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Original Article

Influence of the implant scan body modifications on trueness of digital impressions

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Abstract *Background/purpose:* Effects of implant angulation on digital impression accuracy remain controversial. The purpose of this study was to assess the relationship between the alteration of implant scan bodies and the trueness of digital impressions.
Materials and methods: A maxillary typodont without the right premolars and first molar was scanned with a laboratory scanner and saved as a standard triangular language (STL) file. A model from the STL file was fabricated with a 3-dimensional printer. Two implants were placed into the first premolar and first molar sites of the model, followed by the insertion of two scan bodies onto the implants. These scan bodies were divided into four test groups, based on the surface modifications. A digital impression of each typodont was made with three different intraoral scanners. An abutment was digitally seated on each implant. 120 STL files (30 for each group) of the typodont with two implants and two corresponding abutments were used for statistical analysis.
Results: A total of 240 values (two implants for each typodont) were obtained after each sample (4 groups) was scanned 10 times by utilizing three intraoral scanners. The overall linear and angular discrepancies were analyzed. Group 1 showed the lowest linear discrepancy of 14.9 ± 5.4 μm while Group 4 reported the highest linear discrepancy of 137.5 ± 41.7 μm, yielding a statistical significance ($P < 0.05$).
Conclusion: It has been concluded that the more adjustments made to the scan bodies, the greater the linear and angular deviations occur, compromising the trueness of the digital implant impression.

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Introduction

The use of dental implants to restore edentulous sites has become a popular treatment in recent years.[1–3] To achieve high success rate, surgeons must take into consideration many factors such as location of the edentulous area, bone quality and quantity, so the implant can properly integrate with its surrounding tissue.[4,5] Surgeons must also take into account the neighboring vital structures, including maxillary sinus, inferior alveolar nerve, and the adjacent teeth. Therefore, it is critical for the surgeons to undergo proper training and experience to optimize the outcome of the implant treatment. While the surgeon may insert implants at different angles to avoid anatomical landmarks, such surgery can result in severely tilted implants or ones in too close proximity to one another, making it difficult to fabricate prosthesis.[6,7] One can achieve proper osseointegration, but it is also imperative that the implants are angled in such a way where they can also be restored properly. It is of great importance for surgeons to not only be skillful in the surgical placement of implants but also competent in visualizing the restorative plan. Proper training and teamwork between the surgeon and restorative dentist are critical to avoid nonfunctional implants and produce successful clinical outcomes for the patients. Ultimately, prosthetically-driven implant placement with collaboration between the surgeon and restorative dentist is the key to success.[8–10]

Following proper osseointegration and healing, an accurate digital impression must be made of the implants, adjacent dentition, opposing arch, and occlusion in order to design a functional and esthetic implant-supported prosthesis. During the digital impression, a scan body is typically used by the restorative dentist to capture the position of the implant placed by the surgeon.[11–13] The scan body is screwed onto the implant and scanned by using an intraoral scanner (IOS). The data retrieved from the IOS is transferred to a computer-aided designing (CAD) software program where the geometric design of the scan body is used to determine the 3-dimensional (3-D) position of the implant. This virtual implant mimics the actual submerged implant in the patient's oral cavity. The digital data are then used to design and fabricate the proper prosthetic component of this implant-supported prosthesis.

Complications arise when surgeons misposition adjacent implants, resulting in paths not parallel to one another or the adjacent dentition.[14–16] This can make the restorative stage more difficult for the dentist and create unfavorable outcomes, such as poor esthetics. When the scan bodies are attached to multiple poorly placed adjacent implants, they reflect the misalignment and cannot be completely seated due to the proximity to each other. This poses a challenge when capturing the digital impression. One way to potentially overcome this problem is by adjusting the scan bodies with a handpiece and bur.[17] Reducing one surface of the scan bodies produces more space so they can be fully seated onto the implants.

Other factors influencing the success of the digital dentistry are the utilization of a highly accurate IOS and obtaining its digital data for fabrication of the prosthesis. Accuracy of an IOS is comprised of trueness and precision.[18–20] Trueness is determined by the closeness between the scan and the standard measurement of the object being scanned while precision is defined by how consistent multiple measurements are with one another.

The goal of this study was to assess the impact of four differently modified implant scan bodies on the trueness of digital impression.

