THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Accuracy of complete arch nonsplinting and noncalibrated splinting implant scanning techniques recorded by using five intraoral scanners

Marta Revilla-León, DDS, MSD, PhD,[a] Rocio Cascos, DDS,[b] Ghida Lawand, BDS, MSc,[c] Abdul B. Barmak, MD, MSc, EdD,[d] John C. Kois, DMD, MSD,[e] and Miguel Gómez-Polo, DDS, PhD[f]

ABSTRACT

Statement of problem. Splinting implant scan bodies (ISBs) has been reported to improve the accuracy of intraoral scanners (IOSs) compared with nonsplinting methods. However, the accuracy of commercially available horizontal noncalibrated ISBs remains unknown.

Purpose. The purpose of this in vitro study was to compare the accuracy of complete arch scans obtained using horizontal noncalibrated or standard ISBs recorded by using 5 different IOSs.

Material and methods. An edentulous maxillary stone cast with 6 implant abutment analogs (MultiUnit Abutment Plus Replica) was used. The reference scan was obtained by digitizing the reference cast with a calibrated laboratory scanner (T710). Five groups were created based on the IOS tested: TRIOS 5, i700, Primescan, Aoralscan 3, and iTero. Two subgroups were defined based on the ISBs selected to record complete arch implant scans: standard ISBs (Stand subgroup) or horizontal noncalibrated ISBs (Apollo subgroup) (n=10). In the Stand subgroup, a standard ISB (Accurate Implant Body MUA) was positioned on each implant abutment, and experimental scans were captured. In the Apollo subgroup, a horizontal ISB (Apollo) was positioned on each implant abutment, connecting the implants horizontally following the arch shape. The standard tessellation language (STL) files of all the experimental scans were exported. A program (DentalCAD) was used to design a complete arch implant-supported bar from the control and each experimental scan. Then, another program (Geomagic) was used to perform linear and angular measurements of the implant interfaces of each bar. The measurements obtained in the control scan were used as a reference to measure the scanning distortion of each specimen. The 2-way ANOVA Welch and pairwise multiple comparison Tukey tests were used to analyze trueness (α=.05). The Levene and pairwise multiple comparison Wilcoxon rank tests were applied to analyze precision (α=.05).

Results. Significant linear trueness differences were found between the subgroups (P<.001) with a significant interaction group×subgroup (P<.05). The iTero system demonstrated a significantly worse linear trueness compared with the other IOSs (P<.001). The TRIOS 5 obtained the worst linear precision. Significant angular trueness discrepancies were found between the groups (P<.001) and subgroups (P=.048) with a significant interaction group×subgroup (P=.041). The Apollo group obtained better angular trueness (P<.001) and precision (P<.001) compared with the Stand ISBs group.

Conclusions. Both the implant scanning technique and choice of IOS impacted the accuracy of complete arch implant scans. (J Prosthet Dent 2025;133:1581.e1-e10)

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.
The authors did not have any conflict of interest, financial or personal, in any of the materials described in this study.

[a]Affiliate Assistant Professor, Graduate Prosthodontics, Department of Restorative Dentistry, School of Dentistry, University of Washington, Seattle, Wash.; Faculty and Director, Research and Digital Dentistry, Kois Center, Seattle, Wash.; and Adjunct Professor, Department of Prosthodontics, School of Dental Medicine, Tufts University, Boston, Mass.
[b]Collaborating Professor of Postgraduate Specialist in Advanced in Implant-Prosthodontics Program, Department of Conservative Dentistry and Prosthodontics, School of Dentistry, Complutense University of Madrid (UCM), Madrid, Spain; and Assistant Professor, Department of Prosthetic Dentistry, School of Dentistry, European University of Madrid, Madrid, Spain.
[c]Implant Fellow, Center for Implant Dentistry, Department of Oral and Maxillofacial Surgery, College of Dentistry, University of Florida, Gainesville, Fla.
[d]Assistant Professor, Clinical Research and Biostatistics, Eastman Institute of Oral Health, University of Rochester Medical Center, Rochester, NY.
[e]Director, Kois Center, Seattle, Wash; Affiliate Professor, Graduate in Prosthodontics, Department of Restorative Dentistry, School of Dentistry, University of Washington, Seattle, Wash.; and Private Practice, Seattle, Wash.
[f]Associate Professor, Department of Conservative Dentistry and Prosthodontics, School of Dentistry, Complutense University of Madrid (UCM), Madrid, Spain.

Clinical Implications

The horizontal noncalibrated implant scan bodies tested in this study improved the angular trueness and precision of the IOSs tested compared with that of standard implant scan bodies.

Intraoral scanners (IOSs) provide a digital method for obtaining virtual definitive implant casts.[1–8] The accuracy of complete arch implant scans is highly dependent on factors that include the implant positions (depth, angulation, position in the dental arch, and interimplant distance)[9–15] and implant scanning method used to record the intraoral digital scans when using IOSs.[16,17] Moreover, the accuracy of all IOSs is influenced by operator- and patient-related factors that should be considered to optimize the performance and accuracy of IOS systems.[18–20]

Different implant scanning techniques have been described for recording the 3-dimensional (3D) implant positions by using IOSs, including nonsplinting and noncalibrated splinting methods.[16,17] Nonsplinting implant scanning techniques involve recording implant positions with standard implant scan bodies (ISBs), while noncalibrated implant splinting procedures involve connecting the ISBs prior to capturing the intraoral scans.[16] The majority of the studies comparing the scanning accuracy of nonsplinting and noncalibrated splinting techniques have reported better outcomes when using splinting methods.[17,21–36] Different noncalibrated horizontal ISBs splinting methods have been described for recording complete arch implant scans.[17,21–36] However, the optimal design for maximizing the accuracy of IOSs remains uncertain.[16,17,21–33] Additionally, the ideal characteristics of ISBs in terms of height, diameter, geometry, material, and retention system design have not been definitively established.[37] Furthermore, the majority of the proposed noncalibrated splinting methods are not commercially available,[17,21–29,31–35] with only limited horizontal ISBs[30] or splinting devices[36] offered by specific manufacturers.

The purpose of this in vitro study was to compare the accuracy (trueness and precision) of complete arch implant scans obtained using a commercially available horizontal noncalibrated ISB (Apollo; Apollo) and standard ISBs (Accurate Implant Scan Body MUA, Nobel Biocare; Elos Medtech) recorded using 5 IOSs (TRIOS 5; 3Shape A/S, CEREC Primescan; Dentsply Sirona, i700; Medit, Aoralscan 3; Shining 3D, and iTero Element 5D Plus; Align Technologies). The null hypothesis was that no difference would be found in the trueness and precision of the complete arch implant scans recorded with the 2 scanning techniques using any of the IOSs tested.

MATERIAL AND METHODS

A maxillary edentulous stone cast with 6 implant abutment analogs (MultiUnit Abutment Plus Replica; Nobel Biocare) was used. The implant abutment analogs were located at the right and left canines, right and left first premolars, and right and left first molars.

Two groups were created based on the implant scanning technique used to record the complete arch implant scans: a nonsplinting technique with standard ISBs (Stand subgroup) or a noncalibrated splinting method using horizontal ISBs (Apollo subgroup) (n=10). The order of the IOSs for each subgroup was randomized by using a shuffled deck of cards (Fig. 1).

