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Comparison of 3D accuracy of three different digital intraoral scanners in full-arch implant impressions

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PURPOSE. This *in vitro* study aimed to evaluate the performance of digital intraoral scanners in a completely edentulous patient with angled and parallel implants. **MATERIALS AND METHODS.** A total of 6 implants were placed at angulations of 0°, 5°, 0°, 0°, 15°, and 0° in regions #36, #34, #32, #42, #44, and #46, respectively, in a completely edentulous mandibular polyurethane model. Then, the study model created by connecting a scan body on the implants was scanned using a model scanner, and a 3D reference model was obtained. Three different intraoral scanners were used for digital impressions (PS group, TR group, and CS group, n = 10 in each group). The distances and angles between the scan bodies in these measurement groups were measured. **RESULTS.** While the Primescan (PS) impression group had the highest accuracy with 38 µm, the values of 104 µm and 171 µm were obtained with Trios 4 IOSs (TR) and Carestream 3600 (CS), respectively ($P = .001$). The CS scanner constituted the impression group with the highest deviation in terms of accuracy. In terms of dimensional differences in the angle parameter, a statistically significant difference was revealed among the mean deviation angle values according to the scanners ($P < .001$). While the lowest angular deviation was obtained with the PS impression group with 0.185°, the values of 0.499° and 1.250° were obtained with TR and CS, respectively. No statistically significant difference was detected among the impression groups in terms of precision values ($P > .05$). **CONCLUSION.** A statistically significant difference was found among the three digital impression groups upon comparing the impression accuracy. Implant angulation affected the impression accuracy of the digital impression groups. The most accurate impressions in terms of both distance and angle deviation were obtained with the PS impression group. [J Adv Prosthodont 2023;15:179-88]

KEYWORDS
Accuracy; Angled implant; Digital implant impression; Full arch; Intraoral scanner

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INTRODUCTION

Recently, the dental field is undergoing many changes in implant treatment with the introduction of the CAD-CAM system. In particular, advances in digital impression using an intraoral scanner along with the conventional impression for fabricating implant prostheses have been remarkable. Numerous studies conducted to date have evaluated many factors that affect the conventional impressions of implant-supported prostheses, such as different implant impression parts, impression materials, plaster types, impression techniques, different implant numbers and depths, different angles and distances between implants.[1] However, there are limited studies on digital implant impressions.[1]

There are many studies on the comparison of conventional and digital impression techniques. However, a clear consensus has not been reached yet on which impression technique gives more sensitive and accurate impressions in completely edentulous situation when implants are placed at an angle due to existing anatomical limits and when the length of the scanned arch is long, and it is still a subject to discussion.[2] Nevertheless, the influence of digital workflows gradually increases owing to the fact that they save time during the execution of the workflow in dentistry, eliminate errors that may occur in conventional applications, save materials, reduce the number of sessions, and allow more predictable treatment planning.[2]

As a definition, impression accuracy is defined in terms of trueness and precision.[3] Trueness can be defined as the closeness of the measurement to the reference point, and precision is defined as the closeness of repeated measurements to the mean measurements.[4] In other words, trueness means how close the obtained data are to the reference point, and precision means how close the obtained data are to other test results.[5]

Intraoral scanners (IOSs) provide sufficient trueness for quadrant scans or full-arch scans of edentulous patients.[3,4] However, the trueness of IOSs in multiple implant scan body impressions in completely edentulous patients is still controversial since there is no reference point during scanning.[6] The trueness of IOSs is affected by the scanner model and working principle,[3,6] ambient light,[7,8] and software version.[9] Therefore, the introduction of new-generation IOSs with higher expectations requires further research that can prove trueness and precision. Although there are numerous studies in the literature on the trueness of full-arch implant scanning, data on the trueness of the latest generation of IOSs on the market for full-arch implant scanning are lacking.[3,6,10]

This study aimed to compare the accuracy of digital impressions taken with different currently-used IOSs of both angled and parallel implants in a completely edentulous mandible and investigate the effect of implants placed at different angles on impression trueness.

The null hypotheses of this study are that there will be no difference among the impression accuracy of three different IOSs and implant angulation will not affect the digital impression accuracy.

