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RESEARCH AND EDUCATION

Effect of additional reference objects on accuracy of five intraoral scanners in partially and completely edentulous jaws: An in vitro study

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ABSTRACT

Statement of problem. The effect of additional reference objects on the accuracy of different intraoral scanners for partially and completely edentulous patients has not been investigated sufficiently.

Purpose. The purpose of this in vitro study was to evaluate the effect of an additional reference object in the form of additional artificial landmarks on the trueness and precision of different intraoral scanners in partially and completely edentulous areas.

Material and methods. Partially and completely edentulous models with 2 and 4 implants (BLT, RC, Institut Straumann AG), respectively, were used in the study. For the digital scan, scan bodies (CARES Mono Scanbody) were attached, and reference data obtained by using industrial scanners. Ten digital scans of the same model were made with each intraoral scanner: PRIMESCAN, TRIOS 3, TRIOS 4, Carestream 3600, and Medit. Then, additional artificial landmarks were attached, and 10 more intraoral scans were made with each device. Computer-aided design files of the scan bodies were aligned to obtain 3-dimensional surfaces with reference and test scanners. Trueness and precision of distance, angulations, and vertical shift between scan bodies were estimated. The Mann-Whitney Wilcoxon or Student 2-sample *t* test was applied to estimate statistically significant differences between groups (α=.05).

Results. In the partially edentulous model, distance trueness mean ±standard deviation values ranged from −46.7 ±15.4 µm (TRIOS 3) to 392.1 ±314.3 µm (Medit) in models without additional artificial landmarks. When additional artificial landmarks were applied, trueness of distance mean ±standard deviation values ranged between −35 ±13 µm (TRIOS 4) and 117.7 ±232.3 µm (CARESTREAM). Trueness mean ±standard deviation values of angulation varied from −0.0 ±0.5 degrees (CARESTREAM) to 0.2 ±0.0 degrees (PRIMESCAN) without additional artificial landmarks and from 0.0 ±0.2 degrees (TRIOS 3) to 0.4 ±0.5 degrees (CARESTREAM) with additional artificial landmarks. Vertical shift trueness measurements varied from −108 ±47.1 µm (TRIOS 4) to 107.2 ±103.5 µm (Medit) without additional artificial landmarks and from −15.0 ±45.0 µm (CARESTREAM) to −86.9 ±42.1 µm (TRIOS 4) with additional artificial landmarks. The additional artificial landmark technique improved the trueness of all measured parameters for the 5 tested intraoral scanners. No statistically significant differences were found among models with or without additional artificial landmarks, except for Medit in all parameters and PRIMESCAN in angle measurements (P<.05). The best precision for distance was found with TRIOS 3 and with PRIMESCAN for angulation and vertical shift. Larger deviations were observed in the completely edentulous situation. The effect of additional artificial landmarks was limited when the accuracy parameters of digital scans were considered.

Conclusions. Scans with and without additional artificial landmarks of partially edentulous conditions scanned by any of the intraoral scanners tested did not influence precision and trueness, except for Medit i500 in the distance and vertical shift parameters and CARESTREAM3600 in vertical shift. Precision and trueness of digital scans of completely edentulous areas were affected, except for Medit i500 for distance, PRIMESCAN and TRIOS 4 for angle, and all systems except TRIOS 4 for vertical shift precision. (J Prosthet Dent 2023;130:111-8)

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Clinical Implications

Adding artificial landmarks had a limited effect on accuracy parameters when partially edentulous conditions were scanned, while the accuracy of completely edentulous arches improved with the additional artificial landmark technique.

The development of digital dental technologies has enhanced prosthetic treatment planning and oral rehabilitation in partially and completely edentulous patients.[1] However, the application of a completely digital clinical workflow remains a challenge and has been reported to lack accuracy.[2]

Benefits of technologies such as intraoral scanning and digital designing and manufacturing include ease of use, reduced number of treatment sessions, high patient comfort, ability to record soft tissue without compression, and elimination of material errors such as from expansion, shrinkage, and deformation.[3-7] Intraoral scanner (IOS) systems have been reported to provide predictable and accurate digital scans of partially edentulous patients.[7] However, difficulties have been reported in edentulous conditions, which are affected by clinical expertise, the size of the files, and the absence of hard tissue references for the scanner.[8-12] Moreover, different IOS systems seem to provide different precision and accuracy values.[9]

In the prosthetic treatment phase, the radiographic or surgical templates can be used to transfer the definitive jaw relation and to make definitive digital scans, which shortens the treatment time and reduces treatment costs.[5,7,13] However, edentulous arches are still a major challenge for IOS devices, as the accuracy of these scans depends on the number and position of implants, the type of IOS, the scanning protocol, and the skill and experience of the dentist.[9,10] For a clinician, digital scanning presents a challenge, with the need to manage oral fluids, the tongue, and the flexible oral mucosa.[14-17]

Currently available IOS are not yet able to provide reliable scans of edentulous jaws, as the lack of clear anatomic reference structures makes stitching of the individual images difficult for the software program.[10] Furthermore, various IOSs with different scanning techniques and, therefore, accuracies are available.[18-24]