Each group was divided into 5 subgroups depending on the IOS examined: TRIOS 5 (TRIOS 5, v.24.1.7; 3Shape A/S), i700 (i700, Medit scan for clinics v.1.12.2, Medit link v.3.3.2; Medit), iTero (iTero Element 5D Plus, v.2.8.25.70; Align Technologies), Aoralscan 3 (Aoralscan 3, v.1.0.0.3115; Shining 3D), and Primescan (CEREC Primescan, Connect v.5.2.7; Dentsply Sirona). Except for the TRIOS 5 and iTero devices, all the IOS systems evaluated were calibrated before data collection and every 10 scans by using their specific calibration devices and by following the manufacturer's protocol.[38] All the experimental scans were recorded under 1000-lux ambient illumination conditions (LX1330B Light Meter; Dr.

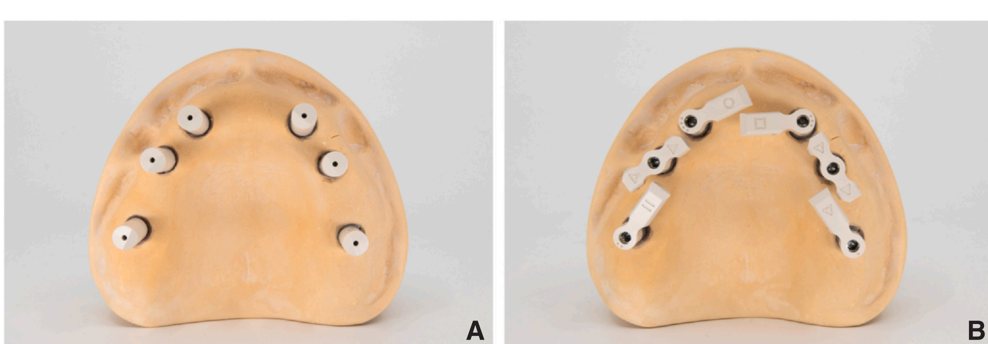

Figure 1. A, Standard implant scan bodies (Stand subgroup). B, Horizontal noncalibrated implant scan bodies (Apollo; Apollo).

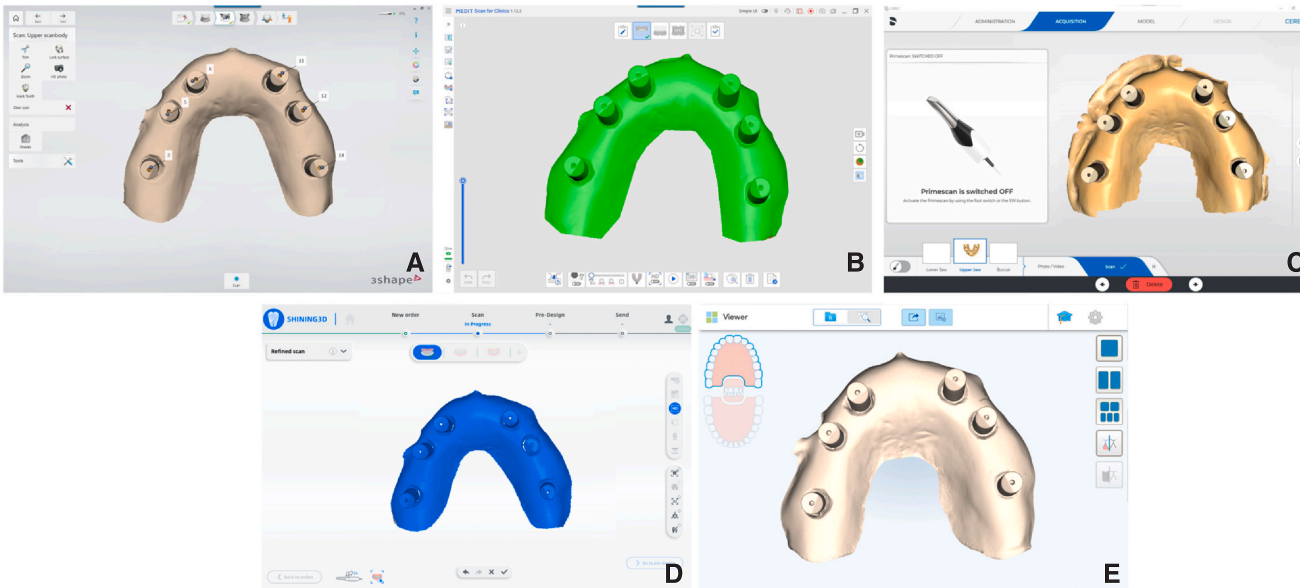

Figure 2. Representative specimens Stand subgroup. A, TRIOS 5-Stand subgroup. B, i700-Stand subgroup. C, Primescan-Stand subgroup. D, Aoralscan 3-Stand subgroup. E, iTero-Stand subgroup.

Meter Digital Illuminance).[39–41] The left hand of the operator was used aiming to maintain the recommended scanning distance specified by each IOS manufacturer (0 mm for TRIOS 5 and iTero, 2 mm for i700 and Primescan, and between 2 and 6 mm for Aoralscan 3).[42] Experimental scans were recorded without rescanning procedures.[43,44] For the i700 system, a 23-mm focal length was chosen. Also, the smart stitching, color, and scan filtering functions were disabled, but the reliability function was activated. All the experimental scans were obtained by a prosthodontist (M.R.-L.) with 11 years of previous experience using IOSs.[45,46]

For the data acquisition of the Stand groups, a new standard ISB (Accurate Implant Scan Body, MUA Abutment Nobel Biocare RP; Elos Medtech) was hand tightened onto each implant abutment of the reference stone cast, as recommended by the manufacturer. The bevel of the ISBs was oriented towards the lingual surface.[47] The ISBs were maintained in the same position until all the specimens of the Stand subgroup were obtained (Fig. 2). Complete arch scans were acquired following a circumferential scanning pattern[48] by using the IOSs examined (TRIOS 5-Stand, i700-Stand, Primescan-Stand, Aoralscan 3-Stand, and iTero-Stand subgroups). Scanning began at the ISB located on the right first molar and continued towards the contralateral ISB following a circumferential motion around each ISB. Each scan was automatically postprocessed by the respective IOS software program All the experimental digital scans were exported in a standard tessellation language (STL) file format. Afterwards, a scan (reference scan) was captured by using a calibrated laboratory scanner (T710; Medit) and following the protocol recommended by the manufacturer. The reference file was also exported in STL file format. Afterwards, the standard ISBs were retrieved from the reference cast.

For data capturing in the Apollo groups, a new horizontal noncalibrated ISB (Apollo; Apollo) was hand tightened onto each implant abutment of the reference cast, as recommended by the manufacturer. There are 2 main types of these horizontal ISBs: those with 1 wing or those with 2 wings. The horizontal ISBs were positioned so that they were close to each other without making contact and followed the natural arch shape. Each horizontal ISB is coded to allow for posterior alignment with the computer-aided design (CAD) file by using a dental CAD program. After positioning the horizontal ISBs on the reference stone cast, consecutive complete arch implant scans were obtained by using the corresponding IOS (TRIOS 5-Apollo, i700-Apollo, Primescan-Apollo, Aoralscan 3-Apollo, and iTero-Apollo subgroups). The intraoral scans involved all the reference marks and surfaces of the horizontal ISBs according to the manufacturer's protocol (Fig. 3). Scanning started at the linguo-occlusal surface of the ISB located on the right first molar and continued towards the occlusal and buccal surfaces. Then, in a continuous linguo-occlusal-buccal motion towards the contralateral ISB, the complete arch scans were recorded. Each scan was automatically postprocessed by the respective IOS software program. The experimental scans were exported in STL file format. Afterwards, the horizontal ISBs were removed from the reference stone cast.

