Original Article

Comparison of the Accuracy and Precision of Digital Scans for Implant-Supported Maxillary Hybrid Prosthesis: An *in vitro* Study

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Abstract

Background: Numerous intraoral scanners (IOS) devices are currently used for intraoral impressions in prosthodontics. It is crucial to assess the accuracy and precision of these devices for clinical use. **Aim:** This *in vitro* study aimed to assess and compare the accuracy and precision of six IOS in the all-on-4 treatment concept. Trueness evaluation involved aligning the data from six dental scanners with the reference model. Precision analysis encompassed aligning the data from all six scanners within their respective groups. **Methods:** An edentulous maxillary model was utilized, with four implants placed at 12, 15, 22, and 25 teeth positions, simulating the all-on-4 approach using resin acrylic. Following the placement of scanbodies, each of the six IOSs (Primescan, Trios 3, Trios 4, Trios 5, Virtuo Vivo, and Medit i 700) performed eight scans of the model. An industrial scanner was employed for the control group. Data alignment and comparison were executed using the CloudCompare software (v2.11.3, General Public License of Telecom ParisTech, Paris, France). Statistical scrutiny encompassed the Shapiro–Wilk, Levene's, and Games–Howell tests. **Results:** Among the scanners, Primescan exhibited the highest trueness (35.75 ± 26.08 μm), whereas the Medit i700 demonstrated superior precision (0.163 μm). **Conclusion:** IOS can be used to make dental impressions within the all-on-4 concept. More comprehensive and clinical studies are needed on this subject.

Keywords: *Accuracy, digital impression, intraoral scanner, precision, trueness*

Introduction

Intraoral scanners (IOS) are devices employed in dentistry to capture direct optical impressions of teeth and surrounding tissues. These scanners utilize various technologies, such as structured light or laser scanning, to create a highly precise digital model of the patient's oral cavity.[1] Accuracy can also be defined as the mathematical quality of digital images obtained from IOS. To establish standardized terminology, the International Organization for Standardization (ISO) has defined accuracy measurements to consist of two essential components: trueness and precision (ISO-5725-1).[2] 'Trueness refers to the degree to which images match the actual surface. Trueness pertains to the extent to which the digital model accurately reflects the true anatomy of the patient's mouth. A scanner with high trueness captures the patient's anatomy with minimal distortion or error. "Precision" refers to the degree of consistency or reproducibility of the scanner's impressions. A scanner with high precision yields consistent results when scanning the same area multiple times.[3,4]

The all-on-4 treatment concept was developed as a solution for edentulous patients facing anatomical limitations and is used to avoid additional surgical treatments in patients with insufficient bone distance or to provide a fixed prosthesis with a single surgical procedure in elderly patients with unsuitable systemic conditions.[5] In the case of an edentulous arch, an

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accurate overlay of digital scans may present more difficulty due to the larger mucosal surface with less detail. Even small errors in the alignment of the scan bodies can lead to a mismatch of the frame at the platform level, compromising the fit and functionality of the implant-supported prosthesis.[6] The accuracy of IOSs (IOS) for edentulous complete-arch scans with scan bodies has been a critical consideration in dental implant treatment planning and the fabrication of implant-supported prostheses.[7,8]

Although there are studies in the literature investigating the accuracy and trueness of IOSs in many aspects such as various IOSs,[7] scan body systems and positions,[8] user differences.,[9] scanning techniques,[6] different surface scans,[10] none of them have compared the Trios 3, Trios 4, Trios 5, Medit i700, Primescan, and Virtuo Vivo scanners with respect to maxillary all-on-four prostheses digital scans. This study aims to compare the accuracy and trueness of these six different IOS systems in the digital workflow of constructing maxillary all-on-four prostheses. The null hypothesis states that no significant differences would be found between the accuracy of digital impressions made by the examined IOSs, irrespective of the superimposition technique.

