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Abstract

Purpose: The accuracy of digital impressions is still controversial for complete arch implant cases. The aim of this study is to compare the accuracy of different intraoral scanners with the conventional technique in terms of trueness and precision in a complete arch implant model.

Material and Methods: Eight implants were inserted asymmetrically in a polyurethane edentulous mandibular model with different angulations. A 3-dimensional (3D) reference model was obtained by scanning this polyurethane model with an optical scanner. First, digital impressions were made by using 3 different intraoral scanners: Carestream 3500 (DC), Cerec Omnicam (DO) and 3Shape Trios 3 (DT). Subsequently, a nonsplinted open tray impression technique was used for conventional impression group (C) and then the master casts were digitalized with a lab scanner. Each 10 STL files belonging to 4 different impression groups were imported to a reverse engineering program, to measure distance and angle deviations from the reference model. All statistical analyses were performed after taking absolute values of the data. After comparing the impression groups with one-way ANOVA, the trueness and precision values were analyzed by Tukey post hoc test and 0.05 was used as the level of significance.

Results: The mean trueness of distance was 123.06 ± 89.83 μm for DC, 229.72 ± 121.34 μm for DO, 209.75 ± 47.07 μm for DT, and 345.32 ± 75.12 μm for C group ($p < 0.0001$). While DC showed significantly lower deviation compared to DO and C, no significant difference was found between DC and DT. C showed the highest distance deviation significantly in all groups; and no significant difference was found between DO and DT groups. In angle measurements; the trueness was 0.26° ± 0.07° for DC, 0.53° ± 0.42° for DO, 0.33° ± 0.30° for DT, and 0.74° ± 0.65° for C group. There was no significant difference between the groups in terms of angular trueness ($p = 0.074$). In terms of the precision for distance, the results of DC 80.43 ± 29.69 μm, DO 94.06 ± 69.96 μm, DT 35.55 ± 28.46 μm and C 66.97 ± 36.69 μm were determined ($p = 0.036$). The significant difference was found only between DT and DO among all groups. Finally, angular precision was determined to be 0.19° ± 0.11° for DC, 0.30° ± 0.28° for DO, 0.22° ± 0.19° for DT, and 0.50° ± 0.38° for Group C. No significant difference was found between the groups, in terms of angular precision ($p = 0.053$).

Conclusions: All digital impression groups yielded superior data compared to conventional technique in terms of trueness. DC formed the impression group with the highest trueness in both distance and angular measurements. The results of this in vitro study suggest the use of intraoral scanners compared to the conventional impression techniques in complete arch implant cases with high angulations.

Digital impressions made with intraoral scanners (IOS) have started to find a comprehensive place in the clinical routine in dentistry, which has entered the era of digital production. The use of IOS, which has demonstrated its success in many studies and clinical applications, has also become a current issue in complete arch implant cases. To date, the standard treatment approach for complete arch implant prosthesis is making the implant impression with elastomeric impression materials conventionally, obtaining a master cast and digitizing it with a laboratory scanner and then performing the digital production steps.[1,2] However, in this conventional impression technique, many factors result in the inability to transfer the impression copings in accurate position or their exposure to micro-motions within the impression. Insufficient interlocking between the analog-impression coping, dimensional deviations in impression materials and gypsum can affect the success.[3–5] Additionally, the conventional procedures take too long and negatively affect the comfort of patients.[6–8]

These limitations of conventional implant impressions were eliminated by the use of the scan body and the 3-dimensional (3D) positions of the implants were able to be transferred to the digital system.[9] However, in edentulous cases IOS has limited reference points to continue scanning properly.[10] Besides, scanning the multiple scan bodies can be quite challenging for the IOS to distinguish these parts from each other and create an image in the correct position within the arch.[11] Although there have been many studies regarding the accuracy of digital impressions on complete arch implant cases,[12–18] in a current systematic review published by Papaspyridakos et al[19] only one study comparing both digital and conventional impression techniques in a jaw containing more than 6 implants has been detected. Tan et al[20] evaluated the accuracy of digital and conventional impression techniques on 8 parallel implants placed in the maxilla. To the best of the authors' knowledge, there is no study in the current literature that compares both impression techniques in an edentulous mandibula where 8 implants are placed with angulations.

