Influence of Different Factors on the Accuracy of Digital Impressions of Multiple Implants: An In Vitro Study

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Purpose: To investigate the effect of implant angulation, non-free-end partial edentulism, and number of scan bodies on the accuracy of digital impressions of multiple implants in partially edentulous arches. Materials and Methods: Four reference models of partially edentulous mandibles with implants (RM1, RM2, RM3, and RM4) representing different intraoral situations were each scanned 10 times by an intraoral scanner. Reference scans were obtained by a laboratory scanner. Test scans were compared with reference scans to obtain the distance deviations (Δd) and angular deviations (Δθ) between scan bodies for trueness assessment. Differences among the repeated test scans of each model were measured and recorded as Δdp and Δθp for precision assessment. The Student t test (α = .05) was used to compare Δd, Δθ, Δdp, and Δθp of different reference models, including RM2 vs RM1 (effect of non-free-end partial edentulism), RM3 vs RM1 (effect of implant angulation), and RM4 vs RM1 (effect of number of scan bodies). Results: The implant with 17-degree angulation in RM3 showed significantly lower Δd, Δθ, and Δθp compared with the parallel implant in RM1 (Δd: P = .0382, Δθ: P = .0267, Δθp: P = .0417). The RM2 of non-free-end partial edentulism had lower distance and angular deviations than RM1, but without a significant difference. The number of scan bodies had no significant effect on the Δd, Δθ, Δdp, and Δθp of RM4 and RM1. Conclusion: Angulated implants showed better accuracy of digital impressions in partially edentulous arches compared with parallel implants. Non-free-end partial edentulism was attributed to improved accuracy, while the number of scan bodies showed no effect. Int J Oral Maxillofac Implants 2021;36:442–449. doi: 10.11607/jomi.8532

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With digital technologies currently gaining more and more attention, digital implant impressions by intraoral scanners (IOS) developed rapidly in the last decade. An IOS uses 3D surface capturing technologies to acquire 3D images of dentition and tissue directly in the oral cavity.1 One of the advantages of digital implant impressions is that the errors caused by material deformation in conventional impressions can be avoided.2 Other advantages include improving patient comfort, as well as saving environmental waste and storage space of impressions and casts.3–5 However, the accuracy of digital impressions needs further investigation, especially for multiple implants, since the accurate transfer of implant position is critical for the passive fit of superstructures and long-term implant success.1,6

With regard to digital implant impressions in partially edentulous arches, inconsistent accuracy outcomes were reported. Multiple bench studies reported the accuracy of digital implant impressions ranging from 15.0 to 71.2 μm,7–9 and clinical studies reported errors from 27.410 to 220 μm.11 Various factors were assumed to affect the accuracy of digital implant impressions, including the scanning length,12,13 implant angulation,14,15 IOS types,8 operator experience,16–22 scan body types,23–25 etc.

Among these factors, studies have found that the deviations of digital implant impressions became higher when the scanning length or the interimplant distance increased,12,13,16,26–31 probably due to the accumulative errors in the stitching process of IOS. Regarding the effect of implant angulation, inconsistent findings were reported. Some studies reported that implant angulation did not affect the accuracy of digital implant impressions18–22,32,33; a few others reported that angulated implants showed lower34,35 or higher accuracy36 than parallel implants. However, most studies analyzing the effect of implant angulation did not eliminate the interfering effect caused by various scanning lengths, since the angulated implants and parallel implants were obviously placed at different positions...
in the scanning path when compared for accuracy,\textsuperscript{16–22,25,32,33} which would probably affect the authenticity of the findings. Therefore, the effect of implant angulation was further examined in this study when the scanning length was controlled.

Except for the aforementioned possible influencing factors, in this study, to the authors’ knowledge, the non-free-end partial edentulism and the number of scan bodies were speculated to be the influencing factors of digital implant impressions for the first time. The basis of this hypothesis is that digital impressions of multiple implants usually become challenging due to the lack of anatomical landmarks and the incorrect stitching process of IOS\textsuperscript{37} while the remaining teeth distal to the edentulous area and the extra scan bodies in a certain distance might serve as landmarks in the stitching process of IOS and thus improve accuracy.

