Accuracy of a Digital Impression System Based on Active Wavefront Sampling Technology for Implants Considering Operator Experience, Implant Angulation, and Depth

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ABSTRACT

Background: There is a scarce knowledge on the accuracy of intraoral digital impression systems for dental implants.

Purpose: The purpose of this study is to evaluate the accuracy of a digital impression system considering clinical parameters.

Materials and Methods: A master model with six implants (27, 25, 22, 12, 15, 17) was fitted with polyether ether ketone scan bodies. Implant no. 25 was placed with 30° mesial angulation in relation to the vertical plane (y axis), and implant no. 15 was positioned with 30° distal angulation. Implant no. 22 was placed 2 mm and no. 12, 4 mm below the gingiva. Experienced ($n = 2$) and inexperienced operators ($n = 2$) performed scanning (Lava Chairside Oral Scanner; 3 M ESPE, St Paul, MN, USA) at standard and high accuracy mode. Measurements involved five distances (27-25, 27-22, 27-12, 27-15, 27-17). Measurements with high accuracy three-dimensional coordinated measuring machine (CMM) of the master model acted as the true values. The data obtained were subtracted from those of the CMM values.

Results: Experience of the operator significantly influenced the results ($p = .000$). Angulation ($p = .195$) and depth of implant ($p = .399$) did not show significant deviation from the true values. The mean difference between standard and high accuracy mode was 90 µm.

Conclusions: With the active wavefront sampling, technology-based digital impression system training seems to be compulsory. Impressions of angulated implants may diminish the accuracy of the impression, yet the results were not significant.

KEY WORDS: accuracy, dental implant, digital impression, implant angulation, implant depth, intraoral scanner

INTRODUCTION

Obtaining absolute passive fit of the prosthetic framework on implants has been reported to be nearly impossible.[1] Because of the multiple steps involved in processing and manufacturing implant-borne prostheses, errors in precision seem to be unavoidable.[2,3] Misfit of prosthesis may lead to mechanical failures such as screw distortion and loosening, component fractures, and even implant failure.[4,5]

Multiple dental implants are generally splinted in order to resist against lateral and torque forces.[6,7] Splinting the implants may improve the distribution of masticatory loads, reduce mechanical complications,[8] decrease stress in peri-implant tissues,[9,10] necessitate less number of implants that eventually decrease the total

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financial cost of the implant therapy.[11] Despite these advantages, splinting the implants has several challenges as high accuracy is a prerequisite to achieve proper fit of the subsequent prostheses.[12] Several studies on making implant impressions have reported that working casts fails to replicate the exact location of the implants.[13–15] The quality of impressions has been demonstrated to be an effective clinical procedure for reducing inaccuracies in prostheses.[16,17] Since the early 1990s, in vitro studies on different impression techniques (e.g., indirect technique with close tray, direct technique with open tray, direct technique splinted with acrylic resin) presented remarkably nonhomogeneous results.[16] The accuracy of the impression depends on a number of factors, some of which are the impression technique, type of impression material, implant angulation, and type of implant connection.[18,19] Nevertheless, even if the impressions are free of defects, the accuracy could still be affected during cast fabrication or because of displacement of the implant components, where the latter is usually dependent on displacement of impression coping on the fitting surface of each implant across the machining tolerance range, the impression technique, material used, and dimensional change in the dental stone.[19] Moreover, lack of parallelism in the implants and depths may also affect the accuracy of the conventional silicon impressions.[18,20,21] The angulation of the implants may increase the dislodgement of the impression material and its subsequent distortion during removal of the impression tray from the mouth.[18] Consequently, in deeply placed implants, less proportion of the coping can be impressed, and this may diminish the stability of the impression coping in the impression material affecting the final accuracy.[21]

In early 1980s, digital impressions and fabricating ceramic restorations using computer-aided design (CAD)/computer-aided manufacturing (CAM) technology have been offered as an alternative to conventional restorative procedures.[22] Thereafter, various optical impression systems have been developed with which direct impressions could be made in the oral cavity. The most commonly used systems are Cerec AC (Sirona, Behnheim, Germany), Lava Chairside Oral Scanner (Lava COS, 3 M ESPE, St Paul, MN, USA), E4D Dentist (D4D Technologies, LLC, Richardson, TX, USA), and iTero (Cadent, Carlstadt, NJ, USA). Digital impressions play an important role in the development of digital dental technology because they are the first step towards a full digital workflow of prosthetic fabrication.[23] Digital impressions improve patient acceptance, reduce possible distortion of impression materials, allow for previsualization of the preparation three-dimensionally, decrease potential cost, and increase efficacy.[24] In the implant field, digital impressions would let virtual assessments of the implant prosthetic space, depth of restoration interface, and emergence profile configuration before proceeding with the laboratory steps.[25] In a study performed on second year dental students, having no experience regarding impression making, digital impression making was reported to be a more efficient method as opposed to conventional impressions for unitary implants.[23]

