Trueness evaluation of latest generation intraoral scanners on complete arch implant impressions.

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Purpose: To evaluate the trueness of five intraoral scanners for a fully edentulous model with seven implants. Materials and Methods: The study model was created from gypsum with seven implant analogs that were placed with 2-mm gingival height and 0-degree angle at tooth sites 47, 45, 43, 31, 33, 35, and 37. The study model was scanned 10 times (n = 10) with five intraoral scanners (CS3600, Emerald S, Primescan, TRIOS 3, TRIOS 4). The study model was digitized with a high-resolution industrial desktop scanner, and the data were imported into a software (Geomagic Studio 2012) as the reference model. The trueness assessment was made digitally with superimposition using the software. Linear measurements were calculated by the differences
between the centers of the scan bodies on the study vs the reference model. Volumetric deviations were calculated with root mean square values. Data obtained in the study were analyzed statistically. One-way analysis of variance and Tukey tests were used to evaluate significant interactions. A value of $P < .05$ was accepted as statistically significant. **Results:** In linear measurements, TRIOS 4 showed the best trueness results, followed by TRIOS 3, Emerald S, Primescan, and CS3600. TRIOS 4 showed statistically truer results than CS3600 ($P = .029$). However, no statistically significant difference was found between groups in volumetric measurements ($P < .05$). **Conclusion:** All of the intraoral scanners used in the study showed favorable deviation values in an edentulous model with seven implants. TRIOS 4 showed the best trueness values. The latest generation of intraoral scanners can be used in full-arch implant impressions. *Int J Prosthodont* 2022. doi: 10.11607/ijp.7824

**INTRODUCTION**

Long term success of implant supported prostheses is directly related to the misfit of the restoration. Therefore, making the accurate impression has great role for avoiding any errors and achieving successful restorations.$^{1–3}$

Trueness can be defined as the closeness of the measurement to the reference point while precision is defined as the closeness of the repetitive measurements. In another words, trueness is how close the test result is to the reference point and precision is how close one test result is to other test results.$^{4–6}$

After the introduction of CAD/CAM systems and intraoral scanners, transferring the oral environment with digital systems have become more popular and the disadvantages of conventional impressions such as micro-motion of the implant impression copings, dimensional stability of the impression material, time consumption, patient discomfort have been eliminated.$^{7–9}$
Intraoral scanners provide adequate accuracy for quadrant scans or full arch scan of dentate patients. However, the trueness of intraoral scanners on full arch implant scanning is still debatable due to lack of reference point while scanning.\textsuperscript{4,10} The trueness of intraoral scanners is affected by the scanner model and working principle \textsuperscript{4,10}, ambient lighting\textsuperscript{11–13}, software version\textsuperscript{14}. Therefore, introduction of new generation intraoral scanners with higher expectations requires more research about their trueness and precision. Even though there are many studies in the literature regarding the trueness of full arch implant scanning\textsuperscript{4,10,15}, the evidence of the trueness of latest generation intraoral scanners on the market on full arch implant scanning is lacking.

The aim of this study is to evaluate the trueness of five intraoral scanners on full edentulous model with seven implants. The null hypothesis is that there is no difference between different intraoral scanners with different working principle on full arch implant scanning.

**MATERIAL AND METHODS**

The study model was created from gypsum by duplicating a typodont mandibular model (Frasaco Study Model ANA 4, Frasaco GmbH, Tettnang, Germany) with 7 implant analogues (4.2 mm diameter, Bone level implant analogs; Straumann, Switzerland). Implant analogues were inserted with 2 mm gingival height and 0° degrees at tooth sites #47, #45, #43, #31, #33, #35, #37 (Figure 1). Polyether-ether-ketone (PEEK) scanbodies (Scanbody; Straumann, Switzerland) were used for the master model digitization and digital impression procedures. Five different intraoral scanners (CS3600, Carestream, Rochester, NY, USA; Emerald S, Planmeca, Helsinki, Finland; Primescan, Dentsply Sirona, York, PA, USA; Trios3, 3Shape, Copenhagen, Denmark; Trios4, 3Shape, Copenhagen, Denmark) were used (Table 1). The study model was scanned 10 times with each intraoral scanner. During the scanning, all of the scanners were used according to the manufacturers’ recommendation.
CS3600, Emerald S, Trios 3 and Trios 4 shared the same recommendation and scans were done as following protocol: Scanning started from the occlusal surface of the most distal tooth with the tip of the scanner pointing towards the distal. The occlusal surface was scanned to the most distal tooth on the opposite side. During the interarch scan, the scanner was rotated back and forth from the lingual to the facial on the anteriors. The scan was continued on the buccal side with 45 degrees tip angle and finalized with the scanning of the all of the lingual side with with 45 degrees tip angle. Finally, the missing scan data were scanned at the end (Figure 2A). However, for Primescan a different scan protocol was followed: the occlusal surface of the most distal tooth was the starting point of the scan. After the first few 3D images, the scanner was swept by 60 degrees to the lingual side and the arch was scanned to the opposite most distal tooth. From there, scanning was continued with an occlusal scan over the insizal edges in the anterior region until the most distal tooth on the opposite side. Afterwards, the scanner was swept by 60 degrees to the facial side and the arch was scanned back to the most distal tooth on the opposite side. Finally, the missing scan data were scanned at the end (Figure 2B).

