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RESEARCH AND EDUCATION

Evaluation of complete-arch implant scanning with 5 different intraoral scanners in terms of trueness and operator experience

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ABSTRACT

Statement of problem. The intraoral scanning of the edentulous arch might be challenging for an inexperienced operator because of the large mucosal area and the use of scan bodies.

Purpose. The purpose of this ex vivo study was to compare the trueness of 5 intraoral scanners in replicating implant scan bodies and soft tissues in an edentulous maxilla and to investigate the effects of operator experience.

Material and methods. The maxilla was resected from a fresh cadaver, 5 implants placed, and a reference scan made. Eight scans were made by experienced operators and 8 by an inexperienced operator with each scanner (iTero Element 2, Medit i500, Primescan, TRIOS 3, TRIOS 4). The implant platform deviation was measured after complete surface alignment and after scan body alignment. Deviation data were analyzed with a generalized linear mixed model (α=.05).

Results. After complete surface alignment, the mean ±standard deviation implant platform deviation was higher for the inexperienced operator (421 ±25 μm) than for experienced ones (191 ±12 μm, P<.001) for all scanners. After scan body alignment, no significant differences were found between operators for Element 2, Primescan, and TRIOS 3. The experienced operators produced a lower deviation for TRIOS 4 (35 ±3.3 μm versus 54 ±3.1 μm, P<.001), but higher deviation for i500 (68 ±4.1 μm versus 57 ±3.6 μm, P<.05). The scanner ranking was Element 2 (63 ±4.1 μm), i500 (57 ±3.6 μm, P=.443), TRIOS 4 (54 ±3.1 μm, P=.591), TRIOS 3 (40 ±3.1 μm, P<.01), Primescan (27 ±1.6 μm, P<.001) for the inexperienced operator and i500 (68 ±4.1 μm), Element 2 (58 ±4.0 μm, P=.141), TRIOS 3 (41 ±2.8 μm, P<.001), TRIOS 4 (35 ±3.3 μm, P=.205), Primescan (28 ±1.8 μm, P=.141) for the experienced operators.

Conclusions. Mucosal alignment greatly overestimated the platform deviation. The intraoral scanners showed different trueness during the complete-arch implant scanning. The operator experience improved the trueness of the edentulous mucosa but not implant platform deviation. (J Prosthet Dent 2022;128:632-8)

The trueness of intraoral scanners for edentulous complete-arch scans with scan bodies has been investigated with a wide range of deviation from 31 μm to 810 μm, depending on the scanner type and measurement method.[1-7] High deviation of the digital scan may result in a misfit of an implant prosthesis, which increases stresses and could lead to fracture of the screw,[8] abutments, or the veneer[9] or induce screw loosening.[10] The deviation at each implant should be less than 50 μm.[11,12] In the contemporary laboratory process, fabrication error falls within a range of 25 to 43 μm.[13-15] Thus, the intraoral scanner error should be in a similar range to keep the total error less than 50 μm. A clinical study using a completely

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Clinical Implications

Experience is beneficial when scanning complete maxillary soft tissue but distortion is still high. However, by excluding the soft tissue to simulate the digital workflow for an implant-supported prosthesis, the implant platform trueness of the Primescan could be within the clinically acceptable range.

digital workflow to fabricate implant-supported prostheses reported that from the 45 prostheses, only 3 failed after a 2-year follow-up (93.3% success rate).[16] However, in 5 prostheses, the marginal adaptation during the clinical evaluation was reported to be deficient, and the frameworks were adjusted. For these prostheses, distances between meshes and the library computer-aided design (CAD) files of scan bodies were greater than 30 μm, which indicated that digital scanning trueness should be within this value.

