Influence of the Angulation and Insertion Depth of Implants on the 3D Trueness of Conventional and Digital Impressions

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Purpose: To study the influence of insertion depth and implant angulation on the 3D trueness of models obtained with different impression techniques. Materials and Methods: Four different reference models (model 1: parallel, depth of 1.5 mm; model 2: parallel, depth of 4 mm; model 3: 20-degree angle, depth of 1.5 mm; and model 4: 20-degree angle, depth of 4 mm) of partially edentulous maxillae were generated by altering implant angulations and subgingival depths. All scans of reference models were done with a laboratory scanner, and obtained data were exported into standard tessellation language format to be used as virtual reference images. Impressions were obtained from each reference model via three conventional techniques (closed tray [CT], non-hexed open tray [NHOT], and hexed open tray [HOT]) and one digital technique (intraoral scanning [IOS]). A total of 160 impressions were made. The reference and experimental scan data were superimposed by using the best-fit alignment algorithm. Angular (AD), linear (LD), and 3D (RMS) deviations were computed, and obtained data were statistically analyzed. Results: In premolar implant sites, AD and LD values were significantly affected by model type (P ≤ .001 for AD and LD) and impression technique (P = .001 for AD, P = .002 for LD). However, no significant interaction was detected (P = .768 for LD). Model 1 (0.44 ± 0.25 for AD, 7.79 ± 6.29 for LD) and the NHOT technique (0.49 ± 0.43 for AD, 9.04 ± 8.14 for LD) exhibited the lowest mean AD and LD values. In molar implant sites, AD and LD values were significantly affected by model type (P ≤ .001 for AD and LD) and impression technique (P ≤ .001 for AD and LD), as well as by their interaction terms (P = .037 for AD, P = .005 for LD). Considering interaction terms, while the highest and lowest mean AD values were exhibited by IOS-model 4 (1.56 ± 0.25) and NHOT-model 2 (0.46 ± 0.28), respectively, the highest and lowest mean LD values were exhibited by CT-model 4 (41.40 ± 14.48) and NHOT-model 2 (8.03 ± 4.86), respectively. RMS estimate values were significantly influenced by model type (P ≤ .001) and impression technique (P ≤ .001), as well as by their interaction terms (P = .019). The highest and lowest mean RMS values were exhibited by IOS-model 4 (70.02 ± 4.74) and NHOT-model 2 (25.96 ± 17.67), respectively. Conclusion: In the case of angulated and deeply placed implants, splinted NHOT and HOT techniques can be recommended for better trueness. Int J Oral Maxillofac Implants 2022;37:1186–1194. doi: 10.11607/jomi.9907

Keywords: 3D compare, 3D deviation, impression, superimposition, trueness

Pa ssive fit can be delineated as the state of simultaneous and equal contact at the implant and prosthetic interface, leading to the absence of strain and thereby inducing long-term success of implant-supported restorations.1,2 This can only be achieved with an accurate prosthodontic workflow, initiated with impression procedures.3,4 In implant impressions, the goal is to precisely transfer the 3D intraoral position of the implants to the cast or digital model.5 The accuracy of implant impressions is affected by manifold factors, including the impression technique, impression material, the number and angulation of implants, subgingival depth of the implant, splinting or nonsplinting impression posts, and design and type of impression posts.5–7

Ideal implant positioning is not always clinically achievable. The anatomical structures, available bone quality and quantity, and esthetic considerations may lead to nonparallel placement or deeper implant insertion.8,9 The lack of parallelism between the implants may distort the impression material during the removal of the tray from the mouth, resulting in an inaccurate cast.10 In the case of deeply placed implants, since a part of the retentive area of the impression post lies subgingivally, impression material can capture a little part of the post that may result in instability of the post in the impression material, jeopardizing the accuracy.8,11 Therefore, in the presence of nonparallel and/or deeply placed implants, the impression technique and material is of clinical significance for obtain an accurate impression.

A number of implant impression techniques have been evaluated in terms of accuracy in previous studies and systematic reviews. The splinted open-tray (OT;
direct) technique was reported as the most consistent and accurate transfer route, followed by the nonsplinted OT technique. The closed-tray (CT; indirect) technique was designated as the least accurate route. However, a systematic review reported that in partially edentulous cases, although the splinted OT technique was more accurate than the nonsplinted technique, no difference was detected between the OT and CT techniques. The implant number and degree of angular difference between implants can influence the accuracy of the transfer route. In the presence of multiple and nonparallel implants, the splinted OT technique is recommended.

