BMC Oral Health

RESEARCH

Open Access

Impact of implant scan body material and angulation on the trueness and precision of digital implant impressions using four intraoral scanners–an in vitro study

Hisham Soltan[1], Xiaoxue Mai[2], Amr S. Ramdan[3], Mohammed Qasem Saleh[4], Sarraj. H. Ashour[5] and Weibo Xie[1*]

Abstract

Background Intraoral scanners (IOS) offer advantages in implant dentistry, but accuracy depends on factors including implant scan body (ISB) material and implant angulation. Conflicting evidence exists on the performance of Titanium (Ti) versus PEEK ISBs, especially with angulated implants. This study aimed to evaluate the combined effect of ISB material (PEEK vs. Ti) and implant angulation (0° vs. 30°) on the trueness and precision of digital impressions obtained from four different IOSs.

Methods A 3D-printed edentulous maxillary model with four implants (two parallel 0°, two angled 30°). Four ISB configurations (Ti 0°, Ti 30°, PEEK 0°, PEEK 30°) were screwed to the implants and scanned ($n=10$ per group) using four IOSs: Primescan, Trios 3, Aoralscan 3, and Fussen S6000. A high-resolution desktop scanner provided the reference. Trueness (RMS error vs. reference model) and precision (RMS error from intra-group comparisons) were calculated using Geomagic software. Data were analyzed using Friedman and Kruskal-Wallis tests ($\alpha=0.05$).

Results ISB configuration significantly affected trueness ($P<0.001$) and precision ($P<0.001$). PEEK ISBs demonstrated significantly higher trueness and precision than Ti ISBs ($P<0.001$). PEEK 30° showed the highest trueness, while PEEK 0° showed the highest precision. Angulation did not significantly affect trueness for Ti ISBs. IOS type significantly influenced trueness and precision across all ISB configurations ($P<0.001$). Primescan and Trios 3 generally exhibited higher trueness and precision compared to Aoralscan 3 and Fussen S6000 (specific pairwise differences varied by condition, $P<0.05$).

Conclusions Both ISB material and implant angulation significantly influence the trueness and precision of full-arch digital implant impressions. PEEK ISBs consistently outperformed Titanium ISBs. Choice of IOS is also critical, with significant performance differences observed among the tested IOSs. Clinicians should consider these interactions when selecting materials and IOSs for optimal accuracy.

Keywords Intraoral scanners (IOS), Dental implants, Dental impression technique, Polyetheretherketone, Titanium

*Correspondence:
Weibo Xie
jiewb@lzu.edu.cn

Full list of author information is available at the end of the article

Background

Intraoral scanners (IOS) have revolutionized implant dentistry, offering a quicker, more efficient, and patient-friendly alternative to traditional impression methods [1, 2]. Acquiring digital implant impressions using IOS technology is increasingly common in fabricating dental restorations, providing significant advantages over conventional techniques. These benefits include reduced impression time, enhanced patient comfort, and the prevention of material distortion that could adversely impact the final restoration. Furthermore, digital impressions simplify model storage and management [3–5].

Despite these advancements, the accuracy of digital impressions remains influenced by several factors. These include the specific IOS used, scanning protocols, the geometry of scanned objects, operator skill, implant position, and importantly, the material and design of the implant scan body (ISB) [6–10]. Among these, the ISB material is crucial for achieving precise digital impressions.

Commonly utilized ISB materials include titanium and PEEK. Titanium is valued for its durability and biocompatibility; however its reflectivity can hinder scanner precision, potentially altering perceived surface geometry, especially in complex areas or where light scatters. Conversely, PEEK is non-reflective and often chosen for its compatibility with optical scanning technologies. Its surface properties can enhance data acquisition, particularly in challenging situations [11, 12]. However, conflicting evidence exists regarding their comparative performance, especially when implants are placed at varying angulations [13].

Implant angulation, often necessary for functional or aesthetic reasons, adds complexity to scanning. While conventional impression accuracy improves with parallel implants due to reduced deformation during tray removal [14, 15], the effect of angulation on digital impression accuracy remains debated. Some studies suggest scan data accuracy is enhanced with angled implants, while others report decreased accuracy [16–18], or no significant difference [19–24].

Therefore, understanding how ISB material (PEEK vs. Titanium) and implant angulation (parallel vs. angled) interact to influence digital impression accuracy is essential for optimizing clinical workflows and patient outcomes. The present study aimed to assess the effect of these two factors (material: PEEK/Titanium; angulation: 0°/30°) on the trueness and precision of digital impressions obtained from four different intraoral scanners.

Methods

Study design and model preparation

The present study employed a factorial design to evaluate the trueness and precision of digital impressions. The two variables investigated were:

IOS Type: Four IOSs: Primescan (Dentsply Sirona, Charlotte, NC, USA), Trios 3 (3Shape, Copenhagen, Denmark), Aoralscan 3 (Shining 3D, Hangzhou, China), and Fussen S6000 (Fussen Technology Co., Shenzhen, China).

Scan Body Configuration: Four scan bodies with combinations of material and angulation: Titanium at 0° angulation (Ti 0), Titanium at 30° angulation (Ti 30), PEEK at 0° angulation (PEEK 0), and PEEK at 30° angulation (PEEK 30).

A 3D-printed resin model of an edentulous maxilla was made using Standard Resin V2 (Anycubic, Shenzhen, Guangdong, China) with an L5 3D printer (Charming3D, Hong Kong). Four implants RP (Nobel Biocare, Zurich, Switzerland) were inserted, following implant positions commonly utilized in all-on-4 implant-supported restorations: two parallel implants (0°) in the lateral incisor sites and two implants angled at 30° in the second premolar sites, the implants were embedded in the model with their platforms positioned at the alveolar crest level, topped with 2 mm of Silicone artificial gingiva (Zhermack, Badia Polesine, Italy) was fabricated using a silicone index, polymerized, polished, and attached to the model to simulate clinical conditions (Fig. 1A) To ensure dimensional stability during the study, the printed model was stored under controlled conditions (20–22 °C, 50% relative humidity), as recommended by the resin manufacturer. All scanning procedures were completed within one week of printing to minimize potential time-dependent deformation.

Reference model digitization and scan body placement

Titanium scan bodies (80610226, 3Shape, Copenhagen, Denmark) were screwed onto the left-side implants, and PEEK scan bodies (IO 2B-B SA, Elos Medtech, Gothenburg, Sweden) onto the right-side implants. All scan bodies were directly connected to the implant analogs. All scan bodies were tightened to 15 Ncm using a calibrated torque wrench. A high-resolution desktop scanner E3 (3Shape, Copenhagen, Denmark) with a manufacturer-declared accuracy of 7 µm was used to scan the prepared model, generating the digital reference model in standard tessellation language (STL) format (Fig. 1B).

