temperature for four days.

Scannable abutments coated with polyether ether ketone were used to ensure minimal interference from reflected light. The shiny surfaces of titanium scan bodies made the scanning process difficult. Scan bodies (RN, WN; Straumann, Switzerland) were screwed into implant analogs manually. The confocal optical imaging technology was employed to generate digital point cloud surfaces by using the digital intraoral scanner (3Shape, Copenhagen, Denmark),

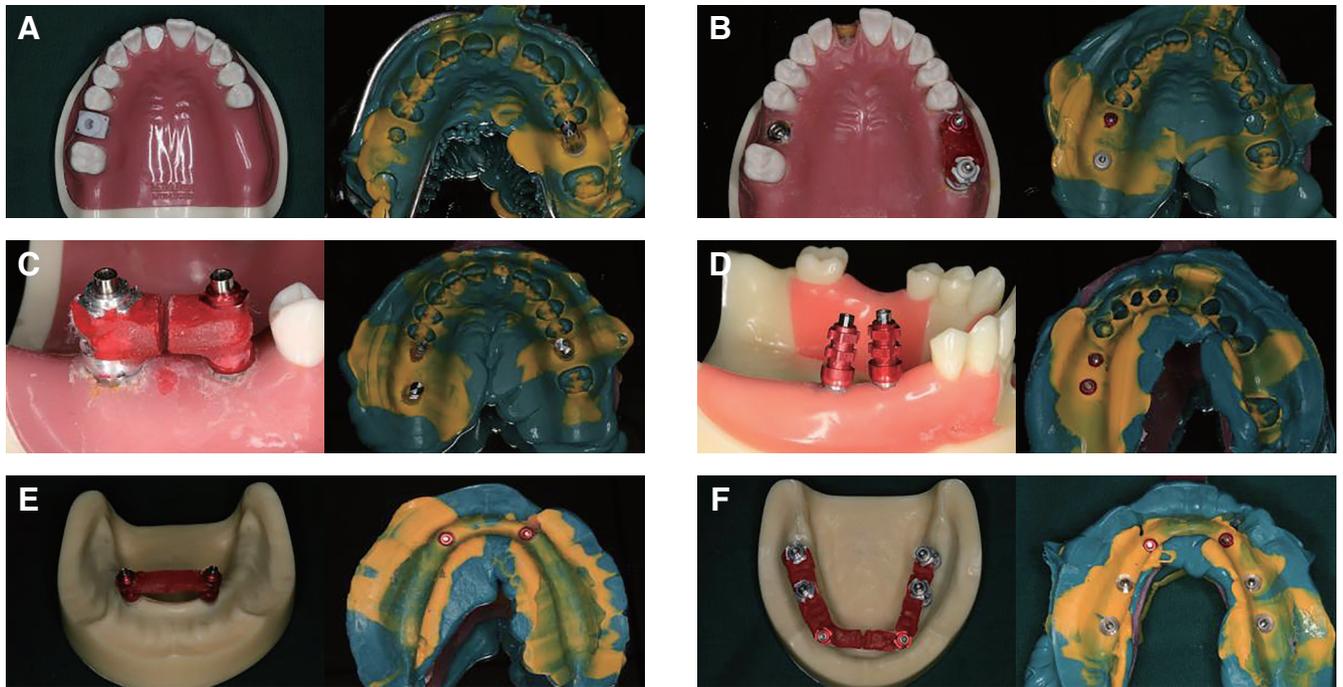


Fig. 2. Conventional impression protocol: open-tray splinted impressions made using the monophasic impression material. (A) Group A: Single implant, (B) Group B: Three-unit implants, (C) Group C: Trans-arch implants, (D) Group D: Angle implants, (E) Group E: Two implants for complete-arch, (F) Group F: Six implants for complete-arch.

