

# Comparison of the Clinical Accuracy of Digital and Conventional Dental Implant Impressions

## Keywords

Dental Implants  
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## ABSTRACT

The aim of this study was to compare the clinical accuracy of digital and conventional dental implant impressions. Two types of implant impressions were made for each case, namely a conventional open-tray impression and a digital implant impression (DI) using a Trios IOS. Master casts were scanned using a D800 laboratory scanner and STL files were retrieved from conventional and digital workflows to be exported for comparison. The distance between center points, angulation, rotation, vertical shift, and surface mismatch of the scan bodies were evaluated and compared between conventional and digital impression techniques. Comparing digital and conventional impression techniques the following factors showed statistically significant differences: distance ( $73.7 \pm 75 \mu\text{m}$ ), angulation ( $0.42 \pm 0.3^\circ$ ), and surface mismatch of scan bodies. The difference in conventional and digital impression techniques as regards to angulation and distance between the implants were associated with distance, angle, and vertical shift differences in scan. The mismatch of the scanned surface of scan bodies was twice higher for the intraoral scanner group. Clinicians should therefore control the implant suprastructures clinically and also using casts (e.g. printed casts) when a digital scan is planned.

## INTRODUCTION

Conventional elastomeric dental implant impressions and plaster cast production has been a standard procedure in implant-supported prosthesis fabrication for a long time. Digital impressions can now be used as an alternative procedure. Despite considerable improvement in intraoral scanners (IOS), their application is still limited in multiple implant or edentulous situations. The scanning of larger edentulous areas for fixed partial dentures, scanning strategy, number of implants, and properties of scan bodies are among the factors that can lead to clinically significant inaccuracies.<sup>1-3</sup>

An accurate implant impression is a key factor to achieve long-lasting, functional, passive and esthetic restorations. During the process of making impressions and fabricating casts and restorations, errors tend to build-up and a certain degree of inaccuracy is unavoidable. Since dental implants are virtually immobile, ill-fitting restorations can potentially cause mechanical complications (screw loosening, chipping of veneering ceramic) and biological complications (periimplantitis, mucositis), which are widely discussed in the literature.<sup>1</sup>

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Data on the accuracy of digital implant impressions (DII) and restorations is of crucial importance to validate the procedure in implant prosthodontics.<sup>2-4</sup>

Since digital workflow is a relatively novel procedure and is becoming widely used, collecting evidence-based information is very important. Unfortunately, the majority of studies evaluating DII accuracy are *in vitro* studies. Having a reference model is a straightforward procedure in an *in vitro* study, and it is usually obtained with industrial scanners or coordinate measurement machines (CMM). However, it is almost impossible in a human clinical trial to create a CMM model. Many *in vitro* experiments were performed using different protocols and simulating edentulous areas of various lengths.<sup>8-11</sup> A recent systematic review on the accuracy of DII reported mean errors ranging from 6 to 337  $\mu\text{m}$ .<sup>12</sup>

Clinical data on IOS is increasing, but they are mostly on patient- and dentist-centered outcomes (patient or dentist preference, procedure efficiency, etc.).<sup>5,6</sup> Intraoral scanning (IOS Data from the clinical studies on the accuracy of DII and resulting restorations is still lacking.

One of the very few clinical studies attempted to evaluate the accuracy of DII for implant-supported bars on 2 implants in the edentulous mandible in 25 patients using iTero IOS.<sup>15</sup> According to the authors of the pilot study, due to poor reference points, saliva, and tissue movements, DII errors were too large to be accepted clinically.<sup>15</sup>

IOS technologies are more frequently used for making DII in clinical practice. Therefore, the aim of this study was to evaluate and compare the clinical accuracy of digital and conventional dental implant impressions, and to identify factors associated with the differences. Currently, clinical evidence with conventional impression procedures is still stronger, therefore they were considered as control group.

## MATERIALS AND METHOD

### INCLUSION CRITERIA

Twenty patients requiring 27 fixed partial restorations on 2 implants (AnyOne, Megagen, Daegu, Korea) participated in this study. The clinical study was performed according to the standards of Declaration of Helsinki and approved by the Vilnius Regional Ethics Committee for Biomedical Research (No 158 200-16-861-370). All patients completed a consent form to participate in this study. Two-unit (n=10), three-unit (n=11), and four-unit (n=6) restorations supported by two implants were evaluated. Three restorations were in the anterior area of the mouth and 24 were in the posterior. The average distance between implants was 14.3 $\pm$ 7 mm.