On the other hand, the features of the IOS and different scanning strategies may also influence the accuracy of digital impressions. It has been reported that different ways of obtaining 3D images, such as creating an image series (Carestream 3500) or producing 3D structure with a video acquisition system (Cerec Omnicam, 3Shape Trios 3);[21] and different working principles used by IOS such as active triangulation (Carestream 3500),[22] optical triangulation and confocal microscopy (Cerec Omnicam) and confocal microscopy with ultrafast optical scanning (3Shape Trios 3); may affect the accuracy of digital impressions at different levels.[13] The scanning strategy can affect the accuracy of digital impressions as well,[23] so it is important to follow the optimal scanning path for each IOS.

The aims of this study are two fold: first is to compare digital and conventional impression techniques in a clinically unfavorable complete arch implant case, and secondly to compare the accuracy of 3 different IOS with different imaging principles in terms of trueness and precision. The null hypotheses were that digital impressions to be made with different IOS provide data with similar accuracy as conventional technique and the scanners working with the video-acquisition system (3Shape Trios 3 and Cerec Omnicam) would be superior to the scanner working with the image-acquisition system (Carestream 3500), when both trueness and precision parameters were evaluated.

Material and methods

The complete arch implant model was obtained by placing 8 Dyna Helix DC implants (Dyna Dental Engineering BV, the Netherlands) (4.2 mmD and 11.5 mmL) in a polyurethane lower jaw model (Promedicus, Poland). These 8 implants were placed in the following areas: right second molar, right first premolar, right canine, right central incisor, left canine, left first and second premolar, left second molar. Four of them (right and left second molars, right and left canines) were tilted distally with 40°, 20°, 15°, 25° angulation, respectively; and the other implants were placed perpendicular to the occlusal plane. By placing the implants with these distal angulations, the goal was to obtain a complete arch model including tilted implants such as in all-on-4 or all-on-6 cases and reflect the effects of the angulations on different impressions techniques.

Eight Dyna universal Ti-base abutments (Dyna Dental Engineering BV, the Netherlands) were attached and screwed to the implants by hand force. Finally, before the digital scans, Dyna scan bodies (Dyna Dental Engineering BV, the Netherlands), which were designed to fit onto the Ti-base abutments, were placed on the model. The reference 3D model was obtained by scanning the lower jaw model with Activity 885 Mark 2 Scanner (Smart Optics, Bochum, Germany) with accuracy of 6 μm and it was exported as standard tesselation language (STL) file.

A single operator carried out all digital impressions to ensure the operator's control over the working methods of different scanners. The first 10 trial scans were performed with each IOS. Between each scanning, the scanner and the operator were given 5-minute intervals. All impressions were started with scanning from the right posterior region (right second molar) and continued towards left posterior region (left second molar) on the opposite side of the arch and the scan paths were determined according to the manufacturer's instructions for each IOS.[24–26]

In the scans carried out with Carestream 3500 (Carestream, Rochester, NY), the occlusal surfaces of all scan bodies were first displayed from right second molar to left second molar, then buccal and finally the lingual surfaces were scanned and the impression was completed. In Cerec Omnicam (Dentsply Sirona, Bensheim, Germany), the scans started from the occlusal surface and then continued by buccal and then the lingual surface of the same scan body and the imaging was completed in the left posterior region. For Trios 3 (3-Shape, Copenhagen, Denmark), the scanning of occlusal surfaces was performed starting from the right posterior region, followed by lingual and finally buccal surfaces. The missing areas, particularly interproximal surfaces, were re-scanned and 10 digital abutment-level impressions for each IOS were completed. Finally, a total of 30 scans as determined in power analysis were obtained and exported as STL files.

