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Accuracy of 14 intraoral scanners for the All-on-4 treatment concept: a comparative *in vitro* study

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PURPOSE. This *in vitro* study aimed to evaluate the accuracy of 14 different intraoral scanners for the All-on-4 treatment concept. **MATERIALS AND METHODS.** Four implants were placed in regions 13, 16, 23, and 26 of an edentulous maxillary model that was poured with scannable Type 4 gypsum to imitate the All-on-4 concept. The cast was scanned 10 times for each of 14 intraoral scanners (Primescan, iTero 2, iTero 5D, Virtuo Vivo, Trios 3, Trios 4, CS3600, CS3700, Emerald, Emerald S, Medit i500, BenQ BIS-I, Heron IOS, and Aadva IOS 100P) after the polyether ether ketone scanbody was placed. For the control group, the gypsum model was scanned 10 times with an industrial scanner. The first of the 10 virtual models obtained from the industrial model was chosen as the reference model. For trueness, the data of the 14 dental scanners were superimposed with the reference model; for precision, the data of all 14 scanners were superimposed within the groups. Statistical analyses were performed using the Kolmogorov-Smirnov, Shapiro-Wilks, and Dunn's tests. **RESULTS.** Primescan showed the highest trueness and precision values ($P < .005$), followed by the iTero 5D scanner ($P < .005$). **CONCLUSION.** Some of these digital scanners can be used to make impressions within the All-on-4 concept. However, the possibility of data loss due to artifacts, reflections, and the inability to combine the data should be considered. [J Adv Prosthodont 2022;14:388-98]

KEYWORDS
Intraoral scanner; Trueness; Precision; Accuracy; Digital impression

INTRODUCTION

The All-on-4 concept has been developed as a treatment alternative for edentulous patients with difficulties due to anatomical limitations.[1,2] This technique can be used to avoid additional surgical interventions in patients without sufficient bone distance due to the maxillary sinus and mandibular nerve or to make a fixed prosthesis with a single surgical procedure in elderly pa-

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tients whose systemic condition is unfavorable.[1,2]

The success of implant-supported full-arch fixed restorations, such as the All-on-4 treatment concept, largely depends on the passive fit.[3] Passive fit starts from the impression and requires high precision in the clinical and laboratory stages.[4] Although, in the literature, passive fit ranges between 10 µm and 150 µ m, it has been stated that this value should range between 30 µm and 50 µm to avoid mechanical and biological complications.[5,6]

Although conventional impression materials are acceptable for implant-supported full-arch restorations in terms of passive fit, there are disadvantages, such as dimensional change, patient discomfort, time, cost, and technical difficulties.[4,7,8] The use of scan bodies with digital impressions enables intraoral scanners (IOS) to be used in implant restoration.[9] However, digital systems for implant-supported restorations are still controversial because of scanning strategies and technologies, implant depth and angles, and scan body materials and shape.[10-15] In particular, knowing the accuracy of new generation IOS is clinically important for achieving passive fit in full-arch implant-supported restorations.[5]

The terms, accuracy, trueness, and precision, are frequently mentioned when testing digital scanning systems.[4-7,9-15] ISO 5725-1 describes the accuracy, trueness, and precision terms.[16] According to this, trueness refers to the closeness of agreement between the arithmetic mean of a measured subject and a known or true value. Precision refers to the closeness of agreement between test results. Trueness and precision refer to total accuracy.

When evaluating the trueness scores of digital scanning systems, it is necessary to use a scanner with superior features. Many studies in the literature have used the ATOS Core 80 (GOM GmbH, Braunschweig, Germany) industrial scanner as the reference scanner, similar to the present study.[14,17,18] This industrial optical scanner has two separate cameras and a projector described as a stereoscopic camera system. A projector that uses a structured light projection with narrow-band blue light is placed between these cameras. The scanner can achieve high-resolution scanning performance due to innovative Triple Scan technology.[14]

This *in vitro* study aimed to evaluate the trueness and precision of 14 different IOS by superimposing virtual models obtained from both the IOS and the reference scanner. The null hypothesis was that the 14 scanners would show no difference within and between groups.

