Precision of Dental Implant Digitization Using Intraoral Scanners

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Purpose: The digitization of scanbodies on dental implants is required to use computer-aided design/computer-assisted manufacture processes for implant prosthetics. Little is known about the accuracy of scanbody digitization with intraoral scanners and dental lab scanners. This study aimed to examine the precision of different intraoral digital impression systems as well as a dental lab scanner using commercially available implant scanbodies.

Materials and Methods: Two study models with a different number and distribution of dental implant scanbodies were produced from conventional implant impressions. The study models were scanned using three different intraoral scanners (iTero, Cadent; Trios, 3Shape; and True Definition, 3M ESPE) and a dental lab scanner (D250, 3Shape). For each study model, 10 scans were performed per scanner to produce repeated measurements for the calculation of precision. The distance and angulation between the respective scanbodies were measured. The results of each scanning system were compared using analysis of variance, and post hoc Tukey test was conducted for a pairwise comparison of scanning devices.

Results: The precision values of the scanbodies varied according to the distance between the scanbodies and the scanning device. A distance of a single tooth space and a jaw-traversing distance between scanbodies produced significantly different results for distance and angle measurements between the scanning systems (P < .05).

Conclusion: The precision of intraoral scanners and the dental lab scanner was significantly different. The precision of intraoral scanners decreased with an increasing distance between the scanbodies, whereas the precision of the dental lab scanner was independent of the distance between the scanbodies. Int J Prosthodont 2016;29:277–283. doi: 10.11607/ijp.4417

Use of computer-aided design/computer-assisted manufacture (CAD/CAM) technologies to manufacture prosthetic frameworks on dental implants is noticeably increasing. This method requires that the position of the implants within the dental arch be acquired and displayed in a virtual model. As the current technologies do not facilitate recording the implant itself, a scanbody is positioned on the implant and optically scanned. The scan is acquired intraorally, or extraorally using a stone cast poured from a conventional implant impression using implant impression posts.

Several intraoral scanning systems that use either recorded video sequences or single images have been introduced into clinical practice. These systems aim at efficient integration of the data into the digital workflow and avoidance of the limitations of conventional impressions. Incomplete information or artifacts in the scan caused by shadowing of neighboring or undercut structures, limited space, and humidity in the oral cavity reduce the precision of the digital information. A pilot study showed that acquisition of a virtual model with dental implant scanbodies was not feasible under intraoral conditions. Therefore the precision of the scanning systems in intraoral use cannot yet be determined.

The overall possible accuracy of prosthetic frameworks depends on the accuracy of the individual steps of the production process, from implant alignment, impression technique and material, framework design, and fabrication to the experience of the clinician and technician. The clinically acceptable degree of inaccuracy has been diversely discussed. Klineberg and Murray considered discrepancies of up to 30 µm at the implant-abutment-interface as acceptable, and Jemt proposed a limit of 150 µm to prevent long-term complications. However, due to the lack of reliable measurement tools and in vivo data...
for prosthetic restorations, the quantification of misfit and its potential influence on biologic and mechanical complications remains unknown.15 A consensus for an acceptable threshold of misfit has yet to be reached.

The term **accuracy** describes the precision and trueness of a system, device, or method.16 The precision expresses how close repeated measurements are to each other, whereas the trueness describes how far measurements deviate from the actual object. To determine the precision of scanning techniques themselves, an extraoral approach must be used.

Few in vitro studies evaluated the accuracy of intraoral scanning under experimental conditions with the teeth of the complete dental arch,17 custom-made optical transfer posts,18 or prefabricated implant abutments instead of commercially available implant scanbodies. In vitro studies showed comparable results for conventional and digital impressions of full dental arches or prepared teeth.17,19 The digitization of teeth follows a completely different protocol than the digitization of dental implants with implant scanbodies, and the precision may not be compared.

Van der Meer et al scanned implants under experimental conditions with individually designed optical transfer copings and did not find significantly different results for the intraoral scanning devices used.18 The transfer copings used by these authors are not available for clinical use, and their three-dimensional (3D) measurements were not validated. The distance between the scanbodies was not disclosed, and the study did not consider different distances between the scanbodies in different clinical situations.