For conventional implant impressions, 8 open tray impression copings (Fig 1) were used with 10 individual open trays prepared to provide uniform thickness of the impression material. The boundaries of trays were arranged to serve as stops at 4 points, 2 of them in molar and 2 of them in

Figure 1 Complete arch implant model with open tray impression copings.

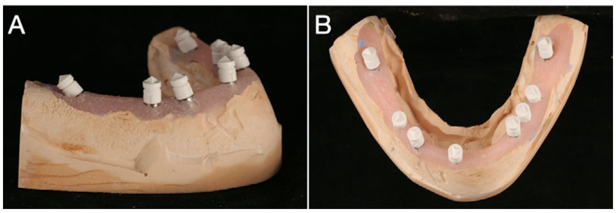

Figure 2 (A) Cast model with scan bodies (B) Angulation between scan bodies.

premolar zone. Kerr polyvinyl siloxane (PVS) tray adhesive (KaVo Dental GmbH, Bismarckring, Germany) was applied to the trays 10 minutes before each conventional impression. Afterwards, the normal set Elite HD + putty soft and Elite HD + light body (Zhermack SpA, Italy) PVS were placed in the tray and it was adapted to the lower jaw model by using one-step impression procedure. The impression material was allowed to set for 10 minutes (manufacturer's setting time of 5.30 minutes). Then, analogs were attached to the impression copings and Zhermack Gingifast Elastic (Zhermack SpA, Italy) was applied around the copings. For the casts, standard 150 g GC Fujirock type IV dental stone (GC Corporation, Tokyo, Japan) was used with a liquid-powder ratio of 1:5 and the minimum separation time of the tray was increased to 2 hours with the cast model specified by the manufacturer, and the trays were kept at room temperature during the setting.

In order to digitize 10 cast models obtained with conventional technique and standardize the scans with abutment-level impressions, 8 Ti-base abutments and 8 scan bodies were placed on the cast models again (Fig 2A, 2B). They were scanned with Straumann 7 Series laboratory scanner (Straumann Group, Basel, Switzerland) and 3D models were obtained. As a result, a total of 40 different STL files (30 scans of digital technique, 10 scans of conventional technique) were obtained to make the comparisons with 3D reference model, in terms of distance and angular parameters.

In order to carry out measurements on 3D images, all STL format files were transferred to Rapidform (INUS Technology Inc., Seoul, South Korea), reverse engineering software. The reference points were determined on the scan bodies. Two circles were created at a distance of 0.7 and 3.4 mm from the

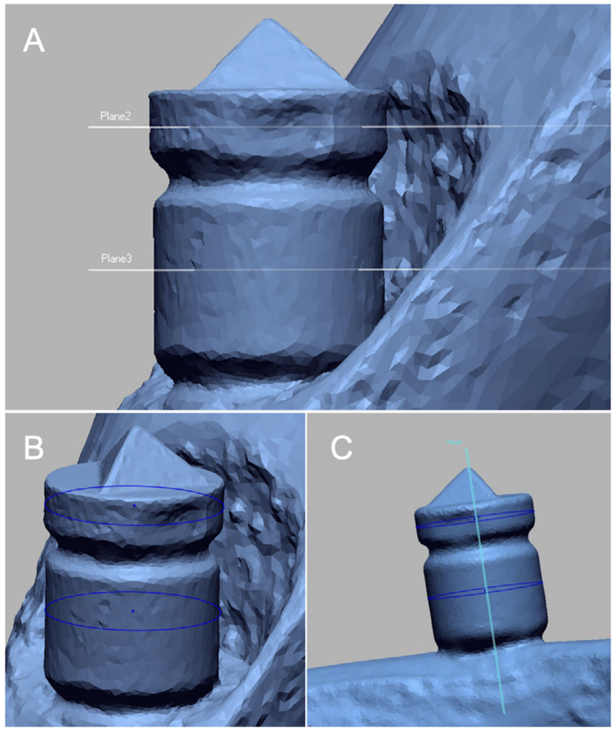

Figure 3 (A) Two planes created on scan bodies, (B) The centers of two circles, (C) The line between the centers of two circles.

triangular pyramid base to center the upper and lower parts of the scan bodies and the center points of these circles where the distance measurements would be made were determined by "point" command (Fig 3A, 3B). Then, the lines connecting these points were formed to be used in angle measurements (Fig 3C).