MATERIALS AND METHODS

To obtain the reference model, a complete-arch maxillary model (KaVo Basic Study Model; KaVo Dental GmbH, Biberarh, Germany) was used. The teeth on the model were removed, and without filling the extraction sockets, the impression was made with a stock tray and polyvinyl siloxane (Hydrorise Implant; Zhermack, Badia Polesine, Italy) impression material. A gypsum model was obtained by pouring a scannable type 4 dental stone (GC Fujirock EP OptiXscan, GC Europe, Leuven, Belgium) into the impression. To simulate the All-on-4 concept (Straumann Pro Arch, Straumann Group, Basel, Switzerland), the implants (3.3 × 10 mm Bone Level, Straumann Group, Basel, Switzerland) were placed straight on the right and left canine regions and at an angle of 30° on the first molar regions. During the implant placement process, straight and angled multi-unit abutments (Straumann Screw-Retained Abutment, Straumann Group, Basel, Switzerland) used for this system were manually screwed into the implants. Then, open-tray impression posts were manually screwed into the multi-unit abutments screwed into the implants. Finally, these open-tray impression posts screwed into the multi-unit abutments were connected to the surveying arm of the parallelometer (Paraflex; BEGO GmbH, Bremen, Germany) (Fig. 1). The gypsum model with extraction sockets was placed on the surveying table of the parallelometer. The surveying arm of the parallelometer connected to the implants was aligned to the extraction sockets of the canine and first molar. The implants were placed in the canine regions parallel to each other through the straight multi-unit abutments screwed onto them. Although the open-tray impression posts were parallel to each other in the four implants used, the implants were placed at a 30° angle to the first molar region due to the abutment angles connected to these impression posts.

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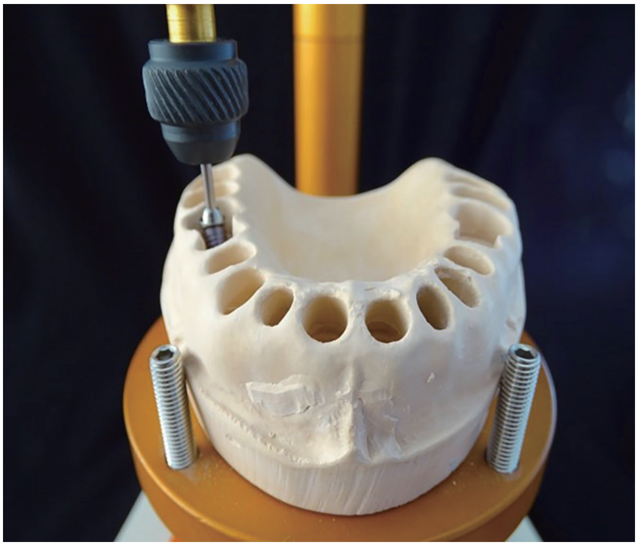

Fig. 1. Placing the implants on the gypsum model with the parallelometer.

In the extraction sockets where the implants would be placed, the surveying arm of the parallelometer was lowered until the neck of the implants was at the bone level. All the extraction sockets and the gaps between the implants and the extraction socket were filled with the same type 4 dental stone. After all these stages, a gypsum model was created in which the dental implants were placed. Before the scanning phase, the polyether ether ketone (PEEK) scan bodies (Straumann CARES Mono, Straumann, Basel, Switzerland) used to digitize the positions and angles of the implants were manually screwed into the model (Fig. 2).

Before the scanning procedure, reference point markers (Reference Point Markers; GOM GmbH, Braunschweig, Germany) with a diameter of 0.8mm were randomly and homogeneously placed on the gypsum model. These reference point markers, which were defined for both the reference scanner and the software, were used to perform the scanning more accurately. To evaluate the precision of the reference scanner used in the study (ATOS Core 80, GOM GmbH, Braunschweig, Germany), the model was scanned 10 times with the reference scanner and data were saved in a standard tessellation language (STL) file format. The first model of the 10 virtual models obtained from the industrial scanner was chosen as the reference model (Fig. 3).