The reference and experimental scans were imported into a CAD program (DentalCAD, v.3.2. Elefsina; exocad GmbH). First, the virtual definitive implant cast was

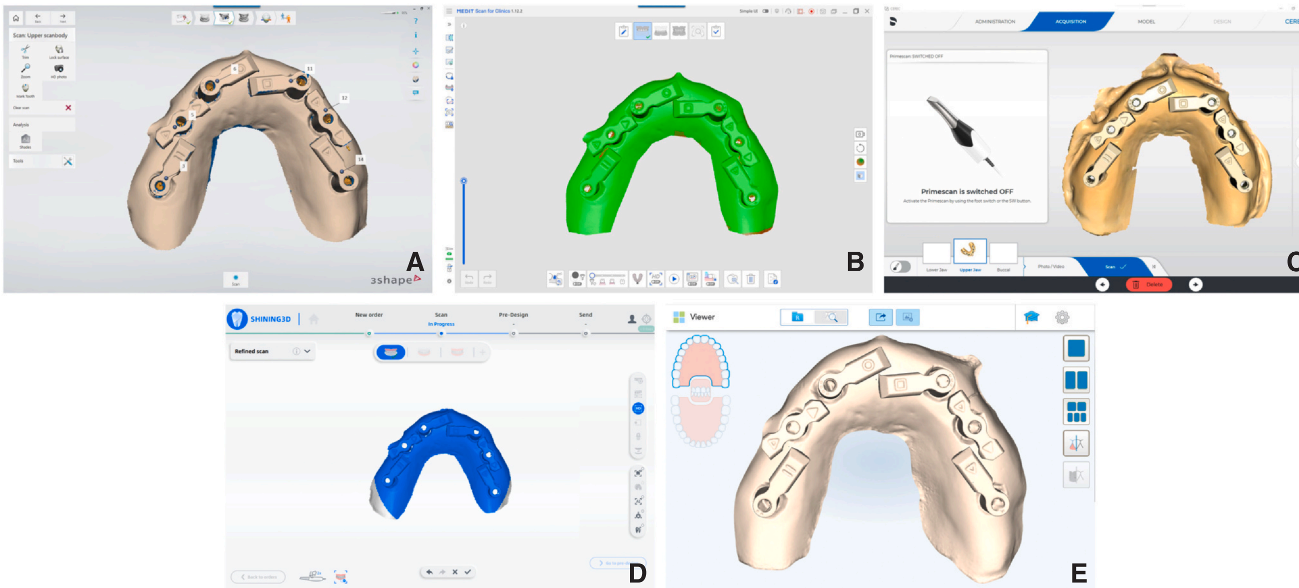

Figure 3. Representative specimens Apollo subgroup. A, TRIOS 5-Apollo subgroup. B, i700-Apollo subgroup. C, Primescan-Apollo subgroup. D, Aoralscan 3-Apollo subgroup. E, iTero-Apollo subgroup.

obtained by superimposing the ISB of each scan to the corresponding CAD object of the ISB (Fig. 4A). Then, a complete arch implant-supported bar was designed by using the CAD tools (Fig. 4B). The STL files of each bar designed were then exported and imported into a reverse engineering software program (Geomagic; 3D Systems). Five linear and 5 angular measurements were performed among the implants on each specimen. The z-plane was positioned at the apical base of each implant interface, followed by the longitudinal axis of each implant. The point located at the intersection between the z-plane and the longitudinal axis of the implant abutment was used to measure the 5 Euclidean linear distances among the 6 implant abutments (Fig. 4C). Moreover, the longitudinal axes of the implant abutments were used to compute the 5 Euclidean angular distances among the implants (Fig. 4D).

Trueness was described as the average linear and angular measurements between the reference and experimental scans.[49] Precision was described as the measurement variations in each subgroup.[49] The Q-Q plots indicated the normality of residuals in regression models, while the variance across the groups was significantly unequal. Therefore, the 2-way Welch ANOVA test followed by the post hoc pairwise multiple comparison Tukey test was used to analyze trueness (α=.05). The Levene test followed by the pairwise multiple comparison using the Wilcoxon rank sum test with continuity correction data was used to analyze precision (α=.05). Data were analyzed using a statistical software program (SAS, v.3.81, Enterprise Edition; SAS Institute Inc).

RESULTS

The linear and angular discrepancies computed among the subgroups tested are presented in Table 1. The 2-way Welch ANOVA test exposed significant linear trueness differences between the subgroups tested (IOSs) (df=4, MS=0.00838, F=15.317, *P*<.001), not among the groups tested (technique) (df=1, MS=0.00168, F=3.077, *P*=.083), with a significant interaction group×subgroup (df=4, MS=4.15e-4, F=0.758, *P*<.05) (Fig. 5A, B). The Tukey test showed significant linear trueness discrepancies between the IOSs examined (Table 2, Fig. 5C). The iTero system (mean of 103 µm) demonstrated significantly worse linear trueness compared with TRIOS 5 (mean of 66 µm) (*P*<.001), i700 (mean of 71 µm) (*P*<.001), Primescan (mean of 51 µm) (*P*<.001), and Aoralscan 3 (mean of 54 µm) (*P*<.001). The results of the pairwise multiple comparisons for group×subgroup are presented in Table 3 (Fig. 5D). Lastly, the Levene test revealed significant precision linear discrepancies among the IOSs tested (*P*=.003), but not among the groups tested (*P*=.791). The TRIOS 5 (mean 37 µm) and iTero (mean 28 µm) (*P*=.009), i700 (mean 16 µm) and iTero (*P*=.001), i700 and Primescan (mean 15 µm) (*P*=.008), i700 and Aoralscan 3 (*P*=.021), iTero and Primescan (*P*<.001), and iTero and Aoralscan 3 (mean 13 µm) (*P*<.001) subgroups were significantly different from each other. Therefore, the TRIOS 5 demonstrated the poorest linear precision.

The 2-way Welch ANOVA test revealed significant angular trueness discrepancies between the groups (df=1, MS=0.26032, F=32.11, *P*<.001) and subgroups