The accuracy of a digital scan has been defined as trueness and precision. Trueness is the ability of a measurement to match actual value while precision is defined as the ability of the scanner to deliver repeatable outcomes when multiple measurements of the same object are made.[25] IOS scans have been reported to be as accurate as conventional impressions.[26]

Whether splinting improves accuracy and thereby the trueness and precision of digital scans is unclear. Digitals splints or splinting of the implants when scanning multiple implants has been reported to improve accuracy.[25] However, splinting has been reported to have no advantage over nonsplinted scanning with a divergence of less than 15 degrees.[26]

The aim of this study was to evaluate the digital scanning accuracy of partially and completely edentulous jaws by using 5 different IOSs with and without additional artificial landmarks. The null hypothesis was that additional artificial landmarks would have no effect on the accuracy of the scanning parameters of distance, angle, and vertical shift with different IOS systems.

MATERIAL AND METHODS

Two maxillary models were printed with a 3D printer (Asiga Max UV; Asiga) from a typodont (frasaco model; frasaco GmbH) design. The workflow chart is presented in Figure 1. One model was missing the right premolars and molars, and dental implants (BLT Implant, Ø 4.1-mm RC; Institut Straumann AG) were inserted to replace the first premolar (straight) and second molar (tilted 20 degrees mesially) (Fig. 2). The second model was completely edentulous, and 4 implants were inserted in the lateral incisor (straight) and first molar (tilted 20 degrees distally) areas (Fig. 2). Scan bodies (CARES RC Mono scan body; Institut Straumann AG) were attached and tightened to 15 Ncm with a cordless electronic screwdriver (NSK iSD900; NSK-Nakanishi International) to the implants, and models were scanned with a reference scanner (Nikon Altera, v 10.7.6; Nikon Metrology) to obtain reference scans.

Digital scans were made with 5 IOSs (Primescan v5.0.1; Dentsply Sirona, TRIOS 3 v1.18.2.10; 3Shape A/S, TRIOS 4 v19.2.2; 3Shape A/S, CARESTREAM 3600 v3.1.0; Carestream dental, Medit i500 v2.0.3; Medit). Ten scans were made for each without additional artificial landmarks. The scanning sequences were applied according to each manufacturer's recommendations according to the IOS manuals. Polymerized glass ionomer cement (Fuji Plus; GC) additional reference objects (approximately Ø2×1 mm) were then attached by using an adhesive (Super Moment glue; Henkel). One was attached in the center of the edentulous area of the partially edentulous model, 6 in the completely edentulous model distributed between scan bodies, and 3 to the palate of the completely edentulous model.

The models were then rescanned with the 5 different IOSs. Scanning data were exported in standard tessellation language (STL) format for analysis. All scans were aligned with the reference scan by applying the best-fit alignment procedure by using a software program (Geomagic Control X 2018; 3D Systems Corp).