The scanning procedure was done by single operator (Author DSA) who is experienced in intraoral scanning and has already used the intraoral scanners of the study. The scans were done in a room with ceiling lighting. The lighting of the room was measured as 1003 lux by a light meter (L-308X-U Flashmate Light Meter (401-305), Sekonic Corp., Tokyo, Japan). The study model was digitized with a high-resolution industrial desktop scanner (Solutionix C500, MEDIT Corp., Korea). After calibration of the industrial scanner, the study model was scanned, the STL (standard tessellation language) file was imported into a reverse engineering software (Geomagic Studio 2012, Geomagic, Morrisville, NC, USA) as the reference model.
The trueness assessment was made digitally with superimposition, using the reverse engineering software (Geomagic Studio 2012, Geomagic, Morrisville, NC, USA) as described previously. All STL data were imported into Geomagic software and the “mesh doctor” tool was used to remove any unexpected artefacts. The superimposition process followed two steps: three-point registration on the scanbodies, also known as “rough alignment”, then application of the best-fit alignment function.

Linear and volumetric measurements were made in order to evaluate trueness of the intraoral scanners. Linear and cross distances were measured between the centers of the scanbodies in both reference data and specimen data (Figure 3). The differences in between two implant centers gave the distortion of the impression. Volumetric mean deviation values and standard deviations were calculated by root mean square (RMS) values that were reported by the software. Briefly, the study model was scanned with 10 times with each intraoral scanner and the STL file of each scan was superimposed with the control STL file. The deviation values were calculated for each scan, then the mean deviation value was calculated for each scanner.

Data obtained in the study were analyzed statistically using NCSS software (Number Cruncher Statistical System 2007; Kaysville, Utah, USA). Descriptive statistical methods were used to evaluate the study data. The conformity of quantitative data to normal distribution was tested with the Shapiro-Wilk test. One-way analysis of variance and Tukey tests were used to evaluate significant interactions. A value of $p<0.05$ was accepted as statistically significant.

**RESULTS**

The mean and standard deviations of the groups are summarized in Table 2. In linear measurements, Trios4 showed the best trueness results, followed by Trios 3, Emerald S, Primescan and CS3600. Trios4 showed statistically truer results than CS3600 ($p:0.029$).
However, no statistically significant difference was found between other groups (p<0.05) (Figure 4). In volumetric measurements with RMS values, the relation among the groups were the same as linear measurements, however, no statistical difference was found between any groups (p: 0.333) (Table 2).

**DISCUSSION**

In cases where overloads are placed on the implants, resorption of bone tissue around the implant and leading to loss of implants are inevitable. In order to produce a well-fitting restoration, the positions of the implants must be transferred to the laboratory accurately.

According to the results obtained from this study, the null hypothesis is partially rejected. Statistical analysis showed significant differences only between Trios 4 and CS3600 on full arch implant scanning in linear measurements. However, no statistically significant difference was observed amongst groups in volumetric measurements.

Marginal and internal gaps between 30-150 μm between the framework and abutments are considered as clinically acceptable in order to prevent misfit related biological and mechanical complications. The results obtained from our study are under those limits in all groups in linear measurements. However, volumetric measurement results showed greater deviation values above those limits. The difference between the two evaluation methods may be attributed to the fact that in linear measurements, the calculations were made in two dimensions but in three dimensions in RMS measurements. In addition, in volumetric measurements, the deviations that occur on the surface of the model was also calculated which may lead to observe higher deviations.