Factors that influence the accuracy of complete-arch scanning include the number and type of scan bodies and their location and angulation.[3,17-25] Operator experience has been reported to improve the precision but not trueness of the TRIOS 3 (3Shape A/S) and CEREC Omnicam (Dentsply Sirona) scanners for a partially dentate arch with 3 implants.[26] On an edentulous resin cast with 6 implants, operator experience was not reported to be a factor with the iTero Element 2 (Align Technology, Inc),[18] but with the LAVA COS (3M) system, experienced users were reported to produce scans with significantly better accuracy.[19] No effect of experience was reported on trueness for a gypsum cast with 4 scan bodies with the Carestream CS 3600 or with the TRIOS 3 scanners.[27] These studies used complete surface alignment, including the edentulous mucosa and the scan bodies, with the deviation being measured on the complete surface. The best-fit algorithm minimizes surface distances[28] and does not recognize identical points. Therefore, the surface deviation resulted in a significantly lower deviation than between identical points of the 2 dentate digital casts.[29] In an edentulous arch, there is a large mucosal surface with few details. Thus, the superimposition might cause even less approximation of identical structures. However, the framework misfit occurs at the platform level, which is determined by the misalignment of the scan bodies.[2,16] Previous attempts have been made to overcome this problem either by applying scan body alignment[2,17] or by measuring the scan body deviation,[6,30] but the 2 methods have not been combined. Furthermore, these studies measured the deviation on the visible part of the scan body; therefore, they might not estimate the displacement of the implant platform.

The accuracy of intraoral scanners has been reported to depend on the physical composition of the substrate.[31,32] Therefore, basing a study on a human specimen is more clinically relevant than studies on gypsum casts or plastic models.[1-7] A human specimen is more likely to be necessary for analyzing completely edentulous arches where long spans of soft tissue are present beyond the dimension of the frame of capture between scan bodies.

The aim of the present study was to evaluate the effect of the experience on the trueness of 5 intraoral scanners for complete-arch implant scans of an edentulous cadaveric maxilla. The implant platform deviation was calculated after complete surface alignment and after scan body alignment. The null hypotheses were that no significant differences would be found among the scanner systems and between experienced and inexperienced operators, regardless of the superimposition technique.

MATERIAL AND METHODS

A fresh cadaver head with a completely edentulous maxilla was procured for this study compliant with the Institutional Review Board for Human Research in the Medical University of South Carolina. The maxilla was resected immediately from the specimen which included both hard and soft tissue and the keratinized and mucosal tissues present. To maintain the fidelity of the specimen, preservatives were not applied during the study.

Five endosseous ASTRA TECH EV dental implants (Ø4.2×13 mm) were placed in the maxilla by an experienced surgeon (Z.E.) in an optimal restorative configuration. A torque of at least 25 Ncm was achieved at each site. Five intraoral Ø4.2-mm scan bodies (Atlantis Intraoral FLO IO-P-03; ASTRA TECH) were attached to the implants (Fig. 1). The specimen was coated with scanning preparation spray (CEREC Optispray; Dentsply Sirona) as per the protocol established for the use of the industrial scanner (ATOS Capsule scanner; GOM GmbH) to obtain a standardized reference scan. As per the manufacturer (GOM GmbH), it has a precision deviation of 3 μm to 15 μm. Five different intraoral scanners were compared (Table 1). With each scanning system, 16 scans were made in total: 8 by an experienced operator and 8 by an inexperienced operator. The inexperienced operator (G.R.) was a dental student without prior experience with any of the systems. However, this user received a lecture on complete-arch scanning. The 4 experienced operators had extensive experience, including intraoral complete arch scanning, with each system (Z.E. for Element 2, A.M. for i500, M.L. for Primescan, W.R. for the TRIOS systems). All operators followed the manufacturers' recommended scan patterns. Scanners were used in a stratified randomization order. The maxilla was kept on ice to prevent degradation

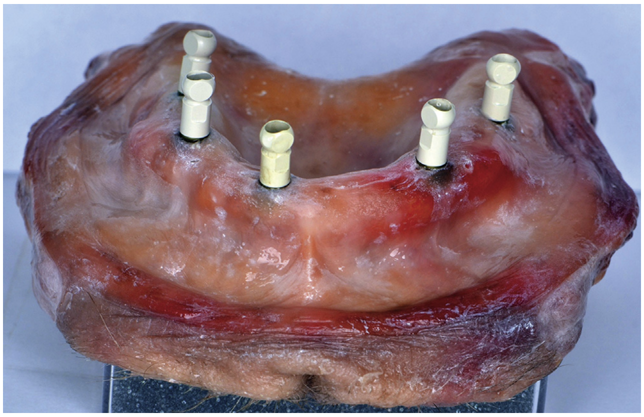

Figure 1. Five endosseous ASTRA TECH EV dental implants installed into completely edentulous human maxilla. Ø4.2×5.5-mm scan bodies (Atlantis IO FLO P-O3, ASTRA TECH) attached to implants.

or dimensional changes of the specimen during the scanning process. It was removed for each scan and was returned to the ice between scans. Apart from those made with the Element 2, all scans were processed by the software program associated with each scanner and were directly exported as standard tessellation language (STL) files. For the Element 2, STL files were downloaded from the manufacturer webpage (myitero.com, Align Technology) after processing was performed off-site by the company.