## STUDY DESIGN

Conventional and digital implant impressions were made for each case in random order by the same operator. A conventional open-tray impression technique with splinted impression copings (AnyOne, Megagen) using vinyl-polysiloxane (Express, 3M ESPE, Minnesota, USA) was used. Splinting was accomplished with light-curing material (Individuo Lux, VOCO, Cuxhaven, Germany). Also, verification of the passive fit of splinted copings was done as separate procedure as described in the literature.<sup>16</sup> Visual inspection, checking for the balance, one-screw test and screw resistance was made by the same operator. Master casts were fabricated from conventional impressions using type IV plaster (FujiRock, GC, Tokyo, Japan) following the manufacturer's instructions and allowed to set at room temperature for 24 hours. Another verification jig (Individuo Lux, VOCO) was fabricated on the master cast to test the accuracy of the position of the implant analogues. This verification jig was tested intraorally, applying finger pressure, Sheffield, and screw-resistance tests.<sup>17</sup> For all cases, no alteration of master cast was needed. The scan bodies (AnyOne, Megagen) were connected to the implant analogues (AnyOne, Megagen) on master casts using 15 Ncm of torque and were scanned using a D800 laboratory scanner (3Shape, Copenhagen, Denmark) and Dental System software (version 2.9.9.3). STL files were exported by the same technician for comparison with the STL files obtained during the DII. Implant-supported restorations were fabricated only from the conventional impressions and finalized on the master casts. During fitting and final delivery of restorations, passive fit was additionally evaluated using the same techniques as were used previously with the verification jigs. The fit of all restorations produced in a conventional way was rated as accurate and clinically acceptable, after applying the same techniques as for the evaluation of the splinted impression copings and a jig fabricated in the lab. Additionally, dental radiographs were made to confirm the adequate seating of the prosthetic components. In this way, due to the multiple verification procedures of the master cast and restorations, the STL file obtained from the laboratory scanner could be considered as the best available reference representing conventional workflow.

For the digital impression, original scan bodies were positioned and torqued to 15 Ncm. A DII was made with a Trios IOS (3Shape, Copenhagen, Denmark; version 1.3.3.1) by applying a standardized scanning technique according to manufacturer's recommendations making less than 1.000 images per arch by the same operator. In the mandible, the scanning started from the occlusal surface and continued to lingual and buccal surfaces, while in the maxilla after occlusal surface scanning, buccal and palatal surfaces were captured subsequently. Standard tessellation language (STL) files were exported for further analysis.

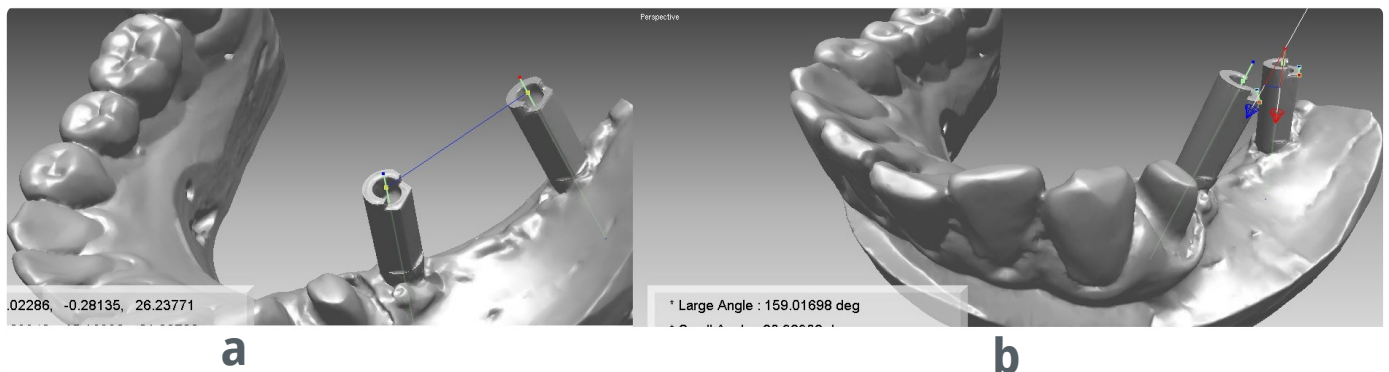
STL files produced from conventional and digital impressions, as well as the high resolution and high accuracy 3D CAD models of scan bodies, were imported and registered using a modified ICP algorithm in reverse engineering software (Rapidform 2006, INUS Technology Inc, Seoul, Korea). The original imported STL file was checked for the presence of any non-manifold, redundant, crossing, and unstable faces in the imported shell. The orientation of different 3D models in the same space is different. For this reason, for rough registration of a scan body model with the scan of the original model, the common geometric features (corresponding points) on two models were selected. Each pair of corresponding points was represented as a small square in a different color. The fine alignment algorithm was used as a stepwise procedure minimizing the mean square error between points of the scan model and the closest points on the scan body surface.

