AJDS ALAZHAR Al-Azhar Journal of Dental Science
Vol. 28- No. 2- 223:230- April 2025
Print ISSN 1110-6751 | online ISSN 2682 - 3314
https://ajdsm.journals.ekb.eg
Restorative Dentistry Issue (Dental Biomaterials, Operative Dentistry, Endodontics, Removable & Fixed Prosthodontics)

ACCURACY OF DIFFERENT INTRAORAL SCANNERS ON MULTIPLE IMPLANTS: AN IN-VITRO STUDY

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ABSTRACT

Objective: The purpose of this study is to assess the trueness, accuracy, and precision of images acquired from various intraoral scanners within oral implantology of partially edentulous maxilla (PEM) situations. **Materials and methods:** A gypsum model was designed that modeled a partially edentulous maxilla (PEM) with two implant analogs with polyether ether ketone (PEEK) scan bodies screwed on it. Scanning of this model was done using a reference scanner (InEos X5) and with 4 Intraoral scanners (IOS) (Trios 4, Prime scan, Medit i700, Carestream 3700); The model was scanned eight times using each IOS. All IOS data were imported into reverse-engineering software, in which they were superimposed on the reference model in order to assess their degree of accuracy and trueness and also superimposed on one another within groups in order to evaluate their precision. Kruskal Wallis, ANOVA, and Pearson coefficient tests were used to conduct a thorough statistical analysis. **Results:** For trueness Trios 4 had the best trueness with median and standard deviation (19.21 ±2.18 µm) followed Medit i700 (20.09 ±0.51 µm) then Prime scan (22.04 ± 1.10 µm) then Carestream (CS) 3700 (41.20 ±2.33 µm). There was a significant difference between CS 3700 and other IOS, and also between Trios and Prime scan. No significant difference was found between Medit i700 and Trios 4 or Prime scan. For precision, Medit i700 had the best precision with median and IQR 12.35 µm (11.75 – 12.90 µm) followed by Prime scan 18.70 µm (16.60 –22.05 µm) then Trios 4 19.75 µm (17.90 –21.95µm) then, CS 3700 was 32.55 µm (29.10 –35.35 µm). There was a significant difference between CS 3700 and other IOS, and also between Medit i700 and Trios 4 & Prime scan. With no significant difference between Trios 4 and Prime scan. **Conclusion:** The IOSs revealed significant variations among them in terms of both precision and trueness for recording impressions in PEM situations with PEEK scan bodies. Trios 4 had the best trueness and Medit i700 had the best precision.

KEYWORDS: Intraoral scanner, Polyether-ether keton, Trueness, Precision

INTRODUCTION

Impression-taking is one of the most important steps for the fabrication of fixed dental prosthesis. A dental impression is a negative reproduction or mold of dental and oral tissues[1]. Conventional methods of impression-taking have many disadvantages, as they may cause anxiety, discomfort for patients especially those with sensitive gag reflexes, risk of retaking impressions, time-consuming, and frequent disinfection of impressions. Due to these problems of conventional impression, digital impression is used widely nowadays. Several research papers have proven that full-arch digital images have been just as precise as traditional impressions[2,3]. No doubt that the most significant

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DOI: *10.21608/ajdsm.2023.223453.1442*

shift in the dental field in recent years is prosthetic dentistry which is transitioning to a more digitally based approach (4-6).

By emitting a light beam, intraoral scanners (IOS) -highly sophisticated instruments- are capable of collecting data and sending it to a computer regarding the size and shape of the dental arches (or the location of dental implants) (7,8). Actually, they send out a beam grid or light (laser or structured light) towards the surface of the targeted teeth (or by implanting some scan bodies) and then capture the deformation which such a grid or beam experiences when it hits these structures using high-resolution cameras (7,8). The data obtained by these cameras is subsequently analyzed by advanced software in order to create a three-dimensional (3D) model that represents the intended structures(8,9). Principally, a polygonal mesh representing the scanned item is obtained from the formation of a "cloud of points"; After processing the scan, a final 3D model is produced (8,9).

The ISO defines "trueness of impression technique" as the difference in measurements between the intraoral scan model and the reference model, while "precision of impression technique" is the difference in measurements across digital models of the exact identical intraoral scanner (10). The tested impression method's divergence from its original geometry serves as an indication of trueness. As a result, a scanner of high trueness will provide results that are roughly identical or extremely close to the real dimensions of the scanned object (11). Precision describes the differences in impressions that occur inside the same test group. As a result, a more precise scanner results in a more frequent and consistent scan (11).

The only possible available technique to calculate an IOS's trueness is overlapping its scans with high-quality industrial equipment (measurement machine coordination ‹industrial optical scanner). After overlapping such models/images, colorimetric maps are created using powerful advanced reverse-engineering software which shows the variations between the reference model and IOS surfaces at the micrometric level. Precision may be easily computed by overlapping many models/scans obtained with the same IOS at a variety of times and reevaluating the differences/distances at the micrometric level.

