



ORIGINAL RESEARCH

A COMPARISON OF FULL ARCH TRUENESS AND PRECISION OF THREE INTRA-ORAL DIGITAL SCANNERS

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ABSTRACT

Background and objectives: Precise full-arch digital impressions serve as a cornerstone in achieving predictable outcomes in fixed prosthodontics and implant-supported rehabilitation While intraoral scanners continue to advance, their trueness and precision relative to laboratory scanners remain critical for clinical application. This study aimed to quantitatively compare the trueness and precision of three contemporary intra oral scanner TRIOS 5, Medit i900, and Cameo Elegant 3 with laboratory reference scanner.

Materials and Methods: This in vitro study, conducted at Khanzad Teaching Center in Erbil from April to July 2025, assessed the full-arch trueness and precision of three intraoral scanners against a laboratory scanner as the reference. A standardized maxillary resin model with three predefined inter-pin distances was scanned, and deviations were analyzed using 3D metrology software.

Results: Across D1, D2, and D3, all intraoral scanners showed mean deviations within approximately 0.2–0.5% of the laboratory reference values. The laboratory scanner consistently demonstrated the lowest variability (<0.1%), while Cameo Elegant 3 exhibited the highest range of variation (up to ~0.4%). Overall, 3Shape TRIOS 5 and Medit i900 maintained deviations within clinically acceptable limits, though Medit i900 showed slightly lower trueness for certain distances.

Conclusions: The laboratory scanner demonstrated superior trueness and precision. Among IOS devices, TRIOS 5 outperformed Mediti900 and Cameo Elegant 3, confirming the established accuracy hierarchy and emphasizing selection based on clinical application.

Keywords: Digital impression accuracy, Digital dentistry, Full -arch trueness, Intra oral scanner, Laboratory scanner, Scanning precision.

INTRODUCTION

Intraoral scanner (IOS) is increasingly replacing the traditional use of elastomer-based impressions and the later indirect digitalization of those impressions or their corresponding casts. Therefore, it can now be regarded as a standard entry point into dental computer-aided design and computer-aided manufacturing (CAD/CAM) workflows¹. Virtual models serve as the fundamental

framework of the digital workflow, facilitating a comprehensive spectrum of advanced diagnostic and rehabilitative strategies that enhance precision and promote individualized, patient-centered care^{2,3}. Interest in (IOS) has been steadily increasing, with new devices being introduced to the market on a continual basis. A recent review on intraoral digital systems highlighted⁴. (IOS)s provide benefits over traditional impressions, as digital impressions are time-efficient and significantly

more comfortable for patients. Patients experiencing the gag reflex derive special benefit ⁵. The optimal (IOS) must accurately reconstruct and reproduce the surface of the scanned object, demonstrating high fidelity; it should also exhibit high precision, yielding consistent and repeatable results without deviations when scanning the same object ⁶). It appears that different brands of (IOS)s can vary greatly in terms of accuracy ^{8,9}. The metrics of accuracy are "Trueness" and "Precision". ISO (International Organization for Standardization) Standards 5725 and 12836 were utilized to assess the accuracy of digital models ^{10,11}. Trueness refers to the extent to which the arithmetic means of several test results closely align with the true or widely recognized reference value ¹⁰. Precision refers to how closely test results agree with one another ¹¹. There is not enough scientific clarity on the digital procedure for full-arch restorations. On the other hand, a newer study analyzing the most recent software versions and IOS hardware appears to suggest that complete arches should be scanned digitally ¹²⁻¹⁵. Numerous factors influence the precision of digital impressions: (IOS) hardware, software, operator experience, scan body characteristics, and clinical considerations. Laboratory scanners are highly accurate and have been used to construct reference models for comparing (IOS)s in various in vitro experiments ¹⁶. Laboratory scanners have been recognized for their enhanced precision, utilizing lasers or structured light instead of depending exclusively on optical techniques, which frequently possess a limited field of vision, as observed in digital (IOS). Moreover, they experience reduced obstacles, like lens wetness, projections from scanned surfaces, and the motion of the tongue or soft tissues, throughout the scanning procedure. ⁷

The aim of this study was to quantitatively assess and compare the full-arch trueness and precision of three contemporary (IOS)s 3Shape TRIOS 5 (A), Medit i900 (B), and Cameo Elegant 3 (C) by benchmarking their performance against a high accuracy lab scanner (Shining 3D DS-EX).