Digital impression acquisition

All intraoral scanning was performed by a single operator with over five years of experience. Scans were obtained in a light-sealed optical darkroom to minimize external light interference. Standardized ambient lighting (1000 lx, 5400 K color temperature) was provided by a specialized

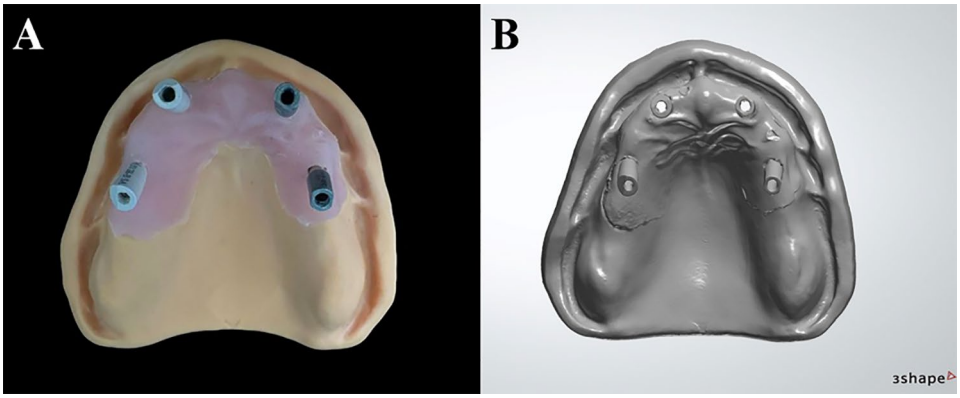

Fig. 1 Reference models with scan bodies, (**A**) physical reference model with four implants: titanium scan bodies (left, 0° and 30°) and PEEK scan bodies (right, 0° and 30°). silicone artificial gingiva simulates clinical conditions, (**B**) digital reference model generated using a high-resolution desktop scanner E3 (3Shape, Copenhagen, Denmark)

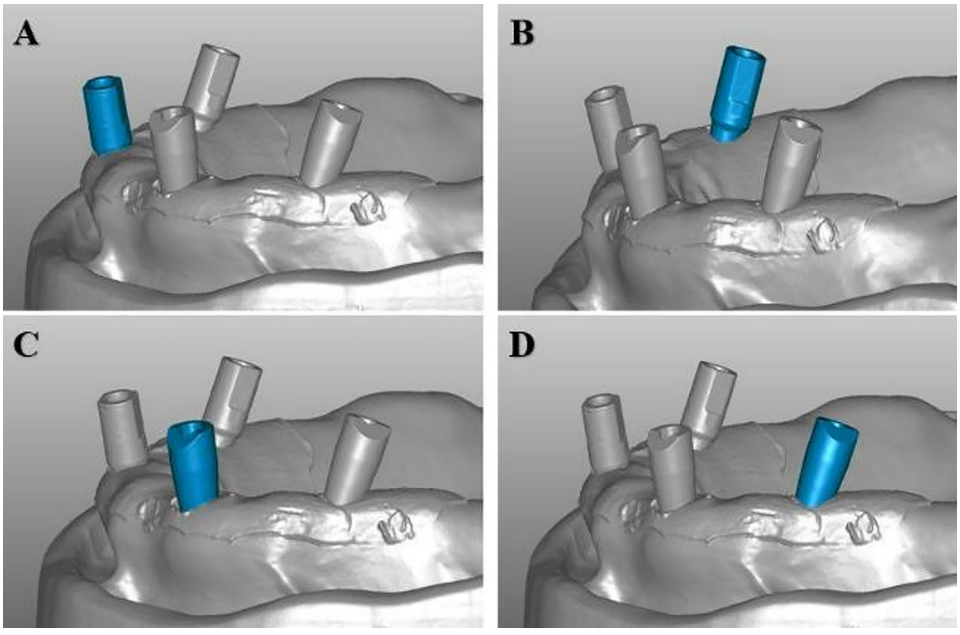

Fig. 2 Segmentation of scan bodies on the reference model, (**A**) titanium scan body at 0° angulation, (**B**) titanium scan body at 30° angulation, (**C**) PEEK scan body at 0° angulation, (**D**) PEEK scan body at 30° angulation

LED source connected to the scanner head, verified using a spectrophotometer CL-200 A (Konica Minolta, Tokyo, Japan). All scanners were calibrated according to manufacturer recommendations before use.

A standardized zigzag scanning pattern was employed, starting from the left posterior implant and moving across to the contralateral side with continuous buccal-to-lingual motions. To minimize operator fatigue, five-minute rest periods were implemented after every fifteen minutes of scanning. Ten digital impressions ($n = 10$) were captured for each combination of scanner and scan body. This resulted in a total of 160 scan body datasets. Each scan took approximately 3 to 4 min to complete. The operator performed 3 to 4 scans per 15-minute interval, followed by a standardized 5-minute rest period to minimize fatigue. All scans obtained from the four IOSs ($n = 40$) were completed on the same day to reduce the risk of time-dependent dimensional changes in the 3D-printed model.

Data Preparation and accuracy evaluation

All acquired STL files were imported into Geomagic Studio 2014® software (Geomagic, Morrisville, NC, USA). Individual scan bodies were digitally segmented based on material and angulation (Fig. 2). To ensure blinding of the accuracy assessor, original file names were replaced with unique, randomly generated alphanumeric codes, concealing the scanner, material, and angulation information.

Trueness evaluation: trueness (accuracy) was assessed using Geomagic Control X software (3D Systems, Rock

Hill, SC, USA). Each segmented intraoral scan ($n = 10$ per group) was aligned to the corresponding segmented reference scan using a best-fit alignment based on the iterative closest point (ICP) algorithm (Fig. 3). The three-dimensional deviation was calculated, and the root mean square (RMS) error was recorded as the trueness metric.

Precision evaluation: precision (repeatability) was assessed by comparing scans within each group. Forty-five pairwise comparisons ($n = 45$) were performed among the ten scans within each group using a best-fit alignment (Fig. 4). The RMS error quantifying the three-dimensional deviations between the paired scans was recorded as the precision metric.

Statistical analysis

Statistical analysis was conducted using JASP (Version 0.19.3; JASP Team, University of Amsterdam, Amsterdam, The Netherlands) for macOS, Data normality was assessed using Shapiro-Wilk and Kolmogorov-Smirnov tests. Homogeneity of variance was checked using Levene's test. As Levene's test indicated violation of homogeneity of variance for most data, non-parametric statistical tests were employed.

The Friedman test for related samples was used to evaluate the overall effect of the scan body configuration (material and angulation) on trueness and precision. Post hoc pairwise comparisons were conducted using Conover's method with Bonferroni correction.

The Kruskal-Wallis test was used to analyze the effect of different intraoral scanner types on trueness and precision within each specific scan body configuration. Post hoc pairwise comparisons were performed using Dunn's method with Bonferroni correction. The level of significance for all statistical analyses was set at $\alpha = 0.05$.

Results

This study evaluated the trueness (accuracy) and precision (repeatability) of digital impressions obtained using four IOSs (Aoralscan 3, Fussen S6000, Primescan, Trios 3) with two ISB materials (Titanium, PEEK) at two angulations (0°, 30°).