Thus, the purpose of this in vitro study was to assess the effect of implant angulation, non-free-end partial edentulism, and number of scan bodies on the accuracy of digital implant impressions in partially edentulous arches. It should be noted that the scanning length during the scanning process was kept consistent when making comparisons. The null hypothesis was that the implant angulation, non-free-end partial edentulism, and number of scan bodies would not affect the accuracy of digital implant impressions.

**MATERIALS AND METHODS**

The study workflow is displayed in Fig 1.

**Reference Model Fabrication**

Four models of partially edentulous mandibles containing implants (Replace CC RP, 4.3 x 10 mm, Nobel Biocare) were designed and printed with opaque light-polymerizing resin as reference models (RM) in this study (Fig 2). To ensure that the scanning distance remained basically the same among the four reference models, the locations of the implant platforms in one model were duplicated to the other models during the computer-aided model design (3Shape Implant Studio, 3Shape). All implants were surrounded by a gingiva mask and placed 2 mm below the gingiva.

The reference models were designed as follows:

1. RM1: Mandibular right canine, first and second premolars, and first and second molars missing, three implants at mandibular canine, first premolar, and first molar sites (all implants: 0 degrees)
2. RM2: Mandibular right canine, first and second premolars, and first molar missing, three implants at mandibular right canine, first premolar, and first molar sites (all implants: 0 degrees)

3. RM3: Mandibular right canine, first and second premolars, and first and second molars missing, three implants at mandibular right canine, first premolar, and first molar sites (mandibular right canine implant: 0 degrees, mandibular right first premolar implant: 17 degrees distal, mandibular right first molar implant: 30 degrees distal)

4. RM4: Mandibular canine, first and second premolars, and first and second molars missing, two implants at mandibular right canine and first molar sites (both implants: 0 degrees)

RM1 was set to be the standard model for the comparison with RM2, RM3, and RM4. To investigate the effect of non-free-end partial edentulism, RM2 was compared with RM1. To examine the effect of implant angulation, RM3 was compared with RM1. To examine the effect of number of scan bodies in a certain scanning length, RM4 was compared with RM1.

For easy description, the implants and scan bodies at the mandibular canine, first premolar, and first molar sites were labeled as implant/scan body 1, implant/scan body 2, and implant/scan body 3, respectively.

Digital Impressions
Digital implant impressions were taken with the four reference models using Trios 3 intraoral scanner (3Shape) and software version 1.3.4.7. Trios IOS employs confocal microscopy and ultrafast optical scanning technology to generate 3D models. Specifically speaking, a light pattern is projected on the surface of scanned items by IOS; then, focusing and defocusing information of images is collected and analyzed at different depths. With each pixel in focus, the distance between the sensor and target is therefore obtained after being calculated by the built-in IOS algorithm. Data collected by every sensor in IOS are integrated and stitched to create a virtual consecutive model.

One experienced intraoral scanning operator (J.S.) was in charge of all the digital impressions following the manufacturer’s protocol. The IOS was calibrated every time before scanning. The scanning procedure was applied to the dentition without scan bodies at first. After the preliminary scan was completed, the implant areas were marked manually and cut off in the software. The matching scan bodies (Scan body, Nobel Biocare) for implant impressions were then manually tightened to implants 1, 2, and 3 with 10 Ncm. The scanning of scan bodies started from scan body 1, proceeded along the palatal side toward scan body 3, and continued with the occlusal and buccal surfaces of the scan bodies sequentially. Some missing areas were partially scanned again for complement. Ten repeated digital impressions were taken of each model, and a total of 40 virtual 3D models were generated. The scan bodies were connected to the same implant as the last time during each scan to eliminate the possible error caused by switching scan bodies. Data of the virtual models were exported in standard tessellation files (STL).