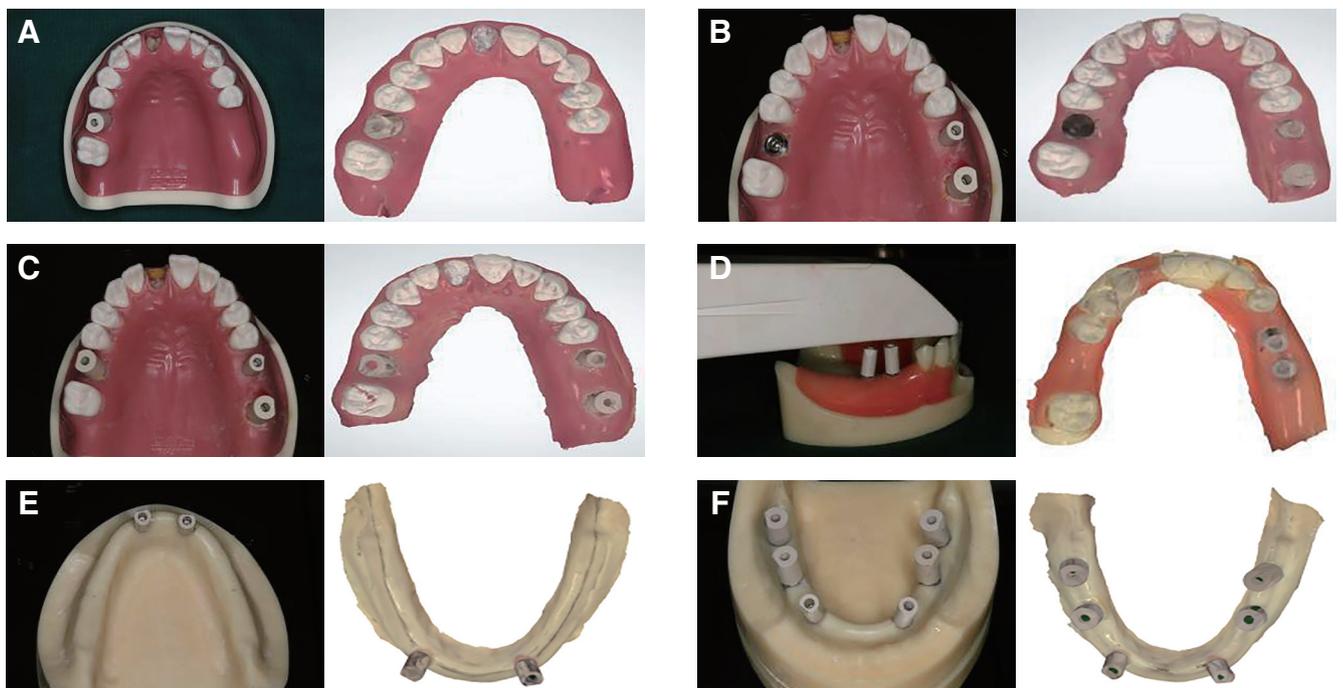


Fig. 3. Digital impression protocol: digital impressions taken using the intraoral scanner. (A) Group A: Single implant, (B) Group B: Three-unit implants, (C) Group C: Trans-arch implants, (D) Group D: Angle implants, (E) Group E: Two implants for complete-arch, (F) Group F: Six implants for complete-arch.

which could be imported as STL datasets and used for both partial- and complete-arch intraoral scans (IOS). The accuracy of the scanner used is $6.9 \pm 0.9 \mu\text{m}$. By using the scanning technique, less than 1,000 images per arch were obtained as per manufacturer's recommendations. The digitally acquired volumes could be viewed on the touch screen during scanning, allowing a direct visual feedback to ensure that no parts were missing. According to manufacturer's recommendation, in groups A, B, C and D, scanning was performed from the distal buccal side of the last molar or scan bodies to the distal buccal side of the last molar in the contralateral quadrant, followed by the transfer of the scanning head to the palatal side. Then, maxillofacial scanning was performed. In groups B and D, scanning was performed starting from the second quadrant to avoid the interference of dental arch length on experimental results. In groups E and F, to observe the influence of dental arch length on the experimental results, the scan bodies at sites 32 and 42 were scanned first, and then, the rear scan bodies and model surface were scanned in the same manner. After the acquisition of digital impressions, the digital volumes were exported as STL files for comparison (Fig. 4 and Fig. 5).

All solid model data were converted into the STL format for the ease of measurement using software. Resin models were tightened into scan bodies and digitized using a high-resolution extraoral scanner with $20\text{-}\mu\text{m}$ precision (D900; 3Shape, Copenhagen, Denmark). The data from resin models were saved that served as the control group. Likewise, the stone casts from conventional impressions were screwed into scan bodies and digitized using an extraoral scanner. The complete 3D images of scan bodies and surface of models were captured. Data files were exported that served as the test group. The resin models and stone casts were digitized using a high-resolution extraoral scanner with $20\text{-}\mu\text{m}$ precision (D900; 3Shape, Copenhagen, Denmark). The STL digital files were saved.

The terms "trueness" and "precision" represent different measures of accuracy (Ender & Mehl 2013).²⁴

Trueness is defined as the comparison between a control dataset and a test dataset. The measured deviations between the control dataset and the test dataset determine the accuracy of a scanner or an

impression material. The data of this experiment explained the trueness of two impression techniques compared with that of the reference model.

Each group's STL files were imported into Geomagic Qualify 14 (3D Systems, Rock Hill, SC, USA). Then, the resin data from the extraoral scan were set as reference data (control data), and the STL data from the gypsum and the digital impressions were individually set as test data. The data in the software were trimmed to ensure that the fitted data were of the same size. Then, the best-fit algorithm was performed between the reference and test data based on similar points on the surface. The deviation between the reference and control data was analyzed using the 3D comparison function (Fig. 4). For quantitative analysis, three points on the scan bodies' slope were established. Deviation was calculated using the following formula:

Deviation = $\sqrt{Dx^2 + Dy^2 + Dz^2}$, where Dx denotes the deviation at x-axis, Dy denotes the deviation at y-axis, and Dz denotes the deviation at z-axis. The three vertices of the scan bodies were measured to determine the position of the implants in the three-dimensional space. The scanning rods of each group of models were repeatedly measured in the same manner, and a total of five measurements were taken. The size of each measured area was set as $0.1 \times 0.1 \text{ mm}$, and the divergences were measured from a uniform position in the reference coordinate axes. Each set of models was measured five times.

For 2D measurements, the straight line function was used, the feature of cylinder on point cloud was selected, and the central axis of cylinder, that is, the rotating center line of cylinder, was fitted. The center line of the cylinder was used to stretch out a surface perpendicular to the central axis of the cylinder. The built surface is stretched on the central axis of the cylinder to ensure that the surface is perpendicular to the center of the cylinder. Therefore, any surface that is obtained lies on the central axis of the cylinder. Coronal and sagittal planes were generated according to the central axis, and then, the distance between two data from the 2D section was calculated (Fig. 5). Five repeated measurements were made for each section.

Statistical evaluation was performed using the software package SPSS Statistics (version 26; IBM, Chi-

