Accuracy of complete-arch implant digital scans: effect of scanning protocol, number of implants and scan body splinting

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ABSTRACT

Purpose: To determine the effects of scanning protocol, number of implants, and implant splinting on the accuracy of digital scanning in the edentulous arch. Materials and Methods: A resin-based model of an edentulous mandible with six implants was scanned with a coordinate measurement machine as a reference and then with two intraoral scanner (IOS) systems (TRIOS 3 and Primescan). Ten scans were taken per IOS in three experiments, and each scan was compared to the reference to evaluate trueness and precision. Analysis involved using engineering software (GOM Inspect) to measure linear and angular discrepancies. In experiment 1, three scanning protocols were compared (linear, zigzag, and half-arch). In experiment 2, three clinical situations were simulated. In experiment 3, the effect of implant splinting with a suture thread was measured. Normal distribution of data was examined with Shapiro-Wilk test. Levene test was used for equality of variance (α = .05). Statistical differences in distance and angular deviations were analyzed by Student t test or ANOVA with post hoc Tukey test (α = .05). Results: The best results in terms of trueness and precision were obtained
with a linear scanning protocol and six implants: TRIOS 3 = trueness 52 µm/0.42 degrees, precision 40 µm/0.26 degrees; and Primescan = trueness 24 µm/0.28 degrees, precision 18 µm/0.27 degrees. The scanning protocol did not significantly affect distance or angular deviation accuracy. Trueness and precision significantly decreased with four implants using both Primescan and TRIOS 3. Splinting implants negatively affected accuracy with both scanners. **Conclusion:** Both IOS systems achieved clinically satisfying accuracy in distance (< 100 µm) and angular (< 0.5 degrees) deviation with six implants and a linear scanning protocol. With four implants, angular deviations sometimes differed between implants within the same digital scan depending on the IOS and the clinical situation. *Int J Prosthodont* 2022. *doi: 10.11607/7332*

**INTRODUCTION**

Currently, digital scanning with intraoral scanners (IOSs) is clinically acceptable alternative for fabricating short-length restorations but is questioned for cross-arch reconstructions, mainly because the accuracy of digital scanning decreases with increasing reconstruction length. (1–6) Indeed, an increase in distance deviation over the length of the arch was found related to an accumulation of registration errors in patched surfaces during reconstruction. (7) Thus, largest discrepancies were generally found at the extremities of the arch, because all errors would lead to a maximal error at one of the endpoints. (8,9) However, there is growing interest in extending the application of digital scanning to complete-arch implant restorations because the technology overcomes the physical steps associated with potential errors in accuracy, such as disinfection, storage, shipping, and gypsum pouring. (10) It also offers greater comfort to the patient and increased speed. (11) So far, the specific limitations associated with digital scanning in the completely edentulous arch have been the surface area to be scanned, (12–15) the lack of anatomic relief, (16–18) and the similarity in
morphology of the scan bodies. (8,19)

Despite few clinical studies reporting the use of digital scanning for complete-arch digital scanning, they gave encouraging short-term results. (20–22) However, they did not allow for direct measurements nor identify a lack of adaptation of the prostheses at the micrometric scale. (11) As a complement, in vitro studies enabled such measurements of scanning accuracy. Accuracy of measurements is analyzed in terms of trueness and precision. Trueness assessment is defined as the measurement of the deviation of each measure from the reference measure, whereas for precision assessment, the dispersion of measurements in each reference distance is analyzed. For complete-arch restorations, the accuracy of digital scanning is equal to or even better than with conventional impression. (23–28) Some studies also investigated the effect of implant angulation, (16,23–26,29) and a recent systematic review underlined that angulation < 15° did not affect accuracy. (30) Connection type (24,26) and implant depth (9) were also found not to affect accuracy, whereas operator experience (9,16,29,31) and scan body material, geometry and design (32,33) were significant parameters.