Cartesian (x, y, z) coordinates of the specified points for all 8 scan bodies in a scan were exported from the software in ".txt" format. The coordinates of the reference points of each scan body were determined by using midpoint of the centers of upper and lower circles. First, trueness level which is the first parameter that constitutes accuracy, was calculated. In this calculation, both distance and angular deviations between scan bodies were determined. The distance between two reference points of $P_1(x_1, y_1, z_1)$ and $P_2(x_2, y_2, z_2)$ was calculated by using the following formula:

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

The first scan body (P_1) in the right posterior region (right second molar) was taken as a reference and distance measurements between the reference scan body and the others (P_1-P_2, P_1-P_3, P_1-P_4, P_1-P_5, P_1-P_6, P_1-P_7, P_1-P_8) were performed from the center coordinates, respectively (Fig 4).

The angle measurements were performed with this formula:

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

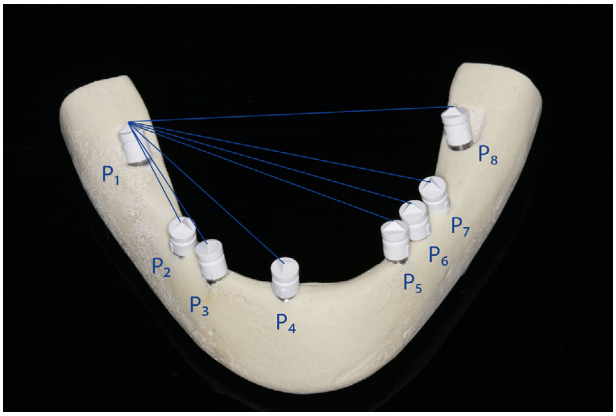

Figure 4 Measurements between reference point (P1) and the other scan bodies.

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

The procedure for measuring the angular deviation is based on the line passing through the center points of the two circles designated for each scan body. In the above formulation, the lines were found according to the points determined first (l_1, l_2) and their direction vectors ($\vec{s_1}$, $\vec{s_2}$). A vector ($\vec{s}$) was defined for each scan body, taking into account the center points of scan body's drawn circles. In a Cartesian coordinate system, a vector with a component "x,y,z" can be calculated with this formula: ($\vec{s}$) = ai+bj+ck". The letters "a,b,c" are the coefficients that express the direction magnitude. Consequently, the angle between the reference scan body ($\vec{s_1}$) and the other scan body ($\vec{s_2}$) was defined in this way and it was calculated with the above formulation ($\vec{s_1}\vec{s_2}$, $\vec{s_1}\vec{s_3}$, $\vec{s_1}\vec{s_4}$, $\vec{s_1}\vec{s_5}$, $\vec{s_1}\vec{s_6}$, $\vec{s_1}\vec{s_7}$, $\vec{s_1}\vec{s_8}$).

Precision, the second parameter of accuracy, was determined through both distance and angular data revealed by impression groups. First, the averages of the distance and angle measurements between the reference scan body (right second molar) and the other scan bodies of the 10 impressions belonging to each impression group were determined. It was then established how much of each impression deviated from the mean value of its own impression group. Thus, distance and angular precision values were determined by evaluating each impression within its own group.

The data were analyzed with IBM SPSS Statistics 20.0 Release Notes program. The difference between the mean values of the variables with normal distribution was analyzed by one-way ANOVA test; and Tukey multiple comparison test was used to determine the groups having different distribution. All statistical analyses were performed after taking absolute values of the data and 0.05 was used as the level of significance.