Accuracy of digital impressions is not widely studied.[26–31] Only the fit of the restorations at the end of the whole manufacturing process but not the impression alone was evaluated.[26,32] In fact, CAD/CAM fabrication process includes various steps such as surface digitization of the object, calculation of the CAD file created based on the acquired surface points, and the CAM process where type of milling machine and the materials used are of importance in accuracy.[33] Thus, there is a scarce knowledge on the accuracy and repeatability of intraoral digital impression systems for dental implants including the implant-related factors and other clinical aspects such as the experience of the operator.

The objectives of this study, therefore, were to evaluate the accuracy of a digital impression system based on active wavefront sampling technology using a six-implant model, with implants located in different given angulations and depths. The null hypotheses were that (1) experience of the operator, (2) the angulation, and (3) the depth of the implants would not affect the accuracy of the impressions.

MATERIALS AND METHODS

Master Model

Six implants (Certain 4, 1/11 mm, Biomet 3i, Palm Beach Gardens, FL, USA) were placed at the sites of lateral incisors (12,22), second premolars (15,25), and second molars (17,27) in an edentulous resin model (Frasaco, Greenville, NC, USA) (Figure 1). This kind of implant was chosen following the metrologies expertise because of the favorable design of the internal connection with two flat surfaces that allows to make the measurements in the best possible way using coordinated

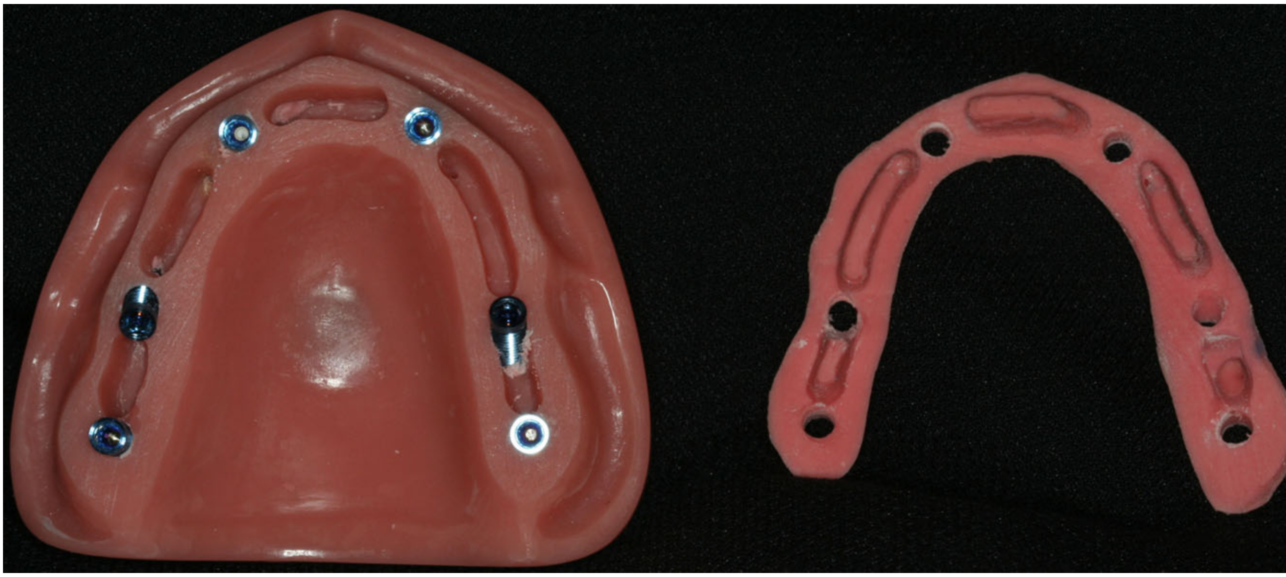

Figure 1 Resin master model with six implants at locations 27, 25, 22, 12, 15, and 17 where angulated implants were no. 15 and no. 25. The depth of implant no. 22 was 2 mm, and implant no. 12 was 4 mm. A removable soft tissue allowed proper measurement with coordinated measuring machine and created depth of the implants.

measuring machine (CMM). An external connection or a conical connection would result in worse "true" values because of the difficulty in measuring such geometries.