## MEASUREMENTS

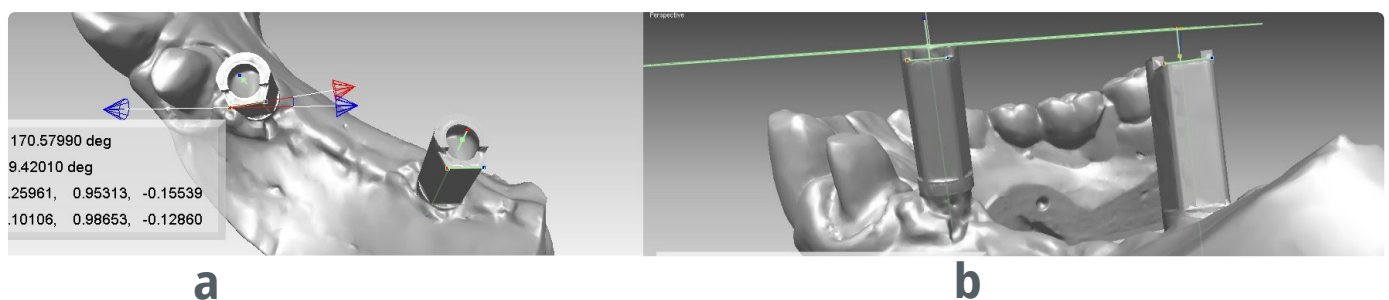
The distance between center points, angulation, rotation, and vertical shift of the scan bodies was evaluated and compared between conventional and digital impression techniques. To evaluate the scan body center point position in 3D space, three reference points were chosen on the top surface of the scan body and a plane was created through these points. The center point of the scan body was at the intersection between a selected axis of the scan body and a selected top plane. The distance between the center points of two scan bodies was measured as the length of the straight line that connected those two points (*Figure 1a*). The angulation of scan bodies

was measured as the angle between two vectors representing the axes of scan bodies in 3D space (*Figure 1b*). To evaluate the rotation, the vertical edges of the scan body had to be identified. In order to identify the edges, the side planes of the scan body were found by choosing three points on each side wall. The result of the intersection of two selected planes was the edge vector. The corner points of the scan body are at the intersection between the edge vectors and a selected top plane. A reference vector representing the top edge was created through two corner points. The angle between the top edges of two scan body models was measured. This angle was the rotation of one scan body in relation to the other one (*Figure 2a*). The distance between a center point of one scan body and a top plane of another scan body was measured and this was evaluated as the vertical shift of the scan body (*Figure 2b*). Five measurements for each parameter were performed for each case.

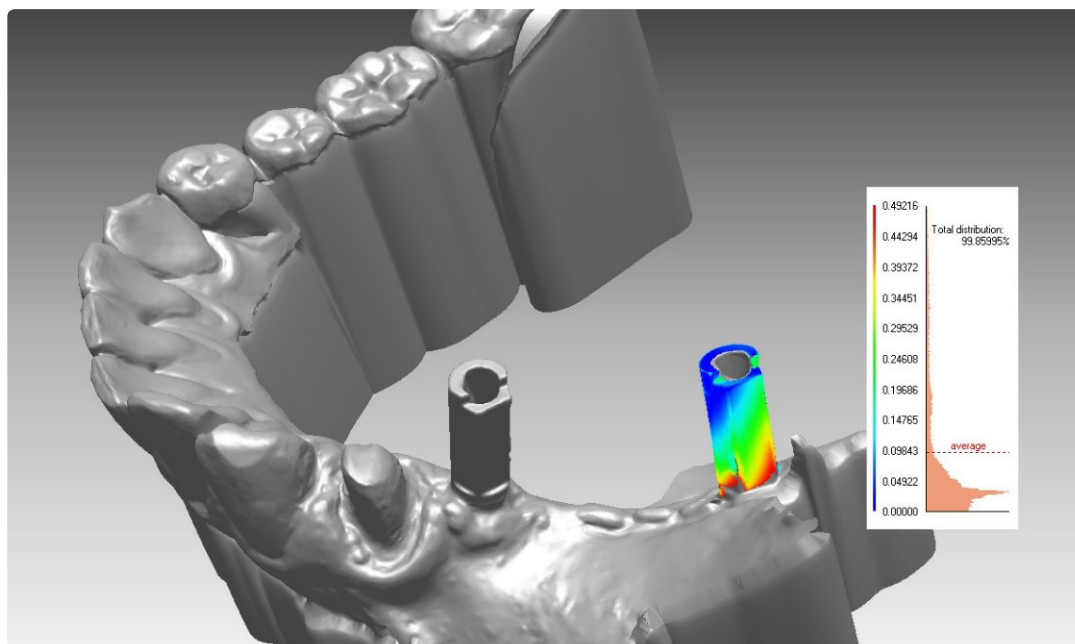
The evaluation of mismatch between the scans of the original model and the 3D CAD model of the scan body consisted of the alignment step and calculation of the average distance between the given surfaces. The Euclidean distance was measured for each pair of corresponding points obtained by ICP algorithm, and the histogram of the distribution of distances and a color map (the distances are presented by colors) were calculated (*Figure 3*). Software superimposition error was specified as  $0.3 \pm 0.3 \mu\text{m}$ .