Trueness analysis

Descriptive analysis, illustrated in (Table 1) and (Fig. 5), suggests variations in trueness across different IOSs and scan body configurations. Notably, the Primescan and Trios 3 generally exhibited lower deviation values,

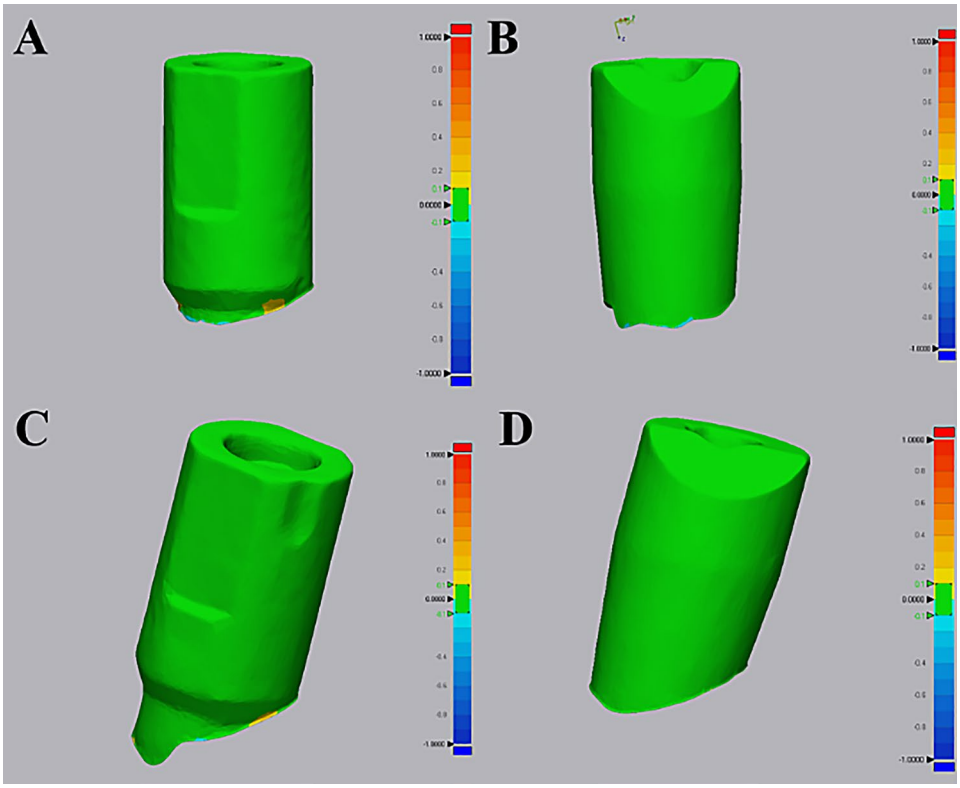

Fig. 3 Three-dimensional (3D) deviation analysis of trueness, (**A**) titanium scan body at 0° angulation, (**B**) PEEK scan body at 0° angulation, (**C**) titanium scan body at 30° angulation, (**D**) PEEK scan body at 30° angulation. The colorimetric maps illustrate the 3D deviation between the digital impressions obtained using intraoral scanners and the reference model. the color scale represents the magnitude of deviation, with red indicating higher positive deviations and blue indicating higher negative deviations

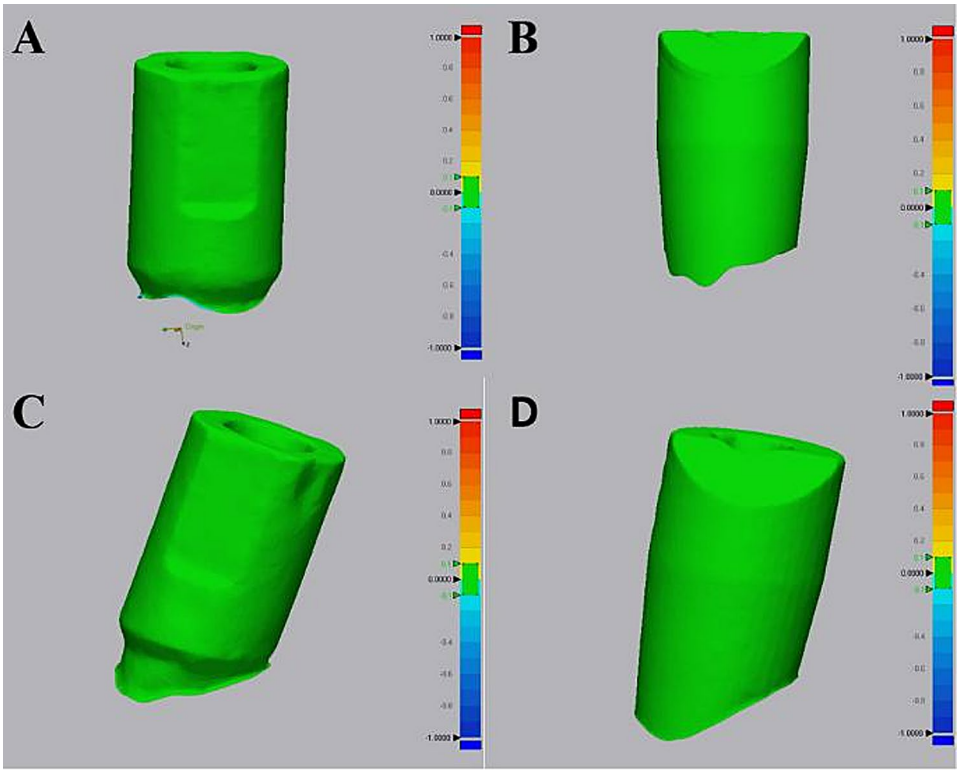

Fig. 4 Colorimetric maps of precision analysis for digital Impressions (**A**) titanium scan body at 0° angulation, (**B**) PEEK scan body at 0° angulation, (**C**) titanium scan body at 30° angulation, (**D**) PEEK scan body at 30° angulation

Table 1 Descriptive statistics for trueness values (accuracy) across the four IOSs and four scan body configurations

		n	Mean	SD	Minimum	Maximum
Ti 0	Aoralscan 3	10	0.076	0.007	0.066	0.088
	Fussen S6000	10	0.083	0.009	0.072	0.099
	Primescan	10	0.043	0.008	0.033	0.061
	Trios 3	10	0.041	0.005	0.037	0.050
Ti 30	Aoralscan 3	10	0.086	0.006	0.078	0.096
	Fussen S6000	10	0.092	0.011	0.078	0.112
	Primescan	10	0.037	0.003	0.033	0.042
	Trios 3	10	0.042	0.008	0.032	0.054
PEEK 0	Aoralscan 3	10	0.052	0.006	0.045	0.061
	Fussen S6000	10	0.054	0.005	0.044	0.061
	Primescan	10	0.030	0.007	0.020	0.040
	Trios 3	10	0.036	0.007	0.029	0.052
PEEK 30	Aoralscan 3	10	0.060	0.004	0.053	0.064
	Fussen S6000	10	0.048	0.014	0.034	0.073
	Primescan	10	0.019	0.007	0.013	0.036
	Trios 3	10	0.026	0.002	0.022	0.029

SD: standard deviation

indicating higher trueness, compared to the Aoralscan 3 and Fussen S6000 across most tested conditions.