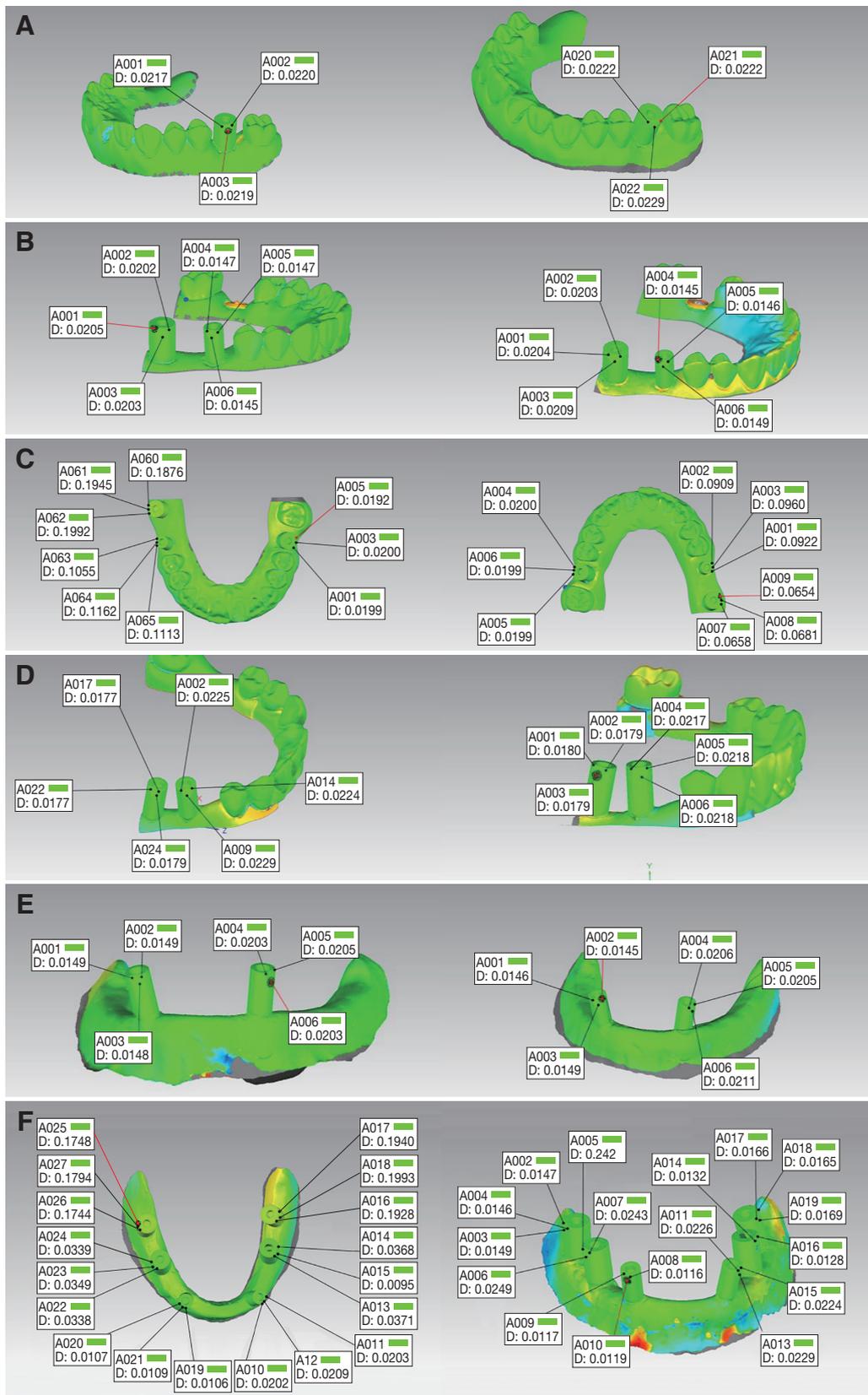


Fig. 4. Three-dimensional comparison between scan bodies (left: digital models; right: conventional models). (A) Group A: Single implant, (B) Group B: Three-unit implants, (C) Group C: Trans-arch implants, (D) Group D: Angle implants, (E) Group E: Two implants for complete-arch, (F) Group F: Six implants for complete-arch.

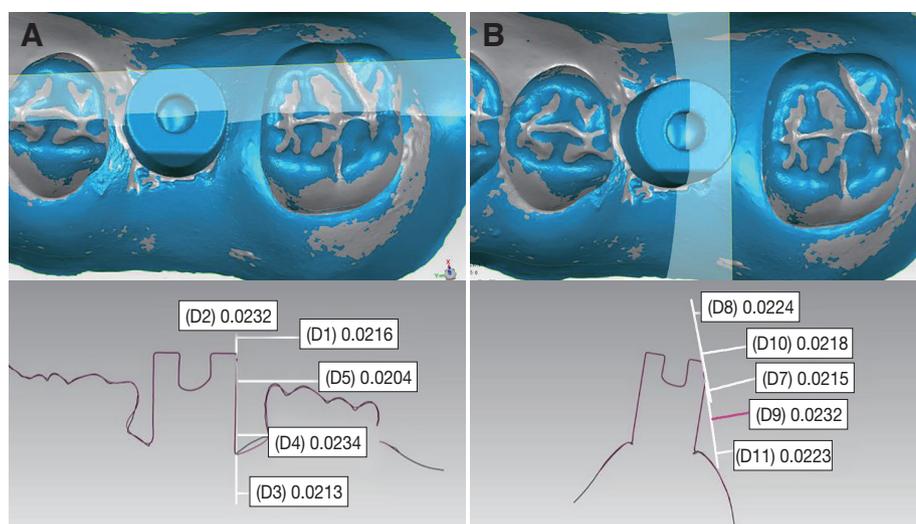


Fig. 5. Superimposed scan body were sectioned by two planes which were created by cylindrical center. Five points were selected to calculate the distance between two models on each plane. (A) Sagittal plane (left side), (B) Coronal plane (right side).

chicago, IL, USA). The repeated measurements were averaged for each scan body. First, repeated measures ANOVA was used to compare and analyze the deviations of all scan bodies for each group of models. Then, the Sidak's post hoc test was adopted to compare each scan body in each pair of models on the same side. P value of $< .001$ was considered extremely statistically significant in the comparison of impression data between the two groups.

RESULTS

The measurement values are shown in Table 1 and Table 2. Each set of data was entered into the mapping software GraphPad Prism version 9.0 (GraphPad Software, San Diego, CA, USA) and exported as deviation graphs (Fig. 6). For 3D comparison, the difference in the scan bodies (both overall scan bodies and a single scan body) between the two impression techniques in the non-cross dental arch group was not statistically significant. However, for cross dental arch, statistically significant differences were observed between the scan bodies ($P < .001$). For 2D comparison, except for group D, the results were the same as those for 3D comparison. In group D, extremely significant deviations were observed between scan bodies in the overall comparison ($P < .001$).