The superimposition and measurement were made in 2 different ways on each scan. The STL files of the master scan and intraoral scan were imported into a comprehensive metrology program (GOM Inspect software; GOM GmbH) individually and aligned by the best-fit algorithm considering all the surface points. Cylinders were fitted onto the cylindriform lower part of each scan body by the Gaussian best-fit method (Fig. 2). The coordinates of the axes of 2 cylinders were exported, and the 2 vectors of the axes were linearly extrapolated in 3 dimension by the length of the scan body, which was 5.5 mm from the top of the cylindrical part to the implant platform. The 3-dimensional deviation was calculated between the endpoint of the 2 vectors by the 3-dimensional Pythagoras term. The angle between the axes of the 2 cylinders within a scan body was also calculated. In the second method, the 5 scan bodies were selected, and the 2 scans were aligned, considering only the scan bodies' surfaces. The deviations in the platform and the angle between cylinders were calculated similarly to the first method. Each scan had 5 scan bodies, and for statistical analysis, these values were averaged.

The data were exported into a statistical software program (IBM SPSS Statistics for Windows, v24.0; IBM Corp) for statistical evaluation. Data in the text and the figures are presented as mean and standard error of the mean. Data were analyzed with a generalized linear mixed model with a gamma distribution and log-link function approach with restricted maximum likelihood estimation. Scanners and experience were the main comparative factors, with their interactions integrated into the model. Four models were run separately, 2 for the platform deviation and 2 for the angulation after either complete surface alignment or after scan body alignment. The *P* values were adjusted by the Bonferroni method for pairwise comparison (α=.05). Correlations between the 2 deviation values measured were assessed by the Spearman rank correlation coefficient (r).

Table 1. Intraoral scanner and software versions used

Intraoral Scanner	Software Version	Manufacturer
iTero Element 2	1.9.3.7	Align Technology
Medit i500	1.2.0.3	Medit Corp
Primescan	5.0.1	Dentsply Sirona
TRIOS 3	1.6.9.1	3Shape A/S
TRIOS 4	1.18.3.5	3Shape A/S

RESULTS

The deviation and the angle measured at the implant platform for various scanners after complete surface and scan body alignment are shown in Table 2. After complete surface alignment, a significant interaction between experience and scanner was found in platform deviation (*P*<.001). With all scanners, the experienced users had significantly lower deviation (all *P*<.001) (Fig. 3A). Significant differences in trueness were found among the scanners at the implant platform depending on operator experience (Table 3). For the inexperienced operator, the greatest deviation was measured with the Element 2, significantly greater than the i500 and the Primescan, but similar to the TRIOS 3 and the TRIOS 4. The trueness of the i500 was not significantly different from the Primescan or the TRIOS 3, but it was better than the TRIOS 4. No significant differences were found between the Primescan and the TRIOS 3, between the Primescan and the TRIOS 4, or between the TRIOS 3 and 4. For experienced operators, the Element 2 had significantly greater deviation than the i500, the Primescan, the TRIOS 3, and the TRIOS 4. The deviation of i500 was not significantly different compared with the Primescan, TRIOS 3, or TRIOS 4. The Primescan was not significantly different from the TRIOS 3 or TRIOS 4. No difference was found between the TRIOS systems.