MATERIALS AND METHODS

Six (3.5 mm × 13 mm) implants (#2-09-10; Medentika GmbH, Hugelsheim, Germany) were placed at different angles in a completely edentulous mandibular model with polyurethane content (#10-1040; Promedicus, Mikołów ul, Poland) in regions #36, #34, #32, #42, #44, and #46. No. 34 implant was placed at distal angulation of 5°, no. 44 implant was placed at distal angulation of 15°, and the other four implants were placed in the model parallel to the bone level. After placing all implants, as practiced in the clinic, six scan bodies (#2-09-10; Medentika GmbH, Hugelsheim, Germany), designed to fit directly into the implant and manufactured entirely of polyetheretherketone (PEEK) material, were screwed to the implants by hand and made suitable for digital scans (Fig. 1A). The mandibular model was scanned with an optical scanner ATOS Capsule (GOM GmbH, Braunschweig, Germany) with a 3 µm trueness and a 2 µm precision, and a 3D reference model was obtained and then exported in the stereolithography (STL) file format (Fig. 1B). After the reference scanning, digital impressions of the models were taken using three different digital IOSs: Carestream 3600 (Carestream Dental, Atlanta, GA, USA), Primescan (Dentsply-Sirona, York, PA, USA)

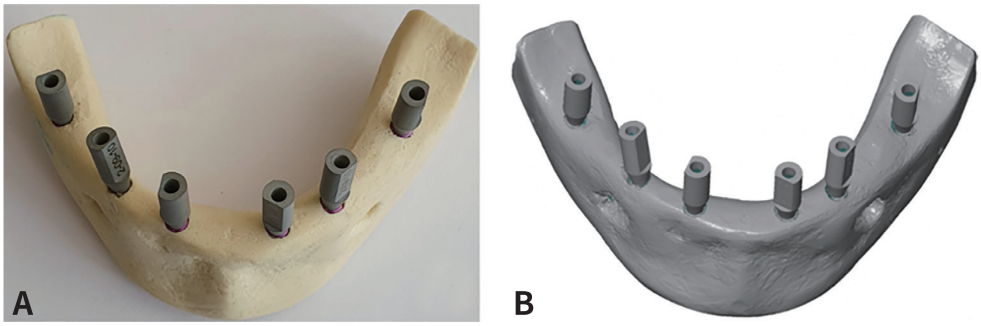

Fig. 1. Real and virtual views of the study model; the study model after placing scan bodies (A) and the digital 3D reference model obtained with the ATOS Capsule (B).

and Trios 4 IOSs (3Shape, Copenhagen, Denmark). A single researcher without previous experience with digital IOSs performed all digital scans in this study. A method conducted by Amin *et al*.[11] in 2015 was applied. At first, 10 trial scans were performed with each IOS. Thus, it was attempted to ensure the researcher's familiarity and mastery of the working methods of different IOSs. After each scan, there was a break of 5 min for the scanner to cool down and the researcher to rest.[12] In this study, after 10 trial scans were performed with each of the Carestream 3600, Primescan, and Trios 4 IOSs, 10 final scans were performed. During scanning, all of the scanners were operated according to the manufacturer's scanning recommendation protocol. Therefore, the same scanning protocol was applied to the CS 3600 and Trios 4 scanners. While performing scanning with these two scanners, all occlusal surfaces were scanned from the occlusal surface of no. 46 scan body to no. 36 scan body located in the opposite arch. Then, the scanner was turned to the vestibular surface at an angle of 45°, and all buccal surfaces were scanned up to no. 46 scan body. Finally, the scanner tip was turned to the lingual surface at an angle of 45°, and all occlusal surfaces were scanned up to no. 36 scan body (Fig. 2A and 2B). The Primescan scanner has a different scanning protocol from other scanners, and scanning was performed as follows. Firstly, the occlusal surface of no. 46 scan body was scanned, and then the scanner tip was turned to the lingual surface at an angle of 60°, and all lingual surfaces were scanned up to no. 36 scan body. Then, the scanner tip was reversed, and scanning was continued from the occlusal surface of no. 36 scan body, and the entire occlusal surface was scanned up to area no. 46 scan body. After the occlusal surface was finished, the scanner tip was rotated at an angle of 60° to the vestibular surface of no. 46 scan body, and scanning of the entire vestibular surface was completed at no. 36 scan body located in the opposite arch (Fig. 2C). All scan data were then retrieved from the computer via Universal Serial Bus (USB) memory stick in the STL file format. A total of 30 different STL files were obtained, including 10 STL files with the Primescan IOS, 10 STL files with the Carestream 3600 IOS, and 10 STL files with the 3Shape Trios 4 IOS including 10 STL files from each scanner.