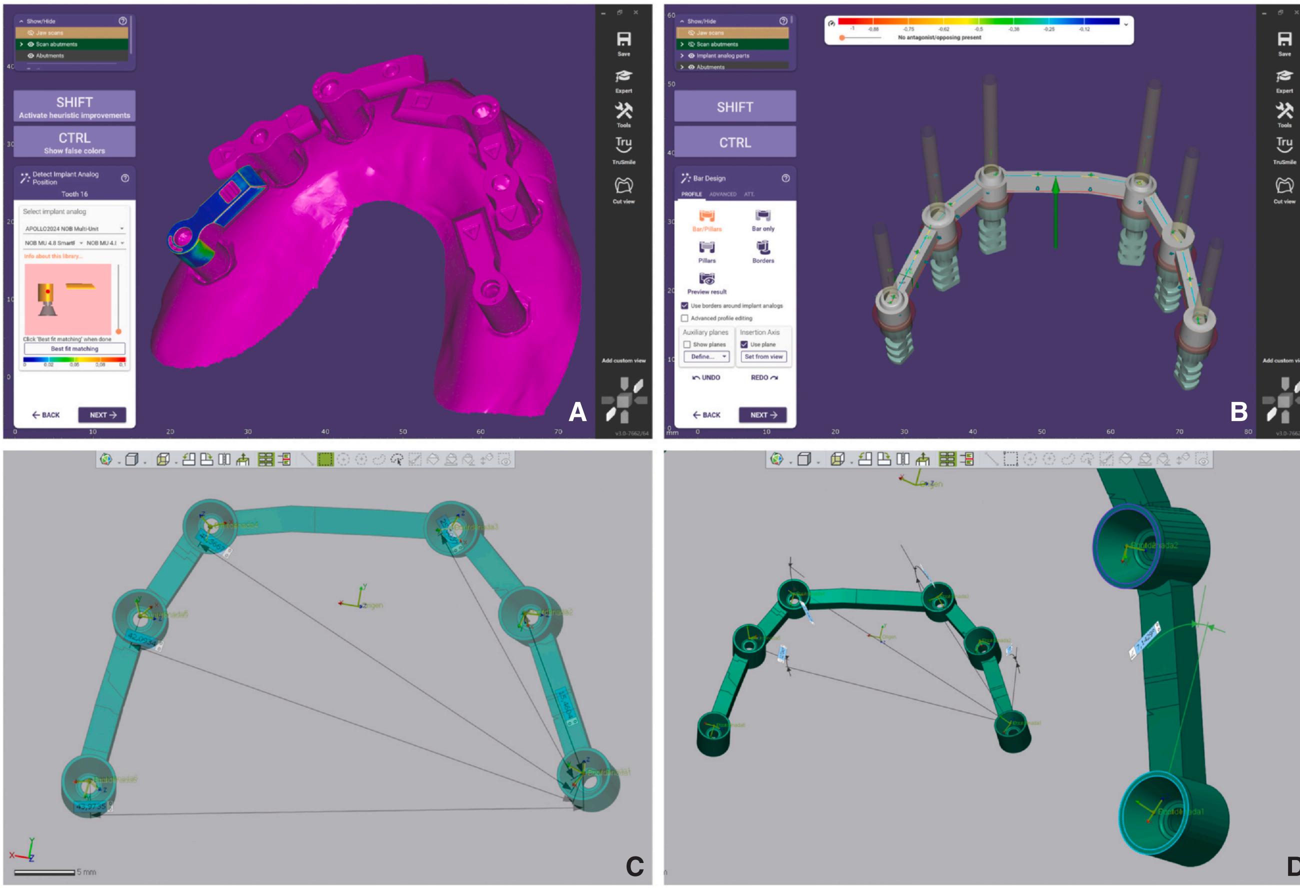

Figure 4. A, Representative procedures for obtaining virtual definitive implant cast of each specimen. Alignment of CAD file and same geometry of experimental scan. B, Representative complete arch implant-supported bar design. C, Representative linear measurements. D, Representative linear measurements. CAD, computer-aided design.

Table 1. Overall linear and angular measurement discrepancies measured among subgroups tested

Group (Techniques)	Subgroup (IOS)	Overall Linear Discrepancy Mean ±SD (µm)	Overall Angular Discrepancy Mean ±SD (Degrees)
Stand ISBs	TRIOS 5	65 ±40	0.411 ±0.201
	i700	81 ±15	0.415 ±0.092
	iTero	105 ±38	0.339 ±0.113
	Primescan	58 ±13	0.304 ±0.106
	Aoralscan 3	57 ±10	0.461 ±0.042
Apollo	TRIOS 5	68 ±35	0.302 ±0.035
	i700	60 ±9	0.278 ±0.034
	iTero	100 ±15	0.290 ±0.048
	Primescan	45 ±13	0.277 ±0.027
	Aoralscan 3	52 ±16	0.275 ±0.032

IOS, intraoral scanner; ISB, Implant scan body; SD, Standard deviation

(df=4, MS=0.02022, F=2.49, P=.048), with a significant interaction group×subgroup (df=4, MS=0.02108, F=2.60, P=.041) (Fig. 5E). The Tukey test demonstrated significant angular trueness discrepancies between the groups (P<.001). Therefore, the Apollo group obtained better angular trueness compared with the Stand ISBs group (Fig. 5F). The Tukey test demonstrated no significant angular trueness discrepancies between the IOSs tested (Table 4, Fig. 5G). The results of the pairwise multiple comparisons for group×subgroup are presented in Table 5 (Fig. 5H). Lastly, the Levene test revealed significant precision angular discrepancies among the groups tested (P<.001), but not among the subgroups tested (P=.054). Therefore, the Apollo group obtained better angular precision compared with the Stand ISBs group (P<.001).

DISCUSSION

The results of this in vitro investigation revealed that the implant scanning technique used and IOS selected impacted the trueness and precision of complete arch implant scans. The noncalibrated splinting implant scanning technique that involved horizontal ISBs demonstrated better angular trueness and precision compared with the nonsplinting method tested. Additionally, significant discrepancies in linear trueness and precision were found among the IOSs evaluated.