MATERIALS AND METHODS

This Experimental Research is in vitro study aimed to evaluate and compare the full-arch trueness and precision of three digital (IOS) 3Shape TRIOS 5, Medit i900, and Cameo Elegant 3, using a high-accuracy lab

scanner (Shining 3D DS-EX) as the control. The measurements focus on three inter-pin distances on a standardized maxillary resin model figure (A), analyzed through 3D metrology software figure (B).

This work was submitted to the Kurdistan Higher Council of Medical Specialties for ethical and scientific approval, The study conducted at Erbil-Kurdistan region of Iraq, started from April to July 2025.

A full dentate maxillary resin cast was fabricated to serve as the reference model for this study. The cast was produced using a Heygears Ultra Craft A2D HD 3D printer with Ultra Print Caramel alcohol-washable resin. Following printing, the model was subjected to a standardized post-processing protocol. Residual uncured resin was removed by washing in an Ultra Craft Air Wash unit for 2 minutes, after which final polymerization was completed in the Heygears Ultra Craft Air Cure system under 5 minutes of light curing, in accordance with the manufacturer's recommendations. This workflow ensured the production of a dimensionally stable and accurate master cast for subsequent scanning procedures. The master cast was initially scanned using a laboratory desktop scanner (Shining 3D DS-EX, Hangzhou, China) to obtain a reference dataset, which served as the control for subsequent comparisons. This laboratory scanner provides high-resolution structured light scanning with a reported accuracy of less than 10µm, making it suitable for generating reference standard datasets in trueness and precision studies. Following the control scan, the cast was digitized using three intraoral scanners: TRIOS 5 (3Shape, Copenhagen, Denmark), Medit i900 (Medit Corp., Seoul, South Korea), and Cameo Elegant 3 (Shining 3D, Hangzhou, China). All scans were performed in accordance with the manufacturers' recommended protocols. During scanning, the tip of the intraoral scanner was maintained at a working distance of approximately 1–2 cm from the cast. For each device, the scanning pathway commenced at the occlusal surface of the right maxillary molar, progressed across the occlusal arch to the contralateral molar, and was then extended to include the palatal and buccal surfaces, ensuring complete arch documentation. The mean scanning time varied slightly among devices, ranging from 1.5–2 minutes for Group A, 2–2.5 minutes for Group B, and 2–3 minutes for the Group C. All scanning

procedures were carried out under constant environmental conditions, with room temperature maintained at 23 ± 1 °C, relative humidity at $50 \pm 10\%$, and scanning performed under controlled daylight illumination to minimize the influence of external light variability on data acquisition. This standardized protocol was applied consistently across all acquisitions to reduce operator- and environment-dependent variability¹⁷.

Data were analyzed utilizing the Statistical Package for Social Sciences (SPSS, version 26). A one-way analysis of variance (ANOVA) was employed to compare the means of the four test groups. A post hoc test (LSD) was utilized to ascertain the significance of the differences between each pair of groups, executed subsequent to the ANOVA. A p-value of < 0.05 was deemed statistically significant.



Figure 1 (A): A Standardized Maxillary Resin Model

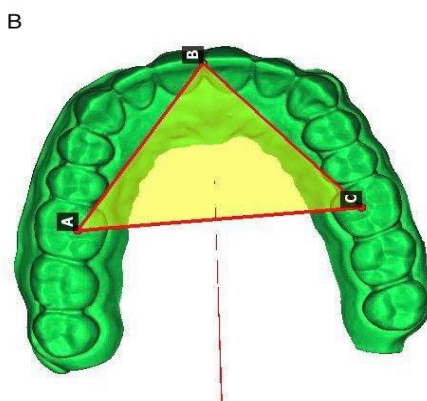


Figure 1 (B): The Scan Method Training Model

RESULTS

Three distances (D1, D2, and D3) were measured in millimeters using a(LS.) and three other scanners (A, B, and C). Each scanner took ten measurements.

The means and standard deviations (SDs) of D1 in millimeters, measured by the Lab., A, B, and C scanners, were as follows: 33.905 (0.020), 33.959 (0.045), 33.752 (0.011), and 33.866 (0.055), respectively. The smallest range of the ten measurements of D1 was 0.069 mm, recorded by the (LS), while the largest range (0.184 mm) was detected with the C scanner.