An implant-supported fixed prosthesis is believed to be a well-proven treatment option for edentulous cases. Long-term clinical investigations have demonstrated that this restoration type may continue to be dramatically successful over several decades (12-14). Impression for implant position can be taken by IOS through scan bodies screwed in implants to detect its positions. Poly ether ether-ketone (PEEK) scan bodies are much better for scanning than metal abutments which can reflect the light of IOS and lead to defects in the impression-taking process (15-17).

The goal of our current study was mainly to compare the scanning accuracy of four different intraoral scanners in partial edentulous maxilla restored using implants.

MATERIALS AND METHODS

Sample grouping

Regarding the study, 32 scans were made on the gypsum model representing partial edentulous maxilla restored by implants and scan bodies screwed on them **Fig (1)**, classified into 4 groups according to the type of scanner with 8 scans per scanner **Group T** = Trios 4 (3 shapes, Copenhagen, and Germany). **Group P** = Pime scan (Dentsply Sirona, York, PN, and USA). **Group C** = Carestream 3700 (USA, Atlanta, Carestream Dental, and GA,). **Group M** = Medit i700 (South Korea, Seoul, and Medit).

Besides, this model was just once scanned using reference extraoral scanner InEos X5 (Dentsply Sirona, York, PN, USA). **Table (1)**

FIG (1) Preparing of gypsum model: partially edentulous maxilla, containing two implant analogs in positions #14 and #16 with PEEK scan bodies screwed on them.

TABLE (1) Characteristics of scanners

Name	Manufactures	Scanning technolog	Light source	Mode of capturing	Necessity of coating
InEos X5	Dentsply Sirona, York, PN, USA	Digital stripe light projection	Bue led light	Image sequence	No
Prime scan	Dentsply· Sirona, York, PN, USA	Confocal technology	Light	Video sequence	No
Trios 4	3shape, Copenhagen, Germany	Confocal technology	Light	Video sequence	No
Care stream 3700	Carestrean Dental, Atlanta, GA, USA	Triangrulation technology	Light	Video sequence	No
Medit i700	Medit, Seoul, South-Korea	Triangrulation technology	Led light	Video sequence	No

Cast Preparation:

A typodont acrylic dental model having A full seat of teeth with missed #14, #15, and #16 to mimic the scenario of an implant-supported partial prosthesis (PP).

Two sterilized failed implants (Flotecno, Italy) were placed in positions #14 and #16 in typodont acrylic models and stabilized by wax. They were placed 2 mm beneath the wax.

Impression transfers are screwed on implants to indicate the position of an implant relative to the teeth and jaw structure, and the open tray impression technique was used with additional silicone (zhermack Elite HD, Dentsply Sirona, Germany).

Two implant analogs are screwed to transfers to provide a replica that shows the exact position of the implants.

Lubricant is used around analogs; tissue mimic material was applied then the impression was mixed and poured according to the manufacturing structure (Zhermack Elite Rock Type 4 X-hard Stone).

After hardening the cast was trimmed and polished and two non-reflective high-precision polyether-ether-ketone (PEEK) scan bodies

(Flotecno, Italy) were screwed and tightened firmly on implant analogs.

Scanning:

The formed cast has been scanned by using the extraoral desktop scanner InEos X5 to get a reference STL file. The scanning process begins by pressing the Start button then the Capture area option was selected to define the areas in which the scan is automatically performed with a high level of detail.

During scanning with IOSs, no external force was applied or scan bodies were removed, all trials were conducted in a room with relative humidity (50±5%), and a constant temperature (23± 1°C). All scan times were roughly (25± 5) seconds on average.

Scanning was performed by a zigzag technique by carrying IOS in the arc of movement starting from the buccal side of the posterior adjacent tooth and passing over the occlusal toward the lingual side of it, with repeating movement passing over the scan bodies and adjacent anterior tooth and ensuring that all details were captured on the software of IOS. Finally, STL files were exported and ready to be used.

Measuring of the Trueness:

The reverse engineering program Geomagic control X 2018" was used for superimposing the file of the reference STL received using the InEos X5 desktop scanner on each of the eight STL files received from each intra-oral scanner in each group.

The reference file data was uploaded and edited in order to remove any data that failed to correspond to the required scan, then thousands of segments were resegmented according to planes, and the zone of interest was then combined using the merge tool to achieve an accurate superimposition.

The measurement data, which is one of the STL data files obtained from the linked scanner, was imported. The primary alignment feature was selected to improve alignment accuracy, and then the best-fit optimal alignment was chosen to guarantee the two models were seated with the least feasible mean of deviation.