DISCUSSION

The results of this study showed that if the implant was limited to one side, digital impressions could completely replace the traditional impressions.

In particular, intraoral scanners are commonly used in dental clinics because the intraoral scanning process has numerous advantages.²⁵ IOS obtained complete optical impressions of dental arch with overlapping images. Optical impressions have been reported to markedly reduce patients' discomfort^{26,27} compared with the previous impression technique, which was not technically demanding and sensitive;^{28,29} therefore, the digital technique could be the alternative to the conventional impression technique, with the popularity of latter showing a decreasing trend.³⁰

The purpose of this study was to compare the accuracy between digital impressions and conventional impressions on the implant models. To the best of our knowledge, this study is the first to compare the impression precision of implants for multiple situations from partial edentulism to full edentulism. Previous studies have compared the accuracy of multiple scanners in implant impressions, proving that the TRIOS scanners could be used in the clinic.³¹ Therefore, in this study, it was used for the comparison.

To date, some literature reviews have indicated that

Table 1. Mean ± standard deviation of 3D deviations of scan bodies between the conventional and digital models to the reference model calculated at the landmarks

Subgroup	Site	Digital (mm)	Conventional (mm)	P-value	Sidak-t	F _{group}	P _{group}
Group A	16	21.70 ± 0.15	22.62 ± 0.11	.006**	5.377	-	-
Group B	26	14.93 ± 0.60	14.72 ± 0.92	.567	0.979	0.065	0.802
	28	20.36 ± 0.25	20.65 ± 0.11	.359	1.340		
Group C	16	19.61 ± 0.16	20.03 ± 0.24	.996	0.195	1554.17	< 0.001
	26	114.79 ± 4.02	96.96 ± 0.91	< .001***	8.356		
	28	193.81 ± 6.24	65.48 ± 3.52	< .001***	60.120		
Group D	26	22.50 ± 0.28	22.37 ± 0.41	.867	0.483	1.072	0.316
	27	17.74 ± 0.14	18.28 ± 0.71	.134	1.948		
Group E	32	20.70 ± 0.35	20.85 ± 0.20	.664	0.827	0.114	0.739
	42	14.82 ± 0.41	14.75 ± 0.09	.928	0.348		
Group F	42	10.67 ± 0.09	11.59 ± 0.13	.469	1.667	77393.78	< 0.001
	32	20.46 ± 0.15	22.43 ± 0.24	.004**	3.619		
	44	34.10 ± 0.25	24.30 ± 0.29	< .001***	18.020		
	34	36.85 ± 0.84	12.88 ± 1.47	< .001***	44.070		
	46	175.03 ± 1.21	14.74 ± 0.18	< .001***	294.80		
	36	195.99 ± 2.05	16.67 ± 0.18	< .001***	329.70		

Group A: implant was drilled into site 16; group B: implants were drilled into the sites 26 and 28; group C: implants were drilled into the sites 16, 26, and 28; group D: implants were drilled into the sites 26 and 27, and the implant at site 27 had an angulation of 15°; group E: implants were drilled into the sites 32 and 42; group F: implants were drilled into the sites 32, 42, 34, 44, 36, and 46.

*statistically significant difference ($P < .05$), **obviously statistically significant difference ($P < .01$), ***extremely statistically significant difference ($P < .001$).

the IOS could be useful for single and short-span cases with 4 - 5 implants on the unilateral arch. Studies have demonstrated that the restorations from IOS have similar prosthetic effects as conventional impressions.³²⁻³⁴ For short-span cases, the optical impressions have been shown to be reliable and meet all clinical requirements.^{29,35} However, for the long-span cases with more than 5 implants, the precision of impressions made from scanning is not comparable to that of conventional impressions.^{36,37} In particular, for edentulism, the error from optical impressions is clinically large, and conventional impression techniques are still used for long-span restorations.

Several studies have reported findings on the intraoral use of digital scanning with edentulous implanting. Papaspyridakos *et al.* compared the optical impressions with splinted and non-splinted impressions; the accuracy of different impressions was reported to be analogous, and the authors concluded that digital impressions could be used for patients with completely edentulous jaws.³⁸ Furthermore, a

study comparing different scanning devices with conventional impressions reported that the accuracy of full-arch digital implant impressions is high.³⁹ The conclusions drawn from the present study are inconsistent with those of previous studies. In our experiment, scan bodies on the contralateral dental arch and terminal had large scanning errors. Scanning distance that is too long may result in the accumulation of more errors, making the scanning process difficult.

The implant position and distance between implants were reported to be the factors important for maintaining the stability of impressions.⁴⁰ In the present study, the errors of scan bodies in groups C and F were significantly different between the two impressions. According to the results, the accuracy would be decreased with an increase in the scanning span in trans-arch implants. In cross-arch implant scanning, the position of scan bodies had an obvious impact on its deviations.⁴¹ For edentulous scanning, our study used the scanning methods that involved scanning of the anterior region first. The difficulties of collect-

Table 2. Mean \pm standard deviation of 2D deviations of scan bodies between the conventional and digital models to the reference model calculated at three sections