Materials and Methods

Master cast

To assess the effectiveness of various IOS systems used in rehabilitating edentulous maxilla with a hybrid prosthesis indication, a printed resin acrylic cast was prepared to mimic the maxilla with a 3D printer. This cast featured resorbed crests and four implants according to the Wheeler dental atlas.[11] To simulate the "all-on-4" concept, four BEGO dental implant analogs (ZIMMER; Biomet Dental, USA) were modeled with a 3D printer. Two anterior implant analogs, with a diameter of 3.75 mm and a length of 15 mm, were placed in the lateral incisors region. Additionally, two posterior implant analogs, with a diameter of 4.1 mm and a length of 13 mm, were angled at 30 degrees and positioned in the second premolars region. Cylindrical Bego scan bodies with PEEK content were inserted and tightened into place following the manufacturer's recommended guidelines [Figure 1]. Six IOS systems were compared in the study [Table 1].

This study has been approved by from the Ethics Committee of University of Health Sciences Hamidiye Scientific Research Ethics (no:23/19). 27.01.2023. We confirm that all methods are performed in accordance with relevant guidelines and regulations. Ethics Committee of University of Health Sciences Hamidiye Scientific Research Ethics waived the need for informed consent as all the work is done in computer environment.

Study design

The Zeiss Comet 6 scanner (Comet L3D; Carl Zeiss, Neubeuern, Germany) was used for control scan data.[12] When evaluating the accuracy of IOS in related studies, it is common to use digital models obtained from industrial-type scanners as a control group.[13,14] In this particular study, all scans were conducted under consistent conditions to ensure the accuracy and reliability of the data. Specifically, the scans were performed in the same room and by the same dentist with a controlled temperature of 20° C, 45% humidity, and 760 ± 5 mmHg air pressure.[15,16] Scanning procedures were carried out for each IOS in accordance with the recommendations of the company's user manual, and in all cases, the scanning strategies recommended by the manufacturer were followed. These measures were implemented to ensure the validity of study results, making it possible to confidently compare the data across different scanner systems. A scan was made with the reference scanner, and then eight consecutive digital scans (n = 8) of the main model were performed with IOS devices. Scans were performed on the same day because there was a risk of distortion of the resin model. The threshold values for our study were determined based on specification no. 19, published by the American Dental Association, focusing on the properties of elastomeric impressions.[17] The collected data were processed in a computer environment using a three-dimensional (3D) mesh processing and comparison software program called Cloud Compare (v2.11.3, General Public License of Telecom Paris Tech, Paris, France), similar to previous publications.[18,19]

Statistical analysis

For statistical analysis, the relevant data underwent testing using IBM SPSS (Statistical Package for the Social Sciences) V24 software, located in Armonk, New York, USA. To assess normal distribution conformity, the Shapiro–Wilk test was employed. For comparison of normally distributed deviation values among groups, one-way analysis of variance (ANOVA) was utilized, whereas Levene's test was applied to evaluate the homogeneity of variance. Given the non-homogeneous variance of the data, multiple comparisons were conducted using the Games–Howell test. To examine repeatability, the coefficient of variation was employed. The analysis results were presented as mean ± standard deviation and median (minimum–maximum) for quantitative data. The significance level was set at $P < 0.05$. To evaluate precision, the coefficient of variation, which is the rate of variation between sample data of various devices, was examined. This coefficient was used to evaluate

how consistent and precise the measurement results of a device are. The coefficient of variation was calculated by dividing the standard deviation of the relevant data series by the arithmetic mean of the same series. The coefficient of variation is the coefficient value obtained by dividing the standard deviation of the series by the arithmetic mean. The standard deviation shows the standard deviation of the accuracy values of the devices. It provides information about variability as it is calculated by dividing the sum of the squares of the deviations from the mean by one less than the number of samples.

Figure 1: Maxillary model images with a body scan were used in the study

Results

The results indicated a statistically significant difference in accuracy values among the devices.

Upon conducting the Games–Howell tests, it was observed that the deviation values of Primescan, Trios4, Trios 5, and Virtuo vivo devices were significantly lower than those of the other devices ($P < 0.001$).

Additionally, the deviation values of the Trios3 device were found to be higher compared to the deviation values of the Medit device [Table 2]. Accuracy values according to devices are shown in Figure 2.