No study has evaluated the effect of scanning protocol in the peculiar case of complete edentulism, although it is a known clinical factor of accuracy in complete arch digital scanning. (34–38) Recommendations are being published for the dentate arch, depending on the IOS, but in these situations, occlusal surfaces serve as the main reference points, and one major purpose of digital scanning is to accurately record the dental anatomy. For the edentulous arch, the main objective is to accurately record the position of the scan bodies in relation to each other while limiting the number of registrations of the same point. (11) In the first studies dedicated to digital scanning for complete-arch implant-supported restorations, the authors insisted on compliance with manufacturers’ recommendations without a precise description of the procedure. (8) Gimenez et al. scanned parallel to the arch to reproduce and connect the bases of the implants. The authors reported significant deviations for the more distant
Implant.(9,16,29) Alikhasi et al. began to scan in the middle of the palate and registered the palatal surfaces and then scanned the buccal and occlusal faces.(26) Mangano et al. adopted a zigzag scanning technique with the tip of the scanner drawing an arc movement from vestibular to palatal and back.(39) Cappare et al. used a scanning procedure of half arches before a final merging, with the anterior implants used as references. (22) No comparison of these procedures has been published.

In complete-arch implant restorations, scan bodies are the main indexes for digital reconstruction. Therefore, the number of implants, the length of the arch to be scanned and the inter-implant distances may affect the accuracy of digital scanning. When scanning a six-implant model, Ciocca et al. showed less deviation between two close implants than between two distant implants. (31) Gintaute et al. compared conventional impressions and digital scanning in four clinical situations, progressively increasing the number of implants and the length of the arch. The authors reported distance and angular deviations below the threshold of 100 µm and 0.5° usually considered clinically acceptable. (40) Tan et al. compared the accuracy between six implants spaced 13 mm apart and eight implants spaced 20 mm apart. The number of implants had a positive effect on accuracy with IOSs but was not a factor with conventional impressions or extraoral scans. However, no study has directly assessed the effect of number of implants, their position and length of the arch in terms of distance and angular deviation.

By analogy with the splinted impression technique, some authors proposed to link scan bodies. In the context of digital scanning, the interest is to multiply reference elements to support the reconstruction algorithm. In their clinical study, Cappare et al. obtained satisfactory results by using orthodontic wire and composite resin to connect the implants. In vitro, Iturrate et al. significantly improved the accuracy of digital scanning by placing an auxiliary geometric device with three different IOSs. (10,41) Huang et al. used CAD/CAM scan bodies with an extensional structure that connected the implants and improved the trueness and precision of
Mizumoto et al. tried a simpler method and tied white floss between the scan bodies; accuracy was significantly decreased when the implants were linked. No consensus has been reached concerning the material and method for scan body splinting.

The purpose of this in vitro study was to determine the effect of scanning protocol, number of implants and implant splinting on the accuracy of digital scanning for the completely edentulous arch. The null hypothesis was that none of these parameters would affect the trueness and precision of digital scanning for the completely edentulous arch.

**MATERIALS AND METHODS**

A model based on the mandible of an edentulous patient was fabricated with pink denture base resin (Lucitone; Dentsply). Six implants (OsseoSpeed EV; Astra Tech, Dentsply) were placed in the areas of the lateral incisors, first premolars, and first molars. First premolar implants were distally tilted with an angulation of 17° by using the SmartFix Guide (SKU: 26205, Dentsply Sirona) (Figure 1). New PEEK scan bodies (Atlantis IO-FLO; Astra Tech, Dentsply) were tightened in the implants with 10-Ncm torque. Furthermore, a 10-mm cube of methyl methacrylate resin was added to the model to provide a reference for measurements. The cube was glued to the model behind the lingual frenum. The upper left anterior corner of the cube was defined as the reference point for measurements.

A coordinate measurement machine (CMM; Renault Automation, equipped with a Touch-trigger probe system: TP2; Renishaw) was used to detect the 3D position of scan bodies. The CMM touch spherical probe (diameter = 1 mm) measured the 3D spatial position of points on scan body surfaces to find their respective coordinates on the x-axis, y-axis, and z-axis. Acquisition of the model was repeated twice. Afterward, the digitized model was saved as a point cloud in a text file formatted in three columns representing the X, Y, Z coordinates of each point and exported as a Standard Tessellation Language (STL) file in an industrial.
Metrology software program (GOM Inspect). Then, measurement protocols were followed to measure reference distances in each of the 3D point clouds obtained with the CMM. With these measurements, reference values were set (mean ± SD), which were later used to determine the accuracy values (trueness and precision) of the IOSs.