**Figure 1a-b:** Measurement of a) inter-implant distance and b) angulation.



**Figure 2a-b:** Measurement of a) rotation and b) vertical shift. of a) inter-implant distance and b) angulation.



**Figure 3:** Evaluation of surface mismatch.

The average values and standard deviations of all parameters examined were calculated. The variables of the conventional and digital groups were compared to each other. In order to evaluate the effect of inter-implant distance and angulation on the differences measured between conventional and digital impressions, the actual values of inter-implant distance and angulation had to be calculated by this formula: (D800 data + Trios data)/2. These variables were used as reference data to find out how they could influence the differences between conventional and digital implant impressions. The workflow chart of the study is presented in the Figure 4.

### STATISTICAL ANALYSIS

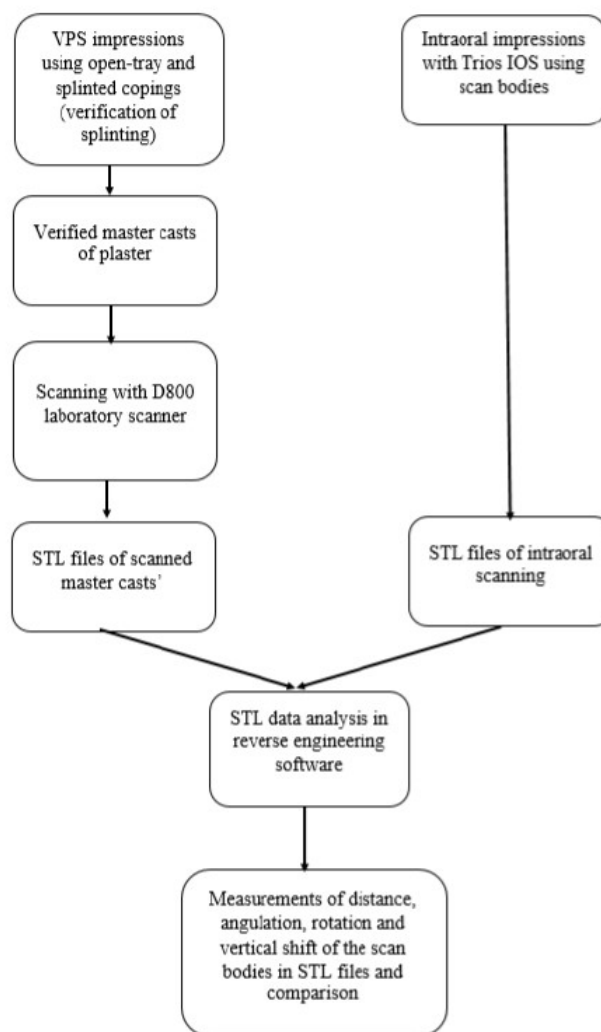
Statistical analysis were performed using R software (Lucent Technologies, Auckland, New Zealand) package 2.3, version 2. The Shapiro-Wilk test of normality was applied to the data. According to the Shapiro-Wilk test, not all data were distributed normally, and therefore the Wilcoxon signed-rank test for paired data was applied to compare medians. To assess the association between measured differences and distances, as well as angulation between implants, the Spearman correlation coefficient and linear regression models were used. Statistical analysis test power was calculated with GPower (Dusseldorf University, Dusseldorf, Germany) version 3.1.9.2 software. The level of statistical significance was considered to be  $p < 0.05$ .

### RESULTS

Statistically significant differences were found between digital and conventional impression measurements for the inter-implant distance, angulation variables, and surface mismatch of scan body parameters ( $p < 0.05$ ). Surface mismatch between mesially and distally located scan bodies were not significantly different in the Trios group and the D800 group (Table 1).