Effect of scan body configuration

The scan body configuration (material and angulation combined: Ti 0, Ti 30, PEEK 0, PEEK 30) significantly impacted trueness, as revealed by the Friedman test ($\chi^2F(3) = 80.441$, $P < 0.001$), with a large effect size (Kendall's $W = 0.670$). Post hoc comparisons, demonstrated that PEEK scan bodies (PEEK 0 and PEEK 30) provided significantly higher trueness compared to Titanium scan bodies (Ti 0 and Ti 30) in all comparisons. The PEEK 30 configuration achieved the highest overall trueness, followed sequentially by PEEK 0, Ti 30, and Ti 0. While the

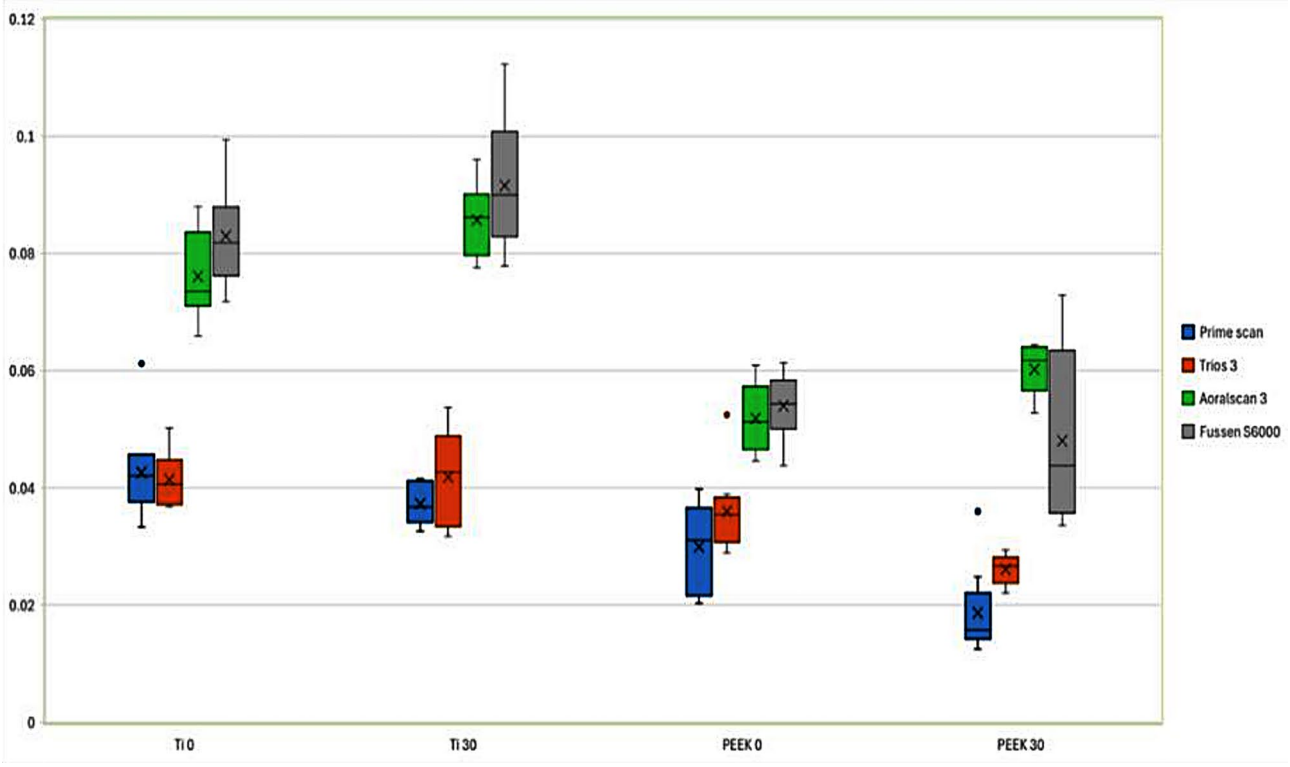

Fig. 5 Box-and-whisker plots for the descriptive analysis of trueness (root mean square RMS) across different intraoral scanners and scan body configurations. data provided in millimeter (mm), Ti (titanium), PEEK (Polyetheretherketone)

Table 3 Comparison of trueness across scan body configurations. *P* and effect sizes (rrb) from pairwise comparisons using conover's method with bonferroni correction

		T-Stat	df	rrb	*p*	^{P}bonf
Ti 0	Ti 30	1.943	117	−0.343	0.054	0.326
	PEEK 0	7.550	117	0.941	< 0.001	< 0.001
	PEEK 30	11.437	117	1.000	< 0.001	< 0.001
Ti 30	PEEK 0	9.493	117	0.917	< 0.001	< 0.001
	PEEK 30	13.380	117	1.000	< 0.001	< 0.001
PEEK 0	PEEK 30	3.887	117	0.410	< 0.001	0.001

df: degree of freedom, rrb: rank-biserial correlation coefficient, ^{P}bonf**: *P* after Bonferroni correction, ($P < 0.05$)

difference between PEEK 0 and PEEK 30 was statistically significant, the difference in trueness between the two Titanium configurations (Ti 0 vs. Ti 30) did not reach statistical significance after Bonferroni correction (Table 3).

Effect of IOSs

The influence of the specific IOS on trueness was statistically significant within each scan body configuration, as determined by Kruskal-Wallis tests.

For the Titanium scan body at 0° (Ti 0), IOS type had a significant effect ($H(3) = 30.398$, $P < 0.001$, Rank $\eta^2 = 0.761$). Pairwise comparisons showed that Primescan and Trios 3 demonstrated significantly higher trueness than both Aoralscan 3 and Fussen S6000. No significant difference in trueness was observed between Primescan and Trios 3 under this condition (Table 2). Similarly, with the Titanium scan body at 30° (Ti 30), IOS type significantly affected trueness ($H(3) = 29.972$, $P < 0.001$, Rank $\eta^2 = 0.749$). Primescan and Trios 3 again exhibited significantly higher trueness compared to Aoralscan 3 and Fussen S6000. No significant differences were found between Primescan and Trios 3 or the lower-performing pair (Aoralscan 3 vs. Fussen S6000) (Table 4).