The means and standard deviations (SDs) of D2 in millimeters, measured by the Lab., A, B, and C scanners, were: 33.966 (0.022), 34.038 (0.038), 33.833 (0.036), and 33.894 (0.042), respectively. The smallest range (0.067 mm) was observed in the (LB) readings, and the largest (0.136 mm) was in the C scanner. Regarding D3, the means (SDs) in

millimeters for the lab and the A, B, and C scanners were: 42.425 (0.025), 42.514 (0.097), 42.286 (0.110), and 42.341 (0.121), respectively. The smallest range of the ten readings for each scanner (0.077 mm) was in the (LS). The largest range (0.421 mm) was in the C scanner readings (Table 1, and Figure 2).

Table 1. Descriptive statistics of the studied distances measured by different scanners.

Distances (mm)	Scanners	Mean	SD	SE	95% Confidence Interval for Mean		Min.	Max.	Range
					Lower	Upper			
D1	Lab.	33.905	0.020	0.006	33.891	33.919	33.878	33.947	0.069
	A	33.959	0.045	0.014	33.927	33.991	33.889	34.013	0.124
	B	33.752	0.034	0.011	33.727	33.777	33.677	33.814	0.137
	C	33.866	0.055	0.018	33.826	33.906	33.767	33.951	0.184
	Total	33.870	0.086	0.014	33.843	33.898	33.677	34.013	0.336
D2	Lab.	33.966	0.022	0.007	33.950	33.982	33.940	34.007	0.067
	A	34.038	0.038	0.012	34.011	34.065	34.002	34.116	0.114
	B	33.833	0.036	0.011	33.807	33.859	33.782	33.895	0.113
	C	33.894	0.042	0.013	33.864	33.923	33.821	33.957	0.136
	Total	33.933	0.085	0.013	33.906	33.960	33.782	34.116	0.334
D3	Lab.	42.425	0.025	0.008	42.407	42.443	42.392	42.469	0.077
	A	42.514	0.087	0.028	42.452	42.576	42.357	42.645	0.288
	B	42.286	0.110	0.035	42.207	42.365	42.106	42.495	0.389
	C	42.341	0.121	0.038	42.254	42.428	42.081	42.502	0.421
	Total	42.391	0.125	0.020	42.351	42.432	42.081	42.645	0.564

In D1, D2, and D3, the highest range (of the ten readings) was in scanner C, and the highest SD was also in scanner C, indicating that it is less reliable (lower consistency), while the lowest range and the lowest SD were in the lab. scanner, indicating high reliability. More details are presented in Table 1 and Figure 2.

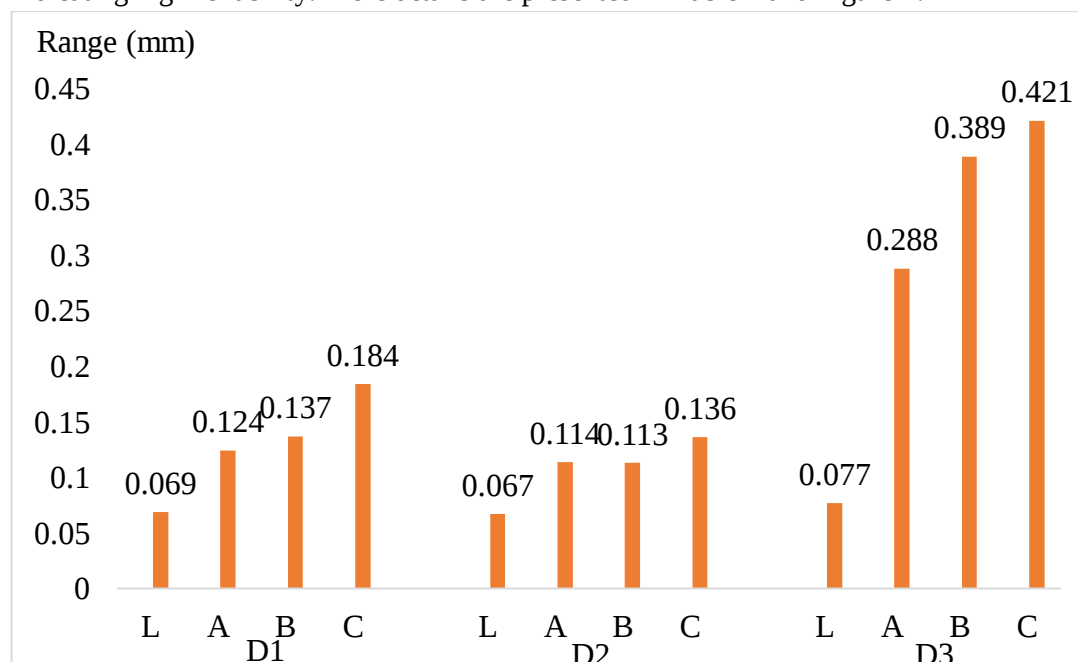


Figure 2. Ranges of the readings of each scanner.