With the advancements in digital technologies, making digital implant impressions using intraoral scanners became an increasingly popular alternative to conventional impression techniques. The advantages of digital impressions over conventional techniques are well-documented in the literature, including eliminating errors based on impression materials or gypsum, bypassing the stages of disinfection and transportation of the impression to the dental laboratory, reducing patient discomfort, decreasing chairside time, allowing storage of digital scans, and providing ease communication both with the dental technician and patient. It has been suggested that the accuracy of intraoral scanning may vary depending on the number, angulation, and depth of implants; span length; scan post type; scanner technology; scanning protocol; and operator experience. The accuracy of conventional and digital impressions has been compared in the literature, and different results were obtained for complete and partially edentulous impressions. Digital scans revealed greater accuracy in completely edentulous arches, while conventional techniques performed better in partially edentulous arches with two or three implants. A limited number of studies comparing the accuracy of digital and conventional techniques in the case of nonparallel implants in partial edentulism reported conflicting findings. Some reported that conventional techniques revealed superior results in terms of accuracy, but the angulation did not affect the accuracy of digital scans, and no significant differences were found between the two techniques in nonparallel models. On the contrary, Lin et al reported that more accurate impressions were detected in digital scan groups when a higher degree of angular difference (30 to 45 degrees) existed between implants, whereas the OT technique demonstrated greater accuracy when minor angular differences (0 to 15 degrees) existed. Although a systematic review concluded that the accuracy of digital impressions is influenced by implant placement depth, a recent study comparing different intraoral scanners and a conventional technique reported that placement depth affects the accuracy of all techniques, but the majority of intraoral scanners showed greater accuracy than the OT technique. The methodology, degree of angulation, conventional technique evaluated, and splinting or nonsplinting of the impression posts were different in those studies, which may account for the inconsistent results.

The lack of consensus on which impression techniques should be preferred in the case of angulated and/or deeply placed implants generates a challenge in decision-making for the clinician. Therefore, this study aimed to evaluate the trueness of a digital impression and different conventional impression techniques in cases of angulated and deeply placed implants in partially edentulous arches. The null hypotheses were that the angulation and placement depth of the implants would not cause alterations in the trueness of impression techniques and that the trueness of impression techniques would not exhibit significant differences from each other.

**MATERIALS AND METHODS**

**Fabrication of Reference Models**

The workflow of the study is displayed in Figs 1 and 2. In the maxillary dentulous mold (AG-3 Silicone Index, Frasco), all indentations extending from the right second premolar to the right third molar were filled with pink baseplate wax, and a partially edentulous region resembling a healed ridge of 8-mm width was simulated. Four casts were obtained by pouring autopolymerizing acrylic resin (Pegasus Plus Repair Acrylic, Davis Schottlander & Davis) into the stated mold. In all four of the casts, two implant sockets were shaped in the second premolar and second molar tooth regions with the aid of a rotary instrument. Demo implants (T6 4110, NucleOSS) were fixed in their corresponding sockets by using autopolymerizing acrylic resin. Four different models were then generated by altering implant angulations and subgingival depths and designated as reference models (Fig 3):

- Reference model 1: Implants were inserted parallel to the vertical axis, to the adjacent first premolar, and to each other. The subgingival depth was determined as 1.5 mm.
- Reference model 2: Implants were inserted parallel to the vertical axis, to the adjacent first premolar, and to each other. The subgingival depth was determined as 4 mm.
- Reference model 3: An implant at the first premolar region was inserted parallel to the vertical axis. The implant at the second molar region was inclined distally to form an angle of 20 degrees with the vertical axis. The subgingival depth was determined as 1.5 mm.
• Reference model 4: An implant at the first premolar region was inserted parallel to the vertical axis. The implant at the second molar region was inclined distally to form an angle of 20 degrees with the vertical axis. The subgingival depth was determined as 4 mm.

Scan posts (T0 32033, NucleOSS) that were compatible with the implants were attached to the demo implants on the reference models. All the scans were done by using a laboratory scanner (inEOS XS, Dentsply Sirona), and obtained data were exported into standard tessellation language (STL) format to be used as virtual reference images. From each reference model, impressions (n = 40 per reference model) were obtained by using three conventional techniques (CT, non-hexed open tray [NHOT], and hexed open tray [HOT]) and one digital (intraoral scanning [IOS]) impression technique (n = 10 per technique). In total, 160 impressions were made on the mannequin head (Phantom head, PK-2 TSE) by a single calibrated clinician (A.K.).