#### Conventional workflow

#### Digital workflow



**Figure 4:** The workflow chart of the study.

**Table 1. Differences between digital and conventional workflow.**

Variable	Conventional impression		Digital impression		Mean of differences $\pm$ SD	P - value	Wilcoxon signed rank test power
	Mean and SD	Median	Mean and SD	Median			
Inter-implant distance	14.28 (6.75) mm	14.99	14.33 (6.77) mm	15.00	73.7 (75) $\mu$ m	0.00	6 %
Angulation	14.17 (9.54) $^{\circ}$	10.16	14.38 (9.8) $^{\circ}$	10.74	0.42 (0.3) $^{\circ}$	0.00	10 %
Rotation	33.58 (23.19) $^{\circ}$	28.40	33.27 (22.61) $^{\circ}$	29.07	0.72 (0.55) $^{\circ}$	0.098	8 %
Vertical shift	1.58 (2.15) mm	0.85	1.57 $^{\circ}$ (2.2) mm	0.83	98.9 (96.33) $\mu$ m	0.63	6 %
Mismatch M implant	14.27 (21.5) $\mu$ m	14.32	31.8 (25.6) $\mu$ m	19.68	-	0.00	100 %
Mismatch D implant	14.65 (19.7) $\mu$ m	14.32	30.68 (28.7) $\mu$ m	22.67	-	0.00	100 %

**Table 2. Results of linear regression model (NS - not significant correlation)**

Dependent variables	Independent variables					
	Actual mean of inter-implant distance			Actual mean of angulation		
	Spearman coefficient	Linear regression model		Spearman coefficient	Linear regression model	
		p - value	Model power		p - value	Model power
Inter-implant distance	0.19	0.35	27 %	0.3	0.02	91 %
Angulation	0.08 (NS)	0.02	93 %	0.53	0.0	100 %
Vertical shift	0.53	0.0	99.9 %	0.52	0.0	100 %

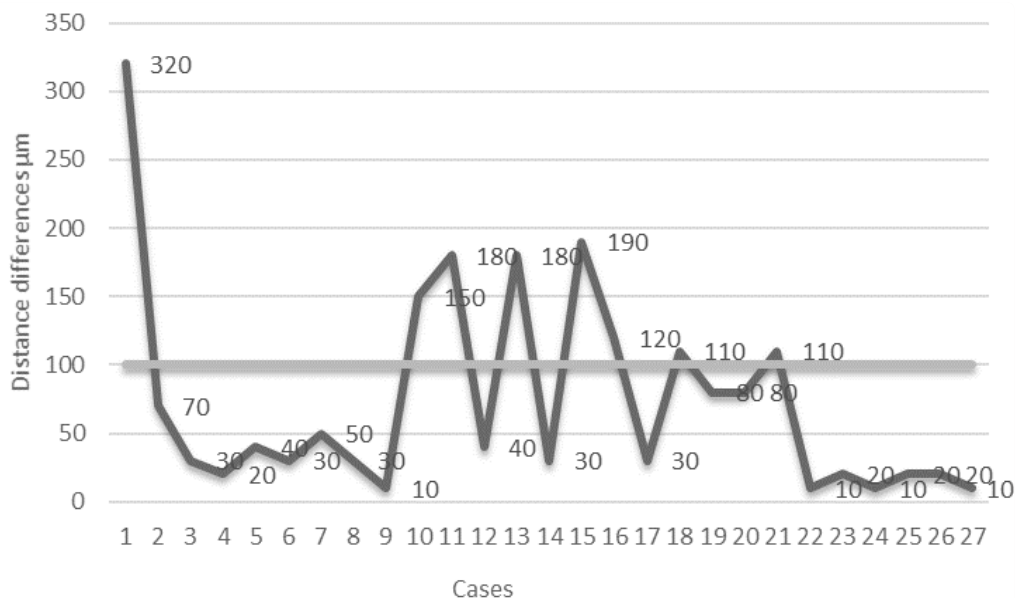
Measurements of surface mismatch show that the D800 scanner is twice as accurate as IOS in this regard. Surface mismatch measurements for the Trios and D800 were  $31.8 \pm 25.6 \mu\text{m}$  and  $14.27 \pm 21.5 \mu\text{m}$  for mesial implant scan bodies, and  $30.68 \pm 28.7 \mu\text{m}$  and  $14.65 \pm 19.7 \mu\text{m}$  for distal implant scan bodies (Table 1).