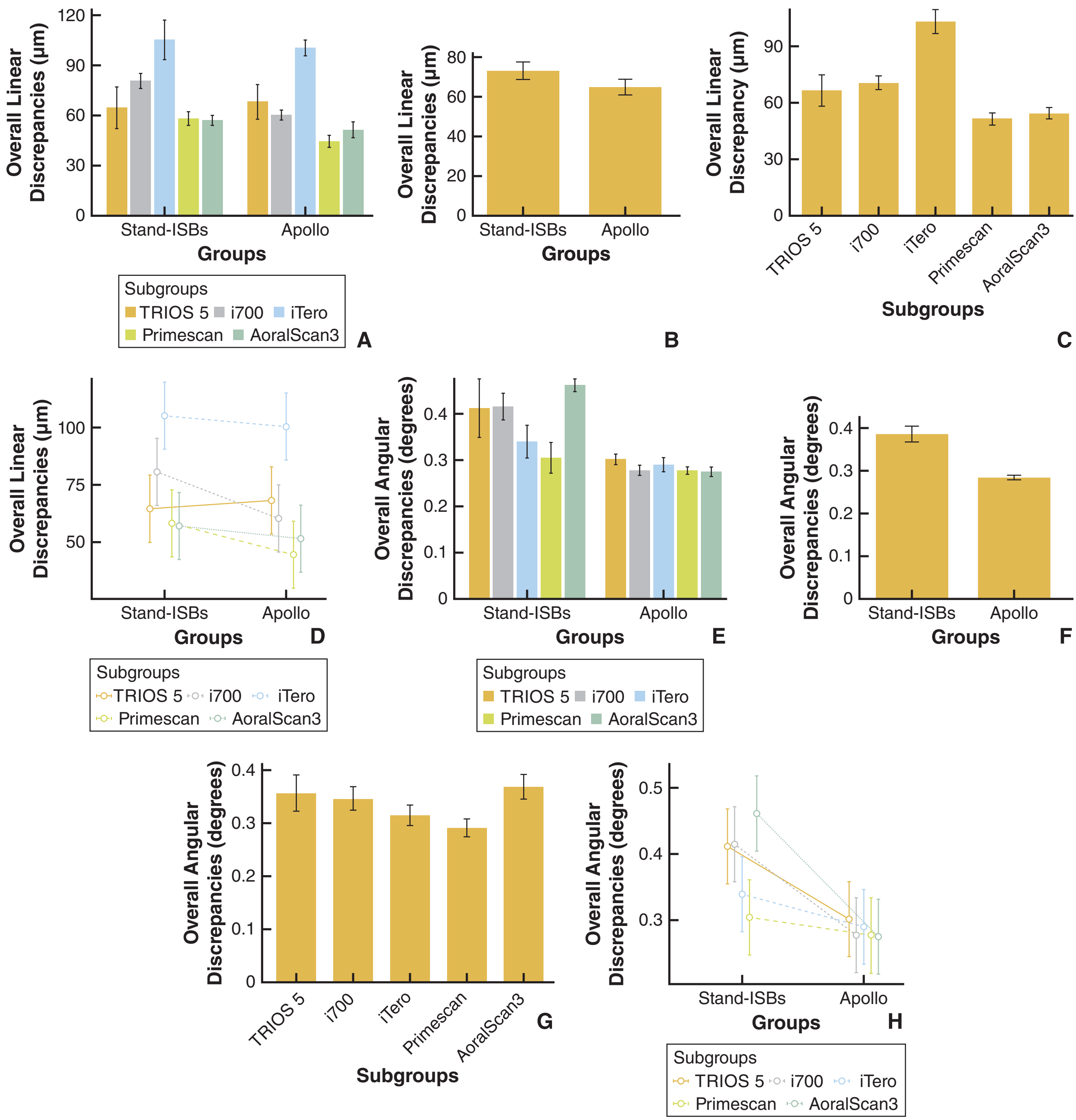

Figure 5. A, Linear discrepancies among subgroups tested. B, Overall linear measurement among groups tested. C, Overall linear measurement among subgroups tested. D, Group×Subgroup interaction plot. E, Angular measurements among subgroups tested. F, Overall angular measurement among groups tested. G, Overall angular measurement among subgroups tested. H, Group×Subgroup interaction plot. ISB, Implant scan body.

Therefore, the null hypothesis that no difference in the trueness and precision of the complete arch implant scans recorded with the 2 scanning techniques using any of the IOSs tested was rejected.

Previous studies have reported that noncalibrated splinting implant scanning methods have higher scanning accuracy than nonsplinting techniques.[17,21–36] These techniques include the varying designs and materials of horizontal ISBs. However, the authors are unaware of a previous investigation that tested the commercially available horizontal ISBs (Apollo; Apollo). Overall, the results of the present study revealed that the noncalibrated horizontal ISBs improved angular trueness and precision compared with the standard ISBs assessed, independently of the IOSs used. Thus, the findings of the present investigation were consistent

Table 2. Post hoc comparisons of linear discrepancies measured among subgroups tested

Comparisons		Mean Difference	SE	df	t	P_{tukey}
Subgroup	Subgroup					
TRIOS 5	i700	−0.00410	0.00740	90.0	−0.554	.981
	iTero	−0.03641	0.00740	90.0	−4.922	<.001*
	Primescan	0.01500	0.00740	90.0	2.028	.261
	5	0.01205	0.00740	90.0	1.629	.483
i700	iTero	−0.03231	0.00740	90.0	−4.368	<.001*
	Primescan	0.01909	0.00740	90.0	2.581	.082
	5	0.01615	0.00740	90.0	2.183	.196
iTero	Primescan	0.05140	0.00740	90.0	6.949	<.001*
	Aoralscan 3	0.04846	0.00740	90.0	6.551	<.001*
Primescan	Aoralscan 3	−0.00295	0.00740	90.0	−0.399	.995

Comparisons based on estimated marginal means

*Statistically significant differences between groups being compared (P<.05)

with previously published data reporting better outcomes when using splinted implant recording techniques.[17,21–36] However, direct comparisons with previous studies is not feasible because of variations in the research methodology, including differences in ISB geometry, height, width, and material.

Table 3. Post hoc comparisons of linear discrepancies group×subgroup

Comparisons					Mean Difference	SE	df	t	P_{tukey}
Group	Subgroup	vs	Techniques	Subgroup					
Stand ISBs	TRIOS 5	-	Stand ISBs	i700	−0.01598	0.0105	90.0	−1.528	
		-	Stand ISBs	iTero	−0.04055	0.0105	90.0	−3.876	.007*
		-	Stand ISBs	Primescan	0.00636	0.0105	90.0	0.608	>.999
		-	Stand ISBs	Aoralscan 3	0.00750	0.0105	90.0	0.717	.999
		-	Apollo	TRIOS 5	−0.00348	0.0105	90.0	−0.333	>.999
		-	Apollo	i700	0.00431	0.0105	90.0	0.412	>.999
		-	Apollo	iTero	−0.03574	0.0105	90.0	−3.417	.031*
		-	Apollo	Primescan	0.02016	0.0105	90.0	1.927	.651
		-	Apollo	Aoralscan 3	0.01312	0.0105	90.0	1.254	.961
	i700	-	Stand ISBs	iTero	−0.02457	0.0105	90.0	−2.349	.369
		-	Stand ISBs	Primescan	0.02234	0.0105	90.0	2.136	.508
		-	Stand ISBs	Aoralscan 3	0.02348	0.0105	90.0	2.245	.435
		-	Apollo	TRIOS 5	0.01250	0.0105	90.0	1.195	.971
		-	Apollo	i700	0.02029	0.0105	90.0	1.939	.643
		-	Apollo	iTero	−0.01976	0.0105	90.0	−1.889	.676
		-	Apollo	Primescan	0.03614	0.0105	90.0	3.454	.027*
		-	Apollo	Aoralscan 3	0.02910	0.0105	90.0	2.782	.159
	iTero	-	Stand ISBs	Primescan	0.04691	0.0105	90.0	4.485	<.001*
		-	Stand ISBs	Aoralscan 3	0.04805	0.0105	90.0	4.593	<.001*
		-	Apollo	TRIOS 5	0.03707	0.0105	90.0	3.544	.021*
		-	Apollo	i700	0.04486	0.0105	90.0	4.288	.002*
		-	Apollo	iTero	0.00481	0.0105	90.0	0.460	>.999
		-	Apollo	Primescan	0.06071	0.0105	90.0	5.803	<.001*
		-	Apollo	Aoralscan 3	0.05367	0.0105	90.0	5.131	<.001*
	Primescan	-	Stand ISBs	Aoralscan 3	0.00114	0.0105	90.0	0.109	>.999
		-	Apollo	TRIOS 5	−0.00984	0.0105	90.0	−0.941	.995
		-	Apollo	i700	−0.00205	0.0105	90.0	−0.196	>.999
		-	Apollo	iTero	−0.04210	0.0105	90.0	−4.025	.004*
		-	Apollo	Primescan	0.01379	0.0105	90.0	1.319	.947
		-	Apollo	Aoralscan 3	0.00676	0.0105	90.0	0.646	>.999
	Aoralscan 3	-	Apollo	TRIOS 5	−0.01098	0.0105	90.0	−1.050	.988
		-	Apollo	i700	−0.00319	0.0105	90.0	−0.305	>.999
		-	Apollo	iTero	−0.04324	0.0105	90.0	−4.134	.003*
		-	Apollo	Primescan	0.01266	0.0105	90.0	1.210	.969
		-	Apollo	Aoralscan 3	0.00562	0.0105	90.0	0.537	>.999
Apollo	TRIOS 5	-	Apollo	i700	0.00779	0.0105	90.0	0.744	.999
		-	Apollo	iTero	−0.03226	0.0105	90.0	−3.084	.077
		-	Apollo	Primescan	0.02364	0.0105	90.0	2.259	.425
		-	Apollo	Aoralscan 3	0.01660	0.0105	90.0	1.587	.851
	i700	-	Apollo	iTero	−0.04005	0.0105	90.0	−3.828	.009*
		-	Apollo	Primescan	0.01585	0.0105	90.0	1.515	.883
		-	Apollo	Aoralscan 3	0.00881	0.0105	90.0	0.843	.998
	iTero	-	Apollo	Primescan	0.05590	0.0105	90.0	5.343	<.001*
		-	Apollo	Aoralscan 3	0.04886	0.0105	90.0	4.671	<.001*
	Primescan	-	Apollo	Aoralscan 3	−0.00703	0.0105	90.0	−0.672	>.999