Materials and methods

In this study, a maxillary arch typodont was modified by removing the maxillary right first and second premolars and first molar and by filling the edentulous sites with wax. The altered maxillary arch was then scanned with a laboratory scanner (Cerec InEosX5, Sirona Dental System, Bensheim, Germany) and saved as a STL file. Then, a photopolymer resin (curable and printable) master model from the STL file was fabricated by using a 3-dimensional (3-D) design program (Exocad DentalCAD, exocad GmbH, Darmstadt, Germany) and a 3-D printer (Photon mono 4K, Anycubic Technology, Hongkong, China). Two implants (4.2 mm × 10 mm, OneQ, Dentis, Daegu, South Korea) were placed into the edentulous sites of the first premolar and first molar of the printed model. In order to properly align the implants, two parallel pins guided the implants for appropriate angulation. Once the implants were inserted, two 12 mm-long scan bodies were screwed into the implants and torqued to 5 Ncm. The scan bodies were cylinder-shaped with one flat proximal surface and one flat occlusal surface. The scannable portion of the scan body was made of non-reflective titanium. This provided each intraoral scanner with the ability to determine the position of implants.

For the reference (control) model, one unaltered scan body was screwed on each implant and then a digital impression of the typodont was made with a calibrated desktop scanner (E3, 3Shape, Copenhagen, Denmark). After this scan was saved as an STL file, the STL file was imported into design software (Exocad DentalCAD). A corresponding abutment (same for all implants and groups) for each implant was selected from the implant library of the design software and digitally seated on each implant, which would later facilitate the digital overlapping procedure between the reference file and test groups for statistical analysis. This single STL file of the typodont with two implants and corresponding abutments was saved and used for reference (Fig. 1).

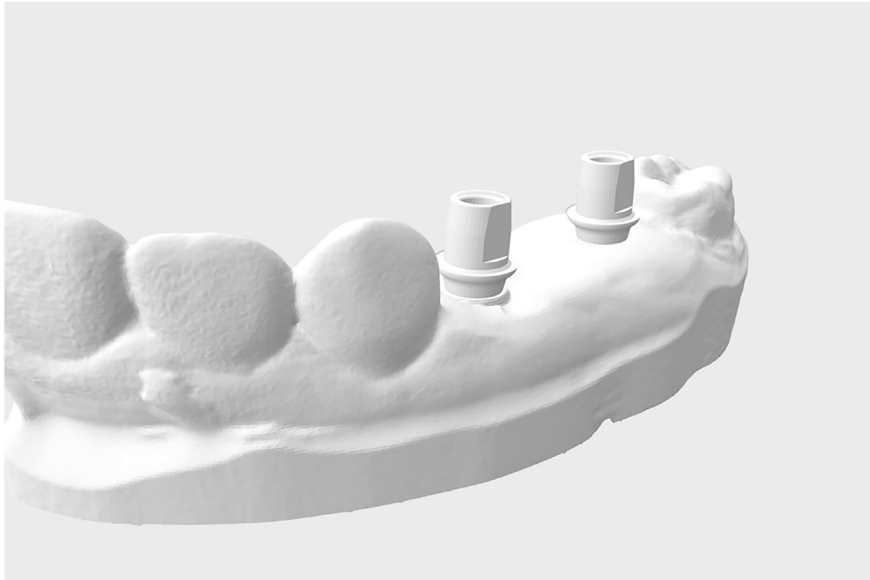

Figure 1 Reference model with implants and abutments.

For test groups, digital impression of each typodont with scan bodies was made with three different intraoral scanners. These scan bodies were divided into four different groups (Figs. 2 and 3).

Each group had a different modification created:

Group 1: No modifications.

Group 2: A 2 mm × 3 mm slot was made on the proximal surface without damage to the occlusal surface.

Group 3: A 3 mm × 4 mm slot was made on the proximal surface without damage to the occlusal surface.

Group 4: A 3 mm × 6 mm slot was made including the occlusal and proximal surfaces.

Similar to the reference file, each test scan was saved as an STL file and then imported into design software (exocad). A corresponding abutment for each implant was selected from the implant library of the design software and digitally seated on each implant. The 120 STL files of the typodont with two implants and two corresponding abutments was saved and used for statistical analysis (Fig. 4).

Three different intraoral scanners were investigated in this study: a) Trios 4 (3Shape, Copenhagen, Denmark), b) iTero Element 2 (Align Technology, California, USA), and c) Medit i500 (Medit corp, Seoul, South Korea). Each of the 4

Figure 2 Scan bodies were divided into four different groups based on the amount of alterations.