When using the PEEK scan body at 0° (PEEK 0), IOS type remained a significant factor ($H(3) = 27.880$, $P < 0.001$, Rank $\eta^2 = 0.691$). Primescan achieved the highest trueness, significantly outperforming Aoralscan 3 and Fussen S6000. Trios 3 also showed significantly better trueness than Aoralscan 3 and Fussen S6000. Comparisons between Primescan and Trios 3, and between Aoralscan 3 and Fussen S6000, revealed no significant differences. Finally, for the PEEK scan body at 30°

Table 2 Descriptive statistics for precision values (repeatability) across the four IOSs and four scan body configurations

		n	Mean	SD	Minimum	Maximum
Ti 0	Aoralscan 3	45	0.064	0.011	0.041	0.087
	Fussen S6000	45	0.037	0.008	0.024	0.057
	Primescan	45	0.027	0.008	0.019	0.053
	Trios 3	45	0.038	0.012	0.023	0.079
Ti 30	Aoralscan 3	45	0.048	0.008	0.036	0.079
	Fussen S6000	45	0.035	0.006	0.025	0.052
	Primescan	45	0.024	0.005	0.015	0.035
	Trios 3	45	0.036	0.006	0.025	0.045
PEEK 0	Aoralscan 3	45	0.026	0.006	0.016	0.039
	Fussen S6000	45	0.019	0.005	0.013	0.031
	Primescan	45	0.021	0.006	0.002	0.035
	Trios 3	45	0.036	0.011	0.020	0.065
PEEK 30	Aoralscan 3	45	0.045	0.014	0.025	0.079
	Fussen S6000	45	0.042	0.016	0.022	0.073
	Primescan	45	0.026	0.010	0.007	0.048
	Trios 3	45	0.027	0.005	0.018	0.038

SD: standard deviation

Table 4 Effect of IOS type on trueness for titanium scan bodies at 0° and 30° angulation. Pairwise comparisons using dunn's method with bonferroni correction

	Ti 0				Ti 30			
Comparison	**z**	**rrb**	***p***	**^{P}bonf**	**z**	**rrb**	***p***	**^{P}bonf**
Aoralscan 3 - Fussen S6000	−1.052	0.550	0.293	1.000	−0.612	0.320	0.540	1.000
Aoralscan 3 - Primescan	3.252	1.000	0.001	0.007	3.806	1.000	< 0.001	< 0.001
Aoralscan 3 - Trios 3	3.348	1.000	< 0.001	0.005	3.233	1.000	0.001	0.007
Fussen S6000 - Primescan	4.305	1.000	< 0.001	< 0.001	4.418	1.000	< 0.001	< 0.001
Fussen S6000 - Trios 3	4.400	1.000	< 0.001	< 0.001	3.845	1.000	< 0.001	< 0.001
Primescan - Trios 3	0.096	0.050	0.924	1.000	−0.574	0.300	0.566	1.000

rrb: rank-biserial correlation coefficient, ^{P}bonf**: *P* after Bonferroni correction, ($P < 0.05$)

Table 5 Effect of IOS type on trueness for PEEK scan bodies at 0° and 30° angulation. Pairwise comparisons using dunn's method with bonferroni correction

	PEEK 0				PEEK 30			
Comparison	**z**	**rrb**	***p***	**^{P}bonf**	**z**	**rrb**	***p***	**^{P}bonf**
Aoralscan 3 - Fussen S6000	−0.555	0.260	0.579	1.000	1.014	0.500	0.311	1.000
Aoralscan 3 - Primescan	3.845	1.000	< 0.001	< 0.001	4.954	1.000	< 0.001	< 0.001
Aoralscan 3 - Trios 3	2.907	0.880	0.004	0.022	3.596	1.000	< 0.001	0.002
Fussen S6000 - Primescan	4.399	1.000	< 0.001	< 0.001	3.941	0.940	< 0.001	< 0.001
Fussen S6000 - Trios 3	3.462	0.940	< 0.001	0.003	2.582	1.000	0.010	0.059
Primescan – Trios 3	−0.937	0.400	0.349	1.000	−1.358	0.740	0.174	1.000

rrb: rank-biserial correlation coefficient, ^{P}bonf**: *P* after Bonferroni correction, ($P < 0.05$)

(PEEK 30), IOS type significantly influenced trueness ($H(3) = 31.275$, $P < 0.001$, Rank $\eta^2 = 0.785$). Both Primescan and Trios 3 demonstrated significantly higher trueness compared to Aoralscan 3 and Fussen S6000. Primescan slightly outperformed Fussen S6000 with greater significance than Trios 3 did. Again, no significant differences were observed between Primescan and Trios 3 or between Aoralscan 3 and Fussen S6000. (Table 5)

Precision analysis

Analysis of precision (repeatability), summarized descriptively in (Table 2) and (Fig. 6) indicated variations depending on the IOSs and configuration. Primescan generally showed high precision across conditions, although Trios 3 demonstrated comparable repeatability for the PEEK 30 configuration.

Effect of scan body configuration

Scan body configuration exerted a statistically significant effect on precision (Friedman test: $\chi^2F(3) = 116.895$,

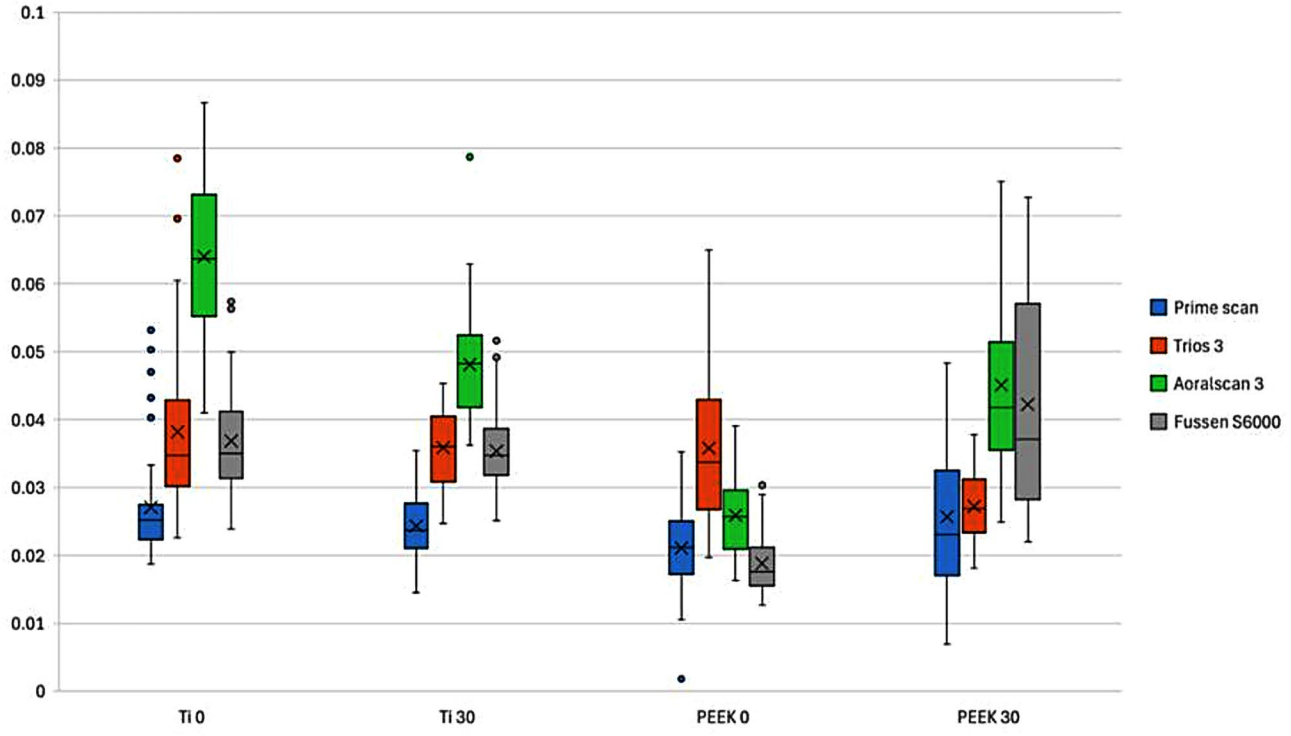

Fig. 6 Box-and-whisker plots for the descriptive analysis of precision (RMS) across different intraoral scanners and scan body configurations. data provided in millimeter (mm), Ti (titanium), PEEK (Polyetheretherketone)