Then, the reference model was scanned with two IOSs: TRIOS 3 (3Shape) and Primescan (Dentsply Sirona). The scans were performed on a table by a single operator, under the same temperature (24°) and light (artificial white light) conditions. The operator was equally experienced with both IOSs.

A summary of the experimental protocol is in Figure 2. Experiment 1 tested the effect of the scanning protocol on accuracy. Three scanning protocols were tested. In the curvilinear protocol, vestibular surfaces were scanned first, starting with the right first molar and moving to the left first molar, and returning via the lingual surfaces. In the zigzag protocol, the three surfaces of each scan body (occlusal, vestibular, and lingual) were sequentially scanned in an S-shaped movement from the right first molar in all directions, without returning to the starting point.(39) The third protocol consisted of a linear scan acquisition of two half mandibles, with an overlap in the anterior region. The software applied a stitching algorithm to merge the scans of the two half mandibles, based on the area between the 2 anterior implants, shared by the separate scans.(22) Then, distance and angular deviations obtained with the three scanning protocols were compared.

In experiment 2, the aim was to compare accuracy of the IOSs in three clinical situations, depending on the number of implants and length of the arch to be digitalized. In the first situation, scan bodies were screwed on the six implants. In the second situation, scan bodies on implants #1 and #6 were removed, so that only the four central scan bodies were present (four implants – short arch). Then, to represent a third situation, scan bodies on implants #2 and #5 were removed and scan bodies on implants #1 and #6 were screwed again. Scan bodies were
not interchanged when replaced and the flat spot on the ball head was used as a marker to check the position in the internal hexagon of the connection. In this configuration, four implants were distributed along a longer distance than in situation two (four implants – long arch). Scanning followed the curvilinear scanning protocol.

In experiment 3, the interest of splinting the scan bodies with suture thread was explored. A blue suture thread (Novosyn, B. Braun Surgical S.A.; Rubi, Spain) was tied around the scan bodies. The knot was supple so as to prevent any constraint on the scan bodies. Scanning followed the curvilinear scanning protocol in the three clinical situations described in experiment 2. Then, distance and angular deviations were compared between splinted and unsplinted scan bodies in each situation.

For each scanning protocol and situation, scans were performed 10 times and exported as STL files.

For measurement, a 3D mesh inspection and processing software were used (GOM Inspect) and the same protocol was used for all STL files obtained with digital scanning and CMM acquisitions. The first step was to create a coordinate system that was used throughout the entire inspection to measure the 3D distance and angular deviation of the scan bodies. The reference point (X point in Figure 1) was defined as the intersection of three planes corresponding to the upper, anterior and left faces of the cube. IO-FLO scan bodies are basically cylinders surmounted by a sphere. Therefore, reference points (center of the sphere) and an axis needed to be created in each mesh, in each scan body (Figure 3). The procedure to determine the reference points and axis was based on the Gaussian best-fit method to create both the cylinders and the spheres. For establishing the geometry with this method, approximately 99.7% of the polygons of the mesh resembling the scan body were selected. Distances were measured between the reference point on the cube and the center of the spheres. The implant angulation was measured between the axis of the cylinders and the vertical axis.
All measurement data were exported for analysis in Microsoft Excel and analyzed by using a program for statistical inquiry (Real Statistics Using Excel). The Shapiro-Wilk test was used to examine the normal distribution of data. Levene’s test was used to assess the equality of variances for all test groups \((α=.05)\). Intra-group statistical differences by implant position were analyzed by one-way ANOVA and post-hoc Tukey test \((α =.05)\). When this preliminary condition was verified, statistical differences between test groups were analyzed by Student \(t\) test or one-way ANOVA with the post-hoc Tukey test \((α =.05)\).

**RESULTS**

Intra-group differences by implant position were calculated by one-way ANOVA and post-hoc Tukey test \((α =.05)\). For distance deviation (Table 1), intra-group differences were found in the four implants (short arch clinical configuration in experiment 3). Because normal distribution of data and equality of variances were checked beforehand, the implant position affected deviation. Therefore, trueness and precision were not calculated for this group, and no further comparisons were performed. Results are grayed out in following tables.

