

Do Type and Shape of Scan Bodies Affect Accuracy and Time of Digital Implant Impressions?

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ABSTRACT

Objectives: Reports concerning the accuracy of intraoral digital impression systems are limited. This study aimed to assess the effects of scan body types and shapes on digital impression accuracy and scanning time in all-on-four restorations. *Methods:* This in vitro study was conducted with two acrylic maxillary models. Two implant systems with different connection types (internal trilobe and external hexagon connection) were inserted according to the all-on-four design. Scanning was performed using Doowon, NT-Trading, and DESS scan bodies. Changes in implants' positions (ΔR) and angulation (ΔA), and the implants' distance from the reference pin (ΔD) compared with the actual model were determined. Scanning times were also measured and compared. *Results:* The effects of implant connections and scan bodies on ΔR and ΔA were significant ($p < 0.05$). Implant angulation could also affect ΔA ($p = 0.019$). ΔD was only affected by scan body ($p < 0.001$). The three scan bodies were significantly different in terms of scanning time ($p = 0.001$). *Conclusion:* The results showed that scan body type and shape, and implant connection and angulation could affect digital impression accuracy in all-on-four restorations. For both internal and external connections, the NT-Trading and DESS scan bodies had the shortest and longest scanning times, respectively.

INTRODUCTION

Impression making is an important step in implant dentistry and is a crucial factor ensuring survival and long-term clinical service of implant restorations.^{1,2} An absolute passive fit of restoration is not always achievable due to procedural errors.³ In the implant-supported restorations, discrepancies are highly destructive due to the rigidity of osseointegrated implants. This may cause adverse mechanical and/or biological complications.⁴ Impression accuracy is a fundamental factor in achieving an optimal fit.⁵ Accuracy refers to precision and trueness.⁶ According to the International Organization for Standardization (ISO) 5725-1, precision refers to similar results from repeated measurements obtained using the same method.⁷ Trueness refers to the similarity of measurement results compared to the actual size of measured object.⁸ Thus, a precise impression for transferring not only the position, but also the implant's direction, to the dental casts is the first step in fabrication of implant-supported restorations.

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Computer aided design-computer aided manufacturing (CAD/CAM) systems were introduced in order to minimize human and technical errors of conventional impressions. The CAD/CAM systems require extra- or intra-oral scanning.⁹ A highly accurate scan leads to restoration longevity.¹⁰ Intraoral scanners are the most recent technology in impression making, resulting in fabrication of virtual and three-dimensional (3D) casts.^{9,11,12} These virtual models can be immediately and easily transferred to the laboratory and used for designing and manufacturing restorations.^{13,14} Intraoral digital impressions have advantages over extraoral impressions. These advantages include a high rate of acceptance by patients, no patient contact with messy impression materials, decreased distortion caused by impression materials, suitability for use in patients with high gag reflexes, possibility of resting during the process, no need to redo the entire impression in case of defective parts within it, enabling 3D observation of tooth preparation, low costs, and faster processing.^{14,15} Intraoral scanners are small and easier to use compared to other conventional methods of impression making.^{16,17} And as the different intraoral scanner systems seem to have an outcome of similar accuracy range, there is no preference for a particular system to be chosen.¹⁸ Regardless of type of scanner (extraoral or intraoral), digital impression making requires the transfer of posts referred to as scan bodies, which are placed on the implants or implant analogs. They are used to transfer the position and direction of implants.⁹ Scan bodies are complex impression posts with notable variability in the features and design.¹⁹ They may be spherical or cylindrical and have different designs in their intermediate region. Their dimensions vary depending on the dimensions and selected implant system. Their height varies from 3 to 17 mm. These characteristics, similar to the conventional impression making, can affect digital impression precision and accuracy and change the scanning time depending on their surface complexities, materials, and size.²⁰ Thus, selection of a suitable scan body with high accuracy and precision and appropriate scanning time is a challenge in digital dentistry. Since in digital impression, impression posts would not be picked up, the matter of connection type seems unimportant. However, proper placement of scan bodies' like any other components could be possibly affected by geometry (the number of corners) and depth of connection. Although there are insufficient studies for the effect of implant connection type in digital dentistry,²¹ the results of the systematic review conducted by Moreira *et al.*²² showed that a deeply tapered connection may cause displacement of the scan body when tightened into implant. Moreover, It should be noted that implant level digital impressions for internal and external connections could be different only because of the depth of implant placement. Depth of connection can cause the subgingival location of the scan body, leaving less surface to be scanned in implant-level digital impression making of deep internal connections. However, nowadays by choosing the proper gingival height of the scan body, this problem would be avoided. The effect of connection type and

different scan bodies' geometries and heights on achieving an accurate and fast scan has not yet been quite evaluated This study aimed to assess the effect of three different scan body types and shapes on digital impression accuracy and scanning time in two implant systems with different connections.