Reference Scans
A structured light laboratory scanner (Easy dental scanner, Open Technologies) with 10 μm accuracy was used to digitize the reference model with scan bodies attached to the implants and export the virtual model as reference STL files. Each reference model was scanned three times to obtain the average distance (d) and angle (θ) between scan bodies (1 to 2 and 1 to 3) as reference. Twelve STL files of reference scans were obtained in total.

Measurement of Distance Deviation and Angle Deviation
The STL files of digital impressions (test) and reference scans (reference) of RM1, RM2, RM3, and RM4 were imported into reverse-engineering software (Geomagic Studio 2014 and Creo Parametric 3.0). A standard cylinder was matched to the scan body according to the best-fit algorithm to determine the central axis of it. A standard plane was superimposed to the top plane of the scan body. The intersection point of the central axis and the plane of the scan body were defined as the reference point for distance measurement (Fig 3).

To determine the change of the position of scan bodies, distances (d) between the reference points of scan bodies and angles (θ) between the axes of scan bodies (scan body 1 to 2 and scan body 1 to 3) were measured. This procedure was performed with all 40 test STL files and 12 reference STL files by one examiner (Y.Z.). After that, the distance deviations (Δd) and angular deviations (Δθ) between scan bodies 1 and 2 and between scan bodies 1 and 3 (Δd12, Δd13, Δθ12, and Δθ13) were...
calculated by subtracting the reference values from the test values of distances and angles, and the absolute values of the results were taken to avoid the offset of positive and negative values.

**Statistical Analysis**

All statistical analyses were performed using SAS version 9.4 statistical software.

The term “accuracy” refers to trueness, describing the proximity of measurements to actual values, and precision, describing the proximity of multiple repeated measurement values.

To compare the effect of different influencing factors on the trueness, the distance and angular deviations between scan bodies (Δd12, Δd13, Δθ12, and Δθ13) measured in different reference models were analyzed.

To compare the effect of different factors on precision, the minimum values of Δd and Δθ among the 10 repeated test scans of each reference model were subtracted from the Δd and Δθ of other test scans of the reference model. The obtained results were labeled as Δdp and Δθp to represent the closeness of the model. The obtained results were labeled as Δdp and Δθp to represent the closeness of the model. The obtained results were labeled as Δdp and Δθp to represent the closeness of the model. The obtained results were labeled as Δdp and Δθp to represent the closeness of the model. The obtained results were labeled as Δdp and Δθp to represent the closeness of the model.

The Shapiro-Wilk test showed that Δd, Δθ, Δdp, and Δθp of each group all accorded with normal distribution. A descriptive analysis of Δd, Δθ, Δdp, and Δθp was reported as means with standard deviation (SD) of each group (RM1, RM2, RM3, and RM4). To examine the effects of different factors on trueness, Δd and Δθ of other test scans of the reference model were subtracted from the Δd and Δθ of RM1, respectively, via Student t test. Δdp and Δθp of different groups were compared in the same way to examine the effects on precision. A two-sided P value of < .05 was considered to indicate statistical significance.

**RESULTS**

The comparison of Δd, Δθ, Δdp, and Δθp between different groups (RM1 vs RM2, RM1 vs RM3, and RM1 vs RM4) are presented in Tables 1 and 2. The median, maximum, and minimum value of Δd and Δθ are displayed in box plots (Figs 4 and 5).

**Non-Free-End Partial Edentulism**

The effect of non-free-end partial edentulism was analyzed by comparing the digital impressions of RM2 with those of RM1.

In terms of trueness (Table 1), Δd12, Δd13, Δθ12, and Δθ13 of RM2 were all lower than the corresponding outcomes of RM1, indicating the improved trueness of group RM2. However, the differences were not statistically significant.

In terms of precision (Table 2), Δdp12, Δdp13, Δθp12, and Δθp13 of group RM2 were also lower than those of RM1, but without statistical significance.

**Implant Angulation**

The effect of implant angulation was analyzed by comparing the digital impressions of RM3 to those of RM1.