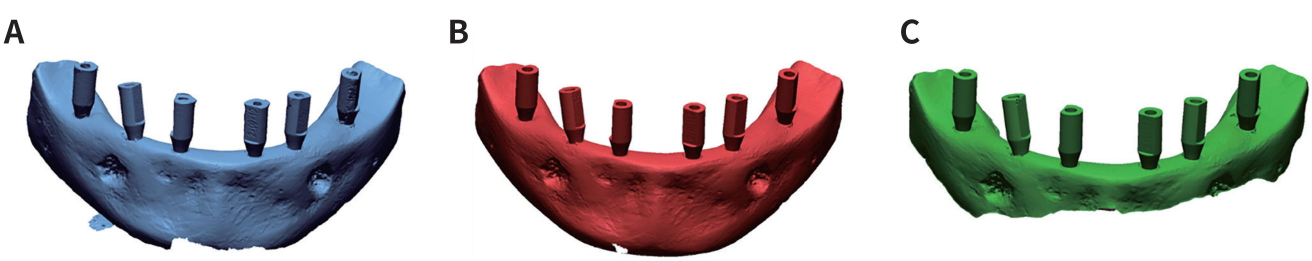

Fig. 2. Views of the study model taken from different browsers in Geomagic Design X software; the CS 3600 scanner (A), the Trios 4 scanner (B) and the Primescan scanner (C).

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To measure distances and angles between scan bodies on 3D images, all STL files taken were transferred to the Geomagic Design X (3D Systems, Inc., Rock Hill, SC, USA) program, reverse engineering software. Three points that would form the plane on the upper surface of the scan bodies were determined, and the reference plane was created. Using this plane, two separate reference planes were created at a distance of 2.5 mm and 5 mm, on which the circles necessary to determine the reference axes of the cylinders in the scan bodies were drawn (Fig. 3A). Afterward, by drawing new circles on the mesh sketch curves on the defined planes, the center point of the section was obtained (Fig. 3B), and in the next step, the points giving the coordinates of the circle centers to be used in distance measurements were defined using the "point" command (Fig. 3C). The scan body center lines passing through the center points used in angle measurements were obtained by combining the defined points (Fig. 3C).

Cartesian (x, y, z) coordinates of the points determined for all 6 scan bodies in a scan image were exported from the software as a (.txt) extension. The coordinates of the point showing the exact center of each scan body were determined by taking the difference of the points showing the lower and upper circle centers for each implant. Firstly, the trueness level, which is the first parameter that makes up the impression accuracy, was calculated. In this calculation, both the distance and angular deviations between the scan bodies were determined. The distance between the two reference points (P_1 and P_2) was calculated using the following formula[2]:

$$|P_1P_2| = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}$$

In this way, distance measurements between the implants with all known center coordinates were carried out between scan bodies no. 46-44, 46-42, 46-32, 46-34, and 46-36, respectively, by referring to no. 46 scan body in the right posterior region first (Fig. 3D).