Subgroup	Site	Digital (mm)	Conventional (mm)	P-value	Sidak-t	F _{group}	P _{group}
Group A	16Coronal	22.24 \pm 0.65	22.32 \pm 0.73	.986	0.152	1.398	0.254
	16Sagittal	21.98 \pm 1.29	22.78 \pm 0.41	.274	1.520		
Group B	26Coronal	14.34 \pm 0.70	14.70 \pm 0.51	.765	1.046	0.615	0.439
	26Sagittal	15.02 \pm 0.72	14.72 \pm 0.33	.861	0.872		
	28Coronal	20.40 \pm 0.51	20.82 \pm 0.27	.651	1.200		
	28Sagittal	20.68 \pm 0.74	20.74 \pm 0.34	> .999	0.174		
Group C	16Coronal	18.80 \pm 1.35	20.64 \pm 1.94	.961	0.818	2973.93	< 0.001
	16Sagittal	19.72 \pm 0.58	19.40 \pm 0.81	> .999	0.142		
	26Coronal	119.30 \pm 6.31	96.18 \pm 1.25	< .001***	10.270		
	26Sagittal	118.08 \pm 2.29	99.08 \pm 1.39	< .001***	8.442		
	28Coronal	192.94 \pm 5.58	65.42 \pm 5.33	< .001***	56.660		
	28Sagittal	200.94 \pm 5.64	68.46 \pm 2.30	< .001***	58.870		
Group D	26Coronal	22.96 \pm 0.18	21.56 \pm 0.78	.003**	3.750	20.250	< 0.001
	26Sagittal	22.80 \pm 0.20	21.50 \pm 0.75	.006**	3.482		
	27Coronal	17.94 \pm 0.51	17.26 \pm 0.63	.277	1.822		
	27Coronal	17.92 \pm 0.11	17.94 \pm 0.93	> .999	0.054		
Group E	42Coronal	14.40 \pm 0.61	14.58 \pm 0.61	.984	0.468	8.028	0.008
	42Sagittal	14.80 \pm 0.94	14.92 \pm 0.11	.997	0.312		
	32Coronal	19.62 \pm 0.43	20.78 \pm 0.94	.020*	3.015		
	32Sagittal	20.30 \pm 0.40	21.02 \pm 0.31	.253	1.872		
Group F	42Coronal	10.82 \pm 0.30	11.60 \pm 0.67	.999	0.809	50946.64	< 0.001
	42Sagittal	10.72 \pm 0.24	12.06 \pm 0.26	.890	1.390		
	44Coronal	20.88 \pm 0.27	22.32 \pm 1.42	.833	1.493		
	44Sagittal	20.86 \pm 0.21	22.68 \pm 0.53	.537	1.888		
	46Coronal	34.36 \pm 1.04	24.68 \pm 0.24	< .001***	10.040		
	46Sagittal	34.06 \pm 1.10	24.84 \pm 1.26	< .001***	9.652		
	32Coronal	37.54 \pm 0.82	12.84 \pm 0.26	< .001***	25.620		
	32Sagittal	37.16 \pm 1.23	14.18 \pm 3.11	< .001***	23.830		
	34Coronal	179.52 \pm 1.04	14.80 \pm 0.34	< .001***	170.800		
	34Sagittal	179.44 \pm 2.53	14.56 \pm 0.52	< .001***	171.000		
36Coronal	199.60 \pm 1.81	16.48 \pm 1.03	< .001***	189.900			
36Sagittal	197.76 \pm 4.92	196.76 \pm 4.92	< .001***	186.700			

Group A: implant was drilled into site 16; group B: implants were drilled into the sites 26 and 28; group C: implants were drilled into the sites 16, 26, and 28; group D: implants were drilled into the sites 26 and 27, and the implant at site 27 had an angulation of 15°; group E: implants were drilled into the sites 32 and 42; group F: implants were drilled into the sites 32, 42, 34, 44, 36, and 46.

*statistically significant difference ($P < .05$), **obviously statistically significant difference ($P < .01$), ***extremely significant difference ($P < .001$).

ing images increased significantly while scanning the posterior area. Our operator should have spent more time in capturing whole scan bodies. We believe that the reasons might be overlapping images that increased the error. van der Meer *et al.* assessed three different intraoral scanners and concluded that

an increase in the scanning errors is inevitable⁴² because an increase in the arch length results in the accumulation of errors. Mizumoto *et al.* concluded that the implant position had a profound impact on accuracy. A study on four parallel implants attached on the maxillary edentulous models, with two scanning