For trueness (Table 1), the results showed that implant 2 of RM3, which had an angulation of 17 degrees, had significantly lower Δd12 (17.16 ± 13.09 μm) and Δθ12 (0.27 ± 0.23 degrees) than the corresponding parallel implant of RM1 (Δd12: 29.91 ± 12.38 μm; Δθ12: 0.38 ± 0.23 degrees)
Δθ12: 0.60 ± 0.37 degrees). However, when examining the implant of 30 degrees, no significant difference was found between Δd13 and Δθ13 of RM3 and RM1.

For precision (Table 2), Δdp13 and Δθp12 of RM3 were significantly lower than those of RM1. Other assessed variables showed no significant difference between the two reference models.

**Number of Scan Bodies**

The effect of the number of scan bodies was analyzed by comparing the digital impressions of RM1 to those of RM4 (Tables 1 and 2). The results showed that Δd, Δθ, Δdp, and Δθp all failed to show any significant difference between the two groups, indicating no significant difference in both trueness and precision of the digital impressions of the two groups.

**DISCUSSION**

In the present study, the effects of different factors on the accuracy of digital implant impressions in partially edentulous arches, including the effect of implant angulation, non-free-end partial edentulism, and number of scan bodies, were investigated in vitro.

For the effect of implant angulation, unlike previous studies, the locations of implants in the dental arch were controlled to be consistent among different reference models, which ensured that the scanning length was maintained approximately the same when analyzing other influencing factors. The results showed that the accuracy of the implant of 17 degrees in RM3 was significantly better than the parallel implant in RM1, according to Δd12, Δθ12, and Δθp12, which had significant differences between the two groups.

In line with the result of this study, Lin et al found that angulated implants showed better accuracy in the casts fabricated from digital impressions, and also kept the scanning distance unchanged during examination.15 However, most previous studies reported different findings. With a partially edentulous model, Basaki et al found that the implant angulation did not affect the accuracy of definitive casts fabricated from digital impressions.14 For fully edentulous scenarios, Giménez et al,18–22 Alikhasi et al,32 and Papaspyridakos et al33 found that the implant angulation had no significant effect on the accuracy of digital impressions. In contrast to the present study, Ribeiro et al35 and Gintaute et al34 found that angulated implants showed lower accuracy compared with parallel implants. Apart from the different study designs and assessment methods applied, a possible reason for the inconsistency was that most studies failed to separate the errors of scanning length when measuring deviations, which had already been
demonstrated to be the influencing factor of digital impressions.\textsuperscript{12,26,40}

The reason for the better accuracy of digital impressions with angulated implants is probably that with different angulations, it is easier for IOS to distinguish one scan body from another. When scanning multiple implants, since identical scan bodies are used, it may be difficult for IOS to recognize various scan bodies, and as a consequence, the images of scan bodies are pasted on top of the others.\textsuperscript{38,41,42} With different angulations, the intersection angle between the scan body and gingiva becomes distinctive, and it may be easier for scan bodies to be recognized with their correct position by IOS. Another possible contributing factor might be the reduction of undercut areas in scan bodies when implants were angulated distally. Undercut areas in scan bodies and neighboring structures may cause incomplete capture of information during intraoral scanning and affect the accuracy negatively.\textsuperscript{26,43}

However, when evaluating the effect of implant angulation of 30 degrees by comparing $\Delta d_{13}$, $\Delta \theta_{13}$, $\Delta \rho_{13}$, and $\Delta \rho_{13}$ of RM1 and RM3, significant differences were only found for $\Delta \rho_{13}$ but no others. It was speculated that the significant difference caused by the positive effect of implant angulation might be canceled out by the negative effect of longer scanning distance from scan body 1 to scan body 3.

When analyzing the effect of non-free-end partial edentulism in this study, the result showed that digital impressions of RM2 presented improved trueness and precision with regard to all the assessed distance deviations and angular deviations, but without any significant difference, probably due to the limited sample size.