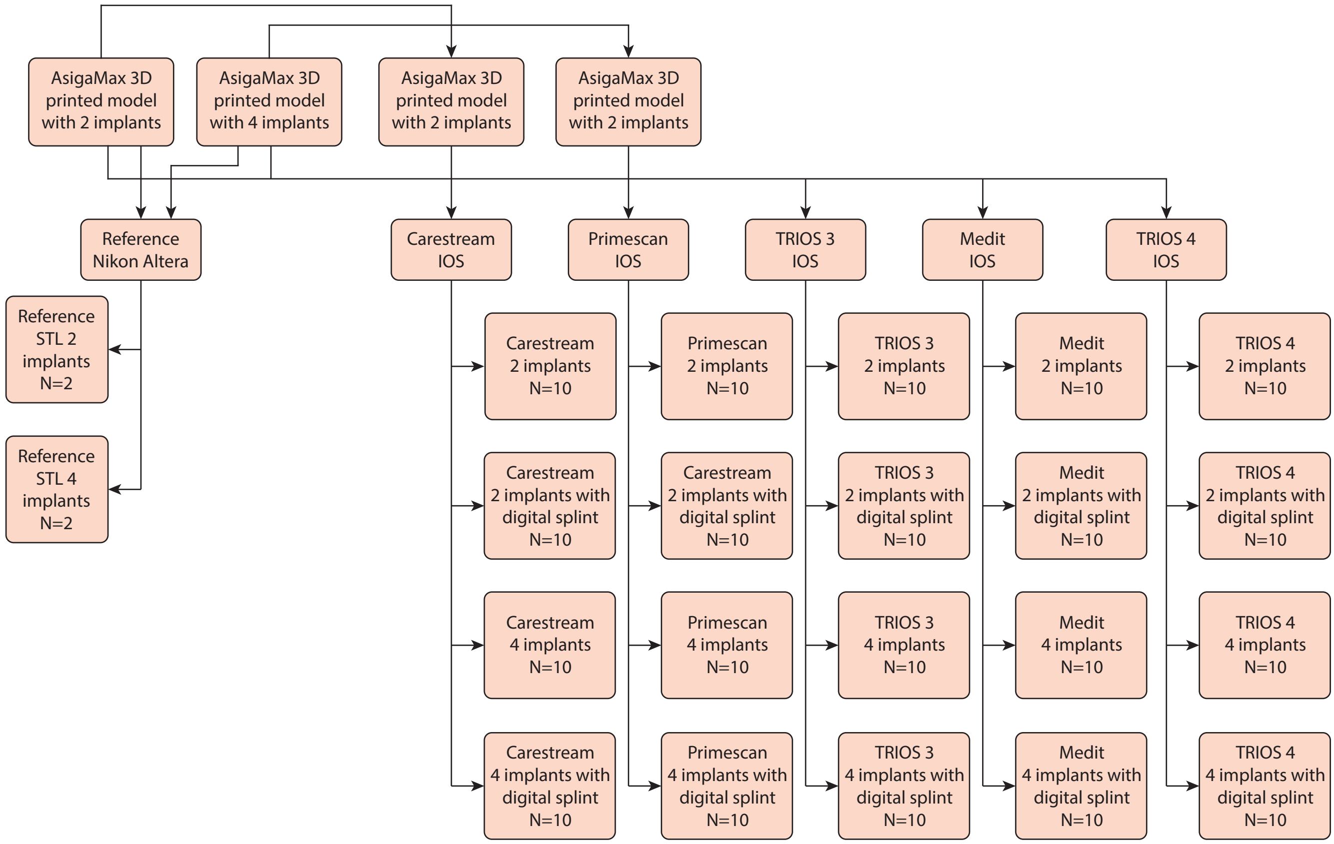

Figure 1. Flowchart of experimental procedures.

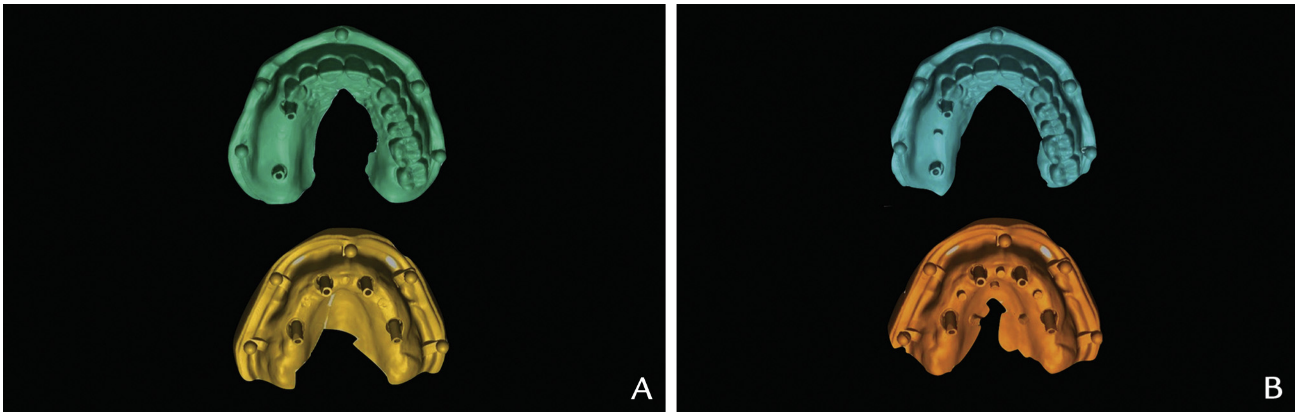

Figure 2. Partially and completely edentulous scanned models. A, Without additional artificial landmarks. B, With additional artificial landmarks.

Distance, angulation, and vertical shift parameters between scan bodies were measured by aligning the computer-aided design file models of the scan bodies to the scanned surfaces of the scan bodies (Figs. 3, 4). The center point of the scan body was determined as the intersection between a selected center axis and a top plane of the scan body. The distance between the center points of the 2 scan bodies was measured (Figs. 3B, 4B). The angulation of the scan bodies was measured as the angle between 2 vectors representing the axes of the scan bodies in 3D space (Figs. 3C, 4C). The shortest distance between a center point of one scan body and the top plane of another scan body was evaluated as the vertical shift of the scan body (Figs. 3D, 4D). Trueness and