Conventional Impression Techniques
Before making the CT impressions, internal surfaces of the prefabricated metallic trays were veneered with tray adhesive (Universal Tray Adhesive; Zhermack,
BadiaPosleine) and left to dry for 2 minutes. CT impression posts (T6 32601, NucleOSS) with CT impression caps (T0 32912, NucleOSS) were screwed to the demo implants on each reference model. All screwing/unscrewing procedures of the impression posts were performed by the same clinician (A.K.) with the aid of a manual screwdriver. To simulate the clinical conditions, screws were tightened until stiff resistance was felt. A monophase vinyl polysiloxane impression material (Elite HD+ Monophase; Zhermack, BadiaPosleine) was automixed with a device (MixStar eMotion, DMG) and then loaded first to the syringe, then to the tray. Some impression material was injected around the impression posts with the help of that syringe, and then the tray loaded with impression material was placed onto the reference models. The impression material was allowed to set for 6 minutes, and then the tray was removed from the reference model. At this stage, CT impression posts remained on the reference model, and CT impression caps remained in the obtained impression. These posts were unscrewed, connected to the implant analogs, and repositioned into the caps fixed in the impression.

Before making the OT impressions, OT impression posts were screwed to the demo implants. The main difference between the two subgroups of the OT technique was the presence or absence of hex structure on the implant-joining side of the impression posts. Resin splints at least 3 mm thick with an approximate thickness of 2 mm around the impression posts were formed by using dental floss and autopolymerizing acrylic resin (Pattern Resin LS, GC America). The splint was sectioned after 24 hours and rejoined with the same acrylic resin just before the impression procedure. Customized impression trays (n = 10 per OT, n = 20 per master model, n = 80 in total) were shaped from light-polymerizing base plates (Plaque Photo, W + P Dental) and then subjected to polymerization (Tray Lux, Ampac Dental). These trays were perforated to access the coronal part of the post through the perforations in the trays while the impression was on the reference model, and the posts together with the impression were removed. These posts were connected to the implant analogs before pouring up.

All conventional impressions were poured up by using type IV dental stone (GC Fujirock EP, GC America) to obtain the experimental casts. After 24 hours, the casts were separated from the impressions. Scan posts were attached to the analogs on the experimental casts. All the scans were done using the same laboratory scanner, and data were exported into STL format to be used as virtual experimental images.

**Digital Impression Technique**

Scanning procedures were performed by a single calibrated clinician (A.K.). One digital impression technique was included in this study: intraoral scanning. For the digital impressions (n = 10 per reference model), scan posts compatible with the implants were attached to the demo implants on the reference models. The scanning protocol was conducted with the aid of an intraoral scanner (CEREC Omnicam, Dentsply Sirona, software version: CEREC SW 4.5) by starting from the implantation side and scanning in a zigzag motion to record the occlusal aspects followed by the lateral surfaces. All the scans were done using the same laboratory scanner, and data were exported into STL format to be used as virtual experimental images.

**Superimposition Procedure**

All STL data were imported into the 3D metrology software (Geomagic Control, 2014, 3D Systems) for 3D analysis, and the whole procedure was conducted by a single observer (Ö.Ö.). One by one, the reference and experimental scan data were superimposed and aligned with the aid of the best-fit alignment algorithm, and the 3D deviation of the experimental scan data from the reference data were analyzed. To understand
how far the deviations were from zero between these datasets and thereby the degree of matching of the superimposed data, the root mean square (RMS) error was checked. Lower RMS error values indicate higher true

Significance of superimposition. During superimposition, the software was forced to perform the best-fit alignment from the dentulous region, as 3D deviation would be minimal in this region.

Linear and Angular Deviations
Virtual scan posts on the reference scan data were converted into virtual hollow cylinders by using the feature creation tab. To achieve standardization, the auto-create tab was used to create the same cylinders on the experimental scan data. Directional Cartesian (x, y, and z) coordinates of the lines passing through the center of these cylinders were subsequently recorded. Linear and angular deviations between the center lines of the reference cylinder and experimental cylinder were computed by using the following formulae, respectively:

Linear Deviation (LD) = \sqrt{((X_1 - X_2)^2 + (Y_1 - Y_2)^2 + (Z_1 - Z_2)^2)}

Angular Deviation (AD) = \arccos\left(\frac{X_1 \times X_2 + Y_1 \times Y_2 + Z_1 \times Z_2}{\sqrt{(X_1^2 + Y_1^2 + Z_1^2)} \times \sqrt{(X_2^2 + Y_2^2 + Z_2^2)}}\right)

where X_1, Y_1, and Z_1 are the Cartesian coordinates of the line on the reference scan data, and X_2, Y_2, and Z_2 are the Cartesian coordinates of the line on the experimental scan data.