After complete surface alignment, a significant interaction between experience and scanner was found in the angle between the cylinder axes (*P*<.01). The experienced users had significantly lower angle deviation with Primescan (*P*<.05), TRIOS 3 (*P*<.05), and TRIOS 4 (*P*<.001). No significant difference was observed for Element 2 (*P*=.556) and i500 (*P*=.181). For the inexperienced operator,

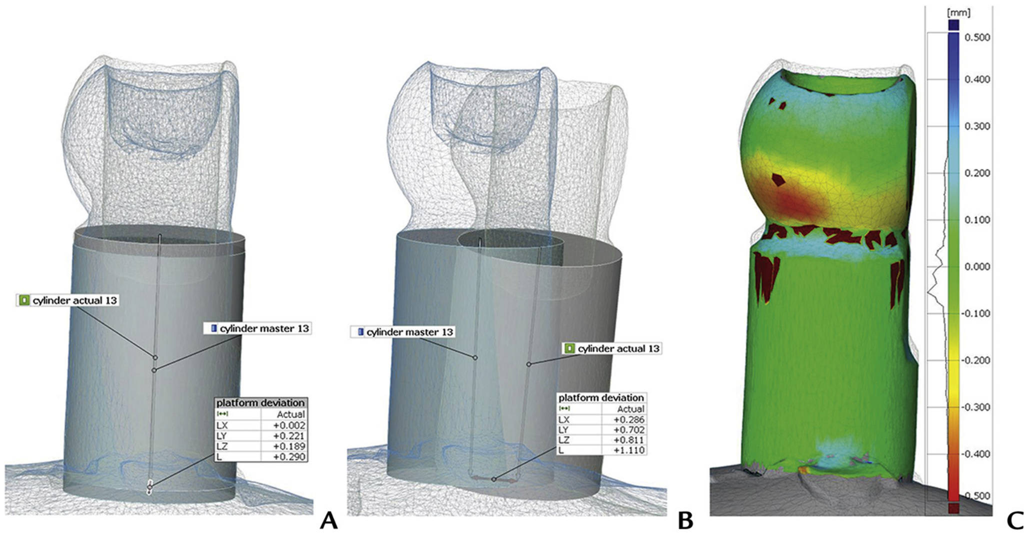

Figure 2. Measurement method of platform deviation. A, Master scan and actual scans aligned by minimizing differences (closest point algorithm). B, Moved away from each other for demonstration purpose to make deviance between 2 fitted cylinders visible. C, Surface comparison map of scan body. Mean surface deviation 0.210 mm, platform 0.290 mm.

Table 2. Deviation and angle in implant platform after different alignment

		Complete Surface Alignment				Scan Body Alignment			
		Platform Deviation (μm)		Angle (Degree)		Platform Deviation (μm)		Angle (Degree)	
Scanners	Experience	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Element 2	Inexperienced	490	34	0.74	0.10	63	4.1	0.30	0.03
–	Experienced	343	31	0.69	0.09	58	3.9	0.28	0.03
i500	Inexperienced	375	25	0.38	0.05	57	3.5	0.25	0.02
–	Experienced	160	12	0.44	0.06	68	4.0	0.39	0.04
Primescan	Inexperienced	391	30	0.47	0.06	27	1.7	0.10	0.01
–	Experienced	157	15	0.36	0.05	28	1.9	0.13	0.01
TRIOS 3	Inexperienced	417	31	0.46	0.06	40	2.9	0.19	0.02
–	Experienced	184	18	0.36	0.05	40	2.7	0.20	0.02
TRIOS 4	Inexperienced	442	28	0.56	0.07	54	3.2	0.17	0.02
–	Experienced	159	14	0.34	0.04	35	3.4	0.17	0.02

SEM, standard error of mean.

the angle deviation for Element 2 was greater than for i500, for Primescan, for TRIOS 3, but it was similar to TRIOS 4 (Table 3). The i500 had a significantly lower angle deviation than the TRIOS 4. No significant differences were found between i500 and Primescan or TRIOS 3, between Primescan and the 2 TRIOS systems, or between the TRIOS systems. For experienced operators, the angle deviation for Element 2 was greater than for i500, for Primescan, for TRIOS 3, and for TRIOS 4. No significant differences were found between i500 and Primescan, between TRIOS 3 and TRIOS 4, between Primescan and the 2 TRIOS systems, or between the TRIOS systems.