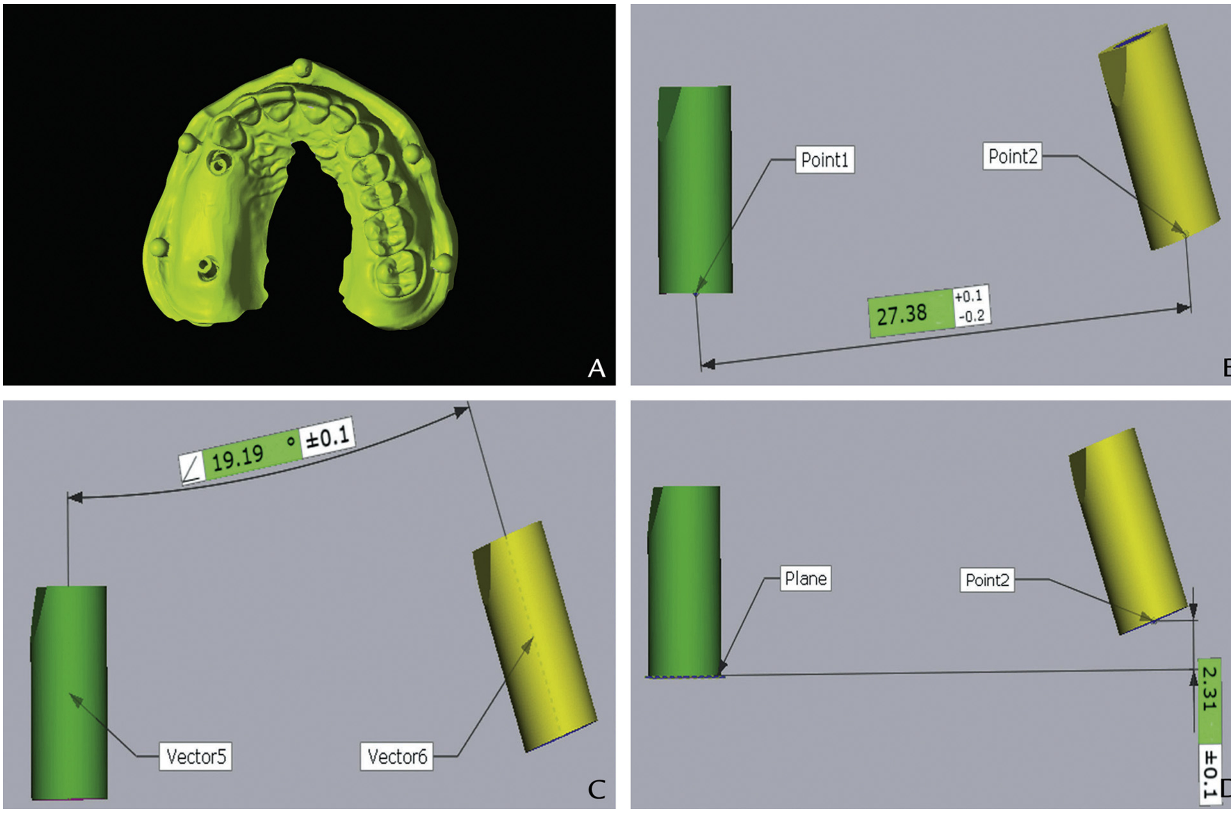

Figure 3. A, Partially edentulous model with scan bodies. B, Distance measurement between scan bodies. C, Angulation measurement between scan bodies. D, Vertical shift measurement of scan bodies.

precision were calculated for all the parameters measured and compared between the model groups with and without additional artificial landmarks.

A statistical analysis was performed with a statistical package (Matlab 2020a; The MathWorks Inc). The Shapiro-Wilk normality tests were used to test for the normal distribution of the data, and depending on the results, the Mann-Whitney Wilcoxon or Student 2-sample *t* test was applied to estimate statistically significant differences between trueness and precision of distance, angulations, and vertical shift among scan body measurements in partially and completely edentulous models (α=.05). A software program (GPower v3.1.9.2; Dusseldorf University) was used to calculate the power of the statistical analysis.

RESULTS

The precision of partially and completely edentulous models regarding distance, angle, and vertical shift parameters is presented in Tables 1 and 2. The power analysis determined that the sample size was sufficient for a reliable statistical analysis. In partially edentulous models, trueness results varied according to measured parameters. For distance measurements, trueness mean values ranged from −46.7 ±15.4 µm for the TRIOS 3 scanner to 392.1 ±314.3 µm for the Medit i500 scanner in models without an additional artificial landmark, while in models with additional artificial landmarks, trueness of distance mean values were from −34.4 ±13.0 µm for the TRIOS 4 IOS to 117.7 ±232.3 µm for the CARESTREAM 3600 IOS.

Trueness mean values of angulation varied from −0.0 ±0.5 degrees for the CARESTREAM 3600 IOS to 0.2 ±0.0 degrees for the PRIMESCAN IOS in models without additional artificial landmarks, while, in models with artificial landmarks, trueness mean values of angulation resulted from 0.0 ±0.2 degrees for the TRIOS 3 IOS to 0.4 ±0.5 degrees for the CARESTREAM 3600 IOS. For vertical shift measurements in models without additional artificial landmarks, trueness varied from −108 ±47.1 µm for the TRIOS 4 IOS to 107.2 ±103.5 µm for the Medit i500 IOS. Trueness mean values of vertical shift in models with additional artificial landmarks ranged from −15 ±45 µm of CARESTREAM 3600 IOS to −86.9 ±42.1 µm. No statistically significant differences were found between measurements of models with or without additional artificial landmarks, except for Medit i500 IOS in all