3D Comparison
For the quantitative (mean ± standard deviation [SD]) evaluation of the 3D deviations between reference scan data and experimental scan data, color-difference maps were generated by using the 3D compare algorithm of the software. The maximum/minimum deviation values were also set at +100/−100 μm with a tolerance range of ±50/−50 μm. This software also automatically calculated the RMS estimate from the color-difference maps, without the need for an additional formula. In this study, the target was the detection of 3D deviation, especially on the scan posts. Accordingly, RMS values were computed only from scan posts, not from whole models.

Statistical Analysis
Statistical analysis software (SPSS Statistics 25.0, SPSS) was used for computations. Normal distributions of the data collected separately for linear deviation, angular deviation, and RMS estimate were confirmed with the aid of Shapiro-Wilk test. Therefore, data were analyzed by using the two-way analysis of variances (ANOVA) with a significance level of .05, followed by one-way ANOVA and Tukey post hoc comparison tests.

RESULTS
Evaluation of Premolar Implant Site
In accordance with the results of two-way ANOVA, AD and LD values were significantly affected by model type (P ≤ .001 for AD, P ≤ .001 for LD) and impression technique (P = .001 for AD, P = .002 for LD). However, no significant interaction was detected (P = .703 for AD, P = .768 for LD).

The mean AD and LD values with SDs are presented in Tables 1 and 2, respectively. Considering the model type, the highest and lowest mean values were exhibited by model 4 (0.80 ± 0.25 for AD, 15.90 ± 9.32 for LD) and model 1 (0.44 ± 0.25 for AD, 7.99 ± 6.29 for LD), respectively. No statistically significant difference was detected between models 1 and 2. Similarly, the difference between models 3 and 4 was insignificant. However, it was observed that models 1 and 2 presented significantly lower AD and LD values than not only model 3 but also model 4 (P < .05). Considering the impression technique, the highest values (0.78 ± 0.36 for AD, 14.90 ± 9.32 for LD) were detected with IOS, followed by CT, HOT, and NHOT, respectively. Only the comparisons of AD values between the CT-NHOT, IOS-NHOT, and HOT-IOS techniques were statistically significant (P < .05). Only the comparisons of LD values between IOS-NHOT and IOS-IOS-techniques were statistically significant (P < .05).

Evaluation of Molar Implant Site
In accordance with the results of two-way ANOVA, AD and LD values were significantly affected by model type (P ≤ .001 for AD, P ≤ .001 for LD) and impression technique (P ≤ .001 for AD, P ≤ .001 for LD), as well as by their interaction terms (P = .037 for AD, P = .005 for LD).

The mean AD and LD values with SDs are presented in Tables 1 and 2, respectively. Considering the model type, the highest and lowest mean values were exhibited by model 4 (1.56 ± 0.25 for AD, 24.73 ± 6.08 for LD) and model 1 (0.54 ± 0.34 for AD, 8.69 ± 6.16 for LD), respectively. No statistically significant difference was detected between models 1 and 2. Moreover, model 4 depicted significantly higher AD and LD values than all the others (P < .05). Considering the impression technique, the highest AD value (1.01 ± 0.46) was detected with IOS, followed by CT, HOT, and NHOT, respectively. Only the comparisons of AD values between CT-IOS and NHOT-HOT techniques were insignificant (P > .05). On the other hand, the highest LD value (20.59 ± 10.49) was detected with CT, followed by IOS, HOT, and NHOT, respectively. Only the comparisons of LD values between the CT-IOS and NHOT-HOT techniques were insignificant (P > .05). Considering the interaction term, while the highest and lowest mean AD values were exhibited by IOS-model 4 (1.56 ± 0.25)
between the CT-IOS and NHOT-HOT techniques were detected. Only the comparisons (50.60 ± 11.56) was detected with IOS, followed by CT, the impression technique, the highest RMS value (RMS) than all the others (P < .05). Moreover, model 4 depicted a significantly higher cant difference was detected between models 1 and 2. Moreover, model 4 depicted a significantly higher RMS value than all the others (P < .05). Considering the impression technique, the highest RMS value (50.60 ± 11.56) was detected with IOS, followed by CT, HOT, and NHOT, respectively. Only the comparisons between the CT-IOS and NHOT-HOT techniques were insignificant (P > .05). Considering the interaction term, the highest and lowest mean RMS values were exhibited by IOS-model 4 (70.02 ± 4.74) and NHOT-model 2 (25.96 ± 17.67), respectively. Significant differences between models were detected only in the CT and IOS groups, (P < .05). Moreover, significant differences between impression techniques were detected only in models 3 and 4 (P < .05).