Only the merged region, which is considered to be the area of interest with auto maximum deviation and the minimum projection of deviation, was compared through 3D.

Finally, a color map was designed using a color scale ranging from a maximum departure of + 100 and - 100 µm, with the optimal outcomes coming from the differences between + 30 and - 30 µm (green color). Blue revealed that the test model surface was negatively positioned with respect to the reference model. Green indicated a flawlessly matching surface; while red indicated that the test model surface was favorably positioned compared to the reference model. **fig (2).**

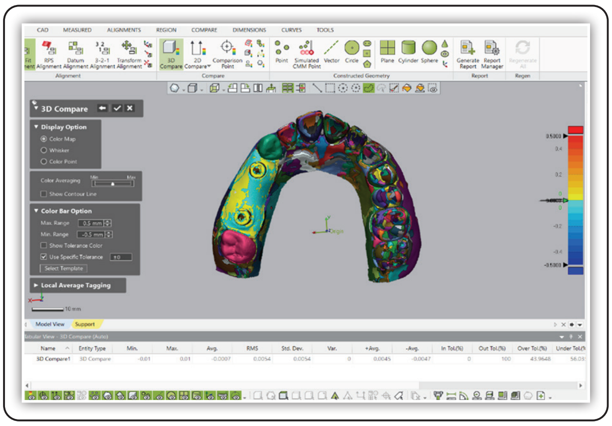

FIG (2) 3D comparison of two superimposed STL files with color map

Reports were written using all of the computed data obtained from the superimposition procedure, and all of the above steps were repeated eight times for each group and compared with its reference scan, and data was finally collected from the total gathered 24 reports.

The Precision measurement:

The exact same steps were followed, but different from the trueness measurement, the computation was performed intra-group; each scan in each group served as a reference model, and the seven additional scans superimposed on it to obtain a total of reports for each group (n=28).

Statistical Analysis

All data were uploaded into the computer and then analyzed through the IBM SPSS software program version 20.0. IBM Corp., Armonk, New York. The distribution normality was verified using the Shapiro-Wilk test. Standard deviation, Range (maximum and minimum), mean, interquartile range (IQR), and median were used to describe quantitative data. The obtained findings were declared significant at the 5% level. The F-test (ANOVA) was used to compare two scanners or more with normally distributed quantitative data, while the Post Hoc test (Tukey) was used for pairwise comparisons. To compare a number of more than two studied scanning devices, the Kruskal Wallis test for abnormally distributed quantitative variables was used, while Post Hoc (Dunn's multiple comparisons test) was used for pairwise comparisons. Pearson coefficient was used for determining the relationship between two normally distributed quantitative variables.

RESULTS

For trueness Trios 4 had the best trueness (19.21 ±2.18 µm) followed Medit i700 (20.09 ±0.51 µm) then Prime scan (22.04 ± 1.10 µm) then CS 3700 (41.20 ±2.33 µm). There was a significant difference between CS 3700 and other IOS, and also between Trios 4 and Prime scan. No significant difference was found between Medit i700 and Trios 4 or Prime scan **Table (2).**

For precision, Medit i700 had the best precision with median and IQR 12.35 µm (11.75 – 12.90 µm) followed by Prime scan 18.70 µm (16.60 –22.05 µm) then Trios 19.75 µm (17.90 –21.95µm) then CS 3700 32.55 µm (29.10 –35.35 µm). There was a significant difference between CS 3700 and other IOS, and also between Medit i700 and Trios 4 & Prime scan. With no significant difference between Trios 4 and Prime scan **Table (3).**

Medit i700 is the only IOS that shows a correlation between trueness and precision (P=0.071) and it was positive however this correlation wasn't statistically significant. **Table (4)**.

TABLE (2) Comparing the four scanners regarding trueness.

	Trios 4 (n = **8**)	Care stream 3700 (n = **8**)	Medit i700 (n = **8**)	Prime Scan (n = **8**)	p
Trueness Min.-Max. Mean± SD.	 16.80 - 22.10 19.21 ± 2.18	 38.10-44.50 41.20 ± 2.33	 19.40 - 20.90 20.09 ± 0.51	 20.70- 24.10 22.04 ± 1.10	$<0.001^{*}$
P0		$<0.001^{*}$	0.735	0.013*	
Sig. bet. grps.	$p_1<0.001^{*}, p_2<0.001^{*}, p_3=0.125$				

SD: **Standard deviation**

p: p-value used to compare the four scanners.

p_0: p-value used to compare the **Trios 4** *with* **other scanners**.