Significant differences were observed both between and within the readings of the four scanners for all the distances (D1, D2, and D3). Regarding D1, all pairwise comparisons between means were significant, including those between the (LS) and the others. The lowest standard deviation (SD) was found in the (LS) readings (0.020), indicating the least

data dispersion from the mean, while the highest SD (0.055 mm) was in scanner C. A similar pattern emerged for D2, where all differences were significant, with the lowest SD (0.022 mm) in the Lab. readings and the highest (0.042 mm) in scanner C. For D3, all mean differences were significant except for the comparison between the (LS) (42.425 mm) and scanner C (42.341 mm), which was close to significance ($p = 0.054$). Once again, the lowest SD (0.025 mm) was in the Lab. readings, and the highest (0.121 mm) was in scanner C (Table 2).

Table 2. Significance of the differences between the groups (using different scanners) regarding the studied distances.

Distances	Scanners	Mean	SD	p-value*	Groups	p-value**
D1 (mm)	Lab. scanner (L)	33.905	0.020	< 0.001	L vs A	0.005
	A	33.959	0.045		L vs B	< 0.001
	B	33.752	0.034		L vs C	0.040
	C	33.866	0.055		A vs B	< 0.001
	Total	33.870	0.086		A vs C	< 0.001
					B vs C	< 0.001
D2 (mm)	Lab. scanner (L)	33.966	0.022	< 0.001	L vs A	< 0.001
	A	34.038	0.038		L vs B	< 0.001
	B	33.833	0.036		L vs C	< 0.001
	C	33.894	0.042		A vs B	< 0.001
	Total	33.933	0.085		A vs C	< 0.001
					B vs C	< 0.001
D3 (mm)	Lab. scanner (L)	42.425	0.025	< 0.001	L vs A	0.039
	A	42.514	0.087		L vs B	0.002
	B	42.286	0.110		L vs C	0.054
	C	42.341	0.121		A vs B	< 0.001
	Total	42.391	0.125		A vs C	< 0.001
					B vs C	0.194

*Calculated by ANOVA. **Calculated by a post-hoc test (LSD).

The distances measured by scanners A, B, and C were subtracted from the distance measured by the lab. Accordingly, a negative difference indicates (in general) that the reading of a scanner is higher than the (LS) reading. It is worth mentioning that any of the ten readings a scanner could be higher or lower than the corresponding reading of the lab. The highest mean of difference (in D1, D2, and D3) was in scanner B (0.153 mm, 0.133 mm, and 0.139 mm, respectively), indicating that it had the least accuracy. Scanner A, in general, gives higher readings than the lab, so the difference was negative, while scanner C gives, in general, lower readings than the lab. Irrespective of the sign (whether positive or negative), scanner C looks more accurate than scanner A in measuring D1 and D3. More details are presented in Table 3 and Figure 3.

Table 3. Differences in distances between the Lab. scanner and other scanners.

	D1*			D2*			D3*		
	L-A	L-B	L-C	L-A	L-B	L-C	L-A	L-B	L-C
Mean	-0.054	0.153	0.039	-0.072	0.133	0.073	-0.090	0.139	0.083
SD	0.055	0.049	0.067	0.043	0.045	0.054	0.088	0.111	0.129
Median	-0.066	0.144	0.024	-0.070	0.134	0.071	-0.120	0.142	0.080
Minimum	-0.135	0.087	-0.070	-0.171	0.050	-0.002	-0.192	-0.026	-0.091
Maximum	0.014	0.270	0.140	-0.012	0.225	0.136	0.069	0.320	0.345