### Table 1 Angular Deviation Values and Standard Deviations with Tukey Post Hoc Comparisons

<table>
<thead>
<tr>
<th>Impression techniques</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td><strong>Implant no. 15</strong></td>
<td></td>
<td></td>
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<tr>
<td>Closed tray</td>
<td>0.46 ± 0.18</td>
<td>0.53 ± 0.41</td>
<td>0.85 ± 0.62</td>
<td>0.89 ± 0.56</td>
<td>0.68 ± 0.53&lt;sup&gt;AB&lt;/sup&gt;</td>
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<td>Non-plexed open tray</td>
<td>0.40 ± 0.38</td>
<td>0.42 ± 0.60</td>
<td>0.55 ± 0.45</td>
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<td>0.49 ± 0.43&lt;sup&gt;ac&lt;/sup&gt;</td>
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<td>Hexed open tray</td>
<td>0.45 ± 0.25</td>
<td>0.43 ± 0.22</td>
<td>0.60 ± 0.42</td>
<td>0.71 ± 0.40</td>
<td>0.55 ± 0.32&lt;sup&gt;d&lt;/sup&gt;</td>
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<tr>
<td>Introral scan</td>
<td>0.47 ± 0.17</td>
<td>0.72 ± 0.67</td>
<td>0.95 ± 0.30</td>
<td>0.97 ± 0.30</td>
<td>0.78 ± 0.36&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total</td>
<td>0.44 ± 0.25&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.53 ± 0.48&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.74 ± 0.50&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.80 ± 0.45&lt;sup&gt;A&lt;/sup&gt;</td>
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<td>Closed tray</td>
<td>0.50 ± 0.52&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.54 ± 0.50&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.97 ± 0.52&lt;sup&gt;AB&lt;/sup,a&gt;</td>
<td>1.45 ± 0.25&lt;sup&gt;AB&lt;/sup,a&gt;</td>
<td>0.86 ± 0.59&lt;sup&gt;A&lt;/sup&gt;</td>
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<td>Non-plexed open tray</td>
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<td>0.46 ± 0.28</td>
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<td>0.53 ± 0.32&lt;sup&gt;d&lt;/sup&gt;</td>
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<td>Hexed open tray</td>
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<td>0.50 ± 0.33</td>
<td>0.65 ± 0.50&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.76 ± 0.11&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.60 ± 0.33&lt;sup&gt;d&lt;/sup&gt;</td>
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<td>Introral scan</td>
<td>0.54 ± 0.34&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.76 ± 0.82&lt;sup&gt;A&lt;/sup&gt;</td>
<td>1.18 ± 0.41&lt;sup&gt;A&lt;/sup,a,b</td>
<td>1.56 ± 0.25&lt;sup&gt;AB&lt;/sup,a</td>
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<td>Total</td>
<td>0.50 ± 0.35&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.56 ± 0.48&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.84 ± 0.60&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.10 ± 0.47&lt;sup&gt;a&lt;/sup&gt;</td>
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Different superscript lowercase letters indicate significant differences in the same column. Different superscript uppercase letters indicate significant differences in the same row. Only the significant differences among experimental groups were given as superscript letters.