MATERIALS AND METHODS

This *in vitro* experimental study was conducted on two edentulous maxillary acrylic resin models with four implants using the all-on-four treatment concept. Two different implant connections (internal trilobe or external hexagon) were used, each in one model. The sample size was calculated to be 5 in each group assuming standard deviation of 1.5, $\alpha=0.05$, and $\beta=0.2$, according to a study by Fluegge *et al.*²³ In order to increase the accuracy and reliability of the results, 10 specimens were considered in each group.

In each resin model, the two anterior implants were placed in a straight position with no angulation and parallel to each other (their longitudinal axis was perpendicular to the plane of resin model) at the site of the canine teeth. The two posterior implants were placed at the site of second premolars with 45° distal angulation. The NobelReplace Implant System was used for one acrylic resin model with regular diameter (4.3 mm), 11 mm height, and internal trilobe connection. The Branemark Nobel Biocare implant system with regular diameter (4.1 mm), 12 mm height, and external hexagon connection was used for the second acrylic resin model. A metal reference cylinder was inserted in the midline of each model's palate as a measurement reference and was defined as the reference pin. Implants were numbered from 1 to 4 starting from posterior right moving toward posterior left (implants number 1 and 4 were angulated, and 2 and 3 had straight position). After one week, digital scanning of each group was done. The TRIOS Cart scanner using classic speed mode with a color detector was used for scanning the digital impressions. Three different scan bodies, namely DESS, NT-Trading, and Doowon, which were compatible with the selected implant systems, were used. DESS 14.005, NT-Trading E9.S3D4.300, and Doowon B051 (*Figure 1*) were used for the NobelReplace, and DESS 14.002, NT-Trading 9.S3D4.100, and Doowon B018-04 (*Figure 2*) were used for the Branemark Nobel Biocare system. Scan bodies were secured according to the manufacturers' instructions. All scans were done by an experienced operator.

Scanning duration was measured from the time of scan bodies placement and initiation of scanning to termination of scanning the model. Scanning duration was reported in seconds. In order to reduce bias and variability, two examiners measured time for each scan by using a chronometer. The mean measured time was then reported as scanning duration. Each model was scanned 10 times. Totally, 30 scans were obtained for each model with the selected implant system and its corresponding scan bodies. The standard scanning protocol according to manufacture' instruction was inadequate



Figure 1: Scan bodies used for the NobelReplace system. a) DESS, b) NT-Trading, c) Doowon



Figure 2: Scan bodies used for the Branemark Nobel Biocare system. a) DESS, b) NT-Trading, c) Doowon

and only relevant to dentate arches. Therefore, in this study, scanning was started from the reference pin in the model's palate and progressed toward the right tuberosity and lingual surfaces of all scan bodies. Next, the buccal surfaces and then the occlusal surfaces of scan bodies were scanned. Care was taken to accurately record the connection area and smooth surface at the intermediate region of each of the scan bodies. If corrections were required, the chronometer was paused, the correction was made, and the process then continued. The actual distance among implants and their spatial coordinates were measured with an optical coordinate measuring machine (ATOS Core 80). This device and its respective software were used for parametric analysis of the values. The output data in Standard Tessellation Language (STL) format were transferred to GOM Inspect software for actual measurement of distances between implants and their actual spatial coordinates (Figure 3a). An Atos Core 80 reference scanner was used to scan the models, and the data from this scanner were also transferred to GOM Inspect software in STL format. The actual distance between implants in each model was used as the control (reference) value for the purpose of comparisons. Intraoral scanning data were transferred to Dental System (3shape CAD) software and converted from 30XZ format to STL format. The distance between implants, angulation, and implants' spatial coordinates were then transferred to GOM Inspect for measurement and comparison with the actual values. Measurements were done by one experienced operator directly on the STL obtained with intraoral scanners.

For the measurements, the best fitted plane to the occlusal surface of each scan body in each reference model was first defined in the software, and a cylinder with the best fit to the external surface of each scan body was then designed. The

central axis of each cylinder was determined, and its intersection with the occlusal plane was marked (Figure 3b). The same definitions for plane, cylinder, axis of each cylinder, and each cylinder's axis intersection with the occlusal plane were also used in scanned model by Trios 3Shape and also for the reference pin in the palate. The best fit was then used for superimposition of scans obtained from Trios 3Shape onto the corresponding images obtained from Atos Core (Figure 3c).