Spearman correlation coefficients showed that angulation and inter-implant distance were positively correlated to the measured differences in inter-implant distance, angulation, and vertical shift between both groups. The values of coefficients varied from 0.19 to 0.53, showing weak to medium correlation between variables (Table 2). According to linear regression results, all these associations were statistically significant ( $p < 0.05$ ), except for the association of the actual mean of inter-implant distance with differences in angulation.

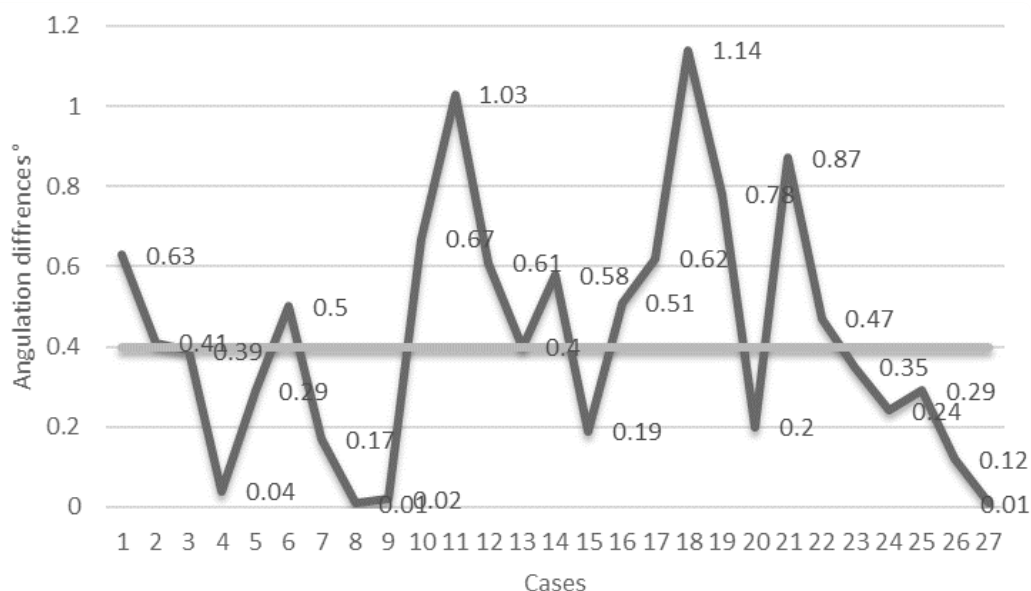
Clinically acceptable threshold has been used in several studies in order to correlate results obtained by *in vitro* studies with clinical conditions. The need to use thresholds further reinforces the nature of the present study. In order to have tentative threshold values, simplified calculations from the clinical study for linear (100  $\mu\text{m}$ ) and angular (0.4 $^{\circ}$ ) measurements by Andriessen *et al* were taken as a reference.<sup>15</sup> The means and standard deviations of all measured parameters in all cases are presented in Figures 5-8.

## DISCUSSION

This study is one of the very few clinical studies comparing conventional and digital implant impressions.<sup>18</sup> The majority of the studies on the accuracy of DII have been performed *in vitro*,<sup>9-18</sup> since the reference positions of the scan bodies can easily be obtained with industrial scanners, coordinate



**Figure 5:** Differences in distance between conventional and digital impression measurements (Mean  $73.7 \pm 75 \mu\text{m}$ ). The light grey line represents the tentative clinical threshold of  $100\text{-}\mu\text{m}$  misfit.