Comparisons based on estimated marginal means

*statistically significant differences between groups being compared (P<.05)

Table 4. Post hoc comparisons of angular discrepancies measured among subgroups tested

Comparisons			Mean Difference	SE	df	t	P_{tukey}
Subgroup	vs	Subgroup					
TRIOS 5	-	i700	0.0104	0.0285	90.0	0.364	.996
	-	iTero	0.0417	0.0285	90.0	1.466	.587
	-	Primescan	0.0657	0.0285	90.0	2.307	.152
	-	Aoralscan 3	−0.0116	0.0285	90.0	−0.408	.994
i700	-	iTero	0.0314	0.0285	90.0	1.102	.805
	-	Primescan	0.0553	0.0285	90.0	1.943	.303
	-	Aoralscan 3	−0.0220	0.0285	90.0	−0.772	.938
iTero	-	Primescan	0.0239	0.0285	90.0	0.841	.917
	-	Aoralscan 3	−0.0534	0.0285	90.0	−1.874	.339
Primescan	-	Aoralscan 3	−0.0773	0.0285	90.0	−2.715	.060

Comparisons based on estimated marginal means

*statistically significant differences between groups being compared ($P<.05$)

Accuracy discrepancies have been reported among the different IOSs.[4,7,8,17,18,20,24,50–53] However, the IOS system and software versions that provide the most accurate intraoral scans based on the purpose of the scan is difficult to determine because of the research methodology heterogeneity among the published

Table 5. Post hoc comparisons of angular discrepancies group×subgroup

Comparison					Mean Difference	SE	df	t	P_{tukey}
Techniques	IOS	vs	Techniques	IOS					
Stand ISBs	TRIOS 5	-	Stand ISBs	i700	−0.00334	0.0403	90.0	−0.08305	>.999
		-	Stand ISBs	iTero	0.07216	0.0403	90.0	1.79223	.738
		-	Stand ISBs	Primescan	0.10716	0.0403	90.0	2.66132	.206
		-	Stand ISBs	Aoralscan 3	−0.04984	0.0403	90.0	−1.23775	.964
		-	Apollo	TRIOS 5	0.11005	0.0403	90.0	2.73304	.177
		-	Apollo	i700	0.13409	0.0403	90.0	3.33029	.039*
		-	Apollo	iTero	0.12134	0.0403	90.0	3.01354	.092
		-	Apollo	Primescan	0.13423	0.0403	90.0	3.33377	.039*
		-	Apollo	Aoralscan 3	0.13664	0.0403	90.0	3.39357	.033*
	i700	-	Stand ISBs	iTero	0.07551	0.0403	90.0	1.87528	.685
		-	Stand ISBs	Primescan	0.11050	0.0403	90.0	2.74437	.172
		-	Stand ISBs	Aoralscan 3	−0.04649	0.0403	90.0	−1.15470	.977
		-	Apollo	TRIOS 5	0.11339	0.0403	90.0	2.81609	.147
		-	Apollo	i700	0.13744	0.0403	90.0	3.41334	.031*
		-	Apollo	iTero	0.12468	0.0403	90.0	3.09659	.074
		-	Apollo	Primescan	0.13758	0.0403	90.0	3.41682	.031*
		-	Apollo	Aoralscan 3	0.13999	0.0403	90.0	3.47662	.026*
	iTero	-	Stand ISBs	Primescan	0.03499	0.0403	90.0	0.86909	.997
		-	Stand ISBs	Aoralscan 3	−0.12200	0.0403	90.0	−3.02998	.088
		-	Apollo	TRIOS 5	0.03788	0.0403	90.0	0.94082	.995
		-	Apollo	i700	0.06193	0.0403	90.0	1.53806	.873
		-	Apollo	iTero	0.04918	0.0403	90.0	1.22131	.967
		-	Apollo	Primescan	0.06207	0.0403	90.0	1.54154	.871
		-	Apollo	Aoralscan 3	0.06448	0.0403	90.0	1.60134	.844
	Primescan	-	Stand ISBs	Aoralscan 3	−0.15700	0.0403	90.0	−3.89907	.007*
		-	Apollo	TRIOS 5	0.00289	0.0403	90.0	0.07172	>.999
		-	Apollo	i700	0.02694	0.0403	90.0	0.66897	>.999
		-	Apollo	iTero	0.01418	0.0403	90.0	0.35222	>.999
		-	Apollo	Primescan	0.02708	0.0403	90.0	0.67245	>.999
		-	Apollo	Aoralscan 3	0.02948	0.0403	90.0	0.73225	.999
	Aoralscan 3	-	Apollo	TRIOS 5	0.15988	0.0403	90.0	3.97080	.005*
		-	Apollo	i700	0.18393	0.0403	90.0	4.56804	<.001*
		-	Apollo	iTero	0.17118	0.0403	90.0	4.25129	.002*
		-	Apollo	Primescan	0.18407	0.0403	90.0	4.57152	<.001*
		-	Apollo	Aoralscan 3	0.18648	0.0403	90.0	4.63132	<.001*
2	TRIOS 5	-	Apollo	i700	0.02405	0.0403	90.0	0.59724	>.999
		-	Apollo	iTero	0.01129	0.0403	90.0	0.28049	>.999
		-	Apollo	Primescan	0.02419	0.0403	90.0	0.60072	>.999
		-	Apollo	Aoralscan 3	0.02660	0.0403	90.0	0.66052	>.999
	i700	-	Apollo	iTero	−0.01275	0.0403	90.0	−0.31675	>.999
		-	Apollo	Primescan	1.40e−4	0.0403	90.0	0.00348	>.999
		-	Apollo	Aoralscan 3	0.00255	0.0403	90.0	0.06328	>.999
	iTero	-	Apollo	Primescan	0.01289	0.0403	90.0	0.32023	>.999
		-	Apollo	Aoralscan 3	0.01530	0.0403	90.0	0.38003	>.999
	Primescan	-	Apollo	Aoralscan 3	0.00241	0.0403	90.0	0.05980	>.999

Comparisons based on estimated marginal means

*statistically significant differences between groups being compared ($P<.05$)

studies.[4,7,8,17,18,20,24,50–53] The results of the present study also obtained scanning discrepancies among the 5 IOSs tested. Specifically, the iTero system demonstrated the poorest linear trueness, while the TRIOS 5 demonstrated the poorest linear precision. However, no angular trueness and precision differences were found among the IOSs compared.