In the same way, implant position affected the angular deviation comparison in seven groups: zigzag scanning protocol, four implants – short arch (splinted and unsplinted), four implants – long arch (splinted and unsplinted) with TRIOS 3 and half-arch scanning protocol and four implants – long arch splinted group with Primescan (Table 2). Therefore, trueness and precision were not calculated for these groups, and no further comparison was performed. Results were grayed out in Tables 3, 4 and 5. Complete comparison (distance + angular) was possible for only eight groups when absence of intra-group differences was assessed for distance and angular deviation.

**Effect of the scanning protocol**
With TRIOS 3, the zigzag scanning protocol was excluded because of intra-group significant differences in terms of angular deviation. No significant differences were found between the linear and half-arch scanning protocol. Trueness was 52 µm/0.42° for the linear path and 67 µm/0.29° for the half-arch path. The precision measurements were 40 µm/0.26° and 70 µm/0.27°, respectively (Table 3).

With Primescan, the trueness was 24 µm/0.28° for the linear path and 40 µm/0.39° for the zigzag path. The precision measurements were 18 µm/27° and 32 µm/0.43°, respectively. The half-arch scanning protocol was excluded because of intra-group significant differences in terms of angular deviation. The linear scanning protocol was significantly more accurate than the zigzag scanning protocol in terms of distance deviation, but no difference was found for angular deviation.

**Effect of number of implants**

These measurements were performed with a linear scanning protocol (Table 4). With TRIOS 3, distance trueness and precision decreased with increasing inter-implant distance. However, no angular comparison was possible with the four-implant configurations that were excluded because of intra-group significant differences.

With Primescan, distance trueness and precision were better with six than four implants. For four implants – short arch, trueness was 42 µm/0.25° and precision 41 µm/16°. For four implants – long arch, trueness was 50 µm/0.26° and precision 40 µm/24°. No significant differences were found for angular deviation (p = 0.81).

**Effect of splinting**

These measurements were performed with a linear scanning protocol. The effect of splinting was explored in each clinical situation: six implants, four implants – short arch and four
implants – long arch. A complete comparison was possible only for the six-implant configuration with TRIOS 3 and Primescan because of significant intra-group differences in distance or angular deviation in the four-implant configuration (Table 5).

With TRIOS 3, splinting had an adverse effect on distance trueness and precision and no effect on angular deviation. With splinting, trueness was 76 µm/0.26° and precision 80 µm/0.36°.

Splinting had no significant effect with Primescan.

With TRIOS 3, splinting had an adverse effect on distance trueness and precision with six implants but had a beneficial effect in the four-implants – long arch situation for distance. However, comparison of angular deviation was not possible.

**DISCUSSION**

The null hypothesis was partially rejected. First, the linear and half-arch scanning protocols showed equivalent performance with the TRIOS 3, but with Primescan, the linear scanning protocol showed better distance deviation results than did the zigzag protocol. Second, four-implant configurations cannot be recommended with TRIOS 3 because angular deviation depended on implant position. With Primescan, distance trueness and precision were increased with increasing number of implants. Third, splinting with a suture thread did not improve the accuracy of digital scanning with the two tested IOSs, especially with TRIOS 3.

In this study, measurements of digital scanning STL files were compared with the CMM references. In the linear scanning protocol with six implants, TRIOS 3 achieved a trueness of 52 µm and precision of 40 µm. Primescan achieved a trueness of 24 µm and precision of 18 µm. The values obtained for TRIOS 3 were consistent with the measurements of Imburgia et al. (trueness 67 µm, precision 31 µm) and Vandeweghe et al. (trueness 28 µm, precision 33 µm) on maxillary and mandibular edentulous models.(8,43) With Primescan, Mangano et al.
reported a trueness of 38.4 µm and 19.3 µm according to the measurement method in a edentulous maxillae with six implants.\cite{44}