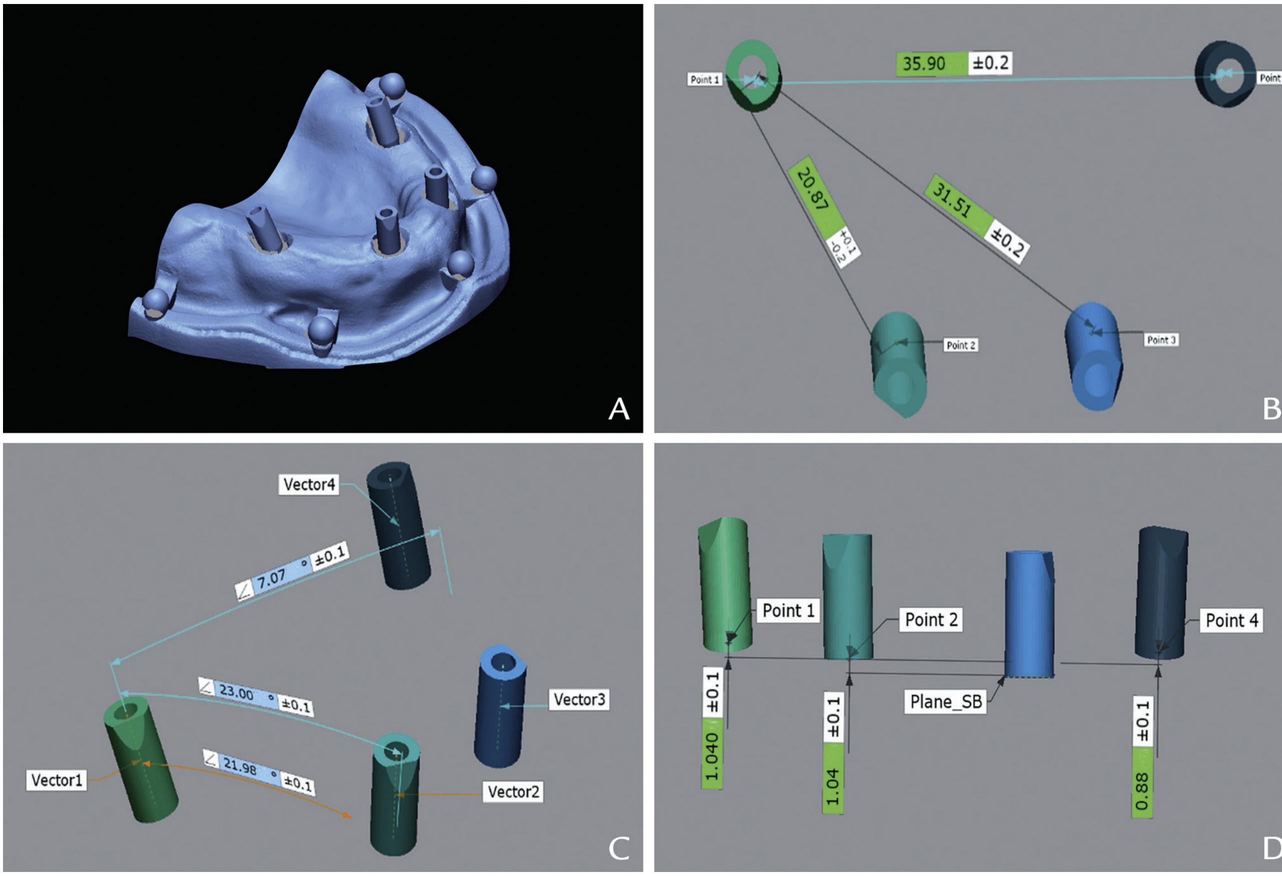

Figure 4. A, Completely edentulous model with scan bodies. B, Distance measurement between scan bodies. C, Angulation measurement between scan bodies. D, Vertical shift measurement of scan bodies.

parameters and PRIMESCAN in angle measurements (P<.05). The best results in precision of the partially edentulous model were demonstrated by TRIOS 3 IOS in distance (12.8 ±7.2 μm) and PRIMESCAN in angulation (0.0 ±0.0 degrees) and vertical shift parameters (9 ±7.4 μm). However, no statistically significant differences were found between the scans with and without additional artificial landmarks (P>.05) of any IOS tested, except Medit i500 in the distance and vertical shift parameters and CARESTREAM 3600 in vertical shift (P<.05).

The precision and trueness of the digital scans of completely edentulous areas were affected, except for Medit i500 for distance (P=.08, P=.07, and P=.36), PRIMESCAN (P=.75, P=.26, and P=.67), and TRIOS 4 (P=.76, P=.7, and P=.84) for angle and all systems except TRIOS 4 (P=.49) for vertical shift precision.

DISCUSSION

Most of the published data on the accuracy of implant locations with intraoral scanners have been from in vitro studies because of the difficulty of obtaining the true reference positions of scan bodies and implants with industrial measuring equipment. Applying an industrial-grade reference scanner in a clinical study can only be performed in the anterior region of the maxilla and under special conditions.[25-27] Moreover, using artificial landmarks in edentulous areas has been suggested for suturing IOS images with few reference points.[25-27] In the first part of the present study, hardened tabs of glass-ionomer cement were used to form the additional artificial landmarks and to test their impact on the trueness and precision of different IOSs in partially and completely edentulous situations on 3D printed models. For partially edentulous conditions, additional artificial landmarks had a positive effect on the scanning trueness and precision of distance, angulation, and vertical shift of scan bodies, especially for recently developed IOSs. However, no statistically significant differences were found between the scans with and without additional artificial landmarks (P>.05).