### Table 2 Linear Deviation Values and Standard Deviations with Tukey Post Hoc Comparisons

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<tr>
<th>Impression techniques</th>
<th>Model 1 (µm)</th>
<th>Model 2 (µm)</th>
<th>Model 3 (µm)</th>
<th>Model 4 (µm)</th>
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<tr>
<td>Non-plexed open tray</td>
<td>7.05 ± 6.51</td>
<td>7.26 ± 10.45</td>
<td>9.55 ± 7.91</td>
<td>12.29 ± 7.27</td>
<td>9.04 ± 8.14&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>7.94 ± 4.28</td>
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<td>10.55 ± 7.25</td>
<td>12.36 ± 7.07</td>
<td>9.59 ± 7.11&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>Introral scan</td>
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<td>13.04 ± 11.24</td>
<td>18.78 ± 5.18</td>
<td>19.57 ± 5.34</td>
<td>14.90 ± 9.32&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>Total</td>
<td>7.79 ± 6.29&lt;sup&gt;A&lt;/sup&gt;</td>
<td>9.31 ± 9.49&lt;sup&gt;A&lt;/sup&gt;</td>
<td>13.88 ± 8.69&lt;sup&gt;b&lt;/sup&gt;</td>
<td>15.86 ± 8.05&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>Closed tray</td>
<td>8.71 ± 9.25&lt;sup&gt;A&lt;/sup&gt;</td>
<td>9.41 ± 8.71&lt;sup&gt;A&lt;/sup&gt;</td>
<td>22.83 ± 9.53&lt;sup&gt;AB&lt;/sup,a,b</td>
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<tr>
<td>Introral scan</td>
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<td>27.26 ± 6.96&lt;sup&gt;AB&lt;/sup,a,b</td>
<td>29.31 ± 3.43&lt;sup&gt;AC&lt;/sup,a</td>
<td>19.82 ± 12.36&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>Total</td>
<td>8.69 ± 6.16&lt;sup&gt;A&lt;/sup&gt;</td>
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<td>24.73 ± 6.80&lt;sup&gt;c&lt;/sup&gt;</td>
<td>15.28 ± 8.70</td>
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</table>

Different superscript lowercase letters indicate significant differences in the same column. Different superscript uppercase letters indicate significant differences in the same row. Only the significant differences among experimental groups were given as superscript letters.

and NHOT-model 2 (0.46 ± 0.28), respectively, the highest and lowest mean LD values were exhibited by CT-model 4 (41.40 ± 14.48) and NHOT-model 2 (8.03 ± 4.86), respectively.

### Evaluation of RMS Estimate

Under the results of two-way ANOVA, RMS estimate values were significantly affected by model type (P < .001) and impression technique (P < .001), as well as by their interaction terms (P = .019). The mean RMS estimate values and SDs with Tukey post hoc comparisons are presented in Table 3. Considering the model type, the highest and lowest mean RMS values were found in model 4 (54.13 ± 17.89) and model 1 (28.77 ± 9.25), respectively. No statistically significant difference was detected between models 1 and 2. Moreover, model 4 depicted a significantly higher RMS value than all the others (P < .05). Considering the impression technique, the highest RMS value (50.60 ± 11.56) was detected with IOS, followed by CT, HOT, and NHOT, respectively. Only the comparisons between the CT-IOS and NHOT-HOT techniques were insignificant (P > .05). Considering the interaction term, the highest and lowest mean RMS values were exhibited by IOS-model 4 (70.02 ± 4.74) and NHOT-model 2 (25.96 ± 17.67), respectively. Significant differences between models were detected only in the CT and IOS groups, (P < .05). Moreover, significant differences between impression techniques were detected only in models 3 and 4 (P < .05).

### DISCUSSION

The use of intraoral scanners is growing; however, limited data are available regarding the accuracy of digital impressions in comparison to conventional techniques, especially when implants are not ideally placed. Therefore, this study compared the angular, linear, and 3D deviations of the scan posts on the virtual models obtained through digital and conventional impression techniques. The null hypotheses were rejected, as significant differences between not only impression techniques but also models were detected.
It is well-known that a lack of passive fit can lead to mechanical or biologic complications.\textsuperscript{1} Therefore, the transfer accuracy of implant positions should be as accurate as possible to keep the remaining discrepancy within the range of acceptability to be compensable by the elasticity of the bone, the residual mobility of the implants, and the fabrication tolerances of the abutments.\textsuperscript{21,22} The level of discrepancy at the interface shared by implant and prosthetic components is used to set the degree of passive fit to a numeric datum. Implant-supported restorations with discrepancies as small as 10 μm present a superior service in terms of passive fit\textsuperscript{23}; however, according to a misfit classification composed considering current fabrication techniques, interface discrepancies up to 100 μm were regarded as clinically acceptable.\textsuperscript{1} In this study, discrepancy measurement has not been made. Therefore, stated thresholds could not be used to assess the findings of the present study. Assuncao et al\textsuperscript{10} highlighted that in a good impression, a discrepancy of 50 μm in any axis is acceptable, and this can be used to digitize the trueness. Accordingly, it might be said that the 3D deviation values of all experimental groups were under the acceptability threshold, except IOS-model 3, CT-model 4, and IOS-model 4. The threshold of clinical acceptability for the angular deviations is also lacking. However, concerning the simple trigonometric functions and assuming that the maximal lateral apex movement of 50 μm is acceptable, it has been suggested that up to 0.4-degree angular deviation could be acceptable.\textsuperscript{15,24} In this study, although all AD values were above this threshold value, the NHTOT technique presented values closer to this threshold.