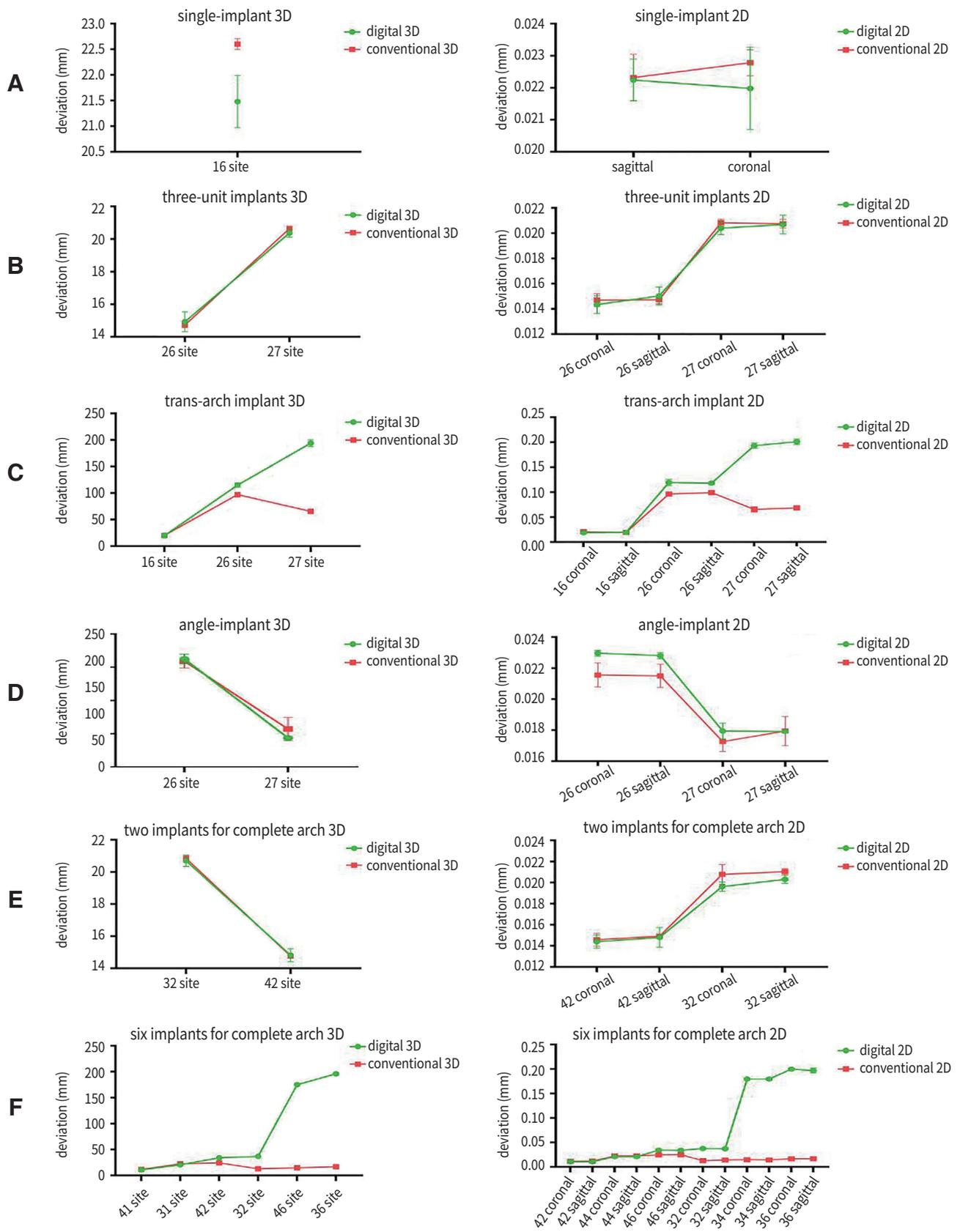


Fig. 6. Three-dimensional (3D) and two-dimensional (2D) deviations (Left: 3D deviations; right: 2D deviations). (A) Group A: Single implant, (B) Group B: Three-unit implants, (C) Group C: Trans-arch implants, (D) Group D: Angle implants, (E) Group E: Two implants for complete arch, (F) Group F: Six implants for complete arch.

modes (stitched and non-stitched), indicated that the implant at the maxillary canine had higher precision than that at the molars.⁴³

The principle of some scanners mainly involves the superposition of images to obtain the final complete image. Therefore, the rear part of an image is definitely more imprecise than the front part.⁴¹ According to a study, the longer the stitching, the greater the cumulative inherent error.⁴³ The scanner started in the anterior region and then continued to the posterior area, which can remarkably increase the deviation between the two quadrants or between the anterior and posterior arches.⁴⁴ Imburgia *et al.* reported that full dental arch scanning was more difficult and less accurate than local area scanning.⁴⁵ This conclusion is consistent with the results of the complete dental arch scan in the present study. Because scanning of the edentulous jaw in this study was executed from the front to the back arch, the error of the bilateral back increased significantly.

In addition to distance, angle might be a factor that affects the scanning accuracy. In this study, the precision of our models was unaffected by implants with 15° angulation. Presently, there is no consensus on the influence of implant angle on digital impression accuracy. Giménez *et al.* reported that implant angles less than 30° did not affect the accuracy.⁴³ However, the technical requirements for scanning of digital impressions are high, and if the angle is too large, the operator might miss some regions while capturing images.⁴⁶ Papaspyridakos *et al.* compared the accuracy of digital and conventional impressions for patients with completely edentulous jaws by using a stone cast with five implants, in which the left distal implant had an angulation of 10° and the right distal implant had an angulation of 15°. These angulations showed no effect on the accuracy of the impressions.³⁸ Similarly, Carr *et al.*⁴⁷ reported that angulations less than 15° had no effect on impressions, whereas Jang *et al.*⁴⁸ reported that angulations greater than 20° had a negative effect. Howell *et al.*⁴⁹ concluded that only the open-tray method was accurate for angulations greater than 30°. In this study, the angle of implants was 15°, and the impression accuracy was not affected at this angle. Therefore, we concluded that the impression accuracy obtained by the in-

traoral scanner at this angle was clinically acceptable. In this study, the experience of the operator played a key role in the accuracy of the scanning. In group D, the overall comparison between scan bodies showed a statistically significant difference, with the deviation of digital impressions being higher than that of traditional impressions. We believe that the undercut of scan bodies increased the difficulty of scanning the adjacent surface. Yang *et al.*⁵⁰ concluded that narrow or angular areas had greater deviations in single crown scanning. They reported that when the angle of the scanning head was greater than 60° from the target plane, the scan deviation would increase. In this study, the 3D comparison involved the comparison with the inclined plane; hence, scanning was a bit easier. Most of the previous studies on angle implants have measured the overall deviation of the scan bodies, necessitating the cross-sectional measurements in further studies.

The consistency of 2D and 3D measurement results confirmed the reliability of the software and measurement method. The consistent 10- μ m difference between the 2D and 3D data sets was due to the differential processing of the software when comparing the 3D and 2D data and not due to an error in the measurement protocol.⁵¹ Most studies have confirmed that with an increase in the distance between implants, the difficulty of complete-arch scanning increases.^{51,52} Therefore, we performed scanning from the anterior to the posterior region and noted the direct influence of distance between implants on the deviation. The data indicated that the deviations of scan bodies increased obviously from front to back. At the free end, a significant difference was noted between the two impression technologies because with an increase in the scanning distance, the deviation would gradually accumulate.⁵³

Although a comprehensive simulation of the clinical situations was conducted in this study, some limitations of this study should be acknowledged. First, this *in vitro* study did not consider the oral environment. Many factors could influence the accuracy of optical impressions in the oral cavity such as oral space, mucous membrane movement, and saliva flow. Second, *in vivo* experiments were lacking in the present study, necessitating future studies involving *in vivo* experi-

ments for further comparison. In the future, clinical decision-making should be based on several aspects, including time efficiency, learning curves, accuracy, and cost-effectiveness. In clinical settings, the intelligent use of digital impressions might provide additional advantages.