The implants were located approximately with the following angulations and depths: (1) implant no. 17 and 27 at 0° and 0 mm depth (gingival margin level); (2) implant no. 15 with 30° distal angulation and 0 mm depth; (3) implant no. 25 with 30° mesial angulation, 0 mm depth; (4) implant no. 12 at 0° and 4 mm depth; and (5) implant no. 22 at 0° with 2 mm depth using a micro-milling machine (Cendres & Metaux, Biel-Bienne, Switzerland).

Soft tissue was simulated using silicone (Vestogum, 3 M ESPE, St Paul, MN, USA) in order to enable accurate measurements of the head of the implants with the CMM. Six high precision scan bodies were manufactured from polyether ether ketone (Createch Medical, Createch Medical S.L., Mendaro, Spain). The height of the scan bodies was 8 mm (Figure 2, A and B).

CMM

An independent laboratory specialized in extreme accuracy of designing and fabricating CAD/CAM structures (Createch Medical S.L.) made the measurements of the master model and the accuracy assessment of the intraoral scanner. An industrial three-dimensional CMM was used to measure the master model in order to obtain the actual truth data of the three-dimensional position of

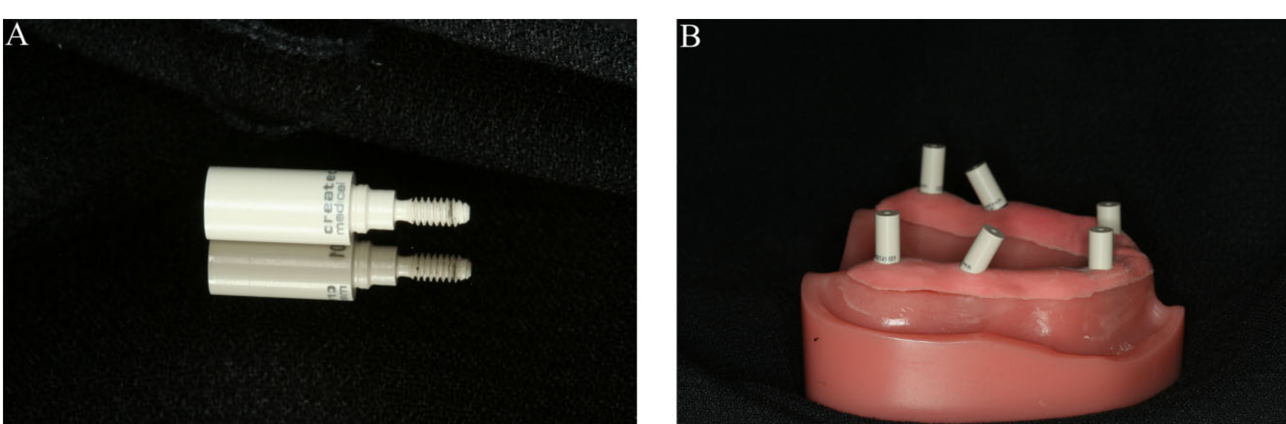

Figure 2 *A*, Polyether ether ketone scan body (height: 8 mm) used for high accuracy measurements. *B*, View of the complete model with the removable artificial gum and the six scan bodies.

the implants. The accuracy of the CMM was certified by the National Entity of Accreditation with a maximum permissible error for length measurement of (1.9 + 3 L/1000 μm) according to ISO 10360-2, geometrical product specifications.[34]

A high-accuracy touch signal probe with 1 mm ruby sphere was used to measure the points of the implants heads to locate them in the *x*, *y*, *z*-axis of the space. The leaning plane of the implant connection was measured to establish the orientation of the implant. Also, the circumference of the implant was measured to determine the center. The coordinates *x*, *y*, *z* give the location of each result from these two figures. This procedure was repeated for three times. A mean of the three measurements performed with the CMM was used as the final location of the implants that constituted the actual truth.

Impression Procedures

The software (version V 0.3.0.2) of the digital scanner (Figure 3) was used for all data capturing. The system captures the image that is reflected from the object through the lens system and ultimately projected onto a sensor. When the image is on focus, the distance of the object coincides with the focal length of the lens. If the image is out of focus, the distance from the lens to the object can be calculated from the size of the blurred image through a mathematical formula.

Figure 3 Lava Chairside Oral Scanner based on active wavefront sampling technology.