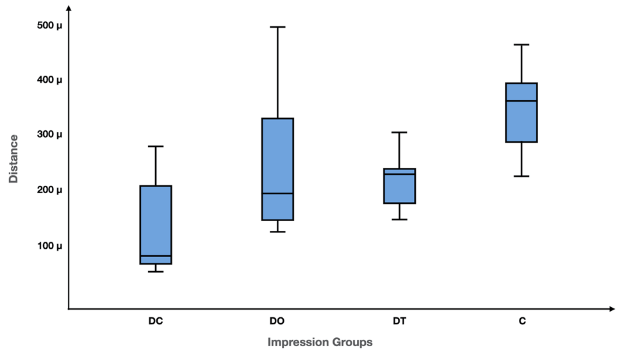

Figure 5 Distance trueness of impression groups.

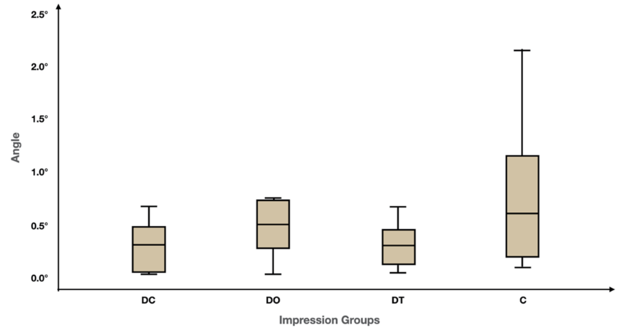

Figure 6 Angle trueness of impression groups.

Results

The data were obtained from the four groups: Carestream 3500 digital impression group (DC), Cerec Omnicam digital impression group (DC), 3Shape Trios 3 digital impression group (DT) and conventional impression group (C). The trueness data were submitted to a one-way ANOVA to assess the differences between impression groups as illustrated in Table 1. According to the one-way ANOVA analysis, there was a significant difference between the groups in the distance parameter ($p < 0.001$), but no significant difference was found for the angular parameter ($p = 0.074$), in terms of trueness. Multiple comparisons were made with Tukey post hoc test; DC showed the lowest distance deviation. While there was no significant difference between DC (123.06 ± 89.83 μm) and DT (209.75 ± 47.07 μm) ($p > 0.05$), the difference between DC and DO (229.72 ± 121.34 μm) was found to be significant ($p < 0.05$); and no significant difference between DT and DO was observed ($p > 0.05$). C (345.32 ± 75.12 μm) was the group that showed the highest distance deviations significantly among all groups. (Fig 5). While there was no significant difference between groups in angular deviations, the amount of deviation increased from DC (0.26° ± 0.07°) group as DT (0.33° ± 0.30°), DO (0.53° ± 0.42°), and C (0.74° ± 0.65°), respectively, similar to distance deviations (Fig 6).

One-way ANOVA analysis was performed for precision data and summarized in Table 2. According to this analysis, significant differences were found between groups in terms of distance ($p = 0.036$), however no significant differences were observed in terms of angular precision ($p = 0.053$). In line with

Table 1 One-way ANOVA results of trueness for distance and angle parameters

Parameters		Sum of squares	df	Mean square	F	Sig.
Distance	Between Groups	251076.567	3	83692.189	10.922	0.000
Within Groups	275860.313	36	7662.786			
Total	526936.881	39				
Angle	Between Groups	1.398	3	0.466	2.507	0.074
Within Groups	6.692	36	0.186			
Total	8.090	39				

Table 2 One-way ANOVA results of precision for distance and angle parameters

Parameters		Sum of squares	df	Mean square	F	Sig.
Distance	Between Groups	18815.700	3	6271.900	3.163	0.036
Within Groups	71387.709	36	1982.992			
Total	90203.408	39				
Angle	Between Groups	0.574	3	0.191	2.822	0.053
Within Groups	2.442	36	0.068			
Total	3.017	39				

Table 3 Tukey post hoc tests used to evaluate the differences between impression groups for distance precision