The mean angular deviations were 0.42° for trueness and 0.26° for precision with TRIOS 3 and 0.28° and 0.27° with Primescan (linear scanning protocol, six implants, unsplinted), with a maximum deviation of 0.42° for both IOSs. Reference data for angular deviation are fewer than for distance deviation, but Mangano et al. compared the accuracy performance in edentulous arches for five IOSs and measured an angular deviation < 1° with four of the tested systems.\cite{39} Menini et al. also reported a mean angular deviation of 0.25° with the True Definition scanner (3M ESPE).\cite{28} These values can be compared to the 1.2° angular deviation obtained after conventional impression (open-tray technique) on straight and tilted implants.\cite{45} Manzella et al. also set their acceptance threshold at 1° when studying framework misfit.\cite{46} However, Gintaute et al. considered a threshold of 0.5°.\cite{40} In light of these previous publications, results obtained in the present study can be considered satisfying. However, angular measurements sometimes differed depending on implant position, with specific scanning protocols or with reduced number of implants. This finding agrees with Tan et al. and Arcuri et al.\cite{1,33} and may represent a limitation to the indications for digital scanning.

Several methodologies for measuring deviations have been described, which limits the comparability of results.\cite{11,47,48} The most common method is the superimposition of a reference scan of the master model with the digital scanning STL file by a best-fit algorithm. However, this method tends to average repositioning, and digital scanning may appear more accurate than it actually is.\cite{47} Thus, some authors described an alternative method, using a local best-fit superimposition centered on the origin point of the scanning, before measuring deviation for key points.\cite{48} Others built a coordinate system in inspection software to measure distances directly on STL files,\cite{9,49} as used in the present study. When the first scanned implant is used as the origin of the coordinate system, especially if this implant is the most
distal of the restoration, the future prosthetic framework can be deformed.\(^9\) The use of a central origin allows for an objective comparison of the deviation for each implant.\(^{49}\) Ambient scanning light is a limitation in the present study. Indeed, intensity and color temperature of the light affect accuracy.\(^{3,50,51}\) Depending on the IOS, optimal results might be achieved with a different intensity and color temperature. Those parameters could not be controlled in the present study and differed between the two IOSs. However, with each IOS, scans were recorded in the same closed room with no window, and the artificial light was the same during experiments 1, 2 and 3. To account for this limitation in the experimental protocol, trueness and precision measurements were not compared between the two IOSs.

To study the effect of number of implants and the inter-implant distance, scan bodies were unscrewed and replaced four times. The exact repositioning of the scan bodies can be questioned. Use of a dynamometer was a key point because the torque applied to screw scan bodies can affect their position.\(^{1,52}\) Fluegge et al. verified that 10 repeated detachments and re-attachments of PEEK scan bodies were not detrimental to the intro-oral digital scanning accuracy.\(^{19}\) Photographs were also taken to ensure that the scan bodies were placed in the same position with respect to the internal hexagon, with the flat side of the sphere and the reference number inscription as references. Particular care was taken in replacing the scan bodies on their initial implants, as Pan et al. indicated that replacement of scan bodies modified their position with greater distortion when the scan bodies were randomly repositioned, with a laboratory scanner at least.\(^{53}\)

Use of a suture thread for implant splinting was investigated as an easy and quick alternative to a prefabricated geometric device \(^{10,41}\) or extension structure.\(^{42}\) Yet, the present study reached the same conclusion as Mizumoto et al.\(^{32}\): whatever the color of the thread, it cannot be used by the IOS and its reconstruction algorithm as an additional index.
CONCLUSION

The present study showed that the two IOSs tested presented clinically acceptable distance and angular deviations, well below the thresholds of 100 µm and 0.5°.

In light of the present results, an additional condition for validating the use of an IOS could be the absence of statistically significant linear and angular differences between the implants within a digital scanning. In this study, differences appeared more often in angular than distance measurements. The number of implants and their placement along the arch were major factors affecting results. Therefore, guidelines would be useful to help practitioners choose between a conventional impression and digital scanning, considering the clinical situation.