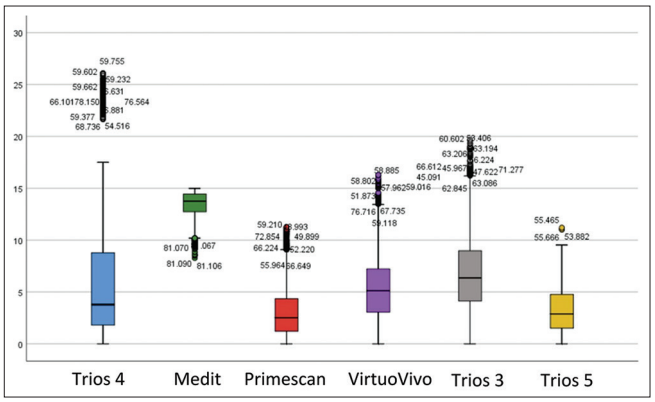

Figure 2: Graphical representation of accuracy values by device

Table 1: IOS systems compared in the study

Scanner Model	Manufacturer	Technology of acquisition	Current version	Imaging system
Trios 3®	3-Shape, Copenhagen, Denmark	Confocal microscopy and ultrafast optical scanning	1.7 40	Multi-image, structured light imaging
Trios 4®	3-Shape, Copenhagen, Denmark	Confocal laser scanning microscopy technology	1.7 40	Multi-image
Trios 5®	3-Shape, Copenhagen, Denmark	Confocal laser scanning microscopy technology	1.7 40	3D Imaging Technology
Primescan®	Sirona Dental System GmbH, Bensheim, Germany	High-resolution sensors and shortwave light with optical high frequency contrast analysis for dynamic deep scan (20 mm)	5.2.6	Uncertain data
i700	Medit, Seoul, South Korea	3D-in-motion video technology	2.6.2	Stereo vision, 3D motion imaging
Virtuo Vivo	Dental Wings, Montreal, Canada	Blue laser-multiscan imaging technology	2.1.0	Uncertain data

Table 2: Differences in trueness (μ) and precision between scanners

	Standard deviation		Precision value	Test statistic	*P*
	Average±SD*	Median (minimum – maximum)			
Virtuovivo	71,25±61,16	53,24 (0-309,99)	0,858	*F*=7368.3	<0.001
Medit i700	128,0±20,86	132,67 (7,77-150)	0,163		
Primescan	35,75±26,08	31,34 (0-146,22)	0,731		
Trios4	45,14±31,63	40,79 (0-179,55)	0,701		
Trios3	69,75±45,53	64,26 (0-202,12)	0,653		
Trios 5	44,45±36,86	34,89 (0-175,35)	0,831		

*SD: Standard deviation

Table 3: Post-hoc analysis of accuracy between scanners

(I) Brand	(J) Brand	Mean difference (I-J)	Standard error	*P*	%95 Confidence interval	
					Lower limit	Upper limit
Trios 3	Medit	-74,329	0.492	<0.001	-75,772	-72,886
	Primescan	30,283	0.484	<0.001	28,863	31,702
	Trios4	7,200	0.501	<0.001	5,728	8,672
	Virtiovivo	-6,181	0.440	<0.001	-7,472	-4,890
	Trios 5	28,299	0.478	<0.001	26,895	29,703
Medit	Primescan	104,612	0.201	<0.001	104,023	105,201
	Trios4	81,529	0.247	<0.001	80,804	82,255
	Virtuovivo	68,148	0.294	<0.001	67,286	69,011
	Trios 5	102,628	0.184	<0.001	102,089	103,167
Primescan	Trios4	-23,083	0.285	<0.001	-23,920	-22,245
	Virtuovivo	-36,464	0.333	<0.001	-37,442	-35,486
	Trios 5	-1,984	0.217	<0.001	-2,622	-1,345
Trios4	Virtuovivo	-13,381	0.330	<0.001	-14,351	-12,411
	Trios 5	21,099	0.283	<0.001	20,267	21,931
Virtuovivo	Trios 5	-34,480	0.321	<0.001	-35,423	-33,538

To evaluate trueness, the coefficient of variation between the sample values of the devices was examined. The Medit i700 instrument showed the lowest trueness value, whereas the Virtuo Vivo instrument showed the highest trueness value [Table 2]. The coefficient of variation was calculated by dividing the standard deviation of the relevant series by its arithmetic mean. Post-hoc analysis of accuracy between scanners is shown in Table 3.