*D: Distance

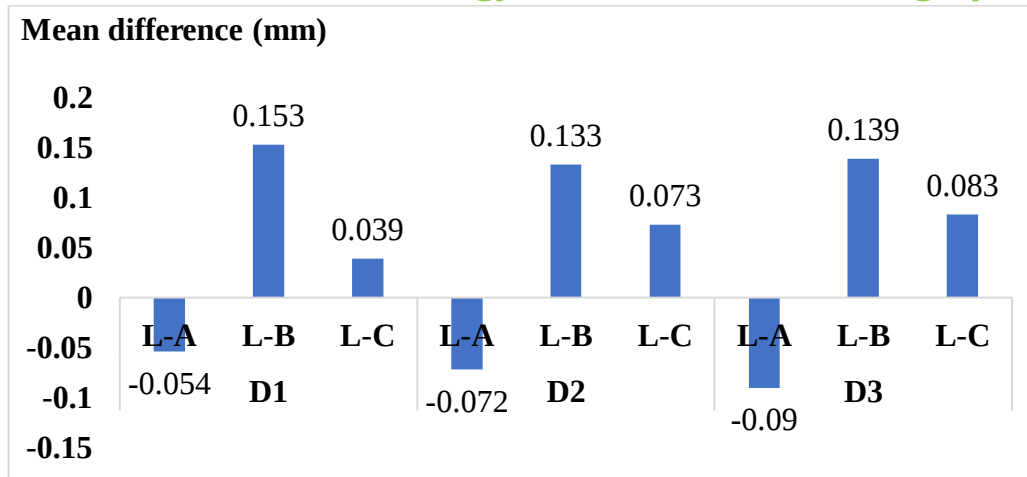


Figure 3. Differences in distances between lab. scanner and other scanners (Lab. scanner reading minus other scanner's reading).