Four operators participated the study. Each operator made five full arch impressions, and measurements were made between 27-25, 27-22, 27-12, 27-15, and 27-17 (Figure 4, A and B). All operators were instructed how to use the device and follow the defined protocol. The first step was to import the Standard Tessellation Language (STL) file into a CAD software (reverse engineering software). The original CAD file of the scan body, which was made in order to manufacture all the scan bodies used in the study, was overlapped with the cylinders of the STL files (digital impressions) using a best fit algorithm, matching all the common points possible between the two cylinders, the original CAD file and the STL file. The corresponding digital implant replica was located fitting each scan body. The center of the cylinders was defined as the point of junction between the horizontal plane of the head of the implant and the vertical line that crosses the center of each scan body. Once the centre points of all the implant were calculated, the shortest distance between implant 27 and the rest of the implants was traced. With the CMM, the centre point of each implant was also calculated, and the lines joining the center point of the implants were traced. The center point of implant no. 27 of the CMM measurements (actual truth) and the center point of implant no. 27 of the STL files were matched. The difference between distances was calculated by subtracting CMM from STL data. The result was considered as the distance deviation. If the STL file distance was larger than the one of the CMM machine, the result was positive. If the STL file distance was shorter than the CMM one, then the result was a negative value.

Two of the operators (Operator 1 and 2) had experience of at least 2 years with digital impression systems. The other two operators (Operator 3 and 4) were dentists who had no experience with either the digital scanner tested or any other intraoral scanner. The

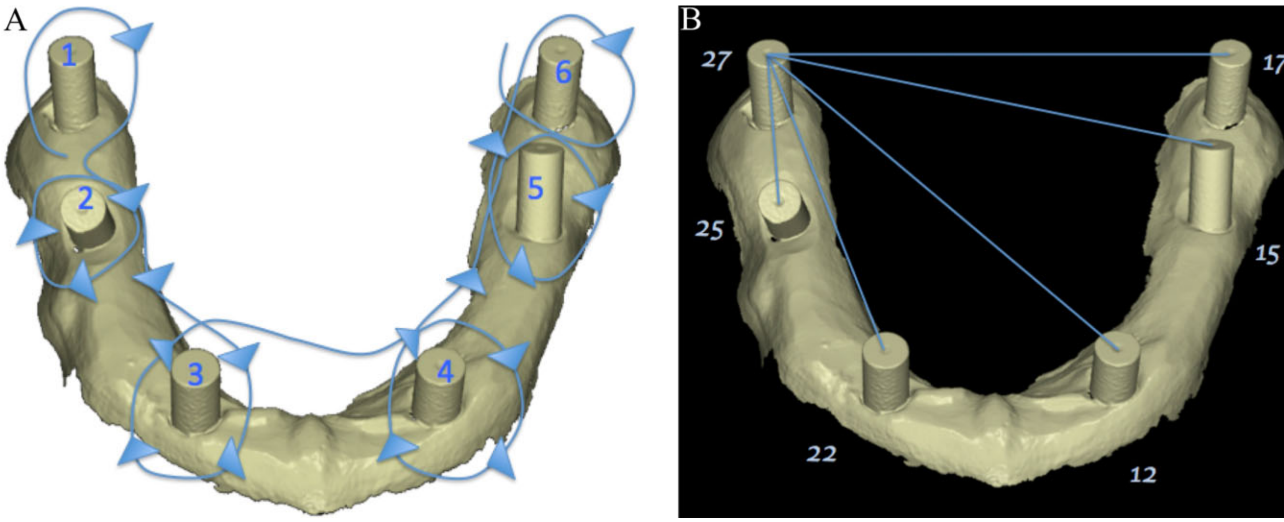

Figure 4 *A*, Scan protocol started from implant no. 27 and carried on in one continuous scan going around the scan bodies in circles until implant no. 17 was captured. *B*, Distances used for the deviation error (27-25, 27-22, 27-12, 27-15, 27-17) analysis from the center points of each implant.

system was explained to the inexperienced operators (3 and 4), and demonstration of only one impression was made to all operators. They were allowed to make three impressions for training prior to making the impressions for the study. An expert was guiding and supervising the operators during the complete data capturing for the study. There were five data points per impression corresponding with the five distances between implants (27-25, 27-22, 27-12, 27-15, 27-17). With four operators, a total of 100 data points (distances) were obtained for the analysis ($n = 50$ for experienced operators and $n = 50$ nonexperienced; $n = 40$ for angulated implants and $n = 60$ for nonangulated implants; $n = 40$ for deeply placed implants and $n = 60$ not deeply placed implants).

For each impression, one *standard* and one *high-accuracy* protocol were followed.

Standard or automated impression: Once the impression was made, the file followed the standard procedure. In the standard procedure, the STL file was sent straight to a case manager and downloaded directly for the study. Thus, the data of the STL file correspond to the data that were directly obtained from the Lava COS without any corrections or process.