For the experimental groups, the gypsum model was scanned 10 times for all 14 scanners: Primescan (Sirona Dental System GmbH, Bensheim, Germany), iTero 2 (Align Technology Inc., San Jose, CA, USA), iTero 5D (Align Technology Inc., San Jose, CA, USA), Virtuo Vivo (Dental Wings Inc., Montreal, Canada), Trios 3 (3Shape, Copenhagen, Denmark), Trios 4 (3Shape, Copenhagen, Denmark), CS3600 (Carestream, Rochester, NY, USA), CS3700 (Carestream, Rochester, NY, USA), Emerald (Planmeca OY, Helsinki, Finland), Emerald S (Planmeca OY, Helsinki, Finland), Medit i500 (Medit Corporation, Seoul, Korea), BenQ BIS-I (BenQ

Fig. 2. Master model.

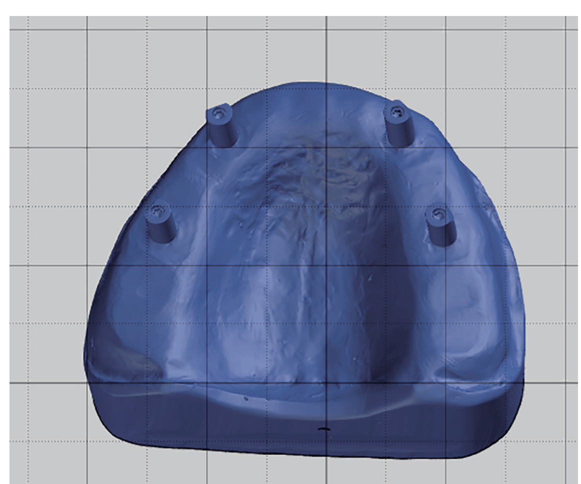

Fig. 3. Virtual reference model.

AB DentCare Corp., Taipei, Taiwan), Heron IOS (3DISC, Herndon, VA, USA), and Aadva IOS 100P (GC Corp, Tokyo, Japan) (n = 10) (Table 1). The output data files of the experimental groups were generated directly as STL files.

After the scanning phase, the unnecessary areas of the STL models obtained from the IOS were deleted. Before superimposition, the areas where the implants were located on the virtual models obtained from the IOS were selected one-by-one, and the remaining areas were deleted and not included in the superimposing procedure (Fig. 4).

The superimposition procedures were carried out using ATOS Professional v. 7.5 SR2' software (GOM GmbH, Braunschweig, Germany) according to the best-fit algorithm method. Before the superimposition processes, the reference model obtained from the industrial scanner was imported into the software. Then, the models obtained from the scanners in the experimental group, which had unnecessary areas, were deleted and imported into the software. The superimposition process was carried out by selecting the best-fit algorithm method from the superimposition options in the software. In this method, the software automatically superimposes the models obtained from the reference scanner and the scanners in the experimental group at common points and indicates the non-overlapping points as the deviation value. A large deviation value indicates that the experimental model is less similar to the reference model (Fig. 5).

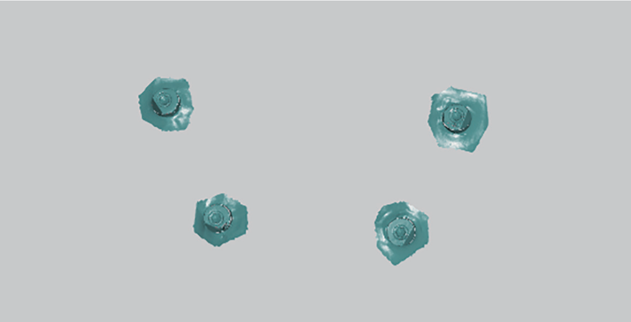

Fig. 4. Selection of implant areas on virtual model.

To evaluate the trueness of the IOS, 10 virtual models obtained from each of the 14 scanners (group = 14, n = 10) were superimposed with the reference model obtained from the industrial scanner. In this way, 140 superimpositions were made, 10 for each group. To evaluate the precision of the reference model and the IOS, the first model obtained from each scanner group was chosen as the reference model and superimposed with the remaining nine models. Then, the