In this study, the result indicated that the remaining natural teeth distal to the edentulous area might play a role as a landmark for stitching and therefore promote trueness.\textsuperscript{37,44,45} Trios IOS applies confocal microscopy technology to obtain a multitude of images and stitches the newly captured images to previous ones by the best-fit algorithm to acquire the best overlapping of images and create a consecutive 3D model.\textsuperscript{13,26,43} The lack of landmarks in the long-distance edentulous area may lead to difficulties in the stitching process because of the limited area covered by the IOS camera in one single image.\textsuperscript{37} Nevertheless, with teeth distal to the edentulous area, IOS may recognize it as a landmark and stitch better. Other approaches to create landmarks for the stitching process were also studied recently, such as splinting the scan bodies, placing artificial markers on the gingiva, and wearing an auxiliary geometric device during intraoral scanning.\textsuperscript{43,45}

It was assumed earlier that the extra scan bodies in a certain distance might also serve as landmarks in the stitching process. However, for the effect of the number of scan bodies in a certain scanning length, no significant difference of trueness or precision was observed between the digital implant impressions of RM1 and RM4 in this study. The stability of the artificial mucosa and model surface in this in vitro study probably contributed to the result. Normally, the large interimplant distance may cause misalignment and wrong stitching in digital impressions in the oral cavity, due to the mobility of mucosa and lack of mucosal landmarks.\textsuperscript{37} However, in the present study, in vitro models with a stable surface and enough simulative oral vestibular height were used; therefore, the effect of scan bodies to serve as landmarks was weakened.

The distance deviations of the longest reference distance ($\Delta d_{13}$) in this study ranged from 46.12 to 75.95 $\mu$m, and the angular deviations ($\Delta d_{13}$) ranged from 0.41 to 0.61 degrees. These results were consistent with the results of previous studies that reported mean deviations of 71.2 $\mu$m$^5$ and 50.2 $\mu$m$^4$ for the digital implant impressions in partially edentulous models using Trios IOS. Andriessen et al suggested 100 $\mu$m and 0.4 degrees to be the maximum acceptable misfit of implant-supported restorations.\textsuperscript{37} Therefore, based on the result of this in vitro study, the overall distance deviations of digital implant impressions in partially edentulous arches were within clinically acceptable limits, while the angular deviations between scan bodies were too large for clinical application. Meanwhile, one RM2 scan and 4 out of 10 RM4 scans had distance deviations greater than 100 $\mu$m, indicating that the digital implant impressions of four-unit implant-supported restorations were sometimes not accurate enough under certain conditions, especially with large edentulous space of mucosa between implants.

However, it should be noted that this study did not contain the error of cast fabrication and was conducted in vitro. Digital impressions in a real oral cavity may involve double errors compared with the ones with in vitro models.\textsuperscript{47} Influencing factors such as mucosa mobility, saliva, oral humidity, tongue movements, and position of the scan body in the arch are not included in bench studies.\textsuperscript{31,39,40} In addition, this study used a laboratory desktop scanner with 10 $\mu$m accuracy to complete the reference scans, while a coordinate measurement machine with 1 to 3 $\mu$m accuracy would be a better choice. Another limitation of this study was that it did not compare the accuracy of conventional implant impressions with digital ones.

For future research, the aforementioned influencing factors should be further verified in clinical studies. Other possible influencing factors for the accuracy of digital implant impressions should be studied not only in partially edentulous arches, but also in fully edentulous arches, such as the locations of implants in the arch, maximal mouth opening, implant depth, width of attached gingiva, neighboring structures, undercut
area, etc. Other scanners applying different technologies should also be studied to see if any difference could be made.

CONCLUSIONS

This in vitro study investigated the influencing factors of the accuracy of digital implant impressions of multiple implants in partially edentulous arches by evaluating the distance and angle deviations between scan bodies. The following conclusions can be made:

- Digital implant impressions of angulated implants showed better accuracy than those of parallel implants.
- Digital implant impressions of non-free-end partial edentulism tended to show improved accuracy compared with those of distal free-end edentulism with all measured variables, but the difference was not significant.
- For partially edentulous arches, the increasing number of scan bodies in a certain distance showed no effect on the accuracy of digital implant impressions in vitro.

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