The high-accuracy protocol or manual calibration of the data: For these cases, a correction algorithm was applied after making each scan. To proceed with the correction, *calibration test* of the Lava COS was run before and after each scan. The calibration test named as *tip target* was accomplished with a little tool that was placed on the camera of the Lava COS. Information recorded by the tip target may contain some deviations in the scan that could be corrected yielding to better results.

The scanning was performed according to the manufacturer's instructions. A thin layer of titanium dioxide powder was applied on the scan bodies and silicone representing the soft tissue. The scanning process started on implant no. 27 and carried on in one continuous scan going around the scan bodies in circles until implant no. 17 was captured. Then, the STL files obtained from the impressions were sent to the laboratory to carry out the accuracy assessment.

Accuracy Assessment

All the data from the CMM and the Lava COS were imported with industrial reverse engineer software that could read the STL files. The distances and angle of the center points of the implants were used to evaluate the accuracy of the intraoral scanner. In order to locate the center point of the implants for the Lava COS system, the STL file and the original design of the Scan bodies (the CAD used to manufacture the scan bodies) were imported in the reverse engineer software. The cylinders of the STL data captured by the scanner were isolated and matched one by one with the original "CAD" design of the scan bodies. The centerline of the cylinder was determined, and consequently, the center point of the implant was established. The linear distance from the center point of implant no. 27 was considered as the reference point for measurements, following the "zero method" described elsewhere,[35] and the center point of the rest of the implants was measured using the CMM data. Subsequently, the same procedure was performed for the data obtained from the Lava COS. The STL (Lava COS) distances were then subtracted from the CMM distances (Truth), and the distance deviation was calculated. If the STL values were higher than the CMM, a positive result was obtained, and if the CMM values were higher than the STL values, then the result was negative. Next, each distance between implants obtained with the Lava COS was compared with the correspondent distance of the CMM. The angulations were measured between the fit plane of implant no. 27, and each fit plane of the other implants was measured by the CMM. The same angulation measurement procedure is repeated with the geometries obtained from the Lava COS system.

The measurements were not divided in the *x*, *y*, and *z*-axis components because the Lava COS, the CMM, and the CAD cylinders have different coordinated systems. The datasets of a measurement arising from digitization were composed of points that were located in a common coordinated system. Each point was defined in *x*, *y*, and *z* coordinates. Concurrently, the points described a part of the surface of the digitized object. Each single dataset produced by independent measurements received its own coordinate system.[28] If the data were broken down into the *x*, *y*, and *z* axis, an error would be introduced and the data would not be compared correctly.[36]

Statistical Analysis

The data were analyzed using statistical software (Minitab Release 14, Minitab Inc., State College, PA, USA). The measured distances (µm) between the implants obtained with the Lava COS were compared with the distance between the implants of the "true data" measured with the CMM. The homogeneity of the data was measured for implant distances, operator, and experience (Anderson–Darling, $\alpha = 0.05$). The significant difference between experienced and inexperienced operators, implant angulation, and depth effect was compared using two sample *t*-test and one-way ANOVA.

RESULTS

The data were normally distributed for the independent variables of *operator*, *experience*, and *implant distances* (Figure 5, A–C).

TABLE 1 Mean and Standard Deviation (µm) Depending on the Experience of the Operators Calculated from Five Distance Measurements in Five Impressions ($n = 50$) Per Group

$p = .000$	n	Mean (µm)	Standard Deviation
Experienced	50	−30.8	25.9
Inexperienced	50	13.3	51.2

Overall, operators and the experience of the operator significantly affected the results ($p = .000$) (Table 1). The difference between the experienced and inexperienced group was 44 µm.

Measured distance between the implants ranged between −45.02 ± 37.31 and −29.39 ± 5.49 µm for the experienced operators, but for the inexperienced ones, it was between −4.37 ± 73.47 and −6.07 ± 14.99 (Table 2, A and B). The mean distance deviation between implants was less accurate for the inexperienced operators compared with those of experienced ones (Figure 6). The accuracy of the measurements following standard and *high accuracy* modes of the scanner showed a difference of 90 µm (Figure 7).