Table 1. The 14 tested intraoral scanners

Scanner	Manufacturer	Acquisition technology	Software version
Trios 3	3Shape	Confocal microscopy and ultrafast optical scanning	v20.2.0
Trios 4	3Shape	Confocal microscopy and ultrafast optical scanning	v20.2.0
CS 3600	Carestream	LED light scanner-Active speed 3D video	v3.1.0
CS 3700	Carestream	Active triangulation with smart shade matching via bidirectional reflectance distribution function	v1.0.4
Primescan	Sirona	High-resolution sensors and shortwave light with optical high frequency contrast analysis for dynamic deep scan	v5.1.3
iTero 2	Align Technology	Parallel confocal microscopy	v1.12.0.990
iTero 5D	Align Technology	Parallel confocal microscopy	v2.7.0.990
Emerald	Planmeca	Red, green and blue lasers-Projected pattern triangulation	v5.3.2.13
Emerald S	Planmeca	Red, green and blue lasers-Projected pattern triangulation	v5.3.2.13
Heron IOS	3DISC	Active stereo imaging	3.7.1014.1
Virtuo Vivo	Dental Wings	Blue laser-Multiscan imaging technology	v2.1.0
Aadva IOS 100P	GC	Confocal microscopy	V2.2.0
Medit i500	Medit	Dual camera optical triangulation-3D in motion video technology	v2.5.2
BenQ BIS-1	BenQ	DLP structured light	v2.4.04

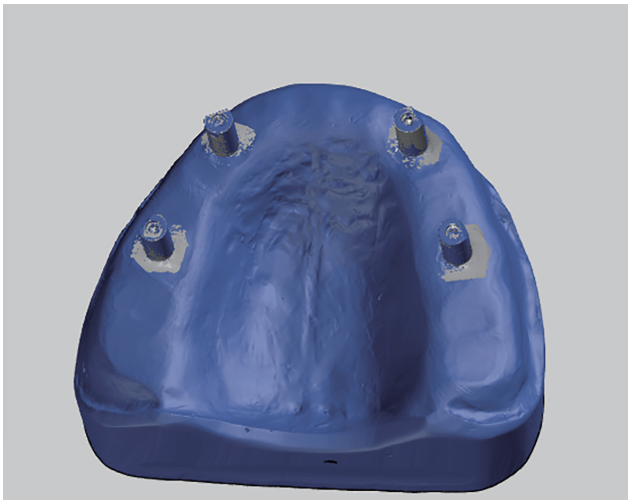

Fig. 5. Superimposing.

second model obtained from each scanner group was chosen as the reference model and superimposed with the remaining eight models. This process continued until the ninth model was selected as the reference model and superimposed with the tenth model. In this way, 675 superimpositions were made, 45 for each group (Fig. 6).

Statistical analysis of the findings was conducted using IBM SPSS Statistics 22 software (IBM, Armonk, NY, USA). The normality of the data distribution was evaluated with the Kolmogorov-Smirnov and Shapiro-Wilks tests, and it was determined that the parameters did not show a normal distribution. The Kruskal–Wallis test was used to compare the parameters among the groups and Dunn's test was used to determine the group that caused the difference. Significance was evaluated at the $P < .05$ level.

RESULTS

The trueness values of the scanners in the experimental group are shown in Table 2. There was a statistically significant difference between the experimental groups in terms of the deviation from the reference model ($P < .001$; $P < .05$) (Table 2, Fig. 7). No significant difference was found between the Primescan, iTero 5D, Virtuo Vivo, Trios 3, and Trios 4 scanners. Additionally, the trueness values of these scanners were found to be significantly lower than the trueness values of the Emerald, Medit i500, BenQ BIS-I, Heron IOS, and Aadva IOS scanners. No significant difference was found between the trueness values of the Emerald, Medit i500, BenQ BIS-I, Heron IOS, and Aadva IOS scanners ($P < .001$; $P < .05$) (Table 2, Fig. 7).