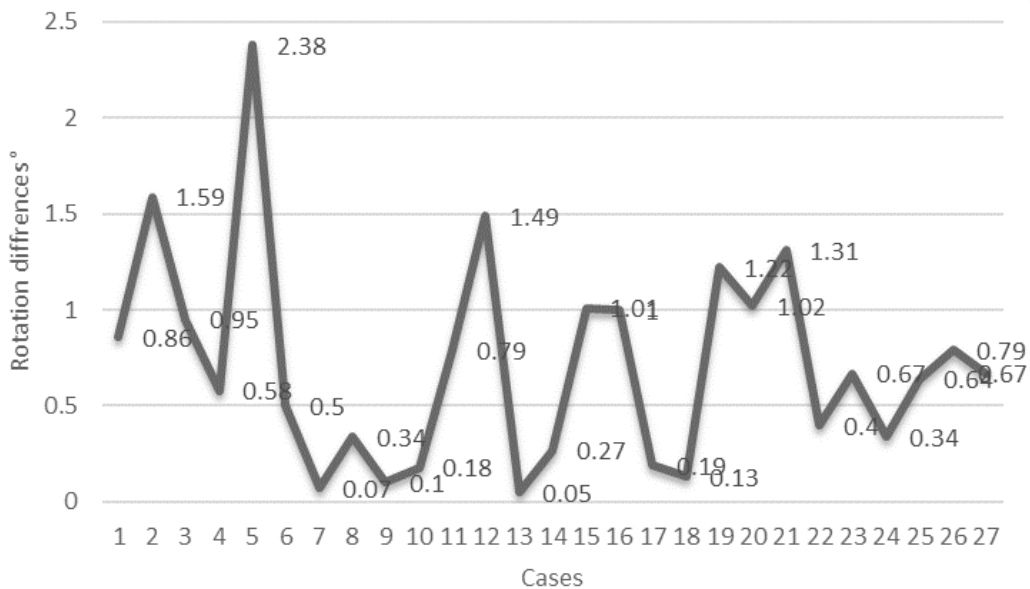


**Figure 6:** Differences in angulation between digital and conventional impression measurements (Mean  $0.42 \pm 0.3^\circ$ ). The light grey line represents the tentative clinical threshold of angular misfit,  $0.4^\circ$

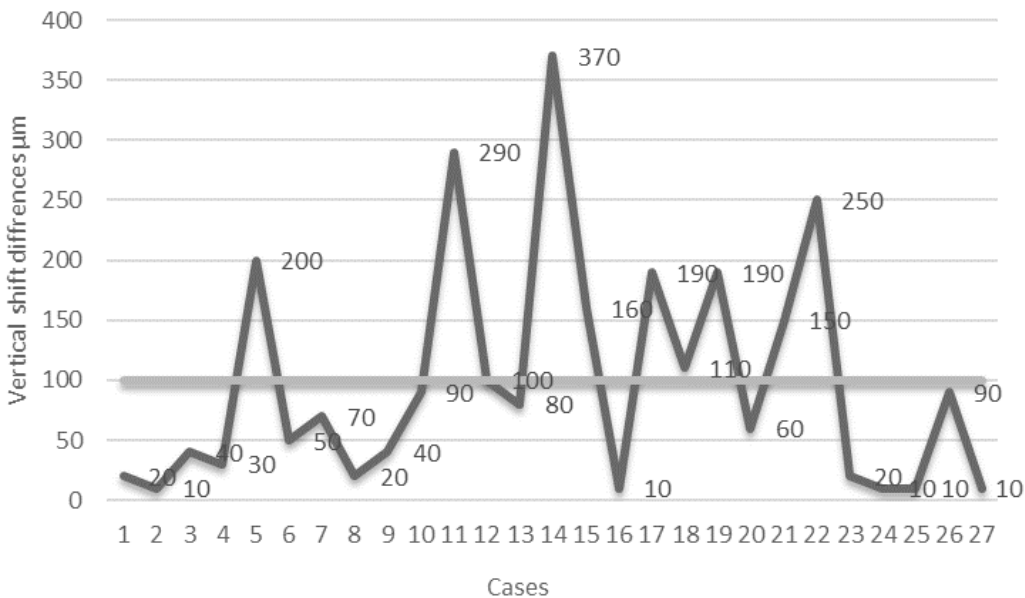
measuring machines, or other equipments. However, these techniques could not be fully applied to the patient to obtain true reference data. The use of industrial-grade scanner in clinical conditions can be considered only in the anterior region of the mouth.<sup>21</sup> In this study the restorations were predominantly in the posterior region and this technique could not be applied. Instead, the master cast resulting from the conventional impression technique, which was verified and confirmed in multiple steps, was used as the best available clinical reference. In this way, the accuracy of digital and conventional implant impressions was compared using the conventional approach as a control. Active wavefront sampling, confocal microscopy and other principles are applied in

many different types of IOS. As different scanners can produce various results, two or more of them are usually evaluated in *in vitro* studies.<sup>21-23</sup> Due to ethical reasons, only one IOS was used in this study.

The clinically significant thresholds of horizontal/vertical misfit and angulation errors of two implant-supported restorations were selected as  $100 \mu\text{m}$  and  $0.4^\circ$ .<sup>15</sup> Despite the complexity of evaluating misfit and its clinical significance,<sup>24</sup> these values were taken for the sake of comparison and in order to have tentative threshold. In this study, differences in the means of inter-implant distance ( $73.7 \pm 75 \mu\text{m}$ ) and vertical shift ( $98.9 \pm 96.33 \mu\text{m}$ ) were lower than  $100 \mu\text{m}$ . However, given that the means approached the tentative threshold and the high



**Figure 7:** Differences in rotation between digital and conventional impression measurements (Mean  $0.72 \pm 0.55^\circ$ ).