After scan body alignment, a significant interaction between experience and scanner was found in implant platform deviation ($P<.001$). The experienced users had significantly lower deviation with TRIOS 4 ($P<.001$) (Fig. 3B) and greater with i500 ($P<.05$). With the other scanners, no difference was observed among the operators (Element 2, $P=.338$; Primescan, $P=.558$; TRIOS 3, $P=.996$). Significant differences were found among the scanners, depending on operator experience (Table 3). For the inexperienced operator, the deviation for the Element 2 was greater than for Primescan and for TRIOS 3. It was similar to the i500 and TRIOS 4. The deviation of the i500 was greater than that of Primescan and TRIOS 3, and it was not significantly different from the TRIOS 4. The deviation of Primescan was lower than that of TRIOS 3 and TRIOS 4. TRIOS 3 had a lower deviation than TRIOS 4. For experienced operators, the Element 2 had significantly greater deviation than Primescan, TRIOS 3, and TRIOS 4, but it was similar to the i500. The deviation of i500 was greater than that of Primescan, TRIOS 3, and TRIOS 4. The Primescan was not significantly different from TRIOS 4, but it had a lower deviation than the TRIOS 3. No significant difference was found between the 2 TRIOS systems.

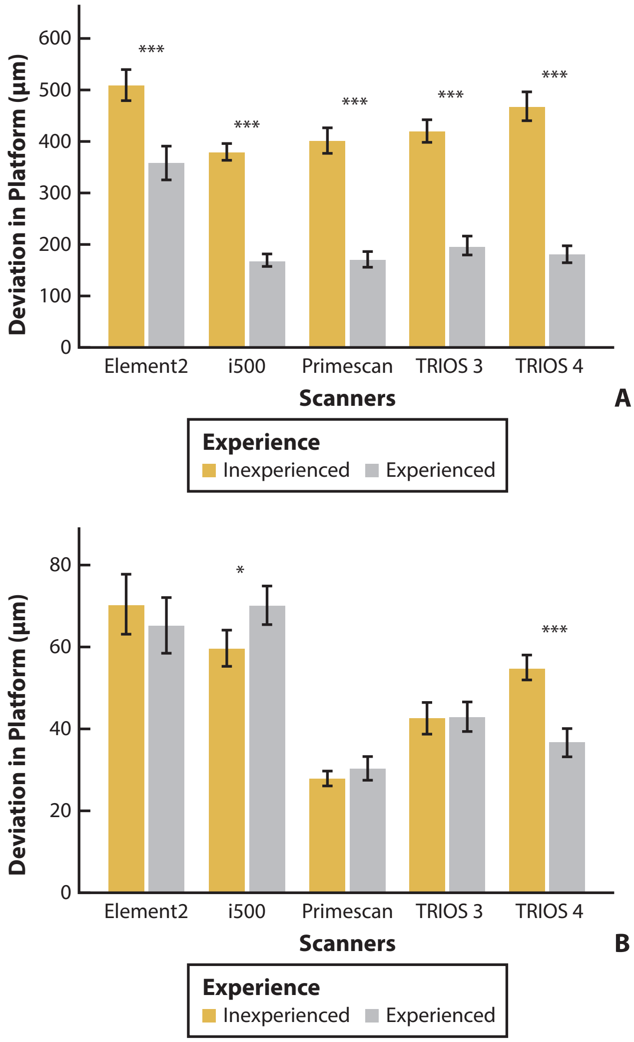

Figure 3. Implant platform deviation differences between inexperienced and experienced users. A, After complete surface alignment. B, After scan body alignment. *Significant differences between inexperienced and experienced users $P<.05$, *** $P<.001$.

After scan body alignment, a significant interaction between experience and scanner was found in the angle between the cylinders ($P<.01$). The experienced users had a significantly lower angle with i500 ($P<.001$) and Primescan ($P<.05$). No significant differences were observed with Element 2 ($P=.436$), TRIOS 3 ($P=.828$), and TRIOS 4 ($P=.966$). For the inexperienced operator, Element 2 had the greatest angle deviation. It was significantly greater than that for Primescan, TRIOS 3, and TRIOS 4 (Table 3). It was not significantly different compared with i500. The i500 had a significantly greater angle deviation than the Primescan and TRIOS 4. No significant differences were found between i500 and TRIOS 3. The Primescan had a significantly lower angle deviation than TRIOS 3 and TRIOS 4. No difference was found between the TRIOS systems. For experienced operators, i500 had the greatest angle deviation, and it was significantly greater than Element 2, Primescan, TRIOS 3, and TRIOS 4. Element 2 had a greater angle deviation than Primescan, TRIOS 3, and TRIOS 4. The Primescan had a significantly lower angle deviation than TRIOS 3, but similar to TRIOS 4. No significant differences were found between the 2 TRIOS systems.