Conventional techniques included in this study were CT, NHOT, and HOT. In a review,\textsuperscript{5} it has been reported that in the presence of two or three implants, accurate impressions can be made by using both OT and CT techniques, and a previous study\textsuperscript{3} concluded that both techniques result in accurate impressions for three implants angulated up to 15 degrees. On the contrary, it has been indicated that the splinted OT technique exhibited greater accuracy when 10 or 20 degrees of angular difference existed between two implants,\textsuperscript{25} and the CT technique led to an inaccurate impression in the case of 20 degrees of angular difference.\textsuperscript{26} Due to the lack of consensus, CT and OT techniques were included in this study, and the distal implant was inclined 20 degrees in angulated models (models 3 and 4). In the present study, while there was no significant difference among the conventional techniques in terms of trueness in the models with parallel implants, significantly higher AD and LD values were detected in CT groups of angulated models in comparison to OT techniques. This inaccuracy of the CT technique in angulated models may be explained by the distortion of impression material during the removal of the tray due to the undercut area generated by the divergent implant. In internal connection implants, it has been suggested that when the OT technique is used and the posts are splinted, longer impression post connection areas can affect the impression accuracy by increasing the amount of distortion.\textsuperscript{6,27,28} A non-hexed impression post with a shorter connection area was developed to reduce that distortion risk. The findings of the present study comparing hexed and non-hexed posts revealed that, regardless of implant angulation, hex geometry of the impression posts did not influence the deviation values of OT groups. A previous study\textsuperscript{14} investigated splinting or not splinting hexed and non-hexed posts and reported that the use of non-hexed posts resulted in lower deviation values in the case of multiple and angulated implants. The discrepancy between the results of the studies can be attributed to the difference in the number of implants evaluated in the studies. In the presence of two implants, the amount of stress generated during withdrawal of the tray due to the angular difference between implants may be negligible.

Considering available impression materials, polyether and vinyl polysiloxane are highly recommended for implant impressions.\textsuperscript{5} In fully edentulous and multi-implant cases, polyether presents good service due to its dimensional stability and stiffness.\textsuperscript{27} However, its stiffness causes interplay between antagonistic factors. On one side, its stiffness helps to hold the impression posts in their corresponding positions and prevent any displacement during the removal of the impression.\textsuperscript{7} On the other side, tray removal becomes difficult.\textsuperscript{27}

<table>
<thead>
<tr>
<th>Impression techniques</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed-tray</td>
<td>28.22 ± 8.46</td>
<td>31.11 ± 13.79</td>
<td>44.22 ± 6.18</td>
<td>66.84 ± 15.74</td>
<td>42.59 ± 11.04</td>
</tr>
<tr>
<td>Non-hexed open-tray</td>
<td>27.15 ± 6.55</td>
<td>25.96 ± 17.67</td>
<td>33.30 ± 16.36</td>
<td>36.90 ± 8.95</td>
<td>30.83 ± 13.52</td>
</tr>
<tr>
<td>Hexed open-tray</td>
<td>27.86 ± 8.33</td>
<td>28.64 ± 17.92</td>
<td>36.20 ± 5.77</td>
<td>42.76 ± 7.12</td>
<td>33.86 ± 9.79</td>
</tr>
<tr>
<td>Intraoral scan</td>
<td>31.85 ± 13.13</td>
<td>40.03 ± 9.96</td>
<td>58.64 ± 8.39</td>
<td>70.02 ± 4.74</td>
<td>50.13 ± 9.066</td>
</tr>
</tbody>
</table>

Different superscript lowercase letters indicate significant differences in the same column. Different superscript uppercase letters indicate significant differences in the same row. Only the significant differences among experimental groups were given as superscript letters.
With this demand, the use of a material depicting higher elastic recovery, such as vinyl polysiloxane, would be more logical, especially in the presence of nonparallel and internal connection implants.\textsuperscript{25,27} Accordingly, permanent deformation can be reduced, as less stress would be formed between impression posts and the material.\textsuperscript{27,29} In light of this, monophase vinyl polysiloxane impression material was used in this study.