To date, no study has evaluated the precision of implant digitization using different intraoral scanning systems and commercially available scanbodies in addition to considering different distances between the scanbodies within the dental arch.

The present study examined the precision of three different optical impression systems used for intraoral implant digitization (Trios, 3Shape; iTero, Cadent; True Definition, 3M ESPE) using commercially available scanbodies and different interscanbody distances.

**Materials and Methods**

Stone casts from two partially edentulous patients were used for this study. The first study model (SM1) was acquired from a patient with a partially dentate mandible with a missing left second premolar and first molar, who had received two implants in this region. SM1 contained one tissue level implant analog (REF 048.124) in the mandibular left second premolar region and a bone level implant analog (REF 025.4101) in region 36. (b) Study model SM2 with five tissue-level implant analogs (REF 048.124) in regions 33, 35, 36, 45, and 47.

In the second study model (SM2), five implants in the mandible in the region of the left canine, left second premolar, left first molar, right second premolar, and right first molar were present. The remaining teeth were located mainly in the anterior region, from the right first premolar to the left lateral incisor. The second study model consisted of tissue level implant analogs (REF 048.124) in all regions (Fig 1b).

The study models were obtained using polyether pick-up impressions (Impregum Penta, 3M ESPE) with open custom trays and poured with type IV stone (U180, picodent). SM2 received a gingiva mask (Gingifast Rigid, Zhermack) surrounding the implants. The stone casts were stored at room temperature and room atmosphere without exposure to sunlight for 24 hours prior to digitization.

The corresponding scanbodies for implant analogs in SM1 (mandibular left second premolar, REF 048.168, and first molar, REF 025.4915) and SM2 (REF 048.168) were manually screw retained in the implant analogs. The positions of the implant analogs and the scanbody types are listed in Table 1.

**Scanning Procedure**

Each study model with attached scanbodies was scanned 10 times with a laser light scanner that served as control (D250, 3Shape). The dental lab scanning system uses laser planes that are projected onto the surface of the stone cast. Their reflection is recorded by two cameras, and a 3D model is constructed from...
the surface data with triangulation. The accuracy of the device is stated at 20 mm (information provided by 3Shape).

Consecutively, SM1 was scanned 10 times with the iTero intraoral scanner (Cadent), the Trios intraoral scanner (3Shape) and the True Definition Scanner (3M ESPE), resulting in 40 virtual models (VM1). The second study model (SM2) was scanned with iTero and Trios, resulting in 30 virtual models (VM2) (Fig 2). A trained person (T.F.) recorded all scans according to the instructions issued by each manufacturer. The model surface was not prepared for scanning with D250, iTero, and Trios, whereas scanning with True Definition required light dusting with True Definition Scan Powder (3M ESPE) and was therefore the final scan. Scans were acquired one after the other at least 24 hours after stone cast manufacturing.

The 10 virtual models acquired with each scanning system were compared and their differences recorded with a dedicated measurement protocol described below.  

Data Processing

The virtual models, in STL format, were imported into the software Rapidform XOR2 (Inus Technologies). The virtual models were not aligned to one another on the basis of surface characteristics to eliminate a bias of results through surface registration. All measurements were conducted without surface registration, but on the basis of absolute distances and angles between the respective scanbodies.

With manual determination of surface points on the upper horizontal surface of the scanbody, a horizontal plane (HP) was created. Two planes parallel to the HP were created with a defined distance. With these planes, the middle segment of each scanbody was cut out and its surface information was used to create a cylinder with a least-square fitting algorithm. From the cylinder, the central axis (CA) of the scanbody was calculated using the software (Rapidform XOR2). A point at the intersection (IP) of the horizontal plane and the cylinder axis was marked (Fig 3).

The distance (DIP) between each neighboring scanbody in the first study model (DIP1) and in the second study model (DIP2–DIP7) was measured (Fig 4). The angle (ACA) between the scanbody axes (CA–CA) of all scanbodies was measured analog to the distance (ACA1–ACA7) as depicted in Fig 5.