The rankings of the scanners based on the 4 parameters are summarized in Table 4. The overall ranking of the scanners was more explicit in the experienced group than in the inexperienced one. No significant correlation was found in the implant platform deviation between the complete surface alignment and scan body alignment ($r=0.20$, $P=.072$).

DISCUSSION

The null hypotheses were rejected as a significant difference was observed among the scanners and the operators. High deviation on the platform after complete surface alignment suggests that an accurate mucosal scan is problematic, especially for inexperienced users. It also indicates that complete surface distance was minimized by the best-fit algorithm not considering the identical points such as the implant platform. The identical point method could result in higher deviation compared with the surface comparsion method.[29] This was also suggested by the lack of correlation between the 2 alignment methods. Low deviation and no effect of experience were found after scan body alignment. The scan body surface error could be compensated for by fitting the cylinder, canceling out the effect of experience. This analyzing technique best replicates the digital laboratory workflow[2,17]; therefore, these values have more clinical relevance.

The ranking of the scanner performance was more consistent in the experienced than in the inexperienced group. Two scanners shared the worst (Element 2 and i500) and the best (TRIOS 4 and Primescan), with about twice the difference between them. The recommended 30 µm for passive fit[16] was only achieved by the Primescan in the present study. However, the recommended value was achieved in a clinical study by splinting the scan bodies together before intraoral scan,[16] which could decrease the deviation.[17,21] Compared with the present values, the surface deviation of the scan bodies after their alignment was reported to be lower for the i500 (32.2 µm),[2] but it was similar for the Primescan (38.4 µm)[2] and TRIOS 3 (36.4 µm).[1,2] The greater values for axis deviation of the scan bodies after complete surface alignment (ranging from 130 to 220 µm) were found for TRIOS 3,[3,20] which was similar to the platform deviation in the present study, indicating that increasing the amount of soft tissue in the superimposition increases the deviation. However,

Table 3. Differences in implant platform deviation among scanners

		Complete Surface Alignment						Scan Body Alignment					
		Platform Devitation (μm)			Angle (Degree)			Platform Devitation (μm)			Angle (Degree)		
Experience	Scanners	Mean	SEM	P<	Mean	SEM	P<	Mean	SEM	P<	Mean	SEM	P<
Inexperienced	Element 2-i500	115	24	.001	0.36	0.08	.001	6.5	5.3	.442	0.06	0.03	.156
	Element 2-Primescan	99	28	.01	0.26	0.08	.01	36.7	4.4	.001	0.20	0.03	.001
	Element 2-TRIOS 3	73	28	.070	0.28	0.08	.01	23.2	5.0	.001	0.11	0.03	.001
	Element 2-TRIOS 4	48	23	.186	0.18	0.08	.160	9.8	5.1	.164	0.13	0.03	.001
	i500-Primescan	-16	23	.820	-0.10	0.05	.338	30.2	3.8	.001	0.14	0.02	.001
	i500-TRIOS 3	-42	24	.320	-0.08	0.05	.431	16.7	4.5	.001	0.05	0.03	.090
	i500-TRIOS 4	-67	18	.001	-0.18	0.06	.05	3.3	4.7	.473	0.08	0.02	.01
	Primescan-TRIOS 3	-26	28	.820	0.01	0.06	.813	-13.5	3.4	.001	-0.09	0.02	.001
	Primescan-TRIOS 4	-52	23	.151	-0.08	0.06	.431	-26.8	3.6	.001	-0.07	0.02	.001
	TRIOS 3-TRIOS 4	-25	23	.820	-0.10	0.06	.431	-13.3	4.3	.01	0.02	0.02	.318
Experienced	Element 2-i500	183	28	.001	0.24	0.07	.01	-9.9	5.5	.211	-0.11	0.04	.05
	Element 2-Primescan	186	29	.001	0.33	0.07	.001	29.9	4.3	.001	0.14	0.03	.001
	Element 2-TRIOS 3	159	30	.001	0.33	0.07	.001	17.8	4.7	.001	0.08	0.03	.05
	Element 2-TRIOS 4	184	28	.001	0.35	0.07	.001	22.9	5.1	.001	0.11	0.03	.001
	i500-Primescan	3	15	1.000	0.09	0.05	.350	39.8	4.4	.001	0.26	0.04	.001
	i500-TRIOS 3	-24	17	.908	0.09	0.05	.350	27.7	4.8	.001	0.19	0.04	.001
	i500-TRIOS 4	1	14	1.000	0.10	0.05	.188	32.8	5.2	.001	0.22	0.04	.001
	Primescan-TRIOS 3	-27	19	.908	0.00	0.04	1.000	-12.1	3.3	.001	-0.06	0.02	.01
	Primescan-TRIOS 4	-2	16	1.000	0.02	0.04	1.000	-7.0	3.8	.211	-0.04	0.02	.086
	TRIOS 3-TRIOS 4	25	18	.908	0.02	0.04	1.000	5.1	4.3	.240	0.03	0.02	.234