Discussion

The null hypotheses were rejected as a significant difference was observed among the scanners.

The success of all-on-4 treatment concept restorations largely depends on achieving a passive fit.[20] In the literature, the materials of the models used in studies evaluating the accuracy of IOSs varied. There are studies including metal models,[21] plaster models,[22] and acrylic resin[8] models. In our study, a model made of acrylic material, which is a mimic of all-on-4 concept, was used due to its ability to detail the surrounding textures and ease of production. The model was produced from the brand's own resin material with a printer belonging to the brand Primeprint (Dentsply Sirona; North Carolina, USA).

To calculate the linear and angular deviations between implants, reference, and test models must be measured with a suitable device. Distance and angle measurements between implants were performed using the data obtained after digitalizing the physical model or taking intraoral digital measurements.[23] In the literature, there is an evaluation of the digital measurement technique by calculating the deviations between the implant/scan body in the reference and test models in a virtual environment.[16,24,25]

According to ISO 5725,[2,4] dental impression accuracy is evaluated based on two parameters: trueness and precision. Trueness refers to how close a measurement or scan is to its true or actual value, whereas precision indicates the variability or differences observed between repeated scans. During digital scan taking for implant-supported restorations, factors such as the type of scanning device, scan body features, and scanning system may affect the accuracy of the digital scan.[8,15,18] Mizumoto *et al*.[8] in their study evaluating the effect of scan body position on the trueness and precision of digital scans in the edentulous arch. They reported that position significantly affects the trueness of digital scans. In another study, the effects of scan body systems with different geometries, materials and connection types, and scanning methods on the accuracy of digital scans were compared. It has been reported that the difference in scanning technique and scan body systems causes significant differences in the trueness and precision values of the scans.[15] When it comes to studies on IOS, which are part of digital systems, most of these studies tend to compare digital and conventional measurement techniques with each other.[24-27] Nevertheless, there are numerous studies that support the effectiveness and applicability of digital scans and IOS.[28,29] The current study has taken a unique approach by comparing the latest generation IOS devices, including Trios 5 and Medit i700, against an industrial scanner. Additionally, the study included all models of Trios, which further contributes to its distinctiveness in terms of comparison. Furthermore, the study incorporated Virtuo Vivo, a partially new device from the Straumann Group. In