In completely edentulous patients, additional artificial landmarks also had no statistically significant influence on trueness and precision; however, with a longer

Table 1. Precision of partially edentulous models in distance, angle, and vertical shift parameters

	Precision of Distance, μm						
Scanner	**Mean**	**SD**	**Median**	**IQR**	**Min**	**Max**	***P***
CARESTREAM	143.4	83.3	160.7	149.3	16.7	254.2	.17
CARESTREAM_ds	200.5	96.4	194.2	130.3	44.7	377.4	
Medit	238.5	189.6	210.9	198.7	2.7	672.1	.002
Medit_ds	26.5	20.3	26.2	24.8	0.3	59.5	
PRIMESCAN	17.5	9.6	17.8	17.8	4.8	30.7	.27
PRIMESCAN_ds	12.9	8.7	11.7	10.7	1.5	31.4	
TRIOS 3	12.8	7.2	12.4	9	2.5	25.2	.45
TRIOS 3_ds	15.5	7.6	15.2	10.9	4.3	27.3	
TRIOS 4	15.3	8.1	15.2	10.7	2.5	29.1	.20
TRIOS 4_ds	11	5.8	9.8	11.1	4.5	19.9	
	Precision of angle, degrees						
	Mean	**SD**	**Median**	**IQR**	**Min**	**Max**	***P***
CARESTREAM	0.4	0.3	0.4	0.5	0	0.8	.68
CARESTREAM_ds	0.4	0.3	0.2	0.4	0	1.1	
Medit	0.1	0.1	0.1	0.1	0	0.2	.63
Medit_ds	0.1	0.1	0.1	0.2	0	0.3	
PRIMESCAN	0	0	0	0	0	0.1	.79
PRIMESCAN_ds	0	0	0	0	0	0.1	
TRIOS 3	0.1	0.1	0.1	0.1	0	0.3	.64
TRIOS 3_ds	0.1	0.1	0.1	0.2	0	0.4	
TRIOS 4	0.1	0.1	0.1	0.1	0	0.3	.93
TRIOS 4_ds	0.1	0.1	0.1	0.1	0	0.3	
	Precision of vertical shift, μm						
	Mean	**SD**	**Median**	**IQR**	**Min**	**Max**	***P***
CARESTREAM	90.6	63.4	77.9	87.6	2.2	209.2	.04
CARESTREAM_ds	37.1	21.3	32.2	37.7	7.9	63.4	
Medit	81.8	57.3	70.5	38.6	16	205.7	.04
Medit_ds	35.5	25	34.9	33.9	3.1	81.2	
PRIMESCAN	9	7.4	7.4	10	0.3	22.6	.81
PRIMESCAN_ds	8.3	6.4	7.6	9.3	2	21	
TRIOS 3	37.7	31	24.9	60.4	4.1	79.9	.93
TRIOS 3_ds	36.6	22.5	29.9	31.9	9.2	71.7	
TRIOS 4	39.7	21.5	39.3	33.5	6.4	73.4	.49
TRIOS 4_ds	32.4	24.6	34.5	38	4.1	83.5	

CARESTREAM, Carestream 3600 IOS; ds, additional artificial landmark; IQR, interquartile range; Medit, Medit i500 IOS; PRIMESCAN, Primescaner IOS; SD, standard deviation; TRIOS 3, TRIOS 3 IOS; TRIOS 4, TRIOS 4 IOS. *Yellow* represents statistically significant differences between scans with and without additional artificial landmark.

distance between scan bodies, increased deviations in distance, angulation, and vertical shift were found. As various IOS systems are reported to provide different precision and accuracy values, 5 different systems were compared in the present study. For both partially and completely edentulous situations, PRIMESCAN, TRIOS 3, and TRIOS 4 scanners produced more negative trueness values than Medit i500 and CARESTREAM 3600, indicating that the scanned object was smaller than the true reference. The impact of additional artificial landmarks on the scanning trueness and precision for tooth- and implant-supported restorations has been evaluated.[28,29] For completely edentulous models with 4 embedded implants and different scan bodies attached, dental floss, glass beads, and pressure-indicating paste have been used as artificial landmarks. However, none of those were reported to have a significant impact on scanning trueness and precision. Splinting of scan bodies with dental floss compromised the image capturing of the scan body more than other artificial landmarks.[25] In another study, a model with prepared teeth for fixed partial dentures was scanned by using an alumina tab-form marker as the additional artificial landmark. However, the additional artificial landmark also had no significant influence on the scanning trueness, and the procedure required more time and images for suturing than usual for some of the scanners tested. Precision, however, was statistically significantly improved by using additional artificial landmarks.[25] For a completely edentulous metal model with 4 implants and attached scan bodies, tooth-form artificial landmarks statistically significantly improved the trueness and precision of distance measurements for all IOSs tested.[27] Measuring the distances between scan bodies, the deviations tended to accumulate when the distance increased. However, despite the IOS used, additional landmarks improved the scanning accuracy.