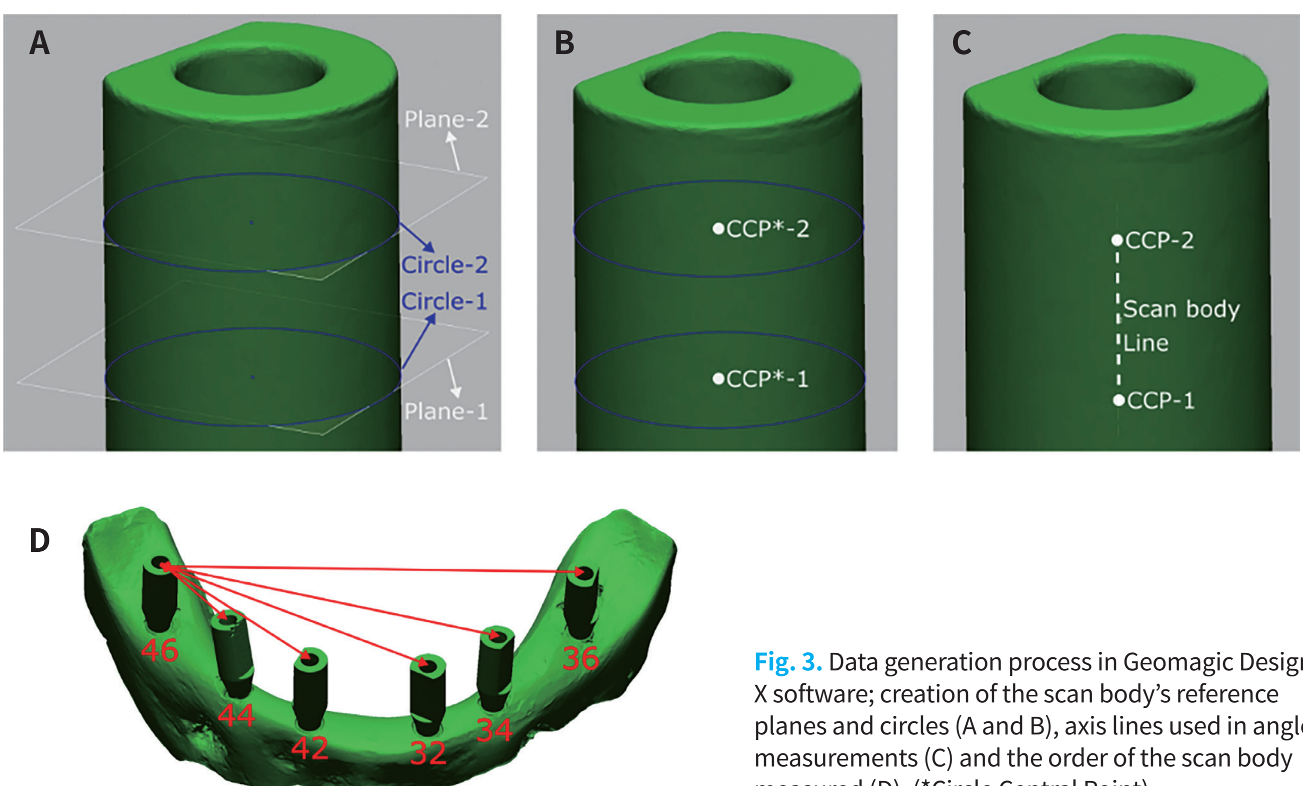

Fig. 3. Data generation process in Geomagic Design X software; creation of the scan body's reference planes and circles (A and B), axis lines used in angle measurements (C) and the order of the scan body measured (D), (*Circle Central Point).

Likewise, the following formula was used to calculate the angle between the implants[2]:

$$l_1 = \frac{x - x_1}{a_1} = \frac{y - y_1}{b_1} = \frac{z - z_1}{c_1} \; ; \; l_2 = \frac{x - x_2}{a_2} = \frac{y - y_2}{b_2} = \frac{z - z_2}{c_2}$$

$$\cos \varphi = \frac{\vec{s_1}\,\vec{s_2}}{\left|\vec{s_1}\right| \cdot \left|\vec{s_2}\right|} = \frac{a_1 . a_2 + b_1 . b_2 + c_1 . c_2}{\sqrt{{a_1}^2 + {b_1}^2 + {c_1}^2} . \sqrt{{a_2}^2 + {b_2}^2 + {c_2}^2}}$$

In the formulation, lines l_1 and l_2 represent the scan body lines between circle center points 1 and 2, and s_1 and s_2 represent their direction vectors. The a, b, c terms are the coefficients used to calculate the s (s = ai + bj + ck) vector in the Cartesian coordinate system (x, y, z).

The procedure was performed according to the line passing through the center points of the two circles determined for the scan bodies. In the formula above, firstly, lines (l_1 and l_2) were found according to the determined points, and then the angle between these lines was calculated. Precision, the second parameter of accuracy, was determined by both distance and angular data revealed by the impression groups. The group data includes data from 10 different scans taken from a scan device using the same scan bodies (e.g. no. 46-32). Firstly, the averages of the distance and angle measurements between the reference scan body (no. 46) and the other scan bodies of 10 impressions belonging to each impression group were found. Then, it was revealed how much each impression deviated from the mean value of its own impression group. Thus, each impression was evaluated within its group, and distance and angular precision values were determined.