Table 6 Comparison of precision across scan body configurations. *P* and effect sizes (rrb) from pairwise comparisons using conover's method with bonferroni correction

		T-Stat	df	rrb	*p*	^{P}bonf
Ti 0	Ti 30	2.830	537	0.433	0.005	0.029
	PEEK 0	11.643	537	0.772	< 0.001	< 0.001
	PEEK 30	5.591	537	0.406	< 0.001	< 0.001
Ti 30	PEEK 0	8.812	537	0.770	< 0.001	< 0.001
	PEEK 30	2.761	537	0.173	0.006	0.036
PEEK 0	PEEK 30	6.051	537	−0.523	< 0.001	< 0.001

df: degree of freedom, rrb: rank-biserial correlation coefficient, ^{P}bonf**: *P* after Bonferroni correction, ($P < 0.05$)

$P < 0.001$), with a small to medium effect size (Kendall's W = 0.216). Post hoc analysis indicated that PEEK scan bodies generally yielded significantly higher precision than Titanium scan bodies. The highest precision was achieved with the PEEK 0 configuration, followed by PEEK 30, Ti 30, and Ti 0. Significant differences in precision were observed between the two PEEK configurations and between the two Titanium configurations (Table 6).

Effect of IOSs

IOS type significantly influenced precision within each scan body configuration, confirmed by Kruskal-Wallis tests, For Ti 0, IOS type was significant ($H(3) = 114.740$, $P < 0.001$, Rank $\eta^2 = 0.635$). Primescan exhibited significantly higher precision than all other IOS. Trios 3 was also significantly more precise than Aoralscan 3. No significant difference was found between Fussen S6000 and Trios 3. With Ti 30, IOS type significantly affected precision ($H(3) = 121.917$, $P < 0.001$, Rank $\eta^2 = 0.676$). Primescan again showed the highest precision, significantly better than the other IOSs. Trios 3 and Fussen S6000 demonstrated significantly higher precision than Aoralscan 3, with no significant difference found between Fussen S6000 and Trios 3 (Table 7).

Using PEEK 0, IOS type remained a significant factor ($H(3) = 81.022$, $P < 0.001$, Rank $\eta^2 = 0.443$). The Fussen S6000 and Primescan both exhibited considerably greater precision than the Trios 3 and Aoralscan 3. Even though the Fussen S6000 displayed marginally better precision than the Primescan, their difference was not statistically significant. Lastly, for PEEK 30, IOS type significantly influenced precision ($H(3) = 68.841$, $P < 0.001$, Rank $\eta^2 =$

Table 7 Effect of IOS type on precision for titanium scan bodies at 0° and 30° angulation. Pairwise comparisons using dunn's method with bonferroni correction

	PEEK 0				PEEK 30			
Comparison	**z**	**rrb**	***p***	**^{P}bonf**	**z**	**rrb**	***p***	**^{P}bonf**
Aoralscan 3 - Fussen S6000	4.982	0.705	< 0.001	< 0.001	1.430	0.158	0.153	0.916
Aoralscan 3 - Primescan	3.029	0.410	0.002	0.015	6.794	0.749	< 0.001	< 0.001
Aoralscan 3 - Trios 3	−3.430	0.557	< 0.001	0.004	6.159	0.849	< 0.001	< 0.001
Fussen S6000 - Primescan	−1.953	0.268	0.051	0.305	5.364	0.607	< 0.001	< 0.001
Fussen S6000 - Trios 3	−8.412	0.900	< 0.001	< 0.001	4.729	0.607	< 0.001	< 0.001
Primescan - Trios 3	−6.459	0.777	< 0.001	< 0.001	−0.635	0.205	0.525	1.000

rrb: rank-biserial correlation coefficient, ^{P}bonf**: *P* after Bonferroni correction, ($P < 0.05$)

Table 8 Effect of IOS type on precision for PEEK scan bodies at 0° and 30° angulation. Pairwise comparisons using dunn's method with bonferroni correction

	Ti 0				Ti 30			
Comparison	**z**	**rrb**	***p***	**^{P}bonf**	**z**	**rrb**	***p***	**^{P}bonf**
Aoralscan 3 - Fussen S6000	6.271	0.950	< 0.001	< 0.001	5.606	0.840	< 0.001	< 0.001
Aoralscan 3 - Primescan	10.641	0.982	< 0.001	< 0.001	11.030	1.000	< 0.001	< 0.001
Aoralscan 3 - Trios 3	6.085	0.875	< 0.001	< 0.001	5.132	0.817	< 0.001	< 0.001
Fussen S6000 - Primescan	4.370	0.716	< 0.001	< 0.001	5.424	0.858	< 0.001	< 0.001
Fussen S6000 - Trios 3	−0.186	0.021	0.852	1.000	−0.473	0.098	0.636	1.000
Primescan - Trios 3	−4.556	0.690	< 0.001	< 0.001	−5.897	0.870	< 0.001	< 0.001

rrb: rank-biserial correlation coefficient, ^{P}bonf**: *P* after Bonferroni correction, ($P < 0.05$)

0.374). Both Trios 3 and Primescan achieved significantly higher precision compared to Aoralscan 3 and Fussen S6000. No significant differences in precision were found between Trios 3 and Primescan, nor between Aoralscan 3 and Fussen S6000 under this condition (Table 8).

Discussion

The accuracy of digital implant impressions is fundamental for fabricating well-fitting, passive full-arch restorations, which directly impacts clinical success and longevity. Factors such as the material properties of ISBs and the angulation of implants relative to the IOS can significantly influence the quality of the acquired data. Therefore, understanding how ISB material (PEEK vs. Titanium) and implant angulation (parallel vs. angled) interact to influence digital impression accuracy is essential for optimizing clinical workflows and patient outcomes. The present study aimed to assess the effect of these two factors (material: PEEK/Titanium; angulation: 0°/30°) on the trueness and precision of digital impressions obtained from four different IOSs, representing both established high-end systems and more affordable market entrants.

The findings revealed that scan body material, angulation (as part of the overall scan body configuration), and the IOS employed all significantly impacted the accuracy outcomes.

Overall, the mean trueness deviations observed across all conditions and IOSs ranged from 0.019 mm to 0.092 mm, while mean precision deviations ranged from 0.019 mm to 0.064 mm. While many mean values fall within ranges considered potentially acceptable for clinical applications [25–28], and consistent with the results of prior studies [29–31].