The findings of in vitro studies should be evaluated with caution because patient-related issues such as saliva, tongue, and soft tissue movements were not replicated and could have had a significant impact on scanning accuracy. Furthermore, attaching small objects in the mouth in the absence of a dental dam has implications for patient safety, as objects may detach and enter the airway. Moreover, although the additional artificial landmarks did not have a statistically significant effect on digital implant scan accuracy in the present study, for some scanners, it improved scanning speed and 3D image formation. Future clinical studies should evaluate the effect of different reference objects and their number on the accuracy of IOSs in partially and completely edentulous patients.

CONCLUSIONS

Based on the findings this in vitro study, the following conclusions were drawn:

1. Digital scans with and without additional artificial landmarks of partially edentulous areas scanned by all the IOS devices tested did not affect the accuracy, except for Medit i500 in the distance and vertical shift parameters and CARESTREAM 3600 in vertical shift.
2. Precision and trueness (accuracy) of completely edentulous regions were affected when different IOS devices were used, except for Medit i500 for distance, PRIMESCAN and TRIOS 4 for angle, and all systems except TRIOS 4 for vertical shift precision.

Table 2. Precision of completely edentulous models in distance, angle, and vertical shift parameters

Scanner		Precision of Distance, µm						
		Mean	SD	Median	IQR	Min	Max	*P*
CARESTREAM	Distance 1	55.6	36.0	48.1	68.7	2.6	105.9	.17
	Distance 1_ds	37.0	20.0	36.6	34.7	5.2	68.0	
	Distance 2	68.6	43.2	58.2	54.7	16.4	146.4	.03
	Distance 2_ds	32.1	23.6	33.6	24.1	0.7	74.3	
	Distance 3	46.8	41.5	37.3	79.1	0.8	105.1	.89
	Distance 3_ds	44.7	26.1	41.4	24.0	19.1	99.4	
Medit	Distance 1	14.4	12.2	11.8	9.5	5.1	44.2	.08
	Distance 1_ds	28.7	17.0	31.6	30.4	6.5	48.4	
	Distance 2	13.7	13.5	12.1	19.8	0.1	42.1	.07
	Distance 2_ds	33.5	26.8	24.3	46.6	3.9	70.8	
	Distance 3	48.3	31.2	50.2	36.3	3.6	108.5	.36
	Distance 3_ds	33.3	22.9	28.2	25.6	11.8	71.3	
PRIMESCAN	Distance 1	6.5	4.2	5.0	6.5	1.4	12.5	.52
	Distance 1_ds	7.7	5.0	6.7	2.6	0.2	19.5	
	Distance 2	5.5	4.4	4.6	6.9	0.4	14.0	.06
	Distance 2_ds	10.8	7.1	9.9	9.5	1.1	24.2	
	Distance 3	3.6	1.8	3.3	2.7	1.6	6.6	.006
	Distance 3_ds	15.3	9.3	15.7	17.5	1.7	26.3	
TRIOS 3	Distance 1	8.4	7.3	6.9	8.7	0.7	24.3	.02
	Distance 1_ds	19.5	11.1	21.3	19.1	5.2	37.3	
	Distance 2	15.1	12.0	14.8	8.7	0.9	40.2	.22
	Distance 2_ds	25.4	22.3	24.5	35.4	0.7	65.3	
	Distance 3	27.8	16.1	26.8	25.9	3.1	49.7	.002
	Distance 3_ds	64.7	27.2	60.6	39.8	20.4	108.1	
TRIOS 4	Distance 1	6.7	4.4	5.7	7.2	1.0	12.9	.04
	Distance 1_ds	13.5	8.0	13.0	13.1	2.6	25.0	
	Distance 2	5.8	4.3	5.6	7.0	0.9	13.6	.12
	Distance 2_ds	11.6	9.9	9.8	12.3	0.1	30.9	
	Distance 3	9.9	9.6	3.8	15.8	2.2	27.6	.47
	Distance 3_ds	13.0	8.9	10.8	8.7	1.3	29.8	

		Precision of angle, degrees						
		Mean	SD	Median	IQR	Min	Max	*P*
CARESTREAM	Angle 1	0.1	0.1	0.1	0.1	0.0	0.3	.016
	Angle 1_ds	0.3	0.1	0.3	0.2	0.0	0.5	
	Angle 2	0.1	0.1	0.1	0.1	0.0	0.2	.17
	Angle 2_ds	0.1	0.1	0.1	0.2	0.1	0.3	
	Angle 3	0.1	0.1	0.1	0.1	0.0	0.2	.14
	Angle 3_ds	0.1	0.1	0.1	0.1	0.0	0.3	
Medit	Angle 1	0.3	0.2	0.3	0.3	0.1	0.6	.19
	Angle 1_ds	0.5	0.3	0.4	0.3	0.2	0.9	
	Angle 2	0.2	0.1	0.2	0.2	0.1	0.4	.002
	Angle 2_ds	0.1	0.0	0.0	0.0	0.0	0.1	
	Angle 3	0.1	0.1	0.2	0.2	0.0	0.3	.03
	Angle 3_ds	0.4	0.3	0.4	0.7	0.1	0.8	
PRIMESCAN	Angle 1	0.1	0.0	0.1	0.1	0.0	0.1	.75
	Angle 1_ds	0.1	0.0	0.1	0.1	0.0	0.1	
	Angle 2	0.1	0.0	0.1	0.1	0.0	0.1	.26
	Angle 2_ds	0.0	0.0	0.0	0.0	0.0	0.1	
	Angle 3	0.1	0.0	0.1	0.1	0.0	0.1	.67
	Angle 3_ds	0.1	0.0	0.1	0.1	0.0	0.1	
TRIOS 3	Angle 1	0.1	0.1	0.1	0.1	0.0	0.2	.72
	Angle 1_ds	0.1	0.1	0.1	0.2	0.0	0.2	