Group	N	1	2
DT	10	35.55 ± 28.46	
C	10	66.97 ± 36.69	66.97 ± 36.69
DC	10	80.43 ± 29.69	80.43 ± 29.69
DO	10		94.06 ± 69.96
Sig.		0.128	0.532

Table 4 Tukey post hoc tests used to evaluate the differences between impression groups for angular precision

Group	N	1
DC	10	0.19° ± 0.11°
DT	10	0.22° ± 0.19°
DO	10	0.30° ± 0.28°
C	10	0.50° ± 0.38°
Sig.		0.059

distance precision, DT (35.55 ± 28.46 μm) group was found to provide the most consistent data. The impressions of C (66.97 ± 36.69 μm), DC (80.43 ± 29.69 μm), and DO (94.06 ± 69.96 μm) groups, respectively, provided data in a wider spectrum within their own impressions. After the Tukey post hoc test for difference analysis, only DT and DO impression groups differed significantly ($p < 0.05$) (Table 3). Finally, it was observed that the angular precision increased from DC (0.19° ± 0.11°) to DT (0.22° ± 0.19°), DO (0.30° ± 0.28°) and C (0.50° ± 0.38°), respectively; however, there was no significant difference between the impression groups as illustrated in Table 4 ($p > 0.05$).

Discussion

The present article is a comparative in vitro study between 3 different IOS and conventional impression technique conducted on a lower jaw model with 8 implants. Based on the results of this study, the null hypothesis that the digital impressions would provide accuracy similar to the conventional technique used as a standard in complete arch implant cases has been rejected. The open tray impression technique showed the highest deviations in distance and angular trueness, and also angular precision. Digital impression groups performed better in terms of accuracy than conventional technique.

The positional, rotational and angular displacements that may occur during the transfer of impression copings from mouth to tray in complete arch implant cases may pose an important problem in terms of conventional impression technique. As a result of a study carried out on a model with 8 implants having 0°, 15°, and 25° angulations by Mpikos et al[27], it was stated that the deviations increased significantly with the high angles, especially for the implants with 25° angulation. In 2018, Alikhasi et al[12] compared the accuracy of nonsplinted open tray and closed tray techniques by using PVS and the digital impressions made with a 3Shape Trios scanner. The impressions were made from a total of 4 implants, two straight and two 45° distally tilted in an edentulous maxillary model. The results of the comparison, in parallel with our study, found that the digital technique was the most accurate group with 188 μm. Accuracy of open tray technique was 280 μm and closed tray technique showed the highest deviation with 885 μm.

One possible reason why the conventional impression group was less accurate than digital impression groups in the present study may be the use of nonsplinted open tray technique. In a systematic review by Papaspyridakos et al[28] regarding conventional implant impressions, it was stated that splinting significantly increases impression accuracy especially in complete arch implant cases. In order to increase the impression accuracy by splinting the copings, preangled multi-unit abutments are required; however these abutments can correct the angle discrepancies in a range of 15° to 30°.[29] Therefore, the use of these standard abutments in higher angulations such as 40° may not provide sufficient parallelism, so customized abutment production may be more useful in such nonideal cases.

On the other hand, when the intraoral scanners used in this study were evaluated within themselves the best trueness results were obtained with Carestream 3500 scanner in both angle and distance measurements. The deviations in the impressions made with Cerec Omnicam and 3Shape Trios 3 were higher. In the evaluation of precision of IOS, it is seen that Trios 3 can obtain high consistency data in both distance and angular terms and Carestream provided the lowest deviation in angular precision. According to these results, the null hypothesis that Cerec Omnicam and 3Shape Trios 3 scanners operating with video-acquisition system would scan the model with higher accuracy than Carestream 3500 that works with image-acquisiton, was rejected.