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scanbody material, position and operator on the accuracy of digital impression for complete-

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### TABLE 1: Intra-group statistical comparison for distance deviation (p-value) by implant position.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Trios 3</th>
<th>Primescan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Linear</td>
<td>Zigzag</td>
</tr>
<tr>
<td>Experiment 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.09</td>
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<td>Experiment 2</td>
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<td>4 implants</td>
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<td></td>
<td>0.09</td>
<td>0.27</td>
</tr>
<tr>
<td>Experiment 3</td>
<td>6 implants</td>
<td>4 implants</td>
</tr>
<tr>
<td>Unsplinted</td>
<td>0.09</td>
<td>0.27</td>
</tr>
<tr>
<td>Splinted</td>
<td>0.65</td>
<td>0.77</td>
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One-way ANOVA and post-hoc Tukey test ($\alpha =.05$).

*Significant differences were found with the zigzag protocol with Primescan.
Table 2: Intra-group statistical comparison for angular deviation (p-value) by implant position.

<table>
<thead>
<tr>
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<th></th>
<th>Primescan</th>
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<td></td>
<td></td>
<td>Zigzag</td>
<td>Half-arch</td>
<td>Linear</td>
<td>Zigzag</td>
<td>Half-arch</td>
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<td>6 implants</td>
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<td>4 implants</td>
<td>6 implants</td>
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<tr>
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<td>0.01</td>
<td>0.01</td>
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<tr>
<td>Experiment 3</td>
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<td>4 implants</td>
<td>6 implants</td>
<td>4 implants</td>
<td>4 implants</td>
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<tr>
<td>Unsplinted</td>
<td>0.10</td>
<td>0.46</td>
<td>0.63</td>
<td>0.01</td>
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<tr>
<td>Splinted</td>
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<td>0.89</td>
<td>0.01</td>
<td>0.11</td>
<td>0.89</td>
<td>0.01</td>
</tr>
</tbody>
</table>

One-way ANOVA and post-hoc Tukey test (α = .05).

Using Trios, significant differences were found with the zigzag protocol and in the clinical situations involving 4 implants. Therefore, no trueness and precision analysis was performed for these groups.

With Primescan, significant differences were found with the half-arch scanning protocol and when splinting 4 implants in the long-arch configuration. Therefore, no trueness and precision analysis was performed for these groups.
Table 3: Experiment 1, distance (µm) and angular (°) deviation.

<table>
<thead>
<tr>
<th>Experiment 1</th>
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<th>Zigzag</th>
<th>Half-arch</th>
<th>p-value</th>
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<td></td>
<td></td>
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<tr>
<td>Trueness</td>
<td>52 µm/0.42°</td>
<td>71 µm/-°</td>
<td>67 µm/0.29°</td>
<td>Distance p=0.09</td>
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<td>Precision</td>
<td>40 µm/0.26°</td>
<td>49 µm/-°</td>
<td>70 µm/0.27°</td>
<td>Angular p=0.74</td>
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<tr>
<td>Primescan</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trueness</td>
<td>24 µm/0.28°</td>
<td>40 µm/0.39°</td>
<td>32 µm/-°</td>
<td>Distance p=0.01*</td>
</tr>
<tr>
<td>Precision</td>
<td>18 µm/0.27°</td>
<td>32 µm/0.43°</td>
<td>33 µm/-°</td>
<td>Angular p=0.23</td>
</tr>
</tbody>
</table>

No significant differences among the scanning protocols with Trios 3 for distance and angular deviation. No angular deviation could be calculated for the zigzag protocol. Thus, the results were grayed out.

With Primescan, distance trueness and precision were significantly better with the linear than zigzag protocol (p = 0.01). No differences were found between linear and half-arch protocols (p = 0.30) and between zigzag and half-arch protocols (p = 0.28). No angular deviation could be calculated for the half-arch scanning protocols. Thus, the results were grayed out. No significant differences were found between linear and zigzag protocols for angular deviation.

* p-value of ANOVA or Student’s test when appropriate. Significance level set at p < 0.05.
Table 4: Experiment 2, distance (µm) and angular (°) deviation.