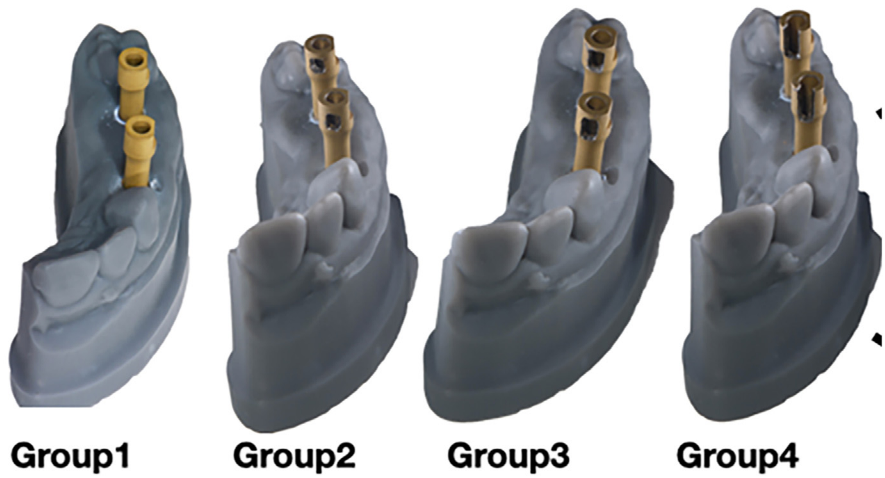

Figure 3 Digital impressions of the typodonts were made after scan bodies were screwed on the implants.

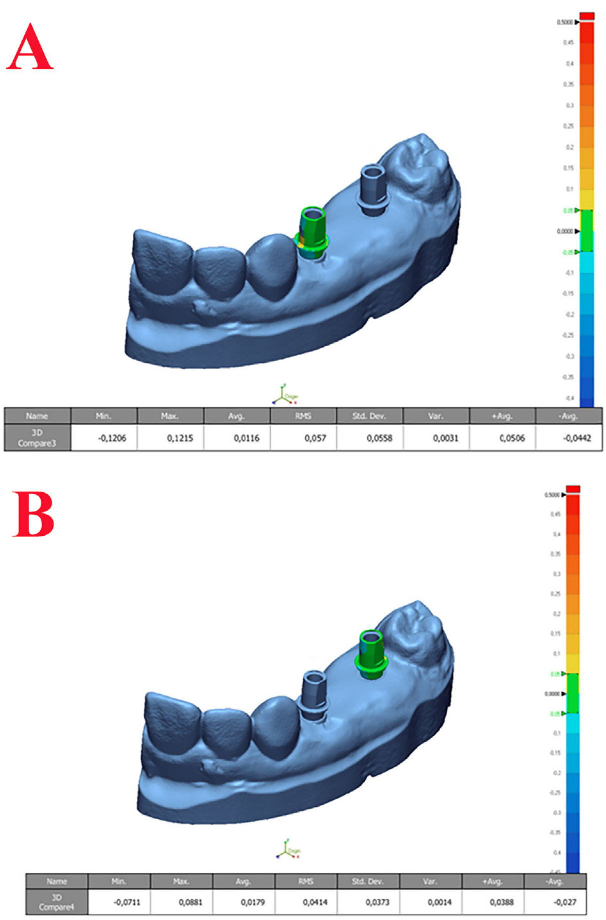

Figure 4 Digital overlapping procedure. (A) Deviations of the first premolar and (B) first molar implants.

groups was scanned 10 times by each scanner, resulting in 120 STL files. A device holder was used to secure the intraoral scanner on one end and a base for the model on the other. The base with the model rotated circumferentially while the intraoral scanner was fixed to the device holder in order to provide consistency during each scan. Each intraoral scanner followed a path recommended by their manufacturer. The Trios 4 intraoral scanner captured the impression starting with the central incisor and moved distally to the second molar. The intraoral scanner then proceeded to scan the buccal surface at a 60—90° angle, followed by the palatal surface. Afterward, a second scan was completed with focus on the two scanning bodies where the plants were located. The same scanning strategy was utilized for the Medit i500 intraoral scanner. The iTero Element 2 intraoral scanner followed a similar path starting with scanning of the central incisor's occlusal surface and ending at the second molar. However, the scanner then proceeded to the palatal side, followed by the buccal surface, and finally, the scan bodies of the two implants.