Data were analyzed using a statistical software program (IBM SPSS Statistics, v23, IBM Corp., Chicago, IL, USA). The conformity to the normal distribution was examined by the Shapiro-Wilk test. The intra-class correlation (ICC) coefficient was used to examine the intra-scanner precision. The paired two-sample *t*-test was used based on the reference scanner (ATOS Capsule; GOM GmbH, Braunschweig, Germany) values in the examination of trueness. Repeated analysis of variance was used to compare the normally distributed angle and distance values according to the scanners. The Pearson correlation coefficient was used to examine the relationship between normally distributed angle and distance values. The level of significance was taken as $P < .05$.

RESULTS

According to the comparison of the mean distance and angle values of the three impression groups with the reference model values, a statistically significant difference (Table 1) was found in terms of a dimensional difference in the distance parameter among the impression groups ($P = .001$). The mean deviation value of the Primescan digital impression group (PS) scanner was 38 ± 22 µm, the mean deviation value of the Trios 4 digital impression group (TR) scanner was 104 ± 14 µm, and the mean deviation value of the Carestream 3600 digital impression group (CS) scanner was 171 ± 55 µm (Fig. 4). In terms of dimensional differences in the angle parameter, a statistically significant difference was revealed among the mean deviation angle values according to the scanners ($P < .001$). The PS digital impression group constituted the impression group with the mean deviation of 0.185° ± 0.115 (Fig. 4), whereas a statistically significant difference was detected between the TR and CS digital impression group ($P < .05$). The CS digital impression group was the impression group that had with 1.250° ± 0.459, and no significant difference between CS and the TR digital impression group was found ($P > .05$). The mean angle deviation of the TR digital impression group was obtained as 0.499° ± 0.077 (Table 2). In accordance with the absolute statistical results of the deviation amounts of IOSs from their average

Table 1. Comparison of distance deviation values by scanners

	Deviation distance Mean ± std. deviation
Primescan (PS)	0.038 ± 0.022[a]
Trios 4 (TR)	0.104 ± 0.014[b]
Carestream 3600 (CS)	0.171 ± 0.055[c]
Test statistics	F = 19.393
P	.001

[a-c]: There is no significant difference between scanners with the same letter.

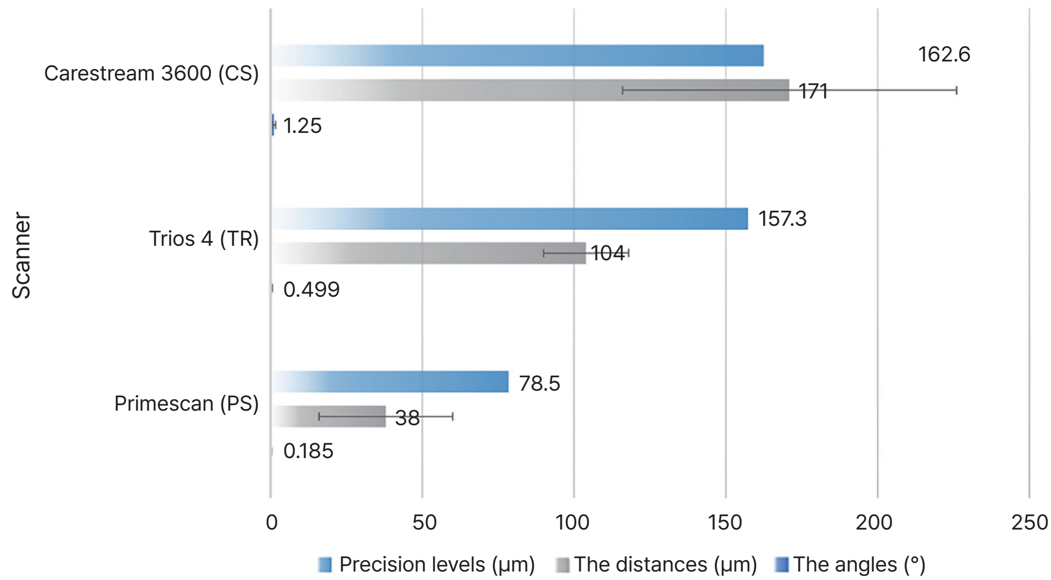

Fig. 4. Results of the measurement; dimensional differences in the distance (µm) and in the angle (°) parameters among the impression groups and precision levels (µm) of intraoral scanners.