SEM, standard error of mean.

Table 4. Ranking of scanners based on deviation values

Experience	Alignment	Deviation	1 (Lowest)	2	3	4	5 (Greatest)
Inexperienced	Complete surface	Implant platform	i500	Primescan	TRIOS 3	TRIOS 4	Element 2
	Scan body	Implant platform	Primescan	TRIOS 3	TRIOS 4	i500	Element 2
	Complete surface	Angle	i500	TRIOS 3	Primescan	TRIOS 4	Element 2
	Scan body	Angle	Primescan	TRIOS 4	TRIOS 3	i500	Element 2
Experienced	Complete surface	Implant platform	Primescan	TRIOS 4	i500	TRIOS 3	Element 2
	Scan body	Implant platform	Primescan	TRIOS 4	TRIOS 3	Element 2	i500
	Complete surface	Angle	TRIOS 4	Primescan	TRIOS 3	i500	Element 2
	Scan body	Angle	Primescan	TRIOS 4	TRIOS 3	Element 2	i500

Same color indicates same scanner. Gray, i500; green, Primescan; yellow, TRIOS 3; pale red, TRIOS 4; blue, Element 2.

Sami et al[4] reported that after scan body alignment, the surface deviation of the scan bodies was 18 times greater (740 μm) for TRIOS than the platform deviation (40 μm) found in the present study. The difference could be explained by calculating the deviation from the surface instead of from the cylinder fit and by using an older software version and by the fact that the root mean square error is more sensitive to outliers than the mean absolute deviation.[23]

All angular deviations were under 0.74 degrees, which should not be clinically relevant, although the clinical acceptance level is unclear.[25] After complete surface alignment without the scan bodies, the angle deviation for TRIOS was 3 times greater[3] than that reported in the present and another study[20] with scan body alignment. The angle was smaller for all scanners with the scan body alignment than the complete surface alignment, indicating that complete surface alignment adversely affected the deviation. Scan bodies are long and protrude from the surface; thus, they can help alignment to the proper axis.

A human specimen should be more realistic than stone or plastic casts, especially for the analysis of a completely edentulous arch. However, limitations of this ex vivo study included that the scanner head better accessed the cadaver tissue than in the oral cavity and cadaver tissue contains less moisture and is immobile. The different ambient light conditions might also have influenced the results.[33-35] Following other studies,[4,29] the present data also confirmed that the standardization of the parameters should be obligatory in future IOS trueness studies. Further research is necessary to assess the effect of alternative scan body designs, as well as splinting them together.

CONCLUSIONS

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

1. Experience with intraoral scanners improved the accuracy of superimposition of a complete arch, including the palatal mucosa, but it had little effect on the trueness of the implant platform after excluding the soft tissues.
2. The best implant platform trueness was obtained by the Primescan and TRIOS 4 (statistically equivalent), followed by TRIOS 3. The trueness for the i500 and Element 2 was about half that of the Primescan and TRIOS 4.

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