Implant angulation did not significantly affect the deviation in the distance (angulated implants: −1.7 ± 39.8 µm; parallel implants: −13.5 ± 49.5 µm) ($p = .195$) (Table 3A). Also, implant depth did not

TABLE 2 Mean and Standard Deviation for Distance Measurement at High-Accuracy Protocol for Both (A) Experienced and (B) Inexperienced Operators

	n	Mean (µm)	Standard Deviation
(A) Experienced High accuracy mode			
Implant distances			
27-25	10	−29.39	5.49
27-22	10	−33.35	15.64
27-12	10	−45.02	37.31
27-15	10	−11.02	28.12
27-17	10	−35.28	22.19
(B) Nonexperienced High accuracy mode			
Implant distances			
27-25	10	−6.07	14.99
27-22	10	15.07	36.65
27-12	10	−4.37	73.47
27-15	10	39.70	54.18
27-17	10	22.13	52.41

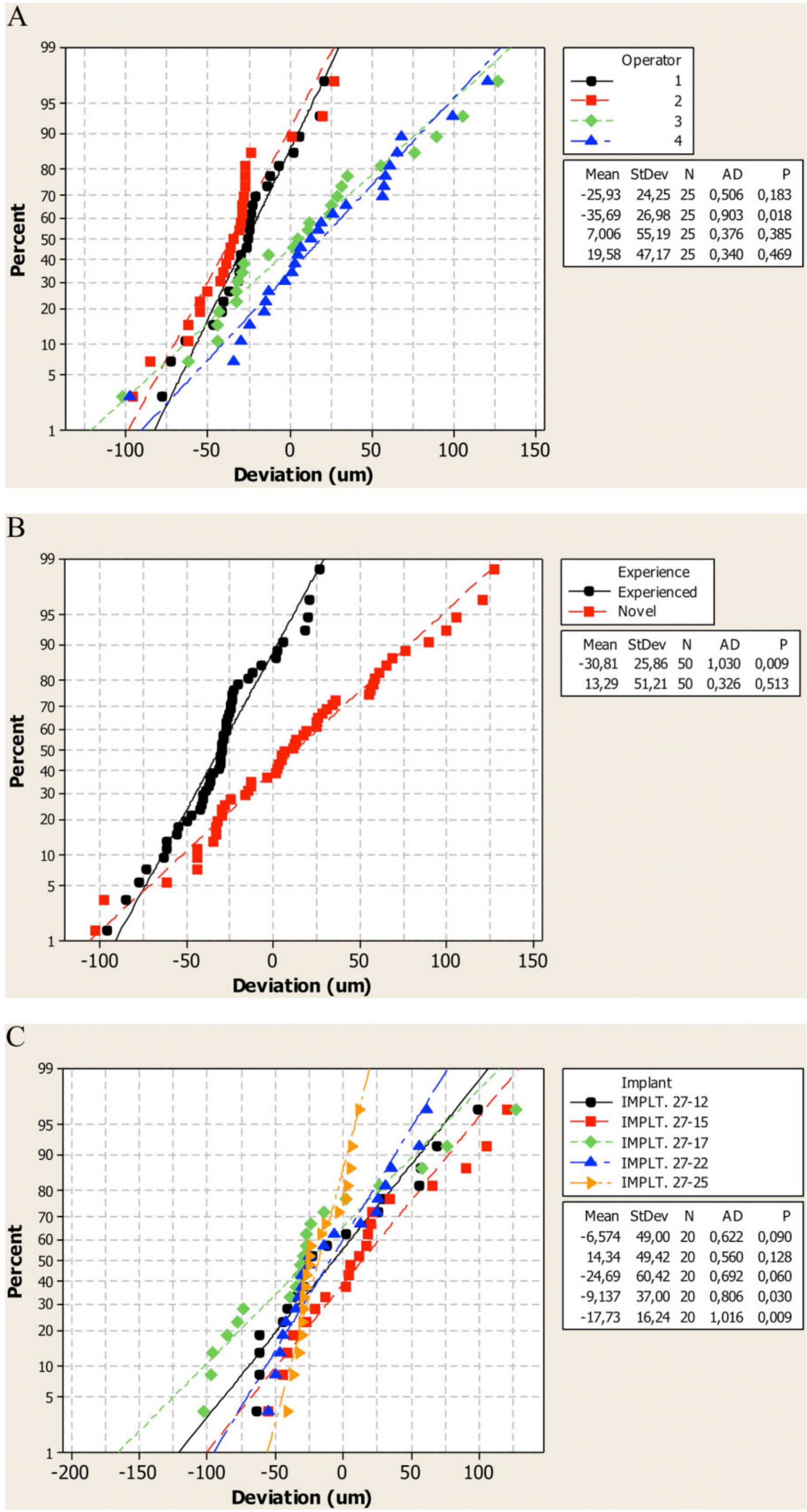

Figure 5 Normality test showing homogeneous distribution of the data for the variables (A) operator, (B) experience, and (C) implant distance.