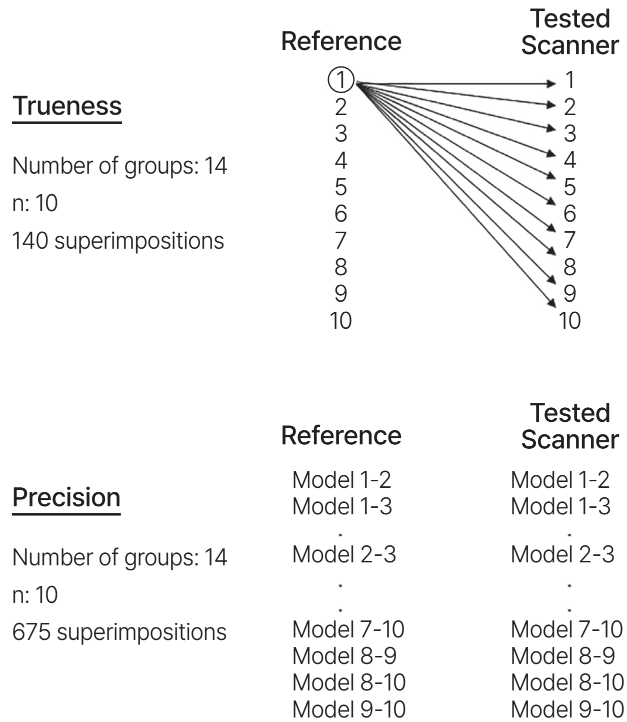

Fig. 6. Chart of accuracy (trueness and precision).

The precision values of the IOS are shown in Table 3. There was a statistically significant difference between the within-group deviations of the scanners ($P < .001$; $P < .05$) (Table 3, Fig. 8). The precision value was found to be significantly lower for the reference scanner than for all the other scanners. The precision value was found to be significantly lower for the Primescan scanner than for the other scanners in the experimental group. While there was no significant difference among the precision values of the iTero 5D, Trios 4, Trios 3, Medit i500, and Virtuo Vivo scanners, the precision values of these scanners were found to be significantly lower than those of the CS3600, BenQ BIS-I, Emerald, CS3700, Aadva IOS, and Heron IOS. No significant difference was found among the precision values of the CS3600, BenQ BIS-I, Emerald, CS3700, Aadva IOS, and Heron IOS ($P < .001$; $P < .05$) (Table 3, Fig. 8).

Table 2. Differences in trueness of scanners

Groups	Trueness					
	Mean (µm)	SD	Median	Minimum	Maximum	*P*
Primescan	13.02	2.47	12.4	9.6	16.8	1.000[a]
iTero 5D	32.19	6.94	32.4	21.3	46.3	1.000[a]
Virtuo Vivo	38.34	15.45	32.4	23.9	67.8	1.000[a]
Trios 3	40.16	12.93	41.4	24.0	65.6	1.000[a]
Trios 4	43.41	7.74	40.3	35.8	58.6	1.000[a]
CS3600	62.44	11.47	65.3	40.5	74.4	.010
Emerald S	64.87	15.93	61.5	43.2	99.0	.007
CS3700	68.00	53.86	53.6	15.5	210.0	.005
iTero 2	71.20	26.48	63.6	47.6	143.3	.002
Emerald	87.31	35.1	72.4	45.7	139.0	1.000[b]
Medit i500	90.77	11.98	89.8	70.3	107.4	1.000[b]
BenQ BIS-I	94.71	28.04	90.0	44.0	131.3	1.000[b]
Heron IOS	106.79	50.34	92.4	49.5	193.7	1.000[b]
Aadva IOS	115.87	46.12	104.6	67.2	205.5	1.000[b]