Confirming findings from previous studies [11, 32–34], scan body material emerged as a critical factor influencing both trueness and precision. Results from the present study demonstrated that PEEK scan bodies generally yielded significantly higher accuracy (lower deviation values) compared to Titanium scan bodies across the tested configurations and IOSs (Trueness: $P < 0.001$, Precision: $P \leq 0.036$). This outcome may be attributed to the favorable optical properties of PEEK material, including its matte, non-reflective surface, which reduces light scattering and enhances scanner detection. Additionally, the surface finish of PEEK may offer better compatibility with intraoral scanner optics, contributing to improved capture accuracy. This aligns with a study conducted by Arcuri et al. [10] and Karthhik et al. [12], who also reported superior performance for PEEK. Notably, the PEEK 30 configuration demonstrated the lowest mean deviations values regarding the trueness overall, while the PEEK 0 configuration showed the lowest deviation mean values regarding the precision. However, the results of the present study were in contrast with Lee et al. [13], who found Titanium superior in trueness. This divergence may be attributed to differences in the specific scan body designs employed across studies, as geometric features can interact with scanner optics in variable ways, potentially influencing the scanning outcome more significantly than material properties alone. In particular, when comparing products from different manufacturers,

such design-related variations can introduce substantial inconsistencies. Additionally, discrepancies between studies may arise from differences in scanner type, software algorithms, and scanning protocols, all of which can affect the accuracy of digital impressions. The overall scan body configuration (Including both material and angulation) significantly affected trueness and precision ($P<0.001$). The influence of angulation, however, appeared complex and interacted with the material type. For trueness, the 30° angulation significantly improved results for PEEK (PEEK 30 better than PEEK 0, $P=0.001$), but had no significant effect for Titanium (Ti 30 vs. Ti 0, $p=0.326$). Conversely, for precision, the 30° angulation significantly improved results for Titanium (Ti 30 better than Ti 0, $P=0.029$), but significantly worsened results for PEEK (PEEK 0 better than PEEK 30, $P<0.001$). This interaction indicates that stating whether angulation improves or hinders accuracy is insufficient, the effect also depends on the scan body material used and whether trueness or precision is the primary measure. This finding contrasts with studies suggesting a more direct relationship where accuracy either improves [13, 16, 17] or diminishes [18, 35] with angulation, highlighting the importance of considering material interactions.

This study also revealed that IOS selection substantially influenced both trueness and precision across all scan body configurations ($P<0.001$). This highlights that IOS performance varies considerably depending on scan body material and angulation rather than being consistent across conditions.

Generally, Primescan and Trios 3 demonstrated significantly higher trueness (lower mean deviations) compared to the affordable IOSs (Aoralscan 3 and Fussen S6000) across most configurations (e.g., $P\leq0.007$ for Ti 0, $P\leq0.007$ for Ti 30, $P<0.001$ for PEEK 0, $P\leq0.002$ for PEEK 30). This suggests that for achieving the highest level of trueness, crucial for the passive fit of full-arch implant prosthetics, the established high-end systems still hold an advantage under the conditions tested.

Precision results showed more variability. While Primescan often demonstrated high precision, Fussen S6000 (an affordable IOS) achieved the lowest mean precision deviation in the PEEK 0 configuration (mean 0.019 mm), outperforming Trios 3 in that specific scenario. However, Aoralscan 3 consistently showed higher mean deviation values for both trueness and precision compared to the other scanners across many configurations. This indicates that while some affordable IOSs may achieve competitive precision in certain situations, the high-end IOSs provided more consistently superior trueness.

The observed performance gap, especially in trueness, between the high-end and affordable IOSs tested warrants consideration. While the availability of cost-effective intraoral scanning (IOS) technology has increased access to digital workflows, clinicians performing complex procedures that require high accuracy, such as full-arch implant restorations, must be aware of potential variations in IOS performance. Careful IOS selection and validation for specific clinical applications remain essential, as reliance solely on lower-cost systems may introduce risks if their accuracy limits under challenging conditions are not fully understood.

Limitations

This study's in vitro nature precludes the influence of clinical variables such as saliva, limited intraoral space, patient movement, humidity, all of which can negatively affect scanning accuracy. Moreover, the potential influence of scan body geometry on the accuracy of digital impressions was not evaluated, which may limit the generalizability of the results. Additionally, the findings are specific to the four IOS models and scan body types tested and may not be universally applicable to all systems available on the market.

Conclusions

Within the limitations of this study, it may be concluded that the scan body material, angulation, and IOS selection significantly influenced trueness and precision of full-arch digital implant impressions. While PEEK scan bodies generally demonstrated superior overall performance compared to titanium, this advantage varied depending on the specific intraoral scanner and implant angulation. For instance, titanium scan bodies, particularly when used with high-end scanners such as Primescan, exhibited highly stable and competitive accuracy outcomes. Substantial accuracy differences were observed between IOS systems, with the tested high-end systems generally providing higher trueness than the tested affordable systems across the studied configurations. While affordable IOSs show potential regarding precision, clinicians should carefully assess IOs capabilities for complex procedures. Further in vivo research is needed to validate these findings clinically and evaluate additional IOS systems and scan body designs.

Abbreviations

IOS	Intraoral Scanner
ISB	Implant Scan Body
Ti	Titanium
PEEK	Polyetheretherketone
RMS	Root Mean Square
STL	Standard Tessellation Language
ICP	Iterative Closest Point

Acknowledgements

Not applicable.

Author contributions

H.S. Conceptualization, Visualization, validation, Methodology, Investigation, Formal analysis, Data curation, original draft preparation; X.X.M. and M.Q.S. Conceptualization, manuscript review and editing; A.S.R. statistical analysis,

original draft preparation; S.H.A. manuscript review and editing; W.B.X. Conceptualization, Supervision, manuscript review and editing. All authors reviewed and approved the final manuscript.

Funding
The work was supported by the Natural Science Foundation of Gansu (No 25JRRA580) and the Cuiying Scientific and Technological Innovation Program of Lanzhou University Second Hospital (CY2023-MS-A11).

Data availability
The.STL files and the 3D surface models obtained in this study with the different four IOS as well as the reference files obtained with the desktop scanner belong to the authors, and are therefore available only upon reasonable request, after approval by all the authors.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]School of Stomatology, Department of Prosthodontics, Lanzhou University, Lanzhou 730000, China
[2]The Second Hospital and Clinical Medical School, Lanzhou University, Lanzhou, China
[3]Department of Prosthodontics, Faculty of Dentistry, MSA University, Giza 6th October, Egypt
[4]Department of Prosthodontics & Research Center of Dental Esthetics and Biomechanics, Fujian Medical University, Fuzhou, China
[5]Department of Oral Implantology, School/Hospital of Stomatology, Fujian Medical University, Fuzhou, Fujian, China