Accuracy of digital impressions can be influenced by the working principles, data processing algorithm, power application methods, scanning strategies and learning curves of IOS.[30,31] The IOS used in this study operate with different principles such as active triangulation, confocal microscopy and ultrafast optical scanning; these methods may affect finding the reference points to continue scanning and establishing 3D structure. In particular for digital implant impressions, it is difficult to find the reference point for IOS due to the use of scan bodies with the same shape and form, and it may not be possible to accurately match the scanned area to the previous images.[9] In the present study, especially in the regions between right second molar and right first premolar and also right central incisor and left canine where the body distances are long, the scanners often lost the reference point during the impression and it was difficult to keep scanning. In these body regions, it is thought that the software of IOS might combine the images improperly and this situation may affect the accuracy. This loss of reference point was frequently observed in the scans performed with Carestream 3500 and the scan was continued after the required calibration. The fact that the DC group obtained high-accuracy data suggests that this situation may not directly affect accuracy.

In the research conducted by Renne et al[32] accuracy of 6 IOS and 1 lab scanner were compared and it was stated that within the IOS, Carestream 3500 and iTero provided the best accuracy, but were also the slowest . The IOS that performed most accurately in this study, Carestream 3500, was also the slowest. However, it should be considered that this feature may be a disadvantage in scanning intraorally.

As a result of research regarding digital implant impressions, it was stated that the increase in the number of implants and the body distances may affect the accuracy of digital impression negatively. Imburgia et al[13] and Mangano et al,[33] compared 4 different intraoral scanners' performances on both partial and total edentulous jaw models; they found that all IOS yielded more accurate data in short distances and partial edentulous models. Besides, in parallel with the present study, Carestream 3500 and Carestream 3600 scanners gave the best results in those studies, compared to Cerec Omnicam and 3Shape Trios. Kim et al[34] inserted 6 implants to the mandibula with partial edentulism and placed one of the implants in the left second molar region mesially and the other distally with angle of 30°. At the end of the comparison between 5 IOS (Cerec Omnicam, Carestream 3600, Medit i500, iTero Element, and 3Shape Trios 3), it was stated that Medit i500 and Trios 3 yielded the best data and the accuracy of the impressions for each scanner decreased as the scanning area expanded.

The measurement technique of the distance and angles between the scan bodies and the selection of the reference point for the measurements can also affect the results. In many studies comparing various implant impression techniques in terms of accuracy, different measurement methods have been used. Some researchers[13,15,17] calculated the accuracies of different impression techniques by superimposing 3D models to the reference model and determining the deviations from the original coordinates of each scan body. However, there may be some difference during the superimposing of the images and this difference may affect the result. For this reason, Moura et al[18] and Gimenez et al,[35] in their studies performed on complete arch implant cases, selected the implants in the most posterior region as a reference and measured the distances between these implants and other implants; then they determined the deviation from the reference model. In this present study, this technique was preferred and the scan body in the right posterior region was accepted as the reference and measurements of the accuracy of the complete arch implant case were completed by using it.

Due to the fact that our study was carried out 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 the oral tissues, patient movements and inability of the scanner tip to reach the posterior regions, especially in patients with limited mouth opening, may affect the accuracy of digital impression.[36] Additionally, differences in the mucosal surface due to jaw movements may affect the scanner's ability to locate the reference point in order to continue imaging, which can lead to various problems during software combining the acquired images.[11] In order to consolidate these results or to adjust them for clinical life, digital and conventional implant impressions should be compared in in vivo studies. Since the reference optical scanners cannot be used intraorally, the compatibility of the implant-supported prostheses and screws produced by both techniques should be tested with abutments by methods such as Sheffield testing, and microscopic and/or radiographic evaluation. Comparison of long-term results after the application of these prostheses to the patients would be very useful for selecting case-based impression techniques. In further studies, it can also be investigated how the accuracy of the impressions is affected by using multiple scan bodies with different shapes.

Conclusion

In a clinically unfavorable complete arch implant case with high angulations and asymmetric distribution, digital impression methods achieved superior results in both distance and angular parameter comparted to a conventional method using nonsplinted open tray impression technique. Different acquisition methods and working principles of IOS can also affect the accuracy. When trueness and precision were evaluated together, Carestream 3500 and 3Shape Trios 3 obtained more accurate data compared to Cerec Omnicam.

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