Kruskal Wallis Test *$P < .05$

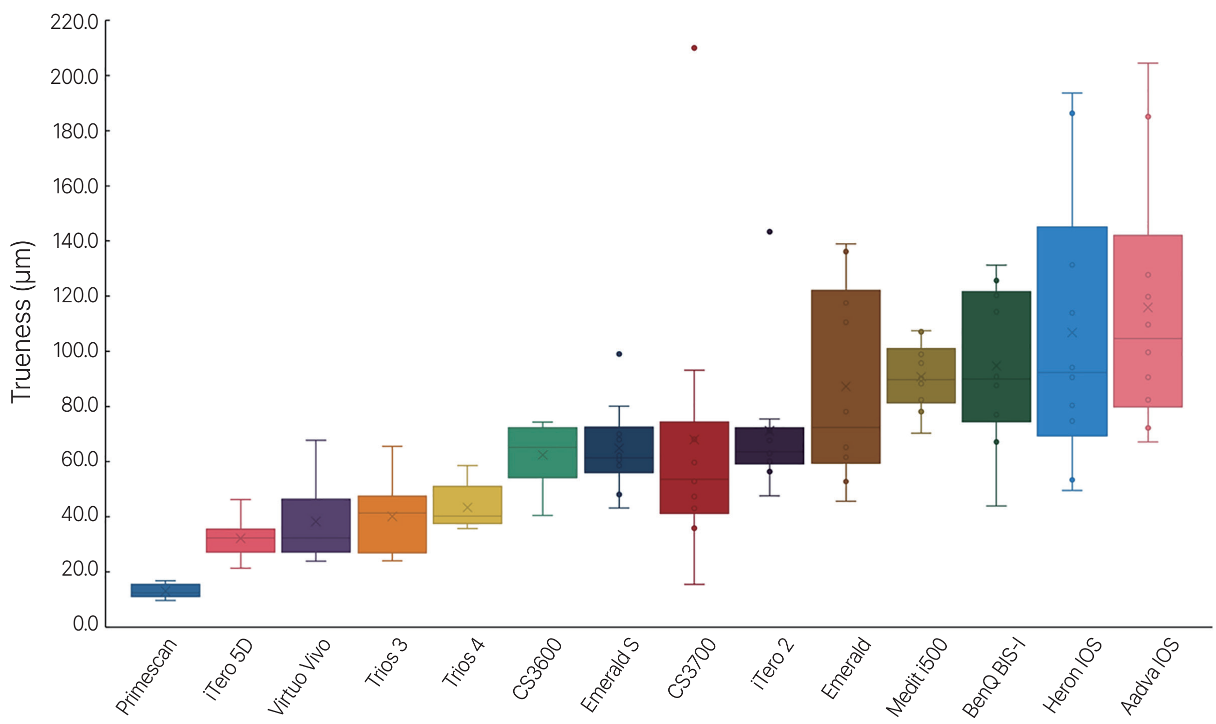

Fig. 7. Trueness of intraoral scanners.

Table 3. Differences in precision of scanners

Groups	Precision					
	Mean (µm)	SD	Median	Minimum	Maximum	*P*
ATOS	1.64	0.28	1.7	1.2	2.0	.002
Primescan	12.15	2.46	12.2	6.9	18.3	.005
iTero 5D	37.01	12.41	36.0	12.7	61.3	1.000[a]
Trios 4	42.86	16.68	40.8	14.8	86.0	1.000[a]
Trios 3	45.95	13.35	47.4	16.8	74.4	1.000[a]
Medit i500	47.80	14.31	44.8	28.0	88.9	1.000[a]
Virtuo Vivo	51.36	23.19	47.0	12.7	105.7	1.000[a]
Emerald S	69.20	20.64	69.8	29.2	121.2	.033
iTero 2	73.77	41.56	55.8	27.2	199.7	.045
CS3600	76.31	21.06	74.4	34.3	131.5	1.000[b]
BenQ BIS-I	78.34	32.48	70.0	34.3	226.5	1.000[b]
Emerald	88.07	36.30	82.3	38.2	157.0	1.000[b]
CS3700	107.56	57.38	85.8	31.9	240.3	1.000[b]
Aadva IOS	116.58	59.83	97.5	38.0	271.8	1.000[b]
Heron IOS	130.10	51.24	123.4	38.7	262.7	1.000[b]