The 2-piece polyetheretherketone (PEEK) horizontal ISBs tested demonstrated a different accuracy outcome based on the IOS selected to record complete arch implant scans, which may be explained by hardware and software variations among the IOS systems. Overall, the horizontal ISBs improved the mean linear discrepancy between 3 and 21 µm and the mean angular discrepancy ranging from 0.027 to 0.186 degrees when compared with the standard ISBs tested, depending on the IOSs: specifically, an improvement of the mean linear discrepancy by 3, 5, 5, 13, and 21 µm when using the TRIOS 5, iTero, Aoralscan 3, Primescan, and i700, respectively, and an improvement of the mean. angular discrepancy by 0.091, 0.137, 0.049, 0.027, and 0.186 degrees when using the TRIOS 5, i700, iTero, Primescan, and i700, respectively. Studies are needed to further assess the impact of these horizontal ISBs on the accuracy of different IOSs, as well as the impact of the implant impression level, implant design, and position.

The horizontal ISBs tested should be positioned in such a way that adjacent implants are connected through the horizontal ISB, but without any direct contact between the ISBs. This arrangement allows the natural arch shape to be followed while connecting the implants being scanned. Additionally, there are 2 horizontal ISB designs, featuring either 1 or 2 wings. Whether the positioning of the horizontal ISBs in the dental arch impacts the scanning accuracy of implant scans recorded by using different IOSs is unclear. Studies are needed to assess the impact of the horizontal ISBs positioning or orientation on the accuracy of intraoral digital implant scans.

The impact of the sterilization, multiple use, and positioning torque of standard ISBs on the accuracy of intraoral digital implant scans has been evaluated.[54,55] It may be reasonable to assume that the horizontal ISBs tested could also be affected by these 2 factors. Studies are needed to further evaluate the effect of the sterilization, multiple use, and positioning torque of the horizontal ISBs included in this study.

Limitations of the present study included the in vitro conditions, limited implant designs, positions, interimplant distances, and the standard ISB designs tested. Furthermore, an extraoral scanner was used to obtain the reference scan. Studies are required to further evaluate the accuracy of the different implant scanning techniques for recording the definitive virtual implant casts, as well as to analyze the impact of the IOS system on the trueness and precision of implant scans involving varying number of implants being restored.

CONCLUSIONS

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

1. The implant scanning technique and the selected IOS impacted the accuracy of complete arch implant scans.
2. The noncalibrated splinting implant scanning technique that involved horizontal ISBs demonstrated better angular trueness and precision compared with the nonsplinting method tested.
3. The iTero system demonstrated the worst linear trueness, while the TRIOS 5 demonstrated the worst linear precision. However, no significant differences in angular trueness and precision were observed among the other IOSs compared, iTero Element 5D Plus, i700, and Aoralscan 3 systems.

REFERENCES

1. Ren S, Jiang X, Lin Y, Di P. Crown accuracy and time efficiency of cement-retained implant-supported restorations in a complete digital workflow: A randomized control trial. *J Prosthodont.* 2022;31:405–411.
2. Mangano FG, Hauschild U, Veronesi G, et al. Trueness and precision of 5 intraoral scanners in the impressions of single and multiple implants: A comparative in vitro study. *BMC Oral Health.* 2019;19:101.
3. Vitai V, Németh A, Sólyom E, et al. Evaluation of the accuracy of intraoral scanners for complete-arch scanning: A systematic review and network meta-analysis. *J Dent.* 2023;137:104636.
4. Ma J, Zhang B, Song H, et al. Accuracy of digital implant impressions obtained using intraoral scanners: A systematic review and meta-analysis of in vivo studies. *Int J Implant Dent.* 2023;9:48.
5. Albanchez-González MI, Brinkmann JC, Peláez-Rico J, et al. Accuracy of digital dental implants impression taking with intraoral scanners compared with conventional impression techniques: A systematic review of in vitro studies. *Int J Environ Res Public Health.* 2022;19:2026.
6. Schmidt A, Wöstmann B, Schlenz MA. Accuracy of digital implant impressions in clinical studies: A systematic review. *Clin Oral Implants Res.* 2022;33:573–585.
7. Flügge T, van der Meer WJ, Gonzalez BG, et al. The accuracy of different dental impression techniques for implant-supported dental prostheses: A systematic review and meta-analysis. *Clin Oral Implants Res.* 2018;29:374–392.
8. Wulfman C, Naveau A, Rignon-Bret C. Digital scanning for complete-arch implant-supported restorations: A systematic review. *J Prosthet Dent.* 2020;124:161–167.
9. Gómez-Polo M, Sallorenzo A, Ortega R, et al. Influence of implant angulation and clinical implant scan body height on the accuracy of complete arch intraoral digital scans. *J Prosthet Dent.* 2024;131:119–127.
10. Sicilia E, Lagreca G, Papaspyridakos P, et al. Effect of supramucosal height of a scan body and implant angulation on the accuracy of intraoral scanning: An in vitro study. *J Prosthet Dent.* 2024;131:1126–1134.
11. Sequeira V, Harper MT, Lilly CL, Bryington MS. Accuracy of digital impressions at varying implant depths: An in vitro study. *J Prosthodont.* 2023;32:54–61.
12. Carneiro Pereira AL, Medeiros VR, Da Fonte Porto Carreiro A. Influence of implant position on the accuracy of intraoral scanning in fully edentulous arches: A systematic review. *J Prosthet Dent.* 2021;126:749–755.
13. Laohverapanich K, Luangchana P, Anunmana C, Pornprasertsuk-Damrongsri S. Different implant subgingival depth affects the trueness and precision of the 3D dental implant position: a comparative in vitro study among five digital scanners and a conventional technique. *Int J Oral Maxillofac Implants.* 2021;36:1111–1120.