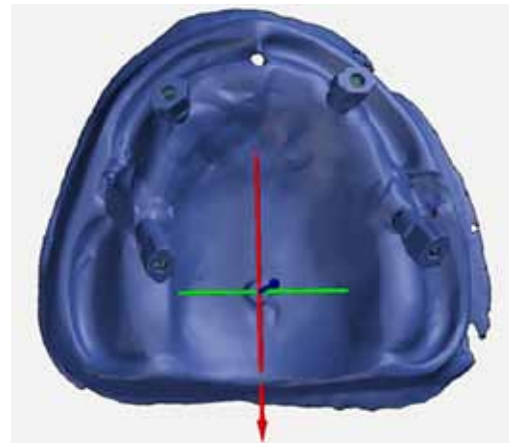


Figure 3a: Scanning of reference model with NT-Trading scan body by reference scanner. Red and green lines are the set-up of coordinate axes system

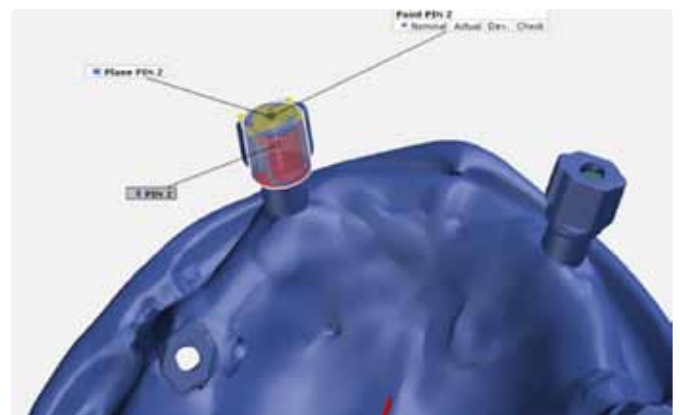


Figure 3b: Plane and cylinder defined for each scan body in GOM Inspect software

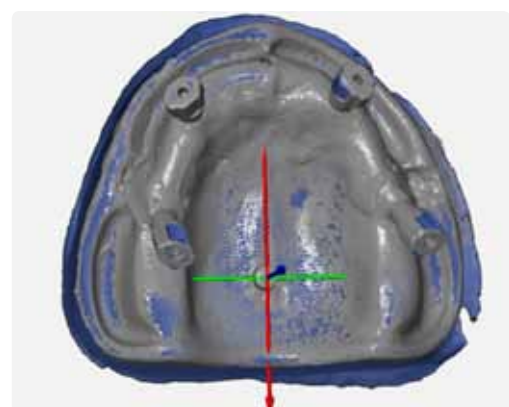


Figure 3c: Trios 3Shape scan (gray areas) superimposed on Atos Core image (blue) (best fit).

The respective measurements were made on each scan, and the differences between scanned and actual values (Δ) were calculated. In order to determine the change in implant position, the intersection of the cylinder's central axis with the occlusal plane on the surface of a scan body was used, and the difference between its value and the actual value was calculated in millimeters by the software and recorded as ΔR . In order to determine the change in each scan body's angular position, the change in angle of each scan body's cylinder axis with its corresponding axis on the reference model was calculated in degrees. The distance between the intersection of each implant cylinder's central axis and the same point of each model's reference pin of was measured, and the difference between its value and actual value was calculated as ΔD . Inter-implant distance was also measured by measuring the distance between implants 1 and 2, 1 and 3, 1 and 4, 2 and 3, 2 and 4, and 3 and 4, and the differences from these aspects with the actual values were reported in millimeters. All measurements were made automatically by the software.

Data were analyzed using SPSS version 23. Normality distribution was checked by using Kolmogorov-Smirnov test. So parametric tests were used for analysis. The mean and standard deviation values for dependent variables, including ΔR , ΔA , ΔD , time, and Δ inter-implant distance (Δ interD) were reported. Considering the presence of three independent variables (scan body, implant connection, and implant angulation), a three-way analysis of variance (ANOVA) was applied. Since the interaction effects of some independent variables were found to be significant, a pairwise comparison of dependent

and independent variables was performed. An independent t-test was used to compare the two implant connections and implant angulations. A one-way ANOVA was used to compare the scan bodies with either Tukey's or Games-Howell *post hoc* test depending on the variances' homogeneities. The level of significance was set at 0.05. All the methodology was reviewed by an independent statistician.