Table 2. Comparison of angle deviation values by scanners

	Deviation angle Mean ± std. deviation
Primescan (PS)	0.185° ± 0.115°[a]
Trios 4 (TR)	0.499° ± 0.077°[b]
Carestream 3600 (CS)	1.250° ± 0.459°[b]
Test statistics	F = 17.783
P	< .001

a-b: There is no significant difference between scanners with the same letter.

values in each scan, the precision levels (Fig. 4) were obtained as 78.5 µm for the PS impression group, 157.3 µm for the TR impression group, and 162.6 µm for the CS group (Table 3). No statistically significant difference was detected among the impression groups in terms of precision values ($P > .05$).

DISCUSSION

In this *in vitro* study, to compare the accuracy of three different digital intraoral scanners used to take impressions of 6 implant placed in a 3D printed mandibular edentulous model, a scan body connected to the implant was scanned and distances and angles were measured. While the highest deviation was obtained from the CS scanner, the lowest mean deviation val-

Table 3. Deviation amounts (mm) of intraoral scanners from their average values in digital impression scans

	Mean	Std. deviation	Std. error	95% Confidence interval		Test statistics	*P*
				Lower limit	Upper limit		
Primescan (PS)	0.0785	0.0542	0.0171	0.0397	0.1173	F = 3.909	.051
Trios 4 (TR)	0.1573	0.0886	0.0280	0.0939	0.2206		
Carestream 3600 (CS)	0.1626	0.1198	0.0379	0.0769	0.2483		
Total	0.1328	0.0966	0.0176	0.0967	0.1689		

F: Analysis of variance test statistics.

ue was acquired from the PS scanner. Based on the results of this study, the null hypothesis stating that the impression accuracies of digital scanners would be similar in full-arch implant cases was rejected. Furthermore, the hypothesis predicting that implant angulation would not affect the digital impression accuracy was rejected. A statistically significant difference was obtained among the scanners (*P* < .05).

There are differences in the operating principle among the three IOSs used in this study. IOSs capture images during scanning and create mesh surfaces by processing data accordingly. This procedure directly affects the scan quality and the trueness of scans. Moreover, there are many factors that affect the trueness of scans, such as operator experience,[13-15] ambient lighting,[7,8,16] patient,[3] implant angle,[17-19] depth of implants,[14,20] software versions,[9] and scan body material used.[5]

Mangano *et al*.[6] took digital impressions on a 6 implant placed edentulous plaster model using five different IOSs (Trios 3, CS 3600, Emerald, DWIO, and Omnicam). CS 3600 yielded better results than Trios 3 and Emerald. The results they obtained contradict the results of our study, but the different results can be attributed to differences in the study models and the reference scanner used. They used a maxillary model with 6 implants, the implants were closer to each other in comparison with the model in the present study, and the study models included a gingival mask. Moreover, they used different reference scanners (Freedom UHD; Dof Inc., Seoul, Korea) from our study.

In a study comparing the impression accuracy of Primescan and Cerec Omnicam digital IOSs in a completely tooth-supported maxillary model, the digital impression group obtained with Primescan yielded more successful results.[21] In two separate models, partially edentulous (with 2 implants placed) and completely edentulous (with 4 implants placed), three different digital IOSs (Primescan, CS 3600, and Trios 3) were used, and the impression accuracies were compared, and Primescan (13.02 ± 2.47 μm) was found to be the most successful IOS group.[22] In a thesis study, four implants were placed in a completely edentulous maxillary model, and the impression accuracies were compared using 14 different IOSs (Primescan, CS 3600, CS 3700, Trios 3, Trios 4, iTero 5D, iTero 2, Dental Wings, Emerald S, Emerald, Medit i500, BENQ, Heron, GC Aadva), and a statistically significant difference was found among the scanners (*P* < .05). As a result of the study, the best digital impression group was obtained with the Primescan scanner.[23] The results of all 3 studies were obtained with the Primescan scanner in parallel with our study. The results of these studies support the results of our current study.

Gimenez *et al.*[24] examined the effect of implant angulation on the impression taken with the iTero digital IOS and placed a total of 6 implants in an edentulous maxillary model, including 4 parallel implants, one implant at distal angulation of 30°, and one implant at mesial angulation of 30°. As a result of the study, they reported that implant angulation did not affect the digital impression trueness.