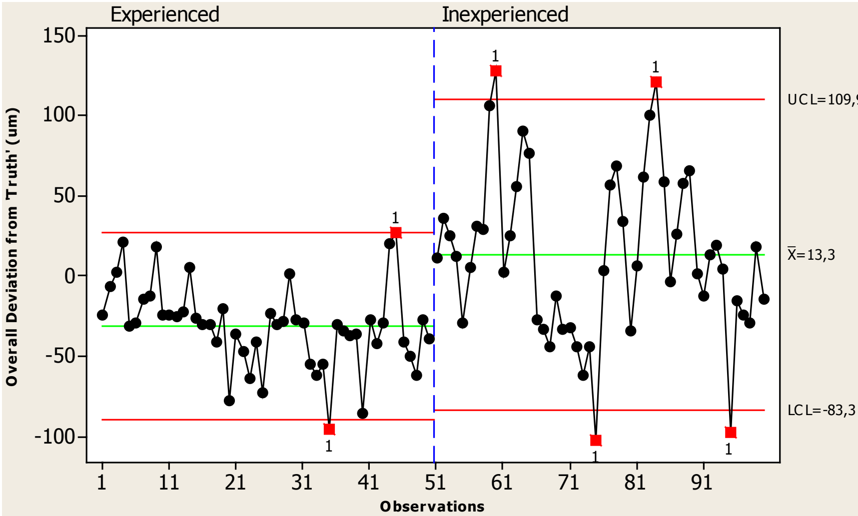

Figure 6 The mean distance deviation (µm) between the implants for experienced and inexperienced operators.

significantly affect the distance deviation (deep implants: −34.3 ± 18.7 µm; normal implants: −28.5 ± 29.8 µm) ($p = .399$) (Table 3B).

With the increased number of trials, the error decreased for the inexperienced operators, indicating the importance of learning curve. With each additional scan, the error was reduced by 19 µm. Such an observation was not made for the experienced operators (Figure 8).

DISCUSSION

To the best knowledge of the authors, this is the first study that analyzed the influence of different clinical aspects such as operator's experience, implant angulation, and implant depth in the accuracy of digital impression making. Based on the results of this study, the experience of the operator affected the accuracy of the digital impressions, but the angulation and depth of the implants did not. Thus, the null hypothesis is partially rejected.

In this study, the experienced operators had a training of more than 2 years in digital dentistry. In principle, experience is a difficult parameter to measure. The number of the digital impressions that experienced ones made until this study cannot be identified. Yet, they have been using such techniques on a daily basis. It was however interesting to note that the inexperienced operators obtained accuracy similar to the experienced ones in their last two impressions which indicates that

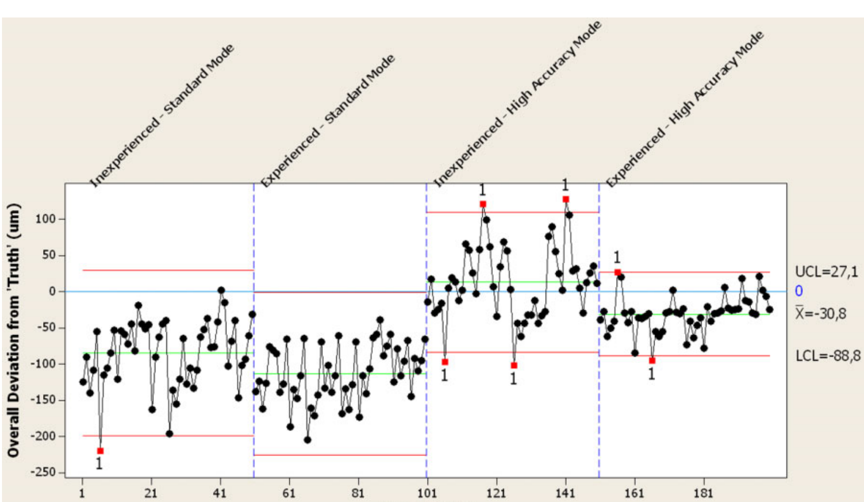

Figure 7 The accuracy measurements (µm) based on the scanning mode.

TABLE 3 Mean Distance Deviation (µm) for (A) Angulated Implants and (B) Deeply Placed Implants

	n	Mean (µm)	Standard Deviation
(A) $p = .013$			
Angulated implant	20	−20.2	21.9
Normal implant	30	−37.9	26.2
(B) $p = .399$			
Deep implant	20	−34.3	18.7
Normal implant	30	−28.3	29.8

gaining experience is a very subjective issue. Hence, it cannot be generalized that eight impressions (three preliminary ones and five for the study) would be sufficient to grade them as experienced, but it can be stated that at least eight impressions should be made before clinical application. The manufacturer suggests 15 to 16 scans to achieve the learning curve. Furthermore, scanning an implant model is certainly more challenging than a dentate one. It can be anticipated that the latter might require less experience. This aspect needs to be further investigated.