p_1: p-value used to compare the **Care stream 3700** *with* **Medit**

p_2: p-value used to compare the **Care stream 3700** *with* **Prime Scan**

p_3: p-value used to compare the **Medit** *with* **Prime Scan**

**: Statistically significant at $p \leq 0.05$*

TABLE (3) Comparison between the four scanners according to precision

	Trios 4 (n = 28)	**Care stream 3700 (n =28)**	**Medit i700 (n =2 8)**	**Prime Scan (n = 28)**	**p**
Precision Min.-Max. Median (IQR)	2.0 - 25.70 19.75 (17.90- 21.95)	1.50- 39.90 32.55 (29.10- 35.35)	1.0-15.10 12.35 (11.75 - 12.90)	14.10 - 27.30 18.70 (16.60 - 22.05)	<0.001*
P0		<0.001*	<0.001*	0.699	
Sig. bet. grps.	p_1<0.001*, p_2<0.001*, p_3<0.001*				

IQR: **Inter quartile range**

p: p-value used to compare the four scanners.

p_0*: p-value used to compare the* **Trios 4** *and other scanners.*

p_1*: p-value used to compare the* **Care stream 3700** *with* **Medit**

p_2*: p-value used to compare the* **Care stream 3700** *with* **Prime Scan**

p_3*: p-value used to compare the* **Medit** *with* **Prime Scan**

**: Statistically significant at $p \leq 0.05$*

TABLE (4) Correlating trueness and precision in each group

	Trueness vs Precision	
	r	p
Trios 4	0.069	0.871
Care stream 3700	-0.206	0.62
Medit i700	0.666	0.071
Prime Scan	0.215	0.609

r: Pearson coefficient

DISCUSSION

The purpose of this study was to assess the precision, accuracy, and trueness of 4 different ISOs in PEM situations with implants. It was carried out in vitro since determining the trueness parameter in vivo is challenging owing to the reference scans shortage [18]. PEEK was mainly chosen since it is unable to reflect light and thus simplifies acquisition with three-dimensional (3D) scanners, unlike metal abutments which have shiny surfaces, and problems scanning reflective, thus this prevents artifacts production which might affect the intraoral scanner's accuracy measurement [17].

As previously stated, this study relays on utilizing a standard laboratory scanner to produce a standard reference model. As per the manufacturer, the inEos X5's accuracy has been verified in accordance with European standard (EN) and International Standardization Organization (ISO) 12836.2015. The accuracy provided on the standard "inlay" test specimens was 1.3 ± 0.4 µm, while on the standard "bridge" test specimens was 2.1 ± 2.8 µm [19-23].

To maintain standardized scanning circumstances, time was averaged to eliminate the temporal influence on scanner trueness and accuracy. To exclude the influence of expertise on scan accuracy, all scans were done by the same clinician who had been trained on how to use reference scanner and all of the four IOSs. Powder wasn't used throughout the scanning process since there is much debate regarding its impact on accuracy [24-27].

The results showed a significant difference in trueness between CS 3700 and other IOS, also between Trios 4 and Prime scan. No significant difference was found between Medit i700 and Trios 4 or Prime scan. This is in agreement with Spagopoulos et al 2023 (28) and Shaikh et al 2022 (29) as they stated that a significant difference between the Trios 4, prime scan, and CS 3700 in trueness was found. And also, with Kaya and Bilmenoglu 2022 (30) who found no significant difference between Medit i700 and Trios 4 and between Medit i700 and prime scan. But results disagree with Çakmak et al 2021 (31) who found no significant difference between Trios 4 and Prime scan, this maybe they used a single implant scan body, also they used different cast material which was made from poly (methyl methacrylate) (PMMA) material. And with Rutkūnas 2021 (32) found a significant difference between Trios 4, Medit i700, and Prime scans in trueness may be because they used additional reference objects on casts, also they used different reference scanners (Nikon Altera, v 10.7.6; Nikon Metrology).

For precision, there was a significant difference between CS 3700 and other IOS, and also between the Medit i700 and Trios 4 & Prime scan. With no significant difference between Trios 4 and Prime scan. This finding was in accordance with Spagopoulos et al 2023 (28) who reported that a significant difference was found between both the Trios 4 and Medit i700 in precision, also agreeing with Rutkūnas et al 2021 (32) who didn't find any significant differences between the Prime scan, Medit i700, and CS 3700. But results disagree with Kaya and Bilmenoglu 2022 (30) who found no significant difference between the Trios 4, Medit i700 and CS 3700 may be due to different restoration designs as they use four scan bodies for all four concepts, also disagree with Shaikh et al 2022 (29) found significant difference between Trios 4 and Prime scan.

CONCLUSION

Within the limitation of our study, the following conclusions may be drawn:

- Trios 4 showed the best trueness followed by Medit i700 then Prime scan and finally CS 3700.
- Medit i700 exhibited the highest precision, followed by Prime scan, Trios 4, and CS 3700.
- Medit i700 was the only scanner that showed correlation between trueness and precision.

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