(*continued on next column*)

Table 2. (*Continued*) Precision of completely edentulous models in distance, angle, and vertical shift parameters

		Precision of angle, degrees						
		Mean	SD	Median	IQR	Min	Max	*P*
	Angle 2	0.1	0.1	0.1	0.1	0.0	0.2	.59
	Angle 2_ds	0.1	0.1	0.1	0.2	0.0	0.3	
	Angle 3	0.1	0.1	0.1	0.1	0.0	0.2	.01
	Angle 3_ds	0.3	0.2	0.3	0.3	0.0	0.5	
TRIOS 4	Angle 1	0.1	0.0	0.1	0.1	0.0	0.1	.76
	Angle 1_ds	0.1	0.1	0.1	0.1	0.0	0.2	
	Angle 2	0.1	0.1	0.1	0.1	0.0	0.2	.70
	Angle 2_ds	0.1	0.1	0.1	0.1	0.0	0.2	
	Angle 3	0.1	0.0	0.1	0.1	0.0	0.1	.84
	Angle 3_ds	0.1	0.1	0.1	0.0	0.0	0.2	

		Precision of vertical shift, µm						
		Mean	SD	Median	IQR	Min	Max	*P*
CARESTREAM	Vertical shift 1	78.6	48.2	85.5	73.9	7.2	158.3	.48
	Vertical shift 1_ds	94.5	50.7	83.1	72.2	18.2	167.8	
	Vertical shift 2	26.4	18.5	24.2	33.5	1.6	55.8	.53
	Vertical shift 2_ds	21.3	15.0	16.6	13.6	3.9	50.1	
	Vertical shift 3	26.9	23.8	14.7	41.9	1.4	62.3	.87
	Vertical shift 3_ds	25.3	19.7	23.8	23.4	4.5	69.9	
Medit	Vertical shift 1	88.8	59.7	93.9	65.4	2.6	184.6	.64
	Vertical shift 1_ds	103.7	62.4	101.2	30.1	11.5	205.6	
	Vertical shift 2	46.8	32.2	39.3	50.2	11.8	111.8	.16
	Vertical shift 2_ds	25.4	18.4	24.8	36.9	3.7	48.2	
	Vertical shift 3	32.7	21.7	28.1	15.2	5.8	78.3	.09
	Vertical shift 3_ds	60.2	39.1	59.6	63.5	18.7	121.4	
PRIMESCAN	Vertical shift 1	13.1	11.0	8.6	16.6	1.8	33.0	.21
	Vertical shift 1_ds	18.7	8.2	16.9	8.2	9.9	38.6	
	Vertical shift 2	10.2	6.6	9.3	5.3	1.0	21.3	.25
	Vertical shift 2_ds	7.4	3.8	7.5	5.8	2.6	14.0	
	Vertical shift 3	10.6	6.0	8.9	4.5	5.3	24.3	.40
	Vertical shift 3_ds	8.1	6.7	7.1	5.5	0.3	22.9	
TRIOS 3	Vertical shift 1	35.4	29.0	39.3	47.4	1.8	87.4	.52
	Vertical shift 1_ds	28.2	11.6	28.6	16.0	11.6	47.3	
	Vertical shift 2	20.5	14.1	18.5	14.6	4.9	49.7	.36
	Vertical shift 2_ds	27.8	19.7	21.4	30.6	8.8	62.0	
	Vertical shift 3	25.7	21.8	22.0	37.7	0.7	59.8	.06
	Vertical shift 3_ds	51.6	35.1	55.9	69.4	11.0	112.0	
TRIOS 4	Vertical shift 1	22.1	20.0	17.2	24.7	0.6	60.5	.10
	Vertical shift 1_ds	39.0	23.6	41.4	44.6	5.6	68.4	
	Vertical shift 2	10.1	7.4	8.5	9.9	0.0	22.2	.049
	Vertical shift 2_ds	26.0	21.3	26.5	29.5	3.0	61.9	
	Vertical shift 3	10.9	6.3	8.3	6.5	4.6	23.5	.13
	Vertical shift 3_ds	18.2	12.2	17.3	20.5	0.6	34.2	

CARESTREAM, Carestream 3600 IOS; ds, additional artificial landmark; IQR, interquartile range; Medit, Medit i500 IOS; PRIMESCAN, Primescaner IOS; SD, standard deviation; TRIOS 3, TRIOS 3 IOS; TRIOS 4, TRIOS 4 IOS. *Yellow* represents statistically significant differences between scans with and without additional artificial landmark.

3. A limited effect of the additional artificial landmark was observed on accuracy parameters when partially edentulous conditions were scanned, while the accuracy of completely edentulous arches improved when the additional artificial landmark technique was used.

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