RESULTS

The highest ΔR s, which were 0.20 ± 0.17 and 0.22 ± 0.15 mm for straight and angulated implants, respectively, were noted in the external hexagon with the DESS scan body. The lowest ΔR s, which were 0.05 ± 0.03 and 0.07 ± 0.03 mm for straight and angulated implants, respectively, were noted in the internal connection with the Doowon scan body. The highest ΔA s were noted in the internal connection with DESS scan body for straight and angulated implants (0.47 ± 0.30 and $0.43 \pm 0.25^\circ$, respectively). The lowest ΔA s, which were $0.28 \pm 0.17^\circ$ and $0.13 \pm 0.10^\circ$ for straight and angulated implants, respectively, were noted in the external connection with the Doowon scan body. The greatest ΔD was noted in the external connection with the DESS scan body for angulated implants in the amount of 0.11 ± 0.09 mm and internal connection with DESS scan body for straight implants in the amount of 0.17 ± 0.13 mm. The lowest changes were noted for straight implants in the internal connection (0.02 ± 0.02 mm) and angulated implants in the external connection (0.02 ± 0.02 mm), both with the Doowon scan bodies (Table 1). The highest changes in Δ interD were

Table 1. Mean±Standard Deviations of ΔR , ΔA and ΔD in all groups.

Implant Connection	Scan Body	Implant Angle	ΔR^1	ΔA^2	ΔD^3
External	DESS	Straight	0.2 ± 0.17	0.32 ± 0.26	0.08 ± 0.07
		Angled	0.22 ± 0.15	0.26 ± 0.19	0.11 ± 0.09
	NT-Trading	Straight	0.09 ± 0.13	0.36 ± 0.18	0.03 ± 0.03
		Angled	0.08 ± 0.04	0.27 ± 0.16	0.05 ± 0.04
	Doowon	Straight	0.07 ± 0.03	0.28 ± 0.17	0.03 ± 0.03
		Angled	0.08 ± 0.03	0.13 ± 0.1	0.02 ± 0.02
Internal	DESS	Straight	0.17 ± 0.07	0.47 ± 0.3	0.13 ± 0.17
		Angled	0.13 ± 0.08	0.43 ± 0.25	0.09 ± 0.12
	NT-Trading	Straight	0.06 ± 0.02	0.35 ± 0.19	0.04 ± 0.04
		Angled	0.07 ± 0.03	0.25 ± 0.16	0.04 ± 0.04
	Doowon	Straight	0.05 ± 0.03	0.52 ± 0.21	0.02 ± 0.02
		Angled	0.07 ± 0.03	0.56 ± 0.2	0.04 ± 0.03

¹changes in implants' positions. ²changes in implants' angulation ³The implants' distance from the reference pin

noted in distance between implants 1 and 3 in the external connection with the DESS scan body (0.25 ± 0.13 mm) while the least change was noted in distance between implants 3 and 4 in the internal connection with the NT-Trading scan body (0.02 ± 0.01 mm) (Figure 4). The shortest scanning times for both the internal and external connections were noted in NT-Trading scan body (645 ± 134 and 648 ± 125 sec, respectively). The longest scanning times in both implant connections were noted in the DESS scan body (1439 ± 158 and 1505 ± 101 sec, respectively) (Figure 5).

Three-way ANOVA showed that implant connection and scan body type could affect ΔR ($p=0.007$ and $p < 0.001$, respectively) although interactions were not significant. Post-hoc tests revealed that DESS had more ΔR compared to the other groups ($p < 0.001$) with respect to both internal and external connections. Comparing internal and external connections with t-test analysis showed significant difference only with DESS scan body ($p=0.046$).

The three-way ANOVA for variable ΔA showed that the implant connection ($p < 0.001$) and angulation ($p=0.019$) had significant effects on ΔA . One-way and *post hoc* tests showed that in external angled implants, DESS produced more ΔA compared to other scan bodies. However, in internal angled implants, the NT-Trading scan body produced less ΔA compared to other scan bodies (DESS p value= 0.021 ; Doooon p value < 0.001). When comparing the effects of implant connections, it was revealed that using the Doooon scan body could produce differences in ΔA between internal and external connections in both angled and straight implants ($p < 0.001$). However, DESS produced differences only in angled implants ($p=0.039$).