The mean and standard deviations of the distances (DIP) and angles (ACA) between the scanbodies were recorded. These values were compared using one-way analysis of variance and post hoc Tukey test between the respective scan methods. The level of significance was set to P < .05 (Stata 13.1, StataCorp).
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Intraoral Scanning of Dental Implant Scanbodies

Results

Comparison of Mean Distances

The DIP in VM1 was 6.665 mm with D250, 6.669 mm with iTero, 6.647 mm with True Definition, and 6.658 mm with Trios (Table 2). The measurement of VM1 scanned with four different scanners resulted in significantly different results for the DIP (F\(_{3.12} = 3.52, P = .03\)). Tukey post hoc comparisons showed that the mean distances measured with iTero were significantly different from the mean distance measured with True Definition (P = .025). The comparison between distances scanned with Trios and True Definition and with Trios and iTero did not yield significant differences. The Trios scanner showed results comparable with the True Definition scanner and was not further tested with SM2.

The measurements of VM2 showed different results for the distance between the respective pairs of scanbodies. The distance measurements (DIP3) of the most proximally located scanbodies, VM2.2 and VM2.3, with a single tooth space (approximately 6.6 mm), were not significantly different when all four scanning devices were compared.

For a distance of about two tooth spaces (approximately 11 mm) between two scanbodies (DIP2 and DIP5), the measured distances were not significantly different. However, the distances measured with iTero and True Definition were significantly different (P = .044).

At an approximate distance of 18 mm between the scanbody centers (DIP4), corresponding with three tooth spaces, no significant difference between the scanning devices was detected.

For jaw-traversing distances of 40 mm (DIP6) and 50 mm (DIP7), the scanning devices revealed significant differences (F\(_{2.12} = 9.71, P = .00\)) according to the scanning method. The measurement of VM1 with two neighboring scanbodies showed significantly different results (F\(_{2.12} = 9.71, P = .00\)) and between iTero and D250 (P = .00). Post hoc Tukey test showed significant differences between the measurements with iTero and D250 (P = .00) and between iTero and D250 (P = .05). The mean distances for the scanbodies in VM1 and VM2 and their standard deviations are displayed in Table 2.

Comparison of Mean Angles

The mean angle (ACA) between the neighboring scanbodies in VM1 was 7.749 degrees with D250, 8.057 degrees with iTero, 8.196 degrees with True Definition, and 8.078 degrees with Trios (Table 3). The measurement of VM1 with two neighboring scanbodies showed significantly different results for the angle between the cylinder axis (F\(_{3.12} = 16.51, P = .00\)) according to the scanning method. The angle between the scanbodies differed significantly between iTero and D250 (P = .00), Trios and D250 (P = .00), and True Definition and D250 (P = .00). Because of the comparable results for Trios and True Definition and Trios and iTero, the Trios scanner was not included in measurements of SM2.
The measurements of VM2 resulted in different results for the angle between the respective pair of scanbodies. The mean angle ACA3 (single tooth space) was significantly different in regard to the scanning device ($F_{2,11} = 11.32$, $P = .0007$). Post hoc Tukey test showed a significant difference between D250 and True Definition ($P = .001$) and between D250 and iTero ($P = .002$).

For distances of two and three tooth distances (approximately 11 mm and 18 mm, respectively) the angles ACA2, ACA5, and ACA4 did not show a difference between the scanning devices ($P = .13$ and $P = .45$, respectively).

For distances of 40 mm (DIP6) and 50 mm (DIP7), the scanning devices revealed significant differences concerning the angle between the cylinder axes ($F_{2,12} = 5.18$, $P = .009$). The differences between iTero and D250 ($P = .016$) and True Definition and D250 ($P = .012$) were significant.

The mean angles between the scanbodies in VM2 and their standard deviations are displayed in Table 3.

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**Table 2** Mean Distances Between Intersection Points and Standard Deviations (µm)

<table>
<thead>
<tr>
<th>Scanbody distance</th>
<th>D250 (µm)</th>
<th>iTero (µm)</th>
<th>True Definition (µm)</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single tooth space</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIP1</td>
<td>6,665 (13)</td>
<td>6,669 (28)</td>
<td>6,647 (4)</td>
<td>.03</td>
</tr>
<tr>
<td>DIP3</td>
<td>6,770 (16)</td>
<td>6,783 (28)</td>
<td>6,778 (7)</td>
<td>.45</td>
</tr>
<tr>
<td>Two tooth spaces</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIP2</td>
<td>11,227 (17)</td>
<td>11,209 (26)</td>
<td>11,224 (5)</td>
<td>.06</td>
</tr>
<tr>
<td>DIP5</td>
<td>10,997 (8)</td>
<td>10,990 (30)</td>
<td>10,999 (5)</td>
<td>.06</td>
</tr>
<tr>
<td>Three tooth spaces</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIP4</td>
<td>17,605 (5)</td>
<td>17,596 (26)</td>
<td>17,610 (9)</td>
<td>.1</td>
</tr>
</tbody>
</table>