**Figure 8:** Differences in vertical shift between the D800 and Trios measurements (Mean  $98.9 \pm 96.33 \mu\text{m}$ ). The light grey line represents the tentative clinical threshold of  $100 \mu\text{m}$  misfit.

standard deviations, these differences could be regarded as potentially having clinical significance. Differences in mean angulation were above  $0.4^\circ$  ( $0.42 \pm 0.3^\circ$ ). In contrast, other *in vitro* studies using similar protocols showed that DII are as accurate as or even more accurate than conventional impressions.<sup>10,25</sup>

Dental implant abutment rotational misfit could be of clinical significance,<sup>26</sup> and therefore rotation of scan bodies was evaluated. No statistically significant differences concerning rotation were found between conventional impressions and DII where the mean difference was found to be  $0.72 \pm 0.55^\circ$ . The clinical significance of these findings is limited given that non-hexed abutments or abutments without other anti-

rotational features are generally recommended for multiple-unit implant-supported reconstructions. It should also be noted that rotational differences represent cumulative errors in scanning and scan body repositioning as well.<sup>21</sup> In cases when titanium interfaces without anti-rotational features are not available in the CAD/CAM workflow, rotational misfit could be clinically relevant depending on the rotational freedom of the abutments.<sup>22</sup>

Comparing surface mismatch data between mesial and distal scan body images obtained by IOS, no statistically significant differences were found. Other authors claimed that scanning location considerably affects DII accuracy because this leads to cumulative errors in the image suturing process,

especially in long span situations.<sup>9,10,13</sup> These aspects could be very relevant for posterior cases where scanning procedure could be more challenging. It has to be noted that in this study 24 out of 27 restorations were in the posterior area.

Surface mismatch data of the laboratory scanner for mesial and distal scan bodies were twice better than IOS (*Table 1*). This could have clinical implications, namely due to the higher surface mismatch, discrepancies in the position of the original CAD image of the scan body can appear, affecting estimated implant positions and resulting in the misfit of the restoration.

Analyzing linear regression models and associations of variables, inter-implant distance had no effect on differences in the angulation of scan bodies (Spearman coefficient 0.08,  $P > 0.05$ ). A similar subject was investigated by Flugge *et al* in another experimental study,<sup>23</sup> but the results showed that distance between implants significantly affected distance and angulation measurements. Vertical shift differences between digital and conventional methods were significantly affected by implant angulation and inter-implant distance. Angulation between implants had a statistically significant impact on differences in the measurement of inter-implant distance, angulation, and vertical shift.

In this study, a very robust protocol was used to verify the accuracy of splints of master casts, and restorations were used for the validation of the conventional technique. It could be expected that in daily clinical practice, the open-tray technique could produce less accurate results. Furthermore, based on the systematic reviews, closed-tray impression procedures are considered to be less accurate than open-tray ones for multiple implant cases.<sup>3,4,24</sup> Therefore, accuracy of digital impressions and closed-tray techniques should be compared in further research.

Certain study limitations should also be considered in that the accuracy of conventional implant impressions could be affected by many factors, including inter-implant distance, implant angulation, implant placement depth, etc.<sup>24</sup> In addition to these factors, the accuracy of digital impressions can also be influenced by scanner type,<sup>17</sup> software, scanning strategy,<sup>25</sup> and other factors specific to the digital workflow. The machining tolerance of scan bodies and repositioning accuracy could also affect the accuracy of DII. There are two alternatives for digitizing dental implants: direct intra-oral data capturing or indirect from a master cast, both with transfer caps (scan-bodies, although in one other study this was not supported.<sup>26</sup> Implant location could influence DII accuracy, as in posterior cases limited mouth opening, salivary flow, tongue movements, and a shallow vestibule in the mandible could interfere with the capturing and stitching of the images.

Differences between DII and conventional implant impressions were found to be of potential clinical significance. However, rapid developments in IOS hardware and softwares have to be taken into account. Newer generation IOS have improved and could possibly offer a better alternative. The scientific literature is struggling to report on the accuracy of

IOS in time due to constantly changing technologies and new software updates. Since the clinical use of digital technologies is increasing rapidly, further clinical studies on the accuracy of IOS need to be done to collect more evidence-based information and to replace conventional techniques.

## CONCLUSIONS

From this study, the following could be concluded:

1. Positional differences of the scan bodies in conventional and digital impressions were of potential clinical significance, especially for angle and vertical shift errors.
2. The angulation and distance between implants were associated with differences in the distance, angle, and vertical shift of scan bodies comparing both impression techniques.
3. Mismatch of the scanned surface of scan bodies was twice higher for the intraoral scanner group.

## DISCLOSURE

The authors declare that they have no conflict of interest.

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