The three-way ANOVA showed that the only parameter that could have an effect on ΔD was the type of scan body. Among three scan bodies evaluated, DESS was less accurate compared to the others ($p < 0.001$). For evaluating distance among implants, the mean value of Δ_{interD} was calculated. A two-way

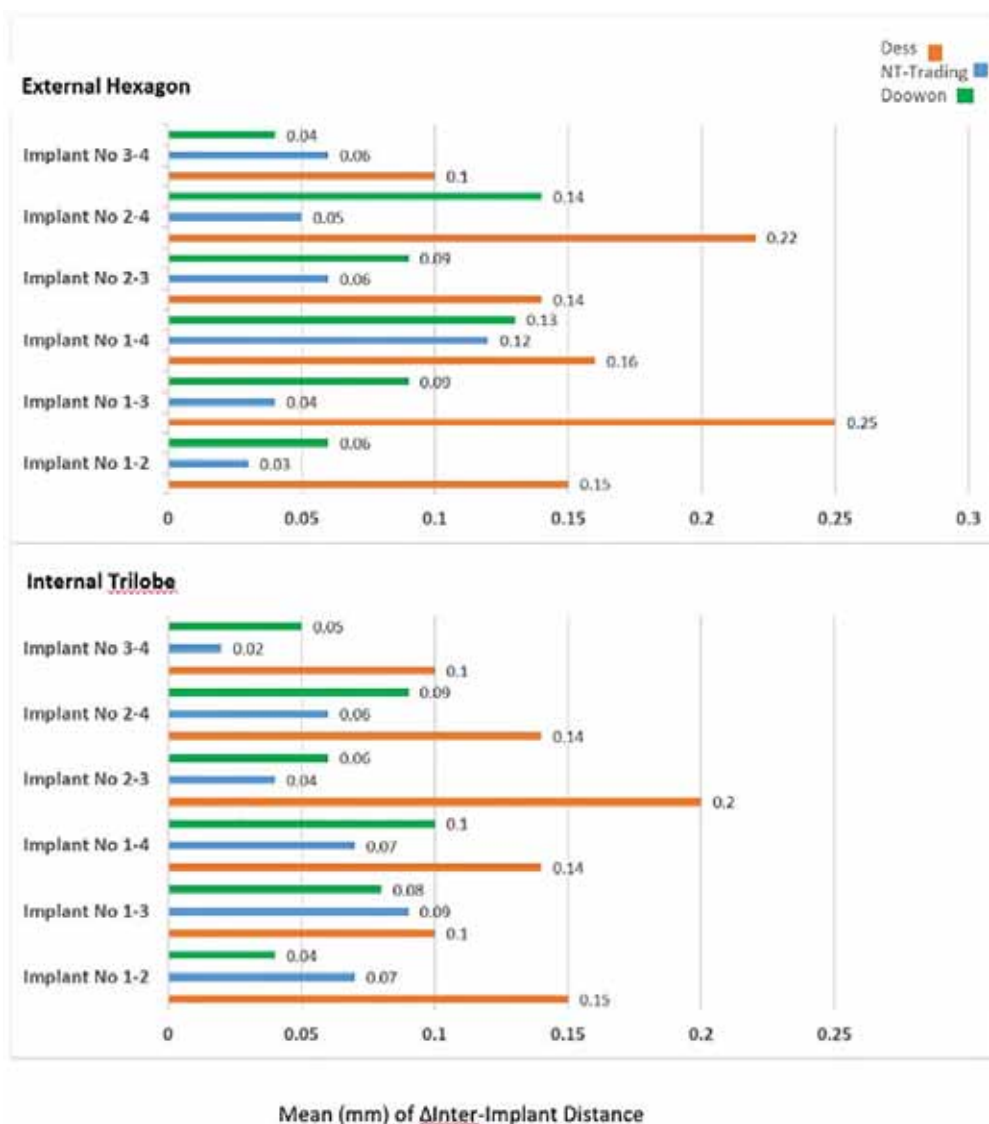


Figure 4: Change in Δ_{interD} in each group of scan body and implant connection.