Scanning data obtained from the reference model (a single STL file) and intraoral scanners (120 STL files) were compared using a best-fit registration program (GOM Inspect Professional 2017, Braunschweig Germany). The root mean square (RMS) and angular deviation values for both implants were calculated. Briefly, the RMS is used to determine the absolute mean distances between corresponding points with each other and shows the similarities and differences of the compared surfaces. The lower RMS values indicated more similarity while higher values indicated more divergence.

Statistical analysis of the data was made using R-software (version 4.1.2) and Turcosa software (www.turcosa.com.tr). Compliance of numerical variables with normal distribution was evaluated by using graphical approaches (Q—Q plot) and hypothesis tests (Shapiro—Wilk normality test) together. Numerical variables with normal distribution were summarized using mean and standard deviations, and numerical variables that were not normally distributed were summarized using medians and quartiles. Since the assumption of normal distribution was not provided in the comparisons of the numerical variables examined between the device and the groups, the Friedman test was used, and if there was a significant difference, Nemenyi paired comparison tests was used to determine the group that created the difference. Comparisons between implants were similarly evaluated using the Mann—Whitney U test, on the condition that the assumption of normal distribution was not met. The statistical significance level for all analyses was accepted as $P < 0.05$.

Results

A reference scan was obtained from the desktop scanner and used as a control while a total of 120 scans were taken by using three of the different participating intraoral scanners. A total of 240 values (two implants for each typodont) from 120 STL files were obtained after each sample (four different groups) were scanned 10 times by utilizing the three intraoral scanners.

When comparing the reference scan with the 10 scans from each group, the overall discrepancies (linear and angular) were analyzed. As seen in Table 1, Group 1 using 3Shape scanner showed the lowest linear discrepancy of 14.9 ± 5.4 μm while Group 4 using Itero scanner reported the highest linear discrepancy of 137.5 ± 41.7 μm, yielding a statistical significance ($P < 0.05$). As presented in Table 2, Group 1 using Itero scanner showed the lowest angular discrepancy of 0.13 ± 0.04° while Group 4 using Itero scanner reported the highest linear discrepancy of 2.56 ± 1.88°, yielding a statistical significance ($P < 0.05$).

The overall linear discrepancies (first premolar + first molar) were 19.6 ± 9.9 μm for Group 1, 22.1 ± 11.6 μm for Group 2, 41.2 ± 17.3 μm for Group 3, and 104.1 ± 45.1 μm for Group 4 respectively, yielding statistical significances ($P < 0.05$) among the groups except Groups 1 and 2 (Table 1).

The overall angular discrepancies (first premolar + first molar) were 0.16 ± 0.11° for Group 1, 0.29 ± 0.18° for Group 2, 0.69 ± 0.32° for Group 3, and 1.69 ± 1.31° for Group 4 respectively, yielding statistical significances ($P < 0.05$) among the groups except Groups 1 and 2 (Table 2).

As depicted in Fig. 5, Group 1 showed the least overall linear deviations while Group 4 showed the highest linear deviations. When comparing the first premolar to the first molar, the first premolar presents with less discrepancies than the first molar in Groups 1, 2 and 3. The tooth first scanned and captured by the IOS is typically the most accurate and the one farthest away from the starting point is least accurate, which is a common limitation with IOS. Our study's path of scanning proceeded from mesial to distal. Thus, the results reflect the scanning pattern, showing that the teeth more distal are less accurately scanned than those mesial.

Discussion

This study aimed to assess the relationship between the modifications made to implant scan bodies and the trueness of the digital impression. Misplaced implants pose a challenge for digital impressions due to the angulation of the scan bodies. Failure to completely capture the scan bodies may result in an inaccurate digital impression, leading to poor restorative outcomes such as ill-fitting restorations and poor esthetics.[21] To alleviate this complication, a handpiece and burr can be used to reduce the surface that is prematurely in contact with the adjacent scan body to allow for proper seating. The modifications made to the scan bodies in this study represent the possible alternations a restorative dentist must make to capture the entire scan body when scanning a digital impression. As shown in the results, the different alterations made to the proximal and occlusal surface of the scan body led to varying accuracy of the digital impressions.

Table 1 Overall (first premolar + first molar) linear deviation values (mean ± standard deviation in microns). Identical (lower case) letters in each row (horizontally) indicated no statistically significant differences ($P > 0.05$), while non-identical letters in each row indicated statistically significant differences ($P < 0.05$). Identical (upper case) letters in each column (vertically) indicated no statistically significant differences ($P > 0.05$), while non-identical letters in each column indicated statistically significant differences ($P < 0.05$).