The accuracy of a digital impression is not expected to be influenced by the angular differences between implants because risks such as deformation of impression material and displacement of the impression post are eliminated in digital scans.\textsuperscript{11,30} In the present study, no difference in accuracy was detected between parallel and angulated implants within digital impression groups. Previous studies supported this finding.\textsuperscript{11,20} However, in the present study, although no significant difference was found among the impression techniques for parallel implants, significantly higher deviation values were detected for digital impressions in angulated models in comparison to OT techniques. In contrast to this finding, previous studies reported higher accuracy for digital impressions in angulated implants.\textsuperscript{19,31} Zhang et al\textsuperscript{31} attributed the better accuracy detected with angulated implants to the fact that intraoral scanners can identify the scan posts more easily when there is an angular difference. The inclination side of the distal implant was also regarded as a contributing factor to digital impression accuracy. When the distal implant is inclined distally, the undercut area of scan posts is reduced, which results in more accurate capture of the scan posts.\textsuperscript{31} On the other hand, tilting the distal implant mesially shortens the distance of the edentulous area between scan posts, which provides a better scan\textsuperscript{22} because the efficacy of intraoral scanners in scanning the plain surfaces like edentulous regions is limited.\textsuperscript{33} Apart from the differences in study designs, scanner types, scan post type, and evaluation methods, the direction of inclination of the distal implants may affect the accuracy outcomes of studies. Further studies are needed to understand the efficacy of digital impressions in case of angulated implants.

The insertion depth of the implant and thereby the height of soft tissue affects the exposed portion of the impression post and scan posts. In the presence of deeply placed implants, the retention of the impression post may be reduced, and positional errors may occur.\textsuperscript{11} In a similar manner, the accuracy of a digital impression is compromised when the visibility and capture of the scan post by the intraoral scanner are reduced due to the deep insertion of the implant.\textsuperscript{9} In the present study, regardless of the impression technique, subgingival depth alone did not influence the trueness of impression when the implants were parallel to each other. However, significantly higher deviations were detected in CT and IOS groups when the distal implant was placed with 20 degrees of angulation at a depth of 4-mm. The lower accuracy found in CT for deeply placed and angulated implant groups may be explained by insufficient stability of the impression post, which may be further decreased due to the non-rigid character of the impression material used. Splintering the impression posts in OT techniques may have contributed to the greater accuracy found in these groups. For the IOS group, inclined and submerged implants might cause incomplete capture of the scan post due to an increased undercut area, resulting in greater deviations.

Rapid advancements in computerized dentistry have led to the emergence of manifold 3D superimposition software. The subsequently launched best-fit-alignment function of this software has allowed the superimposition of virtual datasets to assess accuracy with the aid of the RMS estimate, which is calculated from the average of the distances of all the point clouds in the reference and experimental models that are superimposed.\textsuperscript{11,16} However, the best-fit-alignment algorithm functions by matching a set of measured points or a set of actual features, as closely as possible, to that of their counterpart. Therefore, the actual positional intercourse between the reference and test datasets may deviate much more, and the deviation between the virtual images may be underestimated.\textsuperscript{16} To circumvent this outcome, in this study, 3D superimposition software was forced to conduct the best-fit-alignment function by selecting the dentulous region and thereby excluding the partially edentulous span where implantation had been done. On the other hand, instead of RMS calculation for the whole model, 3D superimposition software was used to compute the RMS estimate value only from the scan posts to acquire more reliable and precise results. Moreover, not only RMS values but also angular and linear deviations were calculated to better understand the trueness of the impression techniques.

In the present study, maxillary partially edentulous models with anatomical undercuts were used. The reference models were mounted on a mannequin head, and all impression techniques were performed in the mannequin’s mouth. In this manner, the path of tray removal was better simulated for conventional techniques, and the IOS was performed under conditions similar to those found in the clinic. Even so, this study had several limitations. The presence of saliva, blood, gingival fluid, and soft tissues—which were not included in this study—may affect the accuracy of the techniques. Although intraoral scans were directly evaluated, the digitization requirement of the conventional impressions with the aid of a laboratory scanner led to additional inaccuracy for those techniques. Moreover, the IOS procedure was not performed in a dark environment, such as inside of the mouth. It was thought that the scanning lighting condition may affect the results. Only one type of impression material and intraoral scanner were used;
different materials and devices may alter the findings. To obtain more clinically relevant results between different impression techniques, prosthetic frameworks should be fabricated. With this attempt, not only the misfit of the frameworks but also the correlation between discrepancies and deviations can be assessed. Therefore, further studies are needed.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be made:

1. Implant angulation did not have an effect on the trueness of the impression techniques, while insertion depth was found to affect the trueness of CT and digital impression techniques when the implants were not parallel to each other.

2. In case of angulated and deeply placed implants, the OT impression technique with splinting of the impression copings can be recommended.

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REFERENCES