The intraoral scanners that are used in the current study have different working principles (Table 1). Therefore, they capture the images and process the data accordingly and create mesh surfaces. That directly affects the scan quality and trueness of the scans.
However, there are many other factors that affect the trueness of the scans such as the operator\textsuperscript{19–21}, ambient lighting\textsuperscript{11–13}, patient\textsuperscript{4}, angulation of the implants\textsuperscript{9,22,23}, depth of the implants\textsuperscript{20,24}, software versions\textsuperscript{14}, scanned substrate material\textsuperscript{6}.

The experience level of the operator may affect the accuracy of the intraoral scanners as reported previously\textsuperscript{19–21}. In the present study, one single operator, who is experienced in digital dentistry and has been using intraoral scanners for many years, conducted the study and performed the scans according to the manufacturers’ recommendations as scan strategy has also been reported to affect the accuracy of intraoral scanners\textsuperscript{6,25,26}. In the current study, the aim was to evaluate the trueness of the intraoral scanners, therefore, the variables that could affect the trueness of the scanners were eliminated by using parallel implants with standardized gingival depths and scanned with PEEK scanbodies. Ambient lighting has an effect on trueness of intraoral scanners as previously reported\textsuperscript{12}. In the current study, all scans were made in a controlled and standardized environment, however this is not completely reflecting the intraoral environment.

Mangano et al.\textsuperscript{10} compared five different intraoral scanners (Trios 3, CS3600, Emerald, DWIO and Omnicam) on an edentulous model with 6 implants. CS3600 showed better results compared to Trios3 and Emerald. The results they obtained contradicts with the results of our study, however the results may be attributed to the difference between the study models and the evaluation method.

In another in vitro study\textsuperscript{4}, the accuracy of 12 different intraoral scanners (CS3600, CS3700, DWIO, Emerald, Emerald S, Itero Elements 5D, Medit I-500, Omnicam, Primescan, Runeyes, Trios 3, Virtuo Vivo) on edentulous maxilla with 6 implants. In that study, linear and cross distances between the scanbodies were calculated. The results in common groups are similar with the current study except Emerald S group. However, the difference between the results may be attributed to difference between the study design. In addition, Mangano et
al. followed one specific scan pattern for all of the intraoral scanners in their study and they stated that following one pattern for all of the groups may have favoured some intraoral scanners over others. However, in the current study, each intraoral scanner was used according to the manufacturers’ recommendation and this may lead us to achieve the best possible results for each intraoral scanner.

This study was conducted in vitro therefore, there are some limitations. First of all, intraoral lighting and the effect of saliva were not simulated in the study. Also, the lack of space during scanning may lead to unintended numbers of captured images therefore, this effect was not taken into account. The implants were placed ideally which could affect the results in positive or negative way. The reference model was digitized with an industrial scanner and superimposition with mesh/mesh method was used rather than using a coordinate measurement machine which could make the measurements deviated into coordinates (x,y,z) as in the current study, the direction of the deviations are not clear. Only one experienced operator scanned the model, therefore the effect of operator on the trueness of those intraoral scanners was ignored. Finally, the study was conducted in a specific period of time (May 2020-June 2020) and the software versions were the latest at the time.

CONCLUSION

Under the limitations of the current study, it can be concluded that the intraoral scanners have different trueness on full arch implant scanning however, all of the tested intraoral scanners showed favorable deviation values. Further studies regarding the explained limitations should be conducted and these results must be supported by in vivo studies.

REFERENCES


19. Kamimura E, Tanaka S, Takaba M, Tachi K, Baba K. In vivo evaluation of inter-


FIGURE LEGENDS

Figure 1. Study model – edentulous mandible with 7 implants

Figure 2. Scan strategies of the intraoral scanners
Figure 2A. Scan strategy of CS3600, Emerald S, Trios 3 and Trios 4 – starting from the occlusal, followed by the facial and the lingual surfaces

Figure 2B. Scan strategy of Primescan – starting from the lingual, followed by the occlusal and the facial surfaces
Figure 3. Linear and cross measurements of the model

Figure 4. Box-plot graphs of the groups
Figure 4A. Box-plot graphs of the linear measurement deviation values of each intraoral scanner
Figure 4B. Box-plot graphs of the volumetric measurement deviation values of each intraoral scanner.
# TABLES

Table 1: Intraoral scanners used in the study.