Flügge *et al*.[25] used three different digital IOSs (iTero, Trios 3, and True Definition) in their study and reported that implant angulation affected digital impression accuracy. In a thesis study,[26] the researchers examined the effect of angled implants on impression accuracy using two different digital IOSs (GC AADVA IOS Intraoral 3D Scanner and Cerec Omnicam) in a completely edentulous maxilla with 6 implants placed at 0°, 15°, and 30° angles. As a result of the study, they found a statistically significant difference among the angles in terms of deviation values.

Upon comparing the angular deviation values of IOSs, the amount of angular deviation obtained with Primascan was found to be significantly lower compared to Trios 4 and Carestream 3600. Our hypothesis predicting that digital IOSs would not be affected by implant angulation was rejected. It is thought that factors such as imaging principles of digital IOSs, scanning protocols, software, and ambient lighting affect this result.

The impression accuracy of digital IOSs can be affected by various factors such as scanning protocol and operator experience. However, since there are few studies investigating scanning protocols and manufacturers do not share sufficient information about scanners, no consensus has been reached yet on which technique yields a better result.[27] The Carestream 3600 scanner operates with active triangulation, the Trios 4 scanner operates with confocal mi-

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croscopy, and the Cerec Primescan scanner operates with the dynamic deep scanningprinciple.[28] Moreover, while Cerec Primescan and Trios 4 perform scanning with a video imaging (continuous imaging) method, Carestream 3600 creates a 3D image with a photo imaging method. It was thought that these differences affected the study results.

Numerous studies comparing various implant impression techniques in terms of accuracy have used different impression methods. Researchers such as Imburgia, Papaspyridakos, and Amin calculated how much each scan body deviated from its original coordinates on the reference model by following the superimposition method of the obtained images with the reference model and revealed dimensional differences.[10,11] However, some researchers state that there may be a certain amount of difference during the superimposition of images and this difference may affect the result. Therefore, Gimenez[14] and Moura[29], in their studies on full-arch implant cases, chose the implant in the most posterior region as a reference and measured distances between this implant and other implants and determined the deviation according to the reference model. In this study, this technique was also preferred, and the scan body in the right posterior region was accepted as a reference, and the measurements of full-arch impression accuracy were completed. Andriessen *et al.*[30] reported that IOSs had difficulty finding the reference point because the scan bodies used when taking digital impressions in an edentulous jaw had the same shape and form, and it was not possible to accurately match the scanned area with the previous images. In a review study published in 2018, Mizumoto *et al.*[31] stated that as a result of scanning by splinting scan bodies with each other, reference points could be perceived more easily and impression accuracy could be increased in this way. In our study, especially when performing scanning with the CS 3600 IOS, the reference point was lost frequently, the scanning was difficult, and there was a return to the previous reference image to capture the reference point. This is thought to be due to the scanner's software. It has been revealed that distances between the scan bodies have problems combining the images obtained previously by scanners with the images of the newly scanned region, and it is thought that this affects the scanning, and that the shape and image of all scan bodies are the same, making it difficult to lose the reference point and combine the reference points during scanning.

As a result of their study, Seelbach *et al.*[32] reported that different results among different intraoral digital impression systems might depend primarily on the physical resolution characteristics of scanning systems, the software in the process of adding data to each other, and the image recording angle of devices during triangulation.

Since our study was conducted *in vitro*, some patient-related factors were eliminated. It is thought that factors such as saliva, transparency, and the amount of reflection of light from oral tissues, patient movements, and the inability of the scanner tip to reach the posterior regions may affect the trueness of digital imaging, especially in patients with limited mouth opening. Additionally, differences in the mucosal surface caused by jaw movements may affect the scanner's ability to find the reference point to continue imaging, which can lead to various problems during software combining the obtained images. To develop these results or to arrange them clinically, the results of digital impression systems obtained in the study should be supported by in vivo studies.

CONCLUSION

Upon evaluating the study results, the best digital impression group in terms of both trueness and precision was obtained with the Primescan scanner. Implant angulation affected the impression accuracy of digital scanners. Considering angular deviation, Primescan was found to be more successful than the other two impression groups.

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