CONCLUSION

The following conclusions can be drawn from the present study:

The difference in the accuracy between the digital impressions and the conventional impressions derived from the reference model for a unilateral implant is nonsignificant; however, for trans-arch implants, the difference in data deviation is statistically significant. Thus, conventional impressions are more accurate for trans-arch scanning.

For long-scan scanning, IOS cannot achieve the necessary accuracy for restorations. Capturing digital impressions for patients with partially or completely edentulous jaws remains to be further confirmed *in vitro*.

REFERENCES

1. Adell R, Lekholm U, Rockler B, Brånemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *Int J Oral Surg* 1981; 10:387-416.
2. Zarb GA, Schmitt A. The longitudinal clinical effectiveness of osseointegrated dental implants in posterior partially edentulous patients. *Int J Prosthodont* 1993;6:189-96.
3. Goll GE. Production of accurately fitting full-arch implant frameworks: Part I--Clinical procedures. *J Prosthet Dent* 1991;66:377-84.
4. Rangert B, Jemt T, Jörneus L. Forces and moments on Branemark implants. *Int J Oral Maxillofac Implants* 1989;4:241-7.
5. Papaspyridakos P, Chen CJ, Gallucci GO, Doukoudakis A, Weber HP, Chronopoulos V. Accuracy of implant impressions for partially and completely edentulous patients: a systematic review. *Int J Oral Maxillofac Implants* 2014;29:836-45.
6. Stumpel LJ 3rd, Quon SJ. Adhesive abutment cylinder luting. *J Prosthet Dent* 1993;69:398-400.
7. Lee SJ, Cho SB. Accuracy of five implant impression technique: effect of splinting materials and methods. *J Adv Prosthodont* 2011;3:177-85.
8. Mangano A, Beretta M, Luongo G, Mangano C, Mangano F. Conventional vs digital impressions: acceptability, treatment comfort and stress among young orthodontic patients. *Open Dent J* 2018;12:118-24.
9. Johansson G, Palmqvist S. Complications, supplementary treatment, and maintenance in edentulous arches with implant-supported fixed prostheses. *Int J Prosthodont* 1990;3:89-92.
10. Gallardo YR, Bohner L, Tortamano P, Pigozzo MN, Lagana DC, Sesma N. Patient outcomes and procedure working time for digital versus conventional impressions: A systematic review. *J Prosthet Dent* 2018;119: 214-9.
11. Joda T, Lenherr P, Dedem P, Kovaltschuk I, Bragger U, Zitzmann NU. Time efficiency, difficulty, and operator's preference comparing digital and conventional implant impressions: a randomized controlled trial. *Clin Oral Implants Res* 2017;28:1318-23.
12. Park HR, Park JM, Chun YS, Lee KN, Kim M. Changes in views on digital intraoral scanners among dental hygienists after training in digital impression taking. *BMC Oral Health* 2015;15:151.
13. Joda T, Brägger U. Time-efficiency analysis of the treatment with monolithic implant crowns in a digital workflow: a randomized controlled trial. *Clin Oral Implants Res* 2016;27:1401-6.
14. Syrek A, Reich G, Ranftl D, Klein C, Cerny B, Brodesser J. Clinical evaluation of all-ceramic crowns fabricated from intraoral digital impressions based on the principle of active wavefront sampling. *J Dent* 2010;38:553-9.
15. Lee SJ, Betensky RA, Gianneschi GE, Gallucci GO. Accuracy of digital versus conventional implant impressions. *Clin Oral Implants Res* 2015;26:715-9.
16. Chochlidakis KM, Papaspyridakos P, Geminiani A, Chen CJ, Feng IJ, Ercoli C. Digital versus conventional impressions for fixed prosthodontics: A systematic review and meta-analysis. *J Prosthet Dent* 2016;116: 184-90.
17. Pradiés G, Zarauz C, Valverde A, Ferreira A, Martínez-Rus F. Clinical evaluation comparing the fit of all-ceramic crowns obtained from silicone and digital in-