Received: 15 April 2025 / Accepted: 26 June 2025
Published online: 31 July 2025

References

1. Mangano F, Gandolfi A, Luongo G, Logozzo S. Intraoral scanners in dentistry: a review of the current literature. BMC Oral Health. 2017;17:1–11.
2. Rutkūnas V, Gečiauskaitė A, Jegelevičius D, Vaitiekūnas M. Accuracy of digital implant impressions with intraoral scanners. A systematic review. Eur J Oral Implantol. 2017;10(Suppl 1):101–20.
3. Siqueira R, Galli M, Chen Z, Mendonça G, Meirelles L, Wang H-L et al. Intraoral scanning reduces procedure time and improves patient comfort in fixed prosthodontics and implant dentistry: a systematic review. Clin Oral Investig. 2021;1–15.
4. Lee SJ, Gallucci GO. Digital vs. conventional implant impressions: efficiency outcomes. Clin Oral Implants Res. 2013;24:111–5.
5. Vecsei B, Czigola A, Róth I, Hermann P, Borbély J. Digital impression systems, CAD/CAM, and STL file. Guided Endodontics. 2021;27–63.
6. Waldecker M, Bömicke W, Behnisch R, Rammelsberg P, Rues S. In-vitro accuracy of complete arch scans of the fully dentate and the partially edentulous maxilla. J Prosthodont Res. 2022;66:538–45.
7. Passos L, Meiga S, Brigagão V, Neumann M, Street A. Digital impressions' accuracy through cut-out-rescan and data exchange by over scanning techniques in complete arches of two intraoral scanners and CAD/CAM software. J Prosthodont Res. 2022;66:509–13.
8. Pan Y, Tsoi JKH, Lam WYH, Chen Z, Pow EHN. Does the geometry of scan bodies affect the alignment accuracy of computer-aided design in implant digital workflow: an in vitro study? Clin Oral Implants Res. 2022;33:313–21.
9. Kim J-H, Son S-A, Lee H, Kim RJ-Y, Park J-K. In vitro analysis of intraoral digital impression of inlay Preparation according to tooth location and cavity type. J Prosthodont Res. 2021;65:400–6.
10. Arcuri L, Pozzi A, Lio F, Rompen E, Zechner W, Nardi A. Influence of implant scanbody material, position and operator on the accuracy of digital impression for complete-arch: A randomized in vitro trial. J Prosthodont Res. 2020;64:128–36.
11. Pachiou A, Zervou E, Tsirogiannis P, Sykaras N, Tortopidis D, Kourtis S. Characteristics of intraoral scan bodies and their influence on impression accuracy: A systematic review. J Esthetic Restor Dentistry. 2023;35:1205–17.
12. Karthhik R, Raj B, Karthikeyan BV. Role of scan body material and shape on the accuracy of complete arch implant digitalization. J Oral Res Rev. 2022;14:114–20.
13. Lee J-H, Bae J-H, Lee SY. Trueness of digital implant impressions based on implant angulation and scan body materials. Sci Rep. 2021;11:21892.
14. Rutkunas V, Sveikata K, Savickas R. Effects of implant angulation, material selection, and impression technique on impression accuracy: a preliminary laboratory study. Int J Prosthodont. 2012;25.
15. Jang H-K, Kim S, Shim J-S, Lee K-W, Moon H-S. Accuracy of impressions for internal-connection implant prostheses with various divergent angles. Int J Oral Maxillofacial Implants. 2011;26.
16. Zhang Y-J, Qiao S-C, Qian S-J, Zhang C-N, Shi J-Y, Lai H-C. Influence of different factors on the accuracy of digital impressions of multiple implants: an in vitro study. Int J Oral Maxillofacial Implants. 2021;36.
17. Lin W-S, Harris BT, Elathamna EN, Abdel-Azim T, Morton D. Effect of implant divergence on the accuracy of definitive casts created from traditional and digital implant-level impressions: an in vitro comparative study. Int J Oral Maxillofacial Implants. 2015;30.
18. Gintaute A, Papatriantafyllou N, Aljehani M, Att W. Accuracy of computerized and conventional impression-making procedures for multiple straight and Tilted dental implants. Int J Esthetic Dentistry. 2018;13.
19. Giménez B, Özcan M, Martínez-Rus F, Pradíes G. Accuracy of a digital impression system based on active wavefront sampling technology for implants considering operator experience, implant angulation, and depth. Clin Implant Dent Relat Res. 2015;17:e54–64.
20. Giménez B, Özcan M, Martínez-Rus F, Pradíes G. Accuracy of a digital impression system based on parallel confocal laser technology for implants with consideration of operator experience and implant angulation and depth. Int J Oral Maxillofacial Implants. 2014;29.
21. Alikhasi M, Siadat H, Nasirpour A, Hasanzade M. Three-dimensional accuracy of digital impression versus conventional method: effect of implant angulation and connection type. Int J Dent. 2018;2018:3761750.
22. Basaki K, Alkumru H, De Souza G, Finer Y. Accuracy of digital vs conventional implant impression approach: A Three-Dimensional comparative in vitro analysis. Int J Oral Maxillofacial Implants. 2017;32.
23. Giménez B, Pradíes G, Martínez-Rus F, Özcan M. Accuracy of two digital implant impression systems based on confocal microscopy with variations in customized software and clinical parameters. Int J Oral Maxillofacial Implants. 2015;30.
24. Papaspyridakos P, Gallucci GO, Chen C, Hanssen S, Naert I, Vandenberghe B. Digital versus conventional implant impressions for edentulous patients: accuracy outcomes. Clin Oral Implants Res. 2016;27:465–72.
25. Andriessen FS, Rijkens DR, Van Der Meer WJ, Wismeijer DW. Applicability and accuracy of an intraoral scanner for scanning multiple implants in edentulous mandibles: a pilot study. J Prosthet Dent. 2014;111:186–94.
26. Fukazawa S, Odaira C, Kondo H. Investigation of accuracy and reproducibility of abutment position by intraoral scanners. J Prosthodont Res. 2017;61:450–9.
27. Malik J, Rodriguez J, Weisbloom M, Petridis H. Comparison of accuracy between a conventional and two digital intraoral impression techniques. Int J Prosthodont. 2018;31:107–13.
28. Ender A, Mehl A. In-vitro evaluation of the accuracy of conventional and digital methods of obtaining full-arch dental impressions. Quintessence Int (Berl). 2015;46.
29. Mangano FG, Veronesi G, Hauschild U, Mijiritsky E, Mangano C. Trueness and precision of four intraoral scanners in oral implantology: a comparative in vitro study. PLoS ONE. 2016;11:e0163107.
30. Vandeweghe S, Vervack V, Dierens M, De Bruyn H. Accuracy of digital impressions of multiple dental implants: an in vitro study. Clin Oral Implants Res. 2017;28:648–53.
31. Flügge TV, Schlager S, Nelson K, Nahles S, Metzger MC. Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model scanner. Am J Orthod Dentofac Orthop. 2013;144:471–8.
32. Gracis S, Appiani A, Noè G. Digital workflow in implant prosthodontics: the critical aspects for reliable accuracy. J Esthetic Restor Dentistry. 2023;35:250–61.

33. Mizumoto RM, Yilmaz B. Intraoral scan bodies in implant dentistry: A systematic review. J Prosthet Dent. 2018;120:343–52.
34. Zhang Y-J, Shi J-Y, Qian S-J, Qiao S-C, Lai H-C. Accuracy of full-arch digital implant impressions taken using intraoral scanners and related variables: A systematic review. Int J Oral Implantol (Berl). 2021;14:157–79.
35. Önöral Ö, Kurtulmus-Yilmaz S, Toksoy D, Ozan O. Effect of angulation on the 3D trueness of conventional and digital implant impressions for multi-unit restorations. J Adv Prosthodont. 2023;15:290.

Publisher's note