another study conducted by Nulty *et al*.[18] a comparison was made among nine IOS and four extraoral scanners, such as Trios 4, Medit, Trios 3, and Primescan. They found that Primescan demonstrated the highest overall trueness, followed by Trios 4, Medit i500, and Trios 3. The average trueness of all scanners in the study was below 60 μm deviation. The researchers mentioned that scanning in a completely edentulous arch posed more challenges in terms of accuracy, and they suggested the need for further research in this area.[30] In the present study, results are consistent with those reported by Nulty *et al*.[18] Specifically, Primescan exhibited the highest level of trueness, followed by Trios 5, Trios 4, and Medit i700. However, not all trueness deviation values were below 60 μm. This disparity can be attributed to the difficulty in measuring edentulous arches, as mentioned by Nulty. Moreover, obtaining impressions for implant-supported prostheses is considered even more challenging. In a study by Revell *et al*.[25] they investigated various systems, including Medit i500, Primescan, ITero Element 2, Trios 3, and Trios 4, in a human cadaver maxilla with five implants, analyzing accuracy, and operator experience. The researchers reported that Primescan and Trios 4 achieved the highest trueness (statistically equivalent), whereas Trios 3 showed less accuracy than Primescan and Trios 4. Medit i500 and Element 2 demonstrated approximately half the trueness of Primescan and Trios 4. In our study, operator experience was not tested; however, the scanning was performed by an experienced operator, allowing for a comparison with Revell's results. Although there are partial similarities with Revell's study, Primescan, Trios 5, and Trios 4 yielded the most successful results in terms of trueness in our study. It is possible that Trios 4 was ranked highly in the results of Nulty and Revell because they did not include Trios 5 in their studies. In our current study, the most successful IOS device was Trios 5 following Primescan. Di Fiore *et al*.[28] evaluated scanner deviations in the X, Y, and Z planes for six implant-supported full-arch fixed prostheses. According to their study, the scanners were ranked as follows based on deviation amount: Primescan, Medit i500, and iTero Element 5. Róth *et al*.[31] compared 12 different IOS devices using various methods for full-arch scanning and found that Primescan and Trios 4 scanners achieved the highest accuracy. Kaya *et al*.[32] conducted a comparison of 14 IOS devices, including Trios 3, Trios 4, Virtuo Vivo, Medit i500, and Primescan, in terms of trueness and precision within the all-on-4 concept. They reported that Primescan exhibited the highest trueness (12.2 μm). Following Primescan in terms of trueness were Virtuo Vivo (32.4 μm), Trios 3 (40.3 μm), Trios 4 (41.4 μm), and Medit i500 (89.8 μm). Diker *et al*.[33] also found that Primescan (56 μm) showed the best trueness and precision in 4-unit supported fixed prostheses. Kaya's work is similar to our study, as both are based on the all-on-4 concept. Although Primescan emerged as the most successful in terms of trueness in both studies (31.3 μm in this study), Medit (132.6 μm) exhibited lower trueness values than Virtuo Vivo (53.2 μm), Trios 3 (64.2 μm), and Trios 4 (40.7 μm). The trueness values in our study were higher than those in Kaya's study. However, numerical comparison of deviation amounts is not feasible due to differences in the methodologies employed in the studies. For this reason, we compared the order of trueness values of the IOS devices. Another relevant factor is precision. In Kaya *et al*.'s[32] study, the order of trueness values, from the largest to smallest, was Primescan, Trios 4, Medit i500, Virtuo Vivo, and Trios 3. In our study, Medit i700 (0.16) exhibited the highest precision, whereas Virtuo Vivo (0.85) had the lowest precision. Additionally, Trios 3 (0.65) was found to be more sensitive than Trios 4 (0.70), Trios 5 (0.83), and Primescan (0.73). We evaluated precision using the coefficient of variation method in our study.[18,33] Based on the literature, the Cerec Primescan is one of the most accurate IOS in the dentistry field because there is a built-up computer in the IOS's handpiece. Because of that the scanning procedure is faster, the virtual model is more accurate, and the postprocessing is starting in the handpiece.[34,35]

Many studies comparing IOSs have consistently shown that Primescan performs better than Trios 4 in terms of accuracy, which aligns with our findings.[18,25,33] However, there have been some contradictory results in other studies.[36,37] For instance, Alpkılıç *et al*.[37] compared five IOS devices (CS3600; Emerald S, Primescan, Trios 3, Trios 4) in a model with seven non-angled implants placed. They reported that Trios 4 exhibited the highest accuracy, followed by Trios 3 and Primescan. In a study that solely assessed accuracy and compared 12 scanners, the ranking for trueness values was Medit i500, Trios 3, Primescan, and Virtuo Vivo. These variations in rankings may be attributed to differences in the chin model, materials, or implant brands evaluated in the studies. Furthermore, it has been demonstrated that software version differences in IOS, similar to model differences, can affect the accuracy and precision of digital scans.[38,39]

Regarding the limitations of our current *in vitro* study is that we did not evaluate the laboratory steps after the measurements. However, it is essential to emphasize that the primary objective of the study was not to predict marginal misfits but rather to evaluate the accuracy of IOS as a reference tool.

Within the limitation of this study; it has been observed that IOS can achieve successful results in all-on-4 prostheses. However, more *in vitro* and *in vivo* studies are needed to support the obtained results. Among all the relevant factors examined, the deviation values of the Primescan device were found to be quite low compared to the deviation values of other devices. Primescan has been found to be the most accurate scanner. In terms of precision, the most successful device was the Medit i700.

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Conflicts of interest

There are no conflicts of interest.

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