The accuracy of digital impressions was not significantly affected by the angulation of the implants. The angle chosen in this study, 30°, could be considered very pronounced. Several previous studies where accuracy of silicon impressions was tested, the angulation of implants was reported to be between 5° and 20°.[21] In fact, in a conventional impression, the elastic recovery of the impression material may compensate for the undercuts. This may however cause distortion in the impression, yielding to plastic deformation of the silicon. In a digital impression system, possibly the processing of the STL files posterior to the impression decreased the accuracy in the angulated implants.

Implants placed 2 mm and 4 mm deeper than the gingiva did not significantly affect the accuracy. Apparently, the information of the scan bodies in submerged implants was captured sufficiently without affecting the accuracy by the active wavefront sampling technology. Thus, clinically both bone level and tissue level implants could be scanned with the same scan body.

The accuracy results of the present study were similar to the ones obtained in a previous study where a lower arch stone model was used alternating the teeth and three scan bodies.[36] In that study, a mean deviation of 14.6 ± 12.7 µm was noted for the first distance (between scan bodies one to two) and 23.5 ± 14.2 µm for the second distance (between scan bodies one to three). The error in that study was slightly less than that of the present study which could be attributed to the model design, the presence of the teeth versus the edentulous space scanned in this study, where the latter has less reference points for both the scanner and the operator. Another possible reason could be the dental stone; as it is matt, it is easier for the device to capture the images.

The results obtained here are not comparable with other studies on the accuracy of digital impression methods including Lava COS.[28,29,32] The variation

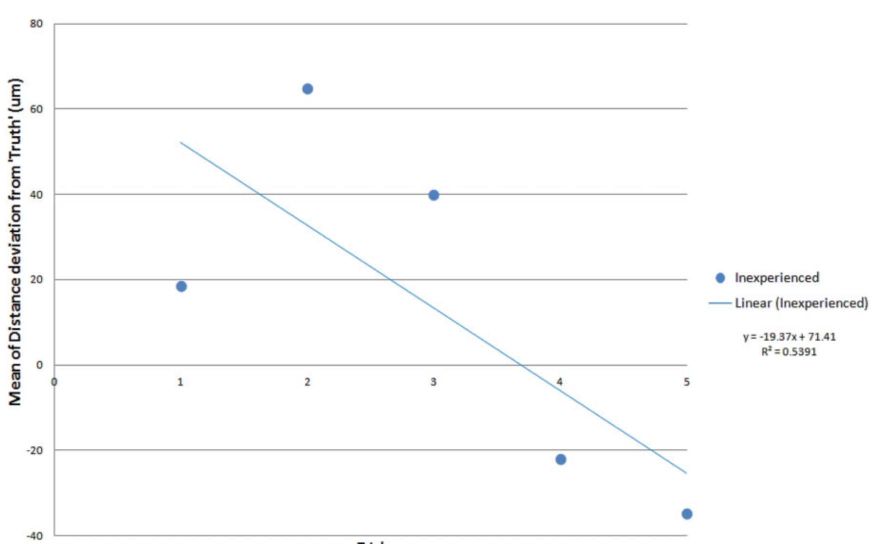

Figure 8 Regression curve for inexperienced operators showing that learning curve increases the accuracy.

between these studies could be because of an important difference in the methodology. In order to compare the digital impressions in these studies, a general overlap of the data (best fit algorithm) was used. The best fit overlaps two point clouds in the best possible way, making an average of the errors and not displaying the real divergences sufficiently.[32] The present study used the *zero method*,[35] considering the center point of the implant no. 27 as the origin, obtaining the linear and angular deviations between implants without making an average in the overlap of the best fit.

A study on the accuracy of conventional impressions with a similar methodology[18] described four displacements of the implant components that occur from the impression to the master cast with two different impression techniques (with splint, without splint). The fabrication tolerance of the impression copings, displacement of the impression coping within the impression material because of the contraction of the material, fabrication tolerance of the implant replica, and displacement of the implant replica within the dental stone because of the expansion of the stone were the cause of errors. Such errors were 98.5 ± 29.9 µm for the nonsplinted impression coping group and 99.3 ± 28.28 µm for the splinted ones. However, the results of the standard mode were comparable. Considering that the *high accuracy* mode was remarkably better than the *standard* mode, this approach should be the best practice for making implant impressions.

CONCLUSIONS

Experienced operators delivered overall more accurate digital impressions of the implants compared with the inexperienced ones, providing that the inexperienced operators presented improved accuracy with the increased number of trials. Angulated implants and the deeply placed implants did not seem to decrease the accuracy in digital impressions with the digital scanning system tested.

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