14. Thanasrisuebwong P, Kulchotirat T, Anunmana C. Effects of inter- implant distance on the accuracy of intraoral scanner: An in vitro study. *J Adv Prosthodont*. 2021;13:107–116.
15. Tan M, Yee S, Wong K, et al. Comparison of three- dimensional accuracy of digital and conventional implant impressions: Effect of interimplant distance in an edentulous arch. *Int J Oral Maxillofac Implants*. 2019;34:366–380.
16. Revilla-León M, Gómez-Polo M, Rutkunas V, et al. Classification of complete-arch implant scanning techniques recorded by using intraoral scanners. *J Esthet Restor Dent* 2024.
17. Paratelli A, Vania S, Gómez-Polo C, et al. Techniques to improve the accuracy of complete arch implant intraoral digital scans: A systematic review. *J Prosthet Dent*. 2023;129:844–854.
18. Revilla-León M, Kois DE, Kois JC. A guide for maximizing the accuracy of intraoral digital scans. Part 1: Operator factors. *J Esthet Restor Dent*. 2023;35:230–240.
19. Revilla-León M, Kois DE, Kois JC. A guide for maximizing the accuracy of intraoral digital scans: Part 2-Patient factors. *J Esthet Restor Dent*. 2023;35:241–249.
20. Revilla-León M, Lanis A, Yilmaz B, et al. Intraoral digital implant scans: Parameters to improve accuracy. *J Prosthodont*. 2023;32:150–164.
21. Wu HK, Wang J, Chen G, et al. Effect of novel prefabricated auxiliary devices attaching to scan bodies on the accuracy of intraoral scanning of complete-arch with multiple implants: An in-vitro study. *J Dent*. 2023;138:104702.
22. Rutkunas V, Bilius V, Simonaitis T, et al. The effect of different implant impression splinting techniques and time on the dimensional accuracy: An in vitro study. *J Dent*. 2022;126:104267.
23. Kernen FR, Recca M, Vach K, et al. In vitro scanning accuracy using different aids for multiple implants in the edentulous arch. *Clin Oral Implants Res*. 2022;33:1010–1020.
24. Revilla-León M, Barmak AB, Lanis A, Kois JC. Influence of connected and nonconnected calibrated frameworks on the accuracy of complete arch implant scans obtained by using four intraoral scanners, a desktop scanner, and a photogrammetry system. *J Prosthet Dent* 2024.
25. Li Y, Fang H, Yan Y, Geng W. Accuracy of intraoral scanning using modified scan bodies for complete arch implant-supported fixed prostheses. *J Prosthet Dent*. 2024;132. 994.e1–8.
26. Ashry A, Abdelhamid AM, Ezzelarab S, Khamis MM. Effect of using scan body accessories and inter-implant distances on the accuracy of complete arch implant digital impressions: An in vitro study. *J Prosthodont* 2024.
27. Canullo L, Pesce P, Caponio VCA, et al. Effect of auxiliary geometric devices on the accuracy of intraoral scans in full-arch implant-supported rehabilitations: An in vitro study. *J Dent*. 2024;145:104979.
28. Cheng J, Zhang H, Liu H, et al. Accuracy of edentulous full-arch implant impression: An in vitro comparison between conventional impression, intraoral scan with and without splinting, and photogrammetry. *Clin Oral Implants Res*. 2024;35:560–572.
29. Zhang T, Yang B, Ge R, et al. Effect of a novel 'scan body' on the in vitro scanning accuracy of full-arch implant impressions. *Int Dent J*. 2024;74:847–854.
30. Nuytens P, Grande F, D'haese R, et al. Novel complete-arch pillar system (CAPS) to register implant position and maxillomandibular relationship in one single visit. *J Dent*. 2024;143:104885.
31. Saaedi TMASE, Thabet YG. Customized scan bodies to facilitate intraoral scanning for full arch implant prosthesis: A dental technique. *J Prosthodont*. 2024;33:297–300.
32. Retana L, Nejat AH, Pozzi A. Effect of splinting scan bodies on trueness of complete-arch implant impression using different intraoral scanners: An in vitro study. *Int J Comput Dent*. 2023;26:19–28.
33. Wulfman C, Naveau A, Rignon-Bret C. Digital scanning for complete-arch implant-supported restorations: A systematic review. *J Prosthet Dent*. 2020;124:161–167.
34. Huang R, Liu Y, Huang B, et al. Improved accuracy of digital implant impressions with newly designed scan bodies: An in vivo evaluation in beagle dogs. *BMC Oral Health*. 2021;21:623.
35. Huang R, Liu Y, Huang B, et al. Improved scanning accuracy with newly designed scan bodies: An in vitro study comparing digital versus conventional impression techniques for complete-arch implant rehabilitation. *Clin Oral Implants Res*. 2020;31:625–633.
36. Crockett RJ, Parikh V, Ahn B, Yao CHD. Use of a dual-purpose implant scan body to obtain both digital and analog records for complete arch fixed implant restorations. *J Prosthet Dent*. 2025;133:36–42.
37. Gómez-Polo M, Donmez MB, Çakmak G, et al. Influence of implant scan body design (height, diameter, geometry, material, and retention system) on intraoral scanning accuracy: A systematic review. *J Prosthodont*. 2023;32:165–180.
38. Revilla-León M, Gohil A, Barmak AB, et al. Influence of ambient temperature changes on intraoral scanning accuracy. *J Prosthet Dent*. 2023;130:755–760.
39. Revilla-León M, Jiang P, Sadeghpour M, et al. Intraoral digital scans-Part 1: Influence of ambient scanning light conditions on the accuracy (trueness and precision) of different intraoral scanners. *J Prosthet Dent*. 2020;124:372–378.
40. Revilla-León M, Subramanian SG, Özcan M, Krishnamurthy VR. Clinical study of the influence of ambient light scanning conditions on the accuracy (trueness and precision) of an intraoral scanner. *J Prosthodont*. 2020;29:107–113.
41. Revilla-León M, Subramanian SG, Att W, Krishnamurthy VR. Analysis of different illuminance of the room lighting condition on the accuracy (trueness and precision) of an intraoral scanner. *J Prosthodont*. 2021;30:157–162.
42. Button H, Kois JC, Barmak AB, et al. Scanning accuracy and scanning area discrepancies of intraoral digital scans acquired at varying scanning distances and angulations among 4 different intraoral scanners. *J Prosthet Dent*. 2024;132:1044–1060.
43. Revilla-León M, Quesada-Olmo N, Gómez-Polo M, et al. Influence of rescanning mesh holes on the accuracy of an intraoral scanner: An in vivo study. *J Dent*. 2021;115:103851.
44. Revilla-León M, Sicilia E, Agustín-Panadero R, et al. Clinical evaluation of the effects of cutting off, overlapping, and rescanning procedures on intraoral scanning accuracy. *J Prosthet Dent*. 2023;130:746–754.
45. Kim J, Park JM, Kim M, et al. Comparison of experience curves between two 3-dimensional intraoral scanners. *J Prosthet Dent*. 2016;116:221–230.
46. Lim JH, Park JM, Kim M, et al. Comparison of digital intraoral scanner reproducibility and image trueness considering repetitive experience. *J Prosthet Dent*. 2018;119:225–232.
47. Gómez-Polo M, Álvarez F, Ortega R, et al. Influence of the implant scan body bevel location, implant angulation and position on intraoral scanning accuracy: An in vitro study. *J Dent*. 2022;121:104122.
48. Gómez-Polo M, Cascos R, Ortega R, et al. Influence of scanning pattern on accuracy, time, and number of photograms of complete-arch implant scans: A clinical study. *J Dent*. 2024;150:105310.
49. International Organization for Standardization. ISO 5725–1:1994. Accuracy (trueness and precision) of measurement methods and results - Part 1: General principles and definitions. ⟨https://www.iso.org/obp/ui/#iso:std:iso:5725:-1:ed-1:v1:en⟩ Accessed 02–01-20.
50. Amornvit P, Rokaya D, Sanohkan S. Comparison of accuracy of current ten intraoral scanners. *Biomed Res Int*. 2021;2021:2673040.
51. Braian M, Wennerberg A. Trueness and precision of 5 intraoral scanners for scanning edentulous and dentate complete-arch mandibular casts: A comparative in vitro study. *J Prosthet Dent*. 2019;122:129–136. .e2.
52. El Osta N, Drancourt N, Auduc C, et al. Accuracy of conventional impressions and digital scans for implant-supported fixed prostheses in maxillary free-ended partial edentulism: An in vitro study. *J Dent*. 2024;143:104892.
53. Ochoa-López G, Cascos R, Antonaya-Martín JL, et al. Influence of ambient light conditions on the accuracy and scanning time of seven intraoral scanners in complete-arch implant scans. *J Dent*. 2022;121:104138.
54. Diker E, Terzioglu H, Gouveia DNM, et al. Effect of material type, torque value, and sterilization on linear displacements of a scan body: An in vitro study. *Clin Implant Dent Relat Res*. 2023;25:419–425.
55. Arcuri L, Lio F, Campana V, et al. Influence of implant scanbody wear on the accuracy of digital impression for complete-arch: A randomized in vitro trial. *Materials (Basel)*. 2022;15:927.

Corresponding author:
Dr Marta Revilla-León
1001 Fairview Avenue North, # 2200
Seattle, WA 98109
Email: marta.revilla.leon@gmail.com

https://doi.org/10.1016/j.prosdent.2025.02.062