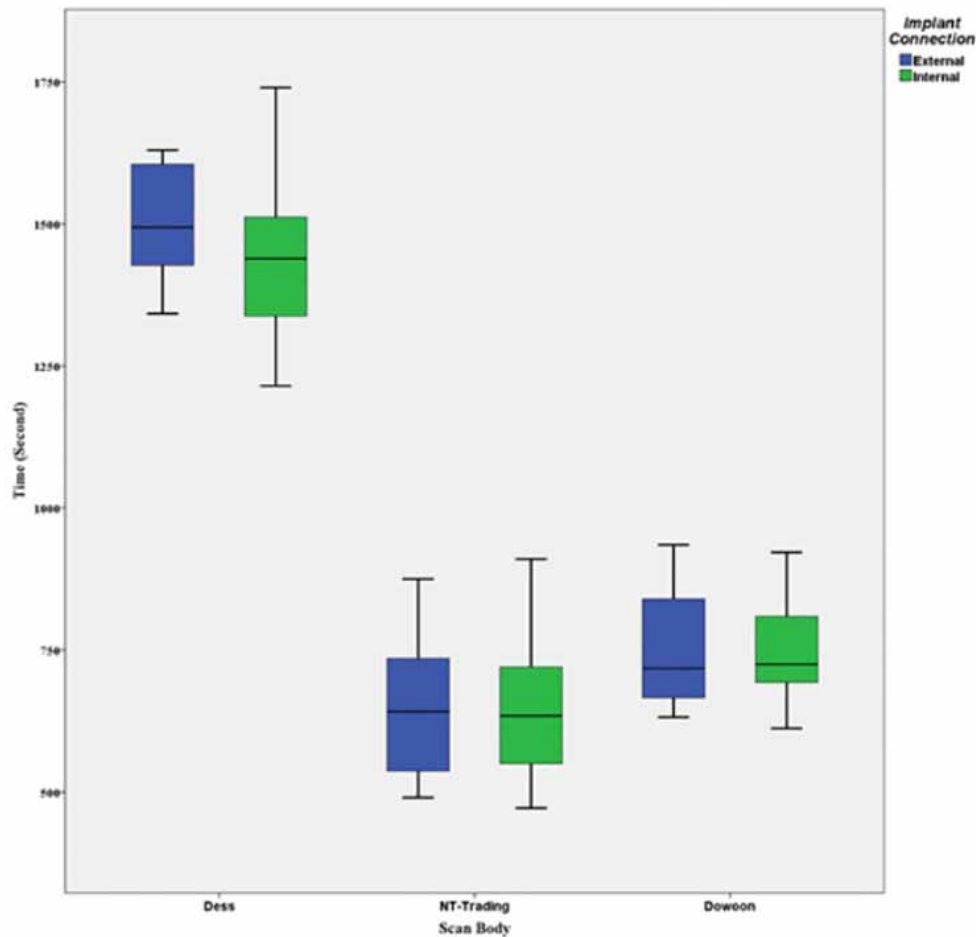


Figure 5: Scanning time in each group of scan body and implant connection.

ANOVA was then used to evaluate the effects of implant connection and type of scan body. It shows that type of scan body could significantly influence the mean Δ interD ($p < 0.001$). For the same Δ D, it was shown that DESS had less accuracy compared to the others ($p < 0.001$).

A two-way ANOVA showed that the scan body type had a significant effect on the scanning time ($P < 0.001$). However, the effects of the implant connection and the interaction of implant system and scan body type on scanning time were not significant ($P > 0.05$). Tukey's test for pairwise comparison showed significant differences in scanning time between DESS and Doowon ($P < 0.001$), DESS and NT-Trading ($P < 0.001$), and Doowon and NT-Trading ($P = 0.03$) with the fastest scanning for NT-Trading followed by Doowon, with the least for the DESS scan body.

DISCUSSION

Use of digital scanning is growing fast in many fields of dentistry.¹¹ Precise registration and accurate transfer of intraoral position of teeth and implants are imperative for fabrication of well-fitting restorations. This study assessed the effects of scan body types on the accuracy and duration of digital scanning of two implant connection designs.

Evidence shows higher precision of direct digital impressions compared to conventional and indirect digital impressions.²⁴ Indirect digital impressions are no longer recommended due to errors caused by elastomeric impression materials added to the errors of digital scanning.²⁵ Digital scanning of smooth surfaces with severe curvatures is more erroneous due to superficial angulations and high reflection of light from the object surface.^{2,26} Three-dimensional analysis of objects with superficial complexities is difficult.²⁵ Superimposition of the resulting and reference data using the best fit algorithm is the most efficient method for assessment of precision.²⁴ In the current study, we used an optical reference scanner with a precision of $< 5 \mu$ in order to provide 3D reference data. Also, the same superimposition algorithm was used to compare the obtained test and reference data by the software; this minimized errors related to improper superimposition and subsequent incorrect analysis of data.

In general, this study showed greater changes in use of external connection design and DESS scan body. Similarly, Kempler showed that systems with external connections have higher error rates, especially in the horizontal plane.²⁷ To the best of the authors' knowledge, no previous study has assessed the effects of scan body geometries and types on the accuracy of digital impressions. Gimenez *et al.*^{28,29} compared the accuracy of the Lava (3M ESPE) and iTero (Cadent Inc.) digital