<table>
<thead>
<tr>
<th>Intraoral scanner</th>
<th>Manufacturer</th>
<th>Working principle</th>
<th>Powder</th>
<th>Color</th>
<th>Recommended Scan Pattern by the Manufacturer</th>
</tr>
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<tbody>
<tr>
<td>CS3600</td>
<td>Carestream Dental, Atlanta, Georgia, USA</td>
<td>Structured light-Active Speed 3D VideoTM</td>
<td>No</td>
<td>Yes</td>
<td>Occlusal – Facial (45°) – Lingual (45°)</td>
</tr>
<tr>
<td>Emerald S</td>
<td>Planmeca, Helsinki, Finland</td>
<td>Red, green and blue lasers-Projected Pattern Triangulation™</td>
<td>No</td>
<td>Yes</td>
<td>Occlusal – Facial (45°) – Lingual (45°)</td>
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<tr>
<td>Primescan</td>
<td>Dentsply Sirona, York, PA, USA</td>
<td>High Frequency Contrast Analysis</td>
<td>No</td>
<td>Yes</td>
<td>Occlusal – Lingual (60°) – Facial (60°)</td>
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<td>Trios 3</td>
<td>3-Shape, Copenhagen, Denmark</td>
<td>Structured light –Confocal microscopy and Ultrafast Optical Scanning™</td>
<td>No</td>
<td>Yes</td>
<td>Occlusal – Facial (45°) – Lingual (45°)</td>
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<tr>
<td>Trios 4</td>
<td>3-Shape, Copenhagen, Denmark</td>
<td>Structured light –Confocal microscopy and Ultrafast Optical Scanning™</td>
<td>No</td>
<td>Yes</td>
<td>Occlusal – Facial (45°) – Lingual (45°)</td>
</tr>
</tbody>
</table>
Table 2: Deviation values of intraoral scanners in linear measurements and volumetric (RMS values) measurements (Mean ± St.Dev).

<table>
<thead>
<tr>
<th>Groups</th>
<th>Linear measurements</th>
<th>Volumetric measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 CS3600</td>
<td>0.14±0.05&lt;sup&gt;B&lt;/sup&gt;</td>
<td>0.21±0.03&lt;sup&gt;C&lt;/sup&gt;</td>
</tr>
<tr>
<td>2 Emerald S</td>
<td>0.12±0.04&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.19±0.04&lt;sup&gt;C&lt;/sup&gt;</td>
</tr>
<tr>
<td>3 Primescan</td>
<td>0.13±0.05&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.20±0.03&lt;sup&gt;C&lt;/sup&gt;</td>
</tr>
<tr>
<td>4 Trios 3</td>
<td>0.09±0.03&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.18±0.02&lt;sup&gt;C&lt;/sup&gt;</td>
</tr>
<tr>
<td>5 Trios 4</td>
<td>0.09±0.01&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.17±0.05&lt;sup&gt;C&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P</th>
<th>0.008*</th>
<th>0.333</th>
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</thead>
<tbody>
<tr>
<td>p (1-2)</td>
<td>0.688</td>
<td>0.954</td>
</tr>
<tr>
<td>p (1-3)</td>
<td>0.997</td>
<td>0.583</td>
</tr>
<tr>
<td>p (1-4)</td>
<td>0.051</td>
<td>0.994</td>
</tr>
<tr>
<td>p (1-5)</td>
<td>0.029*</td>
<td>0.347</td>
</tr>
<tr>
<td>p (2-3)</td>
<td>0.871</td>
<td>0.938</td>
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<tr>
<td>p (2-4)</td>
<td>0.554</td>
<td>0.998</td>
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<tr>
<td>p (2-5)</td>
<td>0.413</td>
<td>0.770</td>
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<tr>
<td>p (3-4)</td>
<td>0.113</td>
<td>0.825</td>
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<td>p (3-5)</td>
<td>0.067</td>
<td>0.995</td>
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<tr>
<td>p (4-5)</td>
<td>0.999</td>
<td>0.594</td>
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*One-way variance analysis and Tukey’s HSD test p<0.05.
Different superscripts indicate statistical significance between groups.