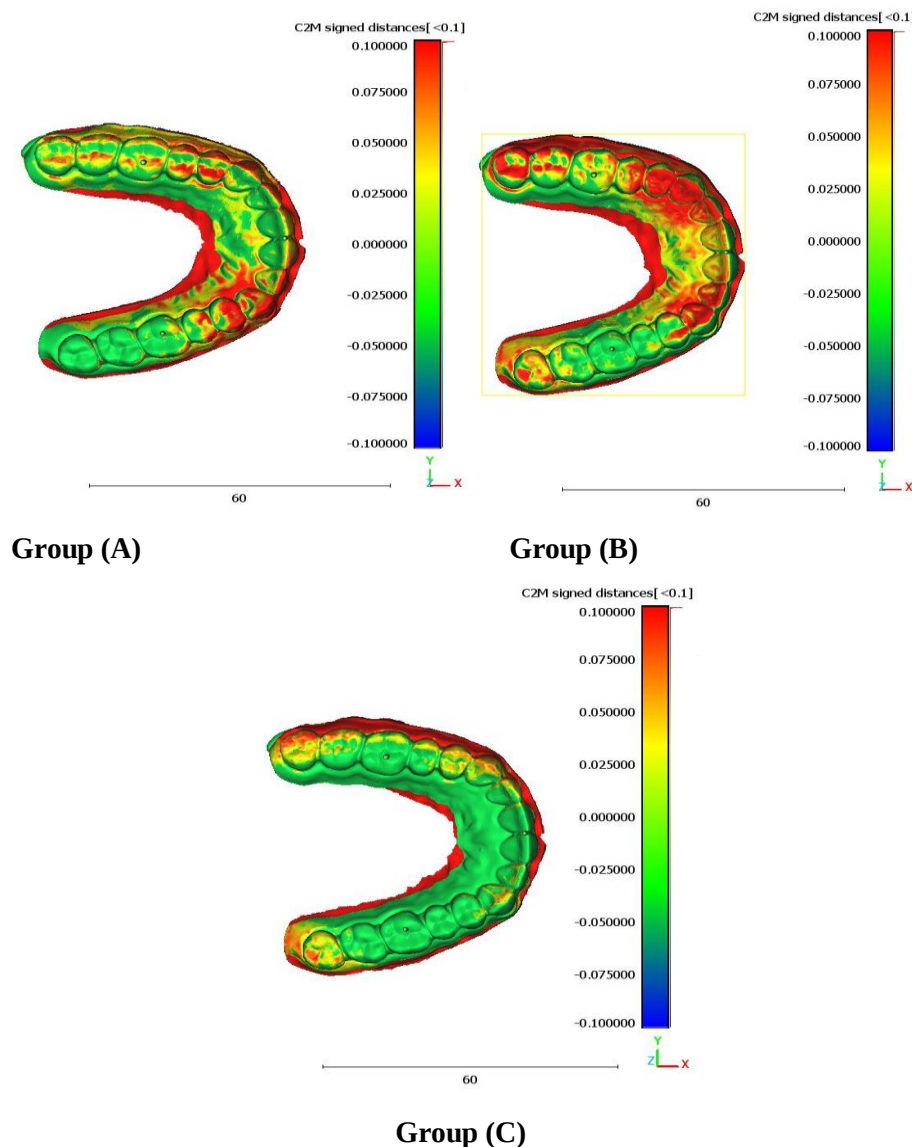


Figure 4. Color- code deviation field of the mean of each intra oral scanner group A, group B, group C, the green color scale shows agreement, whereas the red and blue colors point the location of positive and negative deviations.

DISCUSSION

The lab scanner exhibited superior performance in all span measurements, producing the least variability (SD = 0.020-0.025 mm) and the narrowest error ranges (≤ 0.08 mm), so affirming its designation as the gold-standard reference instrument^{18,19}. In the current study regarding the results Scanner A demonstrated low bias and strong consistency, with SDs of 0.038-0.045 mm and error ranges only marginally higher than the laboratory reference. This is consistent with the large body of literature indicating TRIOS devices as the most accurate IOS systems. In controlled in vitro studies, TRIOS 5 consistently demonstrated superior precision and accuracy, as noted by Jain et al. using full-arch implant models, reporting trueness 54.9 μ m and precision $\sim 37.8 \leq 4.5 \mu$ m¹⁸. Similar to Vasilescu et al., the smallest mean deviation ($\sim 112 \mu$ m) among the tested IOS was observed in TRIOS 5²⁰. These findings support Scanner A's superior performance in full-arch precision compared to other IOS. Group B exhibited the highest repeatability for brief spans, with an SD of ≥ 0.011 mm at D. This demonstrates exceptional accuracy for tiny to moderate scans. This indicates that the readings are executed with exceptional precision for small to moderate measurements. Nonetheless, we noted a consistent underestimate over extended durations. (D_3) suggestive of a little shrinking bias. This pattern aligns with previous research: Jain et al. identified Mediti700 deviations as second only to TRIOS in accuracy ($\sim 40.6 \mu$ m) and trueness ($\sim 60.5 \mu$ m), while observing occasional under-measurement in full-arch models¹⁸. Jivănescu et al. assessed Mediti700's precision as second only to TRIOS and superior to Omnicam²¹. Therefore, Group B's profile of exceptional short-span precision but minimal long-span trueness loss is consistent with the published trends²²⁻²⁴. Group C exhibited the greatest dispersion among intraoral scanners in our full-arch measurements, with standard deviations ranging from ~ 0.042 to 0.121 mm and error ranges up to 0.42 mm. These results align with broader observations that older generation IOS tend to underperform in complete-arch reproducibility. While no peer-reviewed studies have yet evaluated the accuracy of Cameo Elegant 3, manufacturer-reported claims suggest a 30 % improvement in accuracy over prior models though such

data lack independent validation^{25,26}. Our empirical findings therefore fill a critical gap, indicating that Cameo Elegant 3 demonstrates variability similar to CEREC Omnicam, corroborating concerns about its suitability for long-span full-arch scans. In the final analysis, these results correspond with the current literature. The laboratory scanner's SDs (~ 20 - 25μ m) match the claimed ISO calibrated desktop scanner accuracy²⁷⁻²⁹. Scanner A exhibited moderate standard deviations and minimal bias, corroborating its superior precision and accuracy^{18,23}. Group B exhibited outstanding short-span performance and minor long-span underestimate, consistent with previous assessments of Medit systems^{19,21}. Group C demonstrated the highest dispersion, aligning with previous findings about its predecessor and comparable scanners, which exhibited inferior reproducibility compared to newer intraoral scanners, particularly in complete-arch scanning^{20,21,25,26}.

CONCLUSION

The laboratory scanner exhibited the utmost precision. TRIOS 5 (Group A) was the most exact IOS, while Medit i900 (Group B) excelled in short spans with modest long-span bias. Cameo Elegant 3 (Group C) exhibited the highest variability. These findings validate the accuracy hierarchy and the necessity of aligning scanner selection with clinical requirements.

DECLARATIONS**Ethics approval and consent to participate**

Not applicable

Conflicts Of Interests

None

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None

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