impression systems for edentulous maxillary models with six implants and reported Δ interD within a range of 28.12 ± 11.02 to $45.02 \pm 37.11 \mu$ and 25.60 ± 14.30 to $216.10 \pm 32.37 \mu$ for Lava and iTero, respectively. This range was 20 ± 10 to $250 \pm 130 \mu$ in our study. Higher values in our study may be attributed to the use of a different scanner in addition to a fewer number of implants since according to Giminez *et al.*²⁹, higher Δ interD (which is the case with the use of fewer numbers of implants) increases the rate of errors. Our results regarding the changes in Δ interD were comparable to those of Giminez *et al.*³⁰ using scanners based on confocal microscopy. The two studies were different in terms of accuracy assessment methods (use of optical coordinate measuring machine and best fit model in the current study and use of mechanical coordinate measuring machine and zero model in their study), number of implants, type of scanner system (despite the same technology), and model characteristics (models used in their study had an opaque surface, which enabled easier and faster scanning). However, the mean angular changes (ranging from 0.13 ± 0.10 to $0.47 \pm 0.30^\circ$) was in agreement with the values reported by Ajioka *et al.*³¹ using the Lava scanner and Eliason and Örtorp³² using the Robocast.

Mangano *et al.*³³ compared the trueness and precision of four scanners and reported the trueness of Trios to be 72.1μ ; this value was 220 ± 150 to $50 \pm 30 \mu$ in our study. Higher values in the current study were obtained using DESS, and the values in the other scan body groups were similar to those reported by Mangano *et al.*³³ It seems that the DESS scan body has lower accuracy than the other two scan bodies due to its greater height and unique geometry; this result was in contrast to that of Fluegge *et al.*²³ who reported lower precision for shorter scan bodies. Since the scan bodies were cylindrical and had no specific surface geometry in their study, it appeared that in addition to dimensions, the shape of the scan bodies also affected digital impression accuracy. Further studies are required on this topic using different implant systems and scanners. Fluegge *et al.*²³ assessed the accuracy of digital impressions by 3Shape scanner using Camlog and Strumann implants and reported more favorable values in terms of Δ interD and mean angular changes compared to this study. This difference may be due to the fact that they used gypsum partially edentulous models with only two posterior implants. Gypsum models have an opaque surface, which enhances scanning. Also, the presence of teeth in the model facilitate superimposition of scans due to the presence of many reference points compared to the use of edentulous ridge (as in present study).

This study also compared the accuracy of digital impressions of straight and angulated implants and found no significant differences except for two groups. This finding was similar to the finding reported by Al-Abdullah *et al.*³⁴ who showed that implant angulation had no significant effect on the accuracy of impressions although they used encoded healing abutment and adopted a different method for accuracy assessment.

Giminez *et al.* also found no significant difference in accuracy of digital impressions of straight and angulated implants.²⁸⁻³⁰ However, the results of this study showed significantly lower angular deviation for angulated implants of the external connection and Doowon scan body and also for straight implants of internal design and Doowon scan body. Lin *et al.*³⁵ reported higher digital impression accuracies for the 30 and 45° angulated implants, which was in agreement with these findings in external design and Doowon scan body but in contrast to the result of internal system and Doowon scan body. This difference may be attributed to the different implant systems used with different connection types and scan bodies with different geometries and material. Since no previous studies were found on this topic, further studies are required to compare the accuracy of digital impressions of implants with different angulations in use of different scan bodies.

The different connection geometry between and within commercial implant systems may also affect impression accuracy.³⁶ The results of this study showed less impression accuracy for internal-connection implants with angulation. Vigolo *et al.*³⁷ reported a higher level of stress between the impression material and the impression copings when removing the impression from internal connection implants than when removing it from external hexagon implants. This stress may hypothetically cause permanent deformation of impression material or movement of the impression copings inside the impression material. Distortion of an impression manifests itself as a change in the position, orientation, or relative inclination of the implant analogues in the stone model. The same results were shown by other studies.^{36,38} Due to lack of impression material in digital impression it seems the other reasons may be responsible for impression inaccuracy of angulated implants with internal connections. Further research is needed to address this issue.

In the study by Lee and Gallucci,¹⁶ 30 dental students used the iTero scanner to scan a jaw model with one Strumann implant at the first molar site with a Strumann scan body and reported a mean scanning time of $8:54 \pm 3:12$ (min:sec). The time required for corrections was $1:40 \pm 1:05$ (min:sec). In a study by Joda *et al.*, 100 operators (including dental students and dentists) scanned a maxillary model with one Strumann implant at the right canine site using Trios 3Shape digital scanner and reported the mean scanning time of $5:01 \pm 1:56$ (min:sec) for dental students and $4:53 \pm 1:34$ (min:sec) for dentists.³⁹ The mean scanning time was $10:45 \pm 2:14$ to $25:05 \pm 1:41$ (min:sec) in our study. Such a difference in the scanning time reported in studies may be attributed to number of implants and their distribution in the dental arch.