Kruskal Wallis Test *$P < .05$

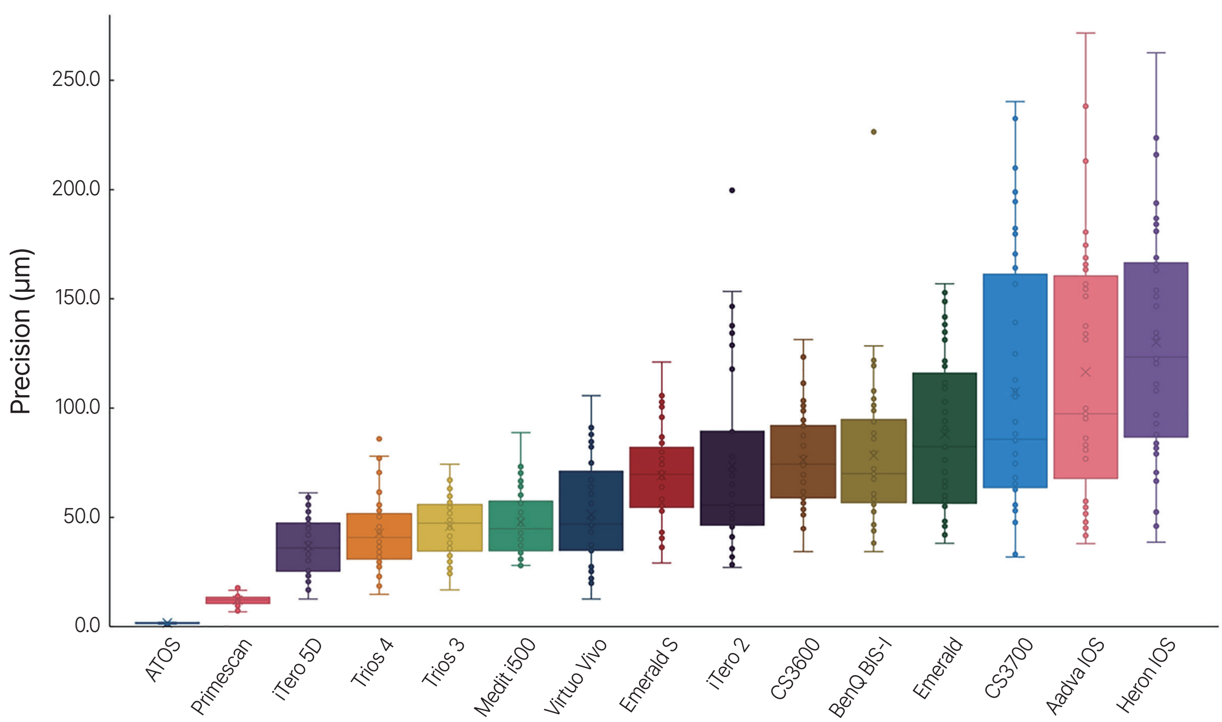

Fig. 8. Precision of all scanners.

DISCUSSION

Although there was no statistically significant difference among the deviation values of some of the IOS, the null hypothesis of the study, which was that the scanners would show no difference within and between groups, was rejected in general. The precision values were significantly higher for all the tested scanners in comparison to the reference scanner.

Recently, the All-on-4 concept has frequently been offered as a new treatment alternative for patients who cannot undergo implant treatment due to anatomical limitations or who need advanced surgical procedures. Clinical studies have shown that the All-on-4 concept is successful.[19-21] Since this system, which provides edentulous patients with fixed prosthetic restoration, is based on four implants, the angle and position of the implants must be adjusted precisely in accordance with the load distribution.[22] The present study tested how accurately these precise angles and positions were transferred digitally by 14 different IOS.

The gypsum model was poured with a scannable type 4 dental stone to avoid reflection and flash, and no finishing/polishing was done so that the scanners could better perceive the surface and find reference points.[23] As in similar studies, the scanning procedures were carried out a few days after the gypsum model was poured, and during this period, the model was stored in a protective box at constant room temperature.[14] However, at the end of the study, the gypsum model was not re-scanned to determine whether it was deformed. This can be considered a limitation of the study.[14]

In our study, the ATOS Core 80 (GOM GmbH, Braunschweig, Germany) industrial scanner, which was also used in similar studies, was used to create the reference digital model.[14,17,18] To compare the scan data, ATOS Professional v. 7.5 SR2 (GOM GmbH, Braunschweig, Germany) was used; the same company produced the ATOS software and the ATOS scanner. The superimpositions were carried out according to the best-fit-algorithm method, which is also frequently used in the literature.[23-26] In this method, the software superimposes the two mesh surfaces by the iterative closest point algorithm to minimize the difference and shows the non-intersecting points as deviations.[27] In the virtual models in the experimental group before the superimpositions, the areas other than the regions where the implants are located were deleted and excluded from the evaluation in order to avoid more common points and not adversely affect the accuracy of the scanners. In addition to not imitating soft tissue, the removal of regions representing soft tissue in the virtual model can be stated as a limitation of this study.

Optical artifacts, distortion of captured images, and missing data have been reported in studies of IOS.[14,28] During the scanning process with the IOS, the points that the scanners can use as references decreased because of the large edentulous areas in the gypsum model, which caused difficulties in combining the images and creating a virtual model. It has been observed that some scanners freeze in a fixed image, especially in edentulous areas, and they have difficulty resuming from that image. Additionally, it was observed that the scanners could not distinguish the locations of the scan bodies and superimpose the data during scanning. In that scenario, we had to start the scanning phase from the beginning or delete that part and scan it again. The 10 virtual models obtained from iTero 2 and iTero 5D were monitored on the computer and approved for completion after the scanning process. These data were then saved to the external disc and imported to the computer, where the superimposition procedures would be made. However, after this process, minor deformations were detected in two of the virtual models for each group. It is possible that this result occurred during the copy-paste and/or data conversion processes. Therefore, superimposing procedures were carried out for the models with minor deformation groups based on two implants instead of four.