<table>
<thead>
<tr>
<th>Experiment 2</th>
<th>6 implants</th>
<th>4 implants</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>– short arch</td>
<td>– long arch</td>
<td></td>
</tr>
<tr>
<td>Trios 3 Trueness</td>
<td>52 µm/0.42°</td>
<td>66 µm/0°</td>
<td>Distance p = 0.01*</td>
</tr>
<tr>
<td>Precision</td>
<td>40 µm/0.26°</td>
<td>52 µm/0°</td>
<td>6 – 4 short p = 0.60</td>
</tr>
<tr>
<td>Primescan Trueness</td>
<td>24 µm/0.28°</td>
<td>42 µm/0.25°</td>
<td>Distance p = 0.01*</td>
</tr>
<tr>
<td>Precision</td>
<td>18 µm/0.27°</td>
<td>41 µm/0.16°</td>
<td>4 long – 4 short p = 0.51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40 µm/0.24°</td>
<td>Angular p = 0.81</td>
</tr>
</tbody>
</table>

With Trios 3, distance trueness and precision decreased with increasing inter-implant distance. The p-value was 0.01 for comparison of 6 implants with 4 implants – long arch, and 4 implants long arch with 4 implants – short arch. However, angular deviation could not be compared. Thus, the results were grayed out.

With Primescan, distance trueness and precision were better with 6 than 4 implants. The p-value was 0.01 for 6 implants with 4 implants – long arch and 0.02 for 6 implants with 4 implants – short arch. No significant differences were found for angular deviation.

* p-value of ANOVA or Student’s test when appropriate. Significance level set at p < 0.05.
Table 5: Experiment 3, distance (µm) and angular (°) deviation.

<table>
<thead>
<tr>
<th>Experiment 3</th>
<th>Trios 3</th>
<th>Primescan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6 implants</td>
<td>4–short</td>
</tr>
<tr>
<td>Unsplinted</td>
<td>Trueness</td>
<td>52 µm/0.42°</td>
</tr>
<tr>
<td></td>
<td>Precision</td>
<td>40 µm/0.26°</td>
</tr>
<tr>
<td>Splinted</td>
<td>Trueness</td>
<td>76 µm/0.26°</td>
</tr>
<tr>
<td></td>
<td>Precision</td>
<td>80 µm/0.36°</td>
</tr>
</tbody>
</table>

p-value

<table>
<thead>
<tr>
<th></th>
<th>Distance</th>
<th>Angular</th>
</tr>
</thead>
<tbody>
<tr>
<td>p-value</td>
<td>p=0.04*</td>
<td>p = 0.62</td>
</tr>
<tr>
<td>Distance</td>
<td>p = 0.21</td>
<td>Distance</td>
</tr>
<tr>
<td>Angular</td>
<td>p = 0.07</td>
<td>p = 0.09</td>
</tr>
</tbody>
</table>

Complete comparison (distance + angular) was possible with only 6 implants because of significant intra-group difference in distance or angular deviation. Thus, these results were grayed out.

With Trios 3, splinting had an adverse effect on distance accuracy (trueness + precision) with 6 implants. Splinting had no significant effect with Primescan.

* p-value of ANOVA or Student’s test when appropriate. Significance level set at p < 0.05.

4–short and 4–long are abbreviations for 4 implants – short arch configuration and 4 implants – long arch configuration.
LEGENDS

Figure 1: Master model. Implants are numbered from 1 to 6 starting from the right retromolar trigone. Spaces between implants and implants angulation are detailed. Measurement reference point is indicated by an x in the upper left corner of the cube.
<table>
<thead>
<tr>
<th>Experiment 1: Influence of scanning protocol</th>
<th>6 or 8</th>
<th>Linear</th>
<th>Zig-zag</th>
<th>Half-arch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L or ZZ or HA</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experiment 2: Influence of number of implants and arch length</th>
<th>4 or 6</th>
<th>Linear</th>
<th>Zig-zag</th>
<th>Half-arch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6 or 8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 implants</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 implants – short arch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 implants – long arch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experiment 3: Influence of splinting</th>
<th>4 or 6</th>
<th>Linear</th>
<th>Zig-zag</th>
<th>Half-arch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6 or 8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2: Summary of the experimental protocol. The three experiments are schematized according to the studied parameters, the number of implants, the scanning protocol and the splining of the implants. L, ZZ and HA are abbreviations for Linear, Zigzag and Half-arch scanning protocol.
Figure 3: Analysis of Standard Tessellation Language on inspection software. Reference points are defined before measurements.