**Table 3** Angle (ACA) Between the Scanbody Axes (CA-CA)

<table>
<thead>
<tr>
<th>Scanbody distance</th>
<th>D250 (degrees)</th>
<th>iTero (degrees)</th>
<th>True Definition (degrees)</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single tooth space</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACA1</td>
<td>7.75 (0.13)</td>
<td>8.06 (0.18)</td>
<td>8.20 (0.04)</td>
<td>.00</td>
</tr>
<tr>
<td>ACA3</td>
<td>8.46 (0.16)</td>
<td>8.19 (0.24)</td>
<td>8.12 (0.10)</td>
<td>.001</td>
</tr>
<tr>
<td>Two tooth spaces</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACA2</td>
<td>2.44 (0.14)</td>
<td>2.35 (0.22)</td>
<td>2.46 (0.10)</td>
<td>.13</td>
</tr>
<tr>
<td>ACA5</td>
<td>15.24 (0.10)</td>
<td>15.23 (0.29)</td>
<td>15.35 (0.09)</td>
<td>.13</td>
</tr>
<tr>
<td>Three tooth spaces</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACA4</td>
<td>8.87 (0.07)</td>
<td>8.85 (0.22)</td>
<td>8.75 (0.10)</td>
<td>.45</td>
</tr>
</tbody>
</table>

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**Fig 6** Box-plot diagrams depicting the distances (DIP) between the central points of neighboring scanbodies in VM1 produced by scanning with True Definition, D250, Trios, and iTero.

**Fig 7** Box-plot diagrams depicting the angles (ACA) between the cylinder axes (CA) of the neighboring scanbodies in VM1 produced by scanning with True Definition, D250, Trios, and iTero.

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**Standard Deviations of Distance and Angle Measurements**

A smaller variation of the distance measurements was observed for the intraoral scanners True Definition and Trios, and a higher variation was seen for the desktop scanner D250 and the intraoral scanner iTero (Fig 6). With regard to the angle and distance measurements, True Definition results showed less variation for consecutive scans compared to iTero, Trios, and D250 (Fig 7).

**Discussion**

This study analyzed the precision of three different intraoral scanning systems in combination with two different system-specific dental implant scanbodies. The precision of the scanning devices was significantly different with regard to specific locations of the scanbodies within the jaw.
The precision of scanning devices may be measured without an immanent error. Intraoral use of scanning devices in combination with dental implant scanbodies was avoided because previous results showed a failure to record an accurate virtual model. To determine the precision of different intraoral scanning systems and to detect clinically relevant deviations of multiple scans, an extraoral approach should be used.

Van der Meer et al. compared different intraoral scanning devices with custom-made optical transfer posts and found no significant differences between the devices. However, there was a trend toward higher precision with one scanning device (Lava COS) with a continuous recording mode compared with imaging systems that used a single image record mode (iTero, Cerec). The precision of the iTero intraoral scanner on a jaw-traversing distance (61 µm; 0.42 degrees) was comparable to the results obtained with iTero on the jaw-traversing distance in this study (64 µm, 0.2 degrees). The differing precision concerning the angle between scanbodies might result from differences in size of the scanbodies and algorithm for the measurement of their surface. Neither scanbody dimensions nor measuring algorithm were disclosed in the study by Van der Meer et al. The experimental scanbodies were arbitrarily allocated to certain regions within the dental arch with no information given on the absolute distance between the scanbodies. Therefore, the results are not comparable with the different clinical situations and multiple scanbody distances within this study.