The best fit superimposition model, which is among the most commonly used models for assessment of accuracy, was used in the present study.⁴⁰ Other techniques used for this purpose include the least squares and zero models.⁴¹ The results of accuracy assessments may vary depending on the type of reference scanner used. In this study, Atos Core 80

which was calibrated for a precision $<5\mu$, was used. The reference scanner was also suggested by Jemt and Hjalmarsson as an efficient method for assessment of accuracy of implant-supported frameworks.³⁴ Future studies are required to compare the effects of other scan bodies on the accuracy of digital impressions using other types of scanners.

A possible limitation of the present study design was absence of clinical conditions, such as saliva, undercuts, and interference of the scanner tip with buccal tissue and tongue. It could be anticipated that clinical conditions result in a decrease in accuracy and increase in time of digital implant impressions. However, models used in this study had shiny surfaces. Hence, in comparison to the models with opaque surfaces, they may reflect light more similar to clinical conditions.

Additionally, it should be noted that the results of the current study are restricted to four implants in a fully edentulous jaw using the described implants, scan bodies, and scanner and may not be relevant for impressions with more or fewer implants with different inter-implant distances and other implant systems, scan bodies, and scanners.

When we scan an edentulous arch, the other limitation we face is the limited number of reference points between the scan bodies.⁴² Thus, the images might not be stitched together appropriately.³⁰

As a consequence, it can be expected that the longer the scanning field, the larger the errors.⁴³ Techniques have been introduced to overcome this challenge by increasing the number of reference data points. They modify the surface of the edentulous ridge by using artificial landmarks⁴⁴ or materials, such as pressure-indicating pastes and interim zinc oxide-eugenol cement.⁴⁵

For complete-arch scans in dentate and partially dentate patients, a scanning path of occlusal-palatal (always including two surfaces) and then buccal side is the recommended strategy by the manufacturer, which has been also confirmed in Muller *et al.*'s study.⁴⁶ However, no guidelines are currently available for a completely edentulous patient.⁴⁶ In this study, we utilized the palatal, buccal, and occlusal paths, which seems to have the advantage of scanning each surface individually. However, different results might be obtained using different scan paths.

For distance measurements, it would be better to choose several points and determine the real center of the scan body. However it seems difficult. So in order to almost eliminate the angulation error, the central point on the top of the scan body was chosen as Fluegge *et al* study.²³

The other limitation of this study is that measurements were done directly on the STL obtained with intraoral scanners. However a CAD file of the scan body from a digital implant library could be used to limit the amount of noise. This library input preset parameters like scan body dimensions and aspects already into the software.⁴⁷

In this study each scan body was scanned 10 times without detachment and repositioning. It is investigated that three-dimensional changes occur in abutment position after manual assembly and reassembly, and this variation depends on the geometry of the implant-abutment complexes.⁴⁸ Even so, Fluegge *et al.*²³ stated that the precision of scan body scanning was not significantly affected by detachment and repositioning of the scan body.

Finally, the present study simply attempted to assess the accuracy of digital impressions and did not check its effect on downstream processes, such as the adaptation of the definitive restoration.

Further studies are recommended for evaluating the various scan body shapes and connection types in terms of accuracy of digital implant impressions. In addition, a comparison of digital impression accuracy with different implant angulations and diverse implant connections, and more or fewer implants with different inter-implant distances are suggested. Moreover, evaluating whether or not surface modification of edentulous ridge significantly affect the accuracy of digital impressions, determining a standard scanning protocol for a fully edentulous arch including scan bodies, and checking the passive fitness of final prosthesis made in the completely digital workflow will require further studies.

CONCLUSION

Within the limitations of this study, the results showed that scan body geometry, implant connection, and implant angulation could affect the accuracy of digital impressions in all-on-four restorations. The NT-Trading scan body had the shortest and DESS had the longest scanning times for both implant connections.

MANUFACTURERS' DETAILS:

- NobelReplace Implant System (Nobel Biocare AB, Göteborg, Sweden).
- Branemark Nobel Biocare implant system (Brånemark System® Mk III, Nobel Biocare AB, Göteborg, Sweden).
- TRIOS Cart scanner v. 1.4.7.5 (Trios® 3 Cart wired, 3shape, Copenhagen, Denmark).
- DESS (DESS Abutment Co., Barcelona, Spain).
- NT-Trading (NT-Trading GmbH & Co. Karlsruhe- Germany).
- Doowon (Doowon International Dental, Daejeon, South Korea).
- Optical coordinate measuring machine (ATOS Core 80, GOM GmbH, Germany).
- GOM Inspect software (GOM GmbH, Germany).
- SPSS version 23 (SPSS Inc., IL, USA).

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