Intraoral scanners	Number (n)	Group 1	Group 2	Group 3	Group 4
Itero	20	23.8 ± 13.4 [a]	28.1 ± 14.6 [a]	51.2 ± 20.7 [b]	137.5 ± 41.7 [c, N]
3Shape	20	14.9 ± 5.4 [d]	16.5 ± 5.7 [d]	32.1 ± 8.5 [e]	74.1 ± 28.2 [f, P]
Medit	20	20.3 ± 7.5 [g]	21.8 ± 10.2 [g]	40.6 ± 15.3 [h]	100.8 ± 40.3 [i, R]
Overall	60	19.6 ± 9.9 [k]	22.1 ± 11.6 [k]	41.2 ± 17.3 [l]	104.1 ± 45.1 [m]

Table 2 Overall (first premolar + first molar) angular deviation values (mean ± standard deviation in degrees). Identical (lower case) letters in each row (horizontally) indicated no statistically significant differences ($P > 0.05$), while non-identical letters in each row indicated statistically significant differences ($P < 0.05$). Identical (upper case) letters in each column (vertically) indicated no statistically significant differences ($P > 0.05$), while non-identical letters in each column indicated statistically significant differences ($P < 0.05$).

Intraoral scanners	Number (n)	Group 1	Group 2	Group 3	Group 4
Itero	20	0.13 ± 0.04 [a]	0.29 ± 0.2 [a]	0.69 ± 0.35 [b]	2.56 ± 1.88 [c, N]
3Shape	20	0.17 ± 0.08 [d]	0.28 ± 0.15 [d]	0.71 ± 0.32 [e]	1.08 ± 0.48 [f, P]
Medit	20	0.19 ± 0.09 [g]	0.32 ± 0.21 [g]	0.68 ± 0.34 [h]	1.43 ± 0.57 [i, R]
Overall	60	0.16 ± 0.11 [k]	0.29 ± 0.18 [k]	0.69 ± 0.32 [l]	1.69 ± 1.31 [m]

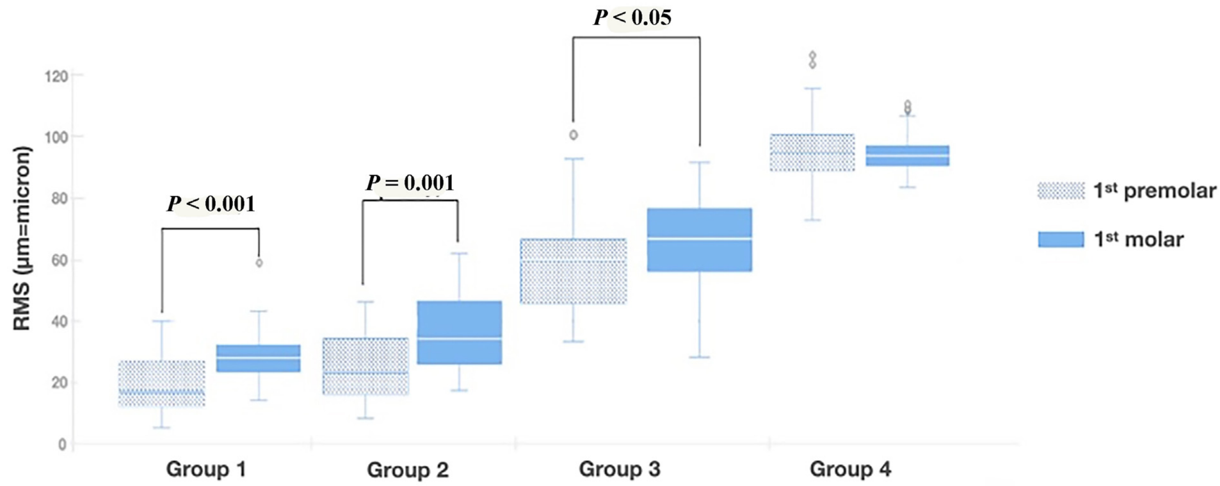

Figure 5 Overall (first premolar + first molar) linear deviation (mean ± standard deviation in microns) using a mesial to distal scanning technique.