Comparative virtual measurements of 3D models are prone to a number of errors. The alignment of virtual models before measurement and error in the measurement process itself can distort the results. The measuring algorithm comprised the manual determination of surface points only for the creation of the horizontal plane. Each consecutive step was conducted not manually, but through the extraction of surface characteristics using the software Rapidform. To exclude possible bias through surface alignment, the virtual models were not aligned with each other. However, the absolute values were measured and the standard deviation was calculated to express the precision. The precision of the described measuring algorithm was previously determined as approximately 2 µm (SD: 1 µm) and 0.031 degrees (SD: 0.01 degrees) for the tissue-level scanbody (SM1 region 35 and SM2) and 5.6 µm (SD: 3 µm) and 0.066 degrees (SD: 0.033 degrees) for the bone-level scanbody (SM1 region 36), showing a lower precision for a smaller and narrower scanbody. The measurement error of angle measurements was smaller than the angle between the scanbodies by two orders of magnitude. Therefore, the error of the angle measurement was not considered relevant. The size of the scanbody and the extent of information optically recorded with a scanning device might therefore be decisive for the accuracy of the measurement and for the determination of the actual implant position in the model. Incomplete acquisition of the surface of a scanbody with the respective scanning device led to imprecise computing of the cylinder and its geometric characteristics.

The extent of information that is recorded depends on the scanbody configuration, the position of the scanbody within the dental arch, and the proximity of neighboring structures (teeth and scanbodies). The obtained data suggest that the extent of recorded information might also depend on the scanning devices, resulting in different values for precision. With regard to the distance and angle measurements, a higher precision was found for the intraoral scanning devices Trios and True Definition in comparison with the intraoral scanning device iTero and the dental lab scanner D250. The size of the iTero scanning wand and the device’s single-picture scanning technique might result in scanning errors. Trios and True Definition record a multitude of images that are either gathered to a whole surface model (Trios) or recorded as a continuous video sequence (True Definition). Concerning the longer distances of 40 mm and 50 mm between two scanbodies, iTero and True Definition were less precise than D250. This might be caused not by a small extent of information obtained of each scanbody, but by a distortion of the surface model associated with the scanning process. The standard deviation, as a parameter of the precision of each scanning method, was constant for D250 independent of the distance between the scanbodies. This might result from the continuous image acquisition technique with laser planes projected on the whole model and the model construction with triangulation. The intraoral scanner True Definition showed a very high precision concerning distances between 6 mm and 18 mm between the scanbodies, but a significantly lower precision for jaw-traversing distances of 40 mm and 50 mm. The data for the Trios scanner suggests a similar precision to True Definition. The iTero scanner showed a lower precision concerning all distances between the scanbodies and an increase in imprecision at the longest distance between two scanbodies (50 mm).

Two different study models replicating clinical situations with a different number and distribution of scanbodies were examined; however, the study did not examine the accuracy of conventional implant impressions. The transfer of a conventional impression acquired with impression posts to a physical model equipped with implant scanbodies includes a number of error sources and might challenge the precision of the actual scanning process.
For the use of CAD/CAM processes, the technical difficulties and inaccuracies that arise from the translation of a physical model to a virtual model may be resolved with direct intraoral optical impressions. However, this study documented a clinically relevant lack in dimensionality accuracy of intraoral scanning systems regarding higher distances within the dental arch and a difference in precision between the intraoral scanning devices under ideal experimental conditions.

Previous studies of the precision of conventional implant pick-up impressions documented a standard deviation between 72 µm (linear) and 0.17 degrees (angulation), respectively, and 17.2 µm (linear), 0.2 degrees, and 0.12 degrees (angulation), respectively, under experimental conditions. The results of Bergin et al and Wegner et al are comparable with the results of different intraoral scanning systems found in this study. However, the range of results for conventional impressions varies depending on impression material, implant system, and implant angulation.

To the knowledge of the authors, this is the first study on the precision of intraoral scanning systems with commercially available implant scanbodies. Further development of the scanning devices, scanning protocols, and imaging techniques is necessary to enhance the precision of optical acquisition of implant scanbodies.

Conclusions

The scanning precision of intraoral scanners is significantly different for the tested scanning devices and with regard to the distance and angulation between scanbodies. The precision of the intraoral scanning systems decreased with an increasing distance between scanbodies, whereas the precision of the extraoral lab scanner was independent of the distance between the scanbodies.

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