- traoral impressions based on wavefront sampling technology. *J Dent* 2015;43:201-8.
18. Vandeweghe S, Vervack V, Dierens M, De Bruyn H. Accuracy of digital impressions of multiple dental implants: an in vitro study. *Clin Oral Implants Res* 2017;28:648-53.
 19. Flügge TV, Schlager S, Nelson K, Nahles S, Metzger MC. Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model scanner. *Am J Orthod Dentofacial Orthop* 2013;144:471-8.
 20. Grünheid T, McCarthy SD, Larson BE. Clinical use of a direct chairside oral scanner: an assessment of accuracy, time, and patient acceptance. *Am J Orthod Dentofacial Orthop* 2014;146:673-82.
 21. Mino T, Maekawa K, Ueda A, Higuchi S, Sejima J, Takeuchi T, Hara ES, Kimura-Ono A, Sonoyama W, Kuboki T. In silico comparison of the reproducibility of full-arch implant provisional restorations to final restoration between a 3D Scan/CAD/CAM technique and the conventional method. *J Prosthodont Res* 2015;59:152-8.
 22. Gan N, Xiong Y, Jiao T. Accuracy of intraoral digital impressions for whole upper jaws, including full dentitions and palatal soft tissues. *PLoS One* 2016;11:e0158800.
 23. Arcuri L, Pozzi A, Lio F, Rompen E, Zechner W, Nardi A. Influence of implant scanbody material, position and operator on the accuracy of digital impression for complete-arch: A randomized in vitro trial. *J Prosthodont Res* 2020;64:128-36.
 24. Ender A, Mehl A. Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. *J Prosthet Dent* 2013;109:121-8.
 25. Zimmermann M. Intraoral scanning systems: purchase decisions and system overview. *Magyar Fogorvos*, 2017;6-14.
 26. Yuzbasioglu E, Kurt H, Turunc R, Bilir H. Comparison of digital and conventional impression techniques: evaluation of patients' perception, treatment comfort, effectiveness and clinical outcomes. *BMC Oral Health* 2014;14:10.
 27. Wismeijer D, Mans R, van Genuchten M, Reijers HA. Patients' preferences when comparing analogue implant impressions using a polyether impression material versus digital impressions (intraoral scan) of dental implants. *Clin Oral Implants Res* 2014;25:1113-8.
 28. Tsirogiannis P, Reissmann DR, Heydecke G. Evaluation of the marginal fit of single-unit, complete-coverage ceramic restorations fabricated after digital and conventional impressions: A systematic review and meta-analysis. *J Prosthet Dent* 2016;116:328-35.
 29. Ender A, Zimmermann M, Attin T, Mehl A. In vivo precision of conventional and digital methods for obtaining quadrant dental impressions. *Clin Oral Investig* 2016;20:1495-504.
 30. van Noort R. The future of dental devices is digital. *Dent Mater* 2012;28:3-12.
 31. Mangano FG, Veronesi G, Hauschild U, Mijiritsky E, Mangano C. Trueness and precision of four intraoral scanners in oral implantology: a comparative in vitro study. *PLoS One* 2016;11:e0163107.
 32. Schepke U, Meijer HJ, Kerdijk W, Cune MS. Digital versus analog complete-arch impressions for single-unit premolar implant crowns: Operating time and patient preference. *J Prosthet Dent* 2015;114:403-6.
 33. Sakornwimon N, Leevailoj C. Clinical marginal fit of zirconia crowns and patients' preferences for impression techniques using intraoral digital scanner versus polyvinyl siloxane material. *J Prosthet Dent* 2017;118:386-91.
 34. Joda T, Brägger U. Time-efficiency analysis comparing digital and conventional workflows for implant crowns: a prospective clinical crossover trial. *Int J Oral Maxillofac Implants* 2015;30:1047-53.
 35. Ender A, Mehl A. Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. *J Prosthet Dent* 2013;109:121-8.
 36. Goracci C, Franchi L, Vichi A, Ferrari M. Accuracy, reliability, and efficiency of intraoral scanners for full-arch impressions: a systematic review of the clinical evidence. *Eur J Orthod* 2016;38:422-8.
 37. Chochlidakis KM, Papaspyridakos P, Geminiani A, Chen CJ, Feng IJ, Ercoli C. Digital versus conventional impressions for fixed prosthodontics: A systematic review and meta-analysis. *J Prosthet Dent* 2016;116:184-90.
 38. Papaspyridakos P, Gallucci GO, Chen CJ, Hanssen S, Naert I, Vandenberghe B. Digital versus conventional implant impressions for edentulous patients: accuracy outcomes. *Clin Oral Implants Res* 2016;27:465-72.
 39. Amin S, Weber HP, Finkelman M, El Rafie K, Kudara Y,

- Papaspyridakos P. Digital vs. conventional full-arch implant impressions: a comparative study. *Clin Oral Implants Res* 2017;28:1360-7.
40. Giménez B, Özcan M, Martínez-Rus F, Pradíes G. Accuracy of a digital impression system based on active triangulation technology with blue light for implants: effect of clinically relevant parameters. *Implant Dent* 2015;24:498-504.
 41. Mizumoto RM, Alp G, Özcan M, Yilmaz B. The effect of scanning the palate and scan body position on the accuracy of complete-arch implant scans. *Clin Implant Dent Relat Res* 2019;21:987-94.
 42. van der Meer WJ, Andriessen FS, Wismeijer D, Ren Y. Application of intra-oral dental scanners in the digital workflow of implantology. *PLoS One* 2012;7:e43312.
 43. Giménez B, Özcan M, Martínez-Rus F, Pradíes G. Accuracy of a digital impression system based on parallel confocal laser technology for implants with consideration of operator experience and implant angulation and depth. *Int J Oral Maxillofac Implants* 2014;29:853-62.
 44. Hack GD, Patzelt SBM. Evaluation of the accuracy of six intraoral scanning devices: An in-vitro investigation. *ADA Prof Prod Rev* 2015;10:1-5.
 45. Imburgia M, Logozzo S, Hauschild U, Veronesi G, Mangano C, Mangano FG. Accuracy of four intraoral scanners in oral implantology: a comparative in vitro study. *BMC Oral Health* 2017;17:92.
 46. Su TS, Sun J. Comparison of repeatability between intraoral digital scanner and extraoral digital scanner: An in-vitro study. *J Prosthodont Res* 2015;59:236-42.
 47. Carr AB. Comparison of impression techniques for a two-implant 15-degree divergent model. *Int J Oral Maxillofac Implants* 1992;7:468-75.
 48. Jang HK, Kim S, Shim JS, Lee KW, Moon HS. Accuracy of impressions for internal-connection implant prostheses with various divergent angles. *Int J Oral Maxillofac Implants* 2011;26:1011-5.
 49. Howell KJ, McGlumphy EA, Drago C, Knapik G. Comparison of the accuracy of Biomet 3i Encode Robocast Technology and conventional implant impression techniques. *Int J Oral Maxillofac Implants* 2013;28:228-40.
 50. Yang X, Lv P, Liu Y, Si W, Feng H. Accuracy of digital impressions and fitness of single crowns based on digital impressions. *Materials* 2015;8:3945-57.
 51. Anadioti E, Aquilino SA, Gratton DG, Holloway JA, Denry I, Thomas GW, Qian F. 3D and 2D marginal fit of pressed and CAD/CAM lithium disilicate crowns made from digital and conventional impressions. *J Prosthodont* 2014;23:610-7.
 52. Knechtle N, Wiedemeier D, Mehl A, Ender A. Accuracy of digital complete-arch, multi-implant scans made in the edentulous jaw with gingival movement simulation: An in vitro study. *J Prosthet Dent* 2021:S0022-3913(21)00019-6.
 53. Ma B, Yue X, Sun Y, Peng L, Geng W. Accuracy of photogrammetry, intraoral scanning, and conventional impression techniques for complete-arch implant rehabilitation: an in vitro comparative study. *BMC Oral Health* 2021;21:636.