When evaluating the overall linear discrepancies, a deviation of 19.6 ± 9.9 μm was found for Group 1, the lowest discrepancy when compared to the three other groups [Group 2 (22.1 ± 11.6 μm), Group 3 (41.2 ± 17.3 μm) and Group 4 (104.1 ± 45.1 μm)] in the present study. The overall angular discrepancies demonstrated similar results, showing the lowest deviation of 0.16 ± 0.11° for Group 1 when compared to the three other groups [Group 2 (0.29 ± 0.18°), Group 3 (0.69 ± 0.32°), and Group 4 (1.69 ± 1.31°)]. Comparable results were found in a previous study by Choi et al.,[22] in which the effects of scan body exposure and different scanners on the accuracy of image matching of the scan body were investigated. However, the exposure was measured by the amount of submergence of the scan body into the gingival tissue, instead of alterations to the scan body as seen in the present study. Six different groups were analyzed (fully exposed, 0.5 mm, 1.0 mm, 1.5 mm, 2.0 mm, and 2.5 mm less exposed). The linear deviation for the group with no reduction reported the lowest value for both the top and bottom of the implant, 16.1 ± 1.1 μm and 43.9 ± 3.2 μm, respectively. The lowest angular deviation was also found for the group with no exposure reduction, with the value of 0.169 ± 0.014° while the highest angular deviation of 4.683 ± 0.146° was reported by the group most submerged in the tissue. Their analysis revealed that as the exposure of the scan body was reduced, the deviations in implant positioning were significantly increased ($P < 0.001$), indicating a decrease in accuracy.

A study by Alqarni et al.,[17] studied a similar technique in the fabrication of implant-supported prosthesis by adjusting the scan bodies and using a completely digital workflow to restore the severely tilted implants. When attempting the conventional method, an accurate traditional impression was not captured due to the extreme modification made on the impression copings. Therefore, they switched to a digital impression and carefully modified the scan bodies, resulting in a successful restoration. However, it is important to note that the researchers were careful to avoid alterations to the facets located on the scan bodies, similar to the present study where adjustments were only made to the proximal and occlusal surface where the markers or reference plane were not present.

As depicted in Fig. 5, Group 1 reported the lowest linear overall deviations while Group 4 presented the highest overall linear deviations. When comparing the first premolar to the first molar in all four groups, less discrepancies were found in the first premolar than the first molar in Groups 1, 2 and 3. One explanation for these findings is the common limitation experienced with IOS, the first point captured by the IOS typically has highest trueness while the one farthest away from the starting point has lowest trueness. In the present study, the first premolar was scanned first, followed by the distal teeth. Thus, results reflect the scanning pattern, indicating that the teeth more distal show less trueness than those mesial. A study by Mennito et al.,[23] aimed to determine whether scan pattern impacts the accuracy of a 3-D model fabricated from the digital impressions and to compare the 5 imaging systems with their scanning accuracy for sextant impressions. Contrary to the results found in the present study, Mennito et al.,[23] concluded that scan pattern does not significantly affect the trueness or precision of the resulting digital model for sextant scanning. A study by Kaewbuasa et al.,[24] compared the accuracy of three IOS systems with three different dental arch widths (small, medium, and large). When assessing the relative length discrepancies of the three IOS, Dental Wings IOS reported values of 1.28% (small) and 1.08% (medium), the highest deviations when comparing to the two other IOS. Dental Wings IOS reported significantly greater angular differences in the small (1.75°) and medium (1.83°) arches when compared to the two other IOS. When investigating the accuracy of the three arches large arch while utilizing Dental Wings IOS, the large arch width showed more trueness and precision than the two other arch sizes ($P < 0.05$). However, when using True Definition IOS, the large arch width presented a greater angular deviation in trueness. No significant deviations were reported in terms of trueness between the three arch widths of Trios IOS group. The study concluded that different widths of the dental arches can impact the trueness and precision in a full arch scan depending on the IOSs used. A study by Bi et al.,[25] investigated the accuracy between digital and conventional implant impressions when scanning models with implants placed in different proximities to one another. For short-span scanning, the accuracy of digital and conventional implant impressions did not report significant deviations. However, for long-span scanning, the precision of digital impressions was significantly lower when compared to traditional impressions.

Based on the findings in this study, it has been concluded that the greater the modifications present on the proximal and occlusal surfaces of the implant scan bodies, the more overall linear and angular discrepancies are found, compromising the trueness of the digital implant impression. Proper treatment planning and communication between the restorative dentist and surgeon is essential to properly position and restore the implant while using digital workflow.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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