Diker and Tak[29] compared the Primescan, Trios 3, Virtuo Vivo, Emerald, and iTero 2 devices for a 4-unit fixed denture. Although the trueness and precision results in that study are similar to our study, the deviation amounts of all the scanners for trueness, especially the Primescan (56 µm) and Virtuo Vivo (59 µm) devices, are lower in our study. In addition, the deviation amount of the Primescan (68.5 µm) device for precision was higher in that study than in our study.

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Di Fiore *et al*.[5] evaluated the deviations of the scanners in the X, Y, and Z planes for six implant-supported full-arch fixed dentures. In that study, the scanners were ranked according to the amount of deviation as follows: Primescan, Medit i500, and iTero Element.[5] In a study conducted by the same authors with a similar method in 2019 with eight scanners, the scanner ranking was Trios 3, CS3600 Emerald, and Dental Wings.[11] Although the deviation amounts could not be compared due to the method differences used in the studies, the rankings of the scanners in those studies were similar to the results in our study.

In a study conducted in 2020, 12 scanners were superimposed surface-based with the best-fit algorithm method.[30] In a study in which only trueness was compared, the trueness values were CS3700 (30.4 µm), iTero5D (31.4 µm), Medit i500 (32.2 µm), Trios 3 (36.4 µm), CS3600 (36.5 µm), Primescan (38.4 µ m), Virtuo Vivo (43.8 µm), Emerald S (52.9 µm), and Emerald (76.1 µm). The trueness values in that study are generally similar to the values found in our study; however, unlike our study, only the Primescan scores were found to be higher and the Medit i500 scores were lower.[30]

Mangano *et al*.[31] scanned a model with six implants using different scanners. The trueness and precision values in that study were: CS3600 (44.9 µm/35.7 µm), Trios 3 (46.3 µm/35.6 µm), Dental Wings (92.1 µm/111 µm), and Emerald (66.3 µm/88 µm).[31] Róth *et al*.[32] compared 12 different IOS for full arch scanning. That study used different comparison methods, and the Primescan and Trios 4 scanners were determined to be the most accurate. While the Emerald scanner showed the lowest accuracy value, the new-generation Emerald S produced by the same company showed better accuracy. Although that study noted that Primescan and Trios scanners are new-generation devices, new models of Dental Wings, Medit i500, iTero 2, and Emerald were launched with more advanced technologies.[32] In our study, among the iTero and Planmeca scanners, the accuracy values of the newer devices (iTero 5D and Emerald S) showed significantly better results than the older models (iTero 2 and Emerald). However, no significant difference was found between the CS3600 and CS3700 scanners or between the Trios 3 and Trios 4 scanners. Additionally, a newer device from the Dental Wings company, Virtuo Vivo, was used in our study.

Scanning procedures were carried out by the author, GK, who had no previous experience with IOS. Intra-group scans were carried out on the same day, and a 5 - 10 minute pause was used after each scan to cool down the machine. However, the illumination levels of the rooms were not standardized or measured during the scanning process. For portable scanners, computers provided by the manufacturers were used. However, in our study, the software and technical features of the computers were not considered. Thus, it is not possible to understand whether the lower or higher deviation values are related to software differences or computer hardware, which impedes the ability to compare the present study's findings with those of other studies in the literature. Moreover, the absence of oral fluids or tissues that complicate the scanning process and the inability to standardize the variables, such as light, temperature, and humidity, in the scanning rooms can be stated as a limitation of the present study.

CONCLUSION

Within the limitations of this *in vitro* study, the following conclusions can be drawn: Primescan, iTero 5D, Virtuo Vivo, Trios 3, and Trios 4 scanners are suitable for making impressions within the All-on-4 concept in terms of trueness and precision values. It should be considered that there may be data loss due to artifacts, reflections, and the inability to combine the data. With the development of scanning technologies, the accuracy of new-generation devices has improved. Further studies are needed to understand the clinical use of these devices.

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