https://doi.org/10.4047/jap.2021.13.2.107

Effects of inter-implant distance on the accuracy of intraoral scanner: An *in vitro* study

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PURPOSE. Several studies focused on the accuracy of intra-oral scanners in implant dentistry, but the data of inter-implant distances were not widely mentioned. Therefore, this study aimed to evaluate the effect of distance between two implants on the surface distortion of scanned models generated by intra-oral scanners. **MATERIALS AND METHODS.** Three models with the distances between two fixed scan bodies of 7, 14, and 21 mm were fabricated and scanned with a highly precise D900L dental laboratory scanner as reference models. Fifteen scans were performed with TRIOS3 and CEREC Omnicam intra-oral scanners. Trueness, precision, and angle deviation of the test models were analyzed (α=.05). **RESULTS.** There was a significant difference among inter-implant distances in both intraoral scanners (P<.001). The error of trueness and precision increased with the increasing inter-implant length, while the angle deviation did not show the same trend. A significant difference in the angle deviation was found among the inter-implant distance. The greatest angle deviation was reported in the 14-mm group of both scanners (P<.05). In contrast, the lowest angle deviation in the 21-mm group of the TR scanner and the 7-mm of the CR scanner was reported (P<.001). **CONCLUSION.** The inter-implant distance affected the accuracy of intra-oral scanner. The error of trueness and precision increased along with the increasing distance between two implants. However, the distortions were not clinically significant. Regarding angle deviation, the clinically significant angle deviation may be possible when using intra-oral scanners in the partially edentulous arch. [J Adv Prosthodont 2021;13:107-16]

KEYWORDS
Inter-implant distance; Intraoral scanner; Trueness; Precision; Angle deviation

INTRODUCTION

The goal of dental implant treatment is to rehabilitate patients' chewing function and esthetics. Thus, data collection needs to be accurate to avoid technical complications, which may occur due to prosthetic misfit. In addi-

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Received January 25, 2021 /
Last Revision March 5, 2021 /
Accepted April 5, 2021

https://doi.org/10.4047/jap.2021.13.2.107

tion, occlusion, crown height space, and prosthetic design should be well planned to prevent post-operative complications and reach treatment success.[1] Furthermore, the passive fit of prostheses is mandatory to avoid active stress to the implants. The constant active force can lead to biomechanical problems to the implant system. It results in the fatigue of implant components and bone. Eventually, it will lead to prosthetic and biological failures (for instance, decementation of restorations, crestal bone loss, implant component fracture, or peri-implantitis).[2] According to biomechanical reasons,[3] the acceptable maximal movement of an osseointegrated implant is 50 μm. Therefore, the maximal misfit of implant-supported substructure can be implied by summation of lateral movement limit of two implants. In another word, the maximum of 100 μm of error is estimated for two implants to stay in physiologic range.[4] Andriessen *et al*. also reported that the angle deviation was limited to 0.194 degrees for an implant length of 14.8 mm.[4] It is because 0.194 degrees can create 50 μm distance at the apical portion of the implants. Therefore, less than 0.4 degrees of implant angular error is recommended for physiologic bone strain. However, some studies reported that the misfit can be found in a range between 22 to 100 μm.[5] So, the number of 100 μm or less is not a clarified number for passive fit.

Providing the passive fit of the implant-supported prosthesis in digital workflow, digital data collection accuracy is necessary. Intraoral scanners are the data collecting devices in digital dentistry. It is equivalent to traditional intraoral impression using materials to mirror oral structure. The digital and conventional implant impressions were widely investigated.[6-17] Although some studies reported inferior results of digital impression,[6,7,12] several studies showed the greater accuracy and patient comfort of the digital impression than the conventional impression.[8-11,13,14,16] Therefore, to provide the optimal fit for implant prostheses, every related factor should be considered.

Several factors affect the accuracy of intraorally scanned models. These factors include illuminance and color temperature of ambient light, regional moisture, presence of saliva or blood, amount of keratinized gingiva, tooth preparation design and margin, the number of teeth in a scan, size of the edentulous area, patient movement, scanner systems, and operator's experience.[4,17-22] It was reported that the accuracy of the scanning for a single tooth or short-span restoration was comparable to the conventional impression technique using polyvinyl siloxane. On the other hand, for longer-span or full-arch impression, digital scanning revealed inferior accuracy.[4,17,21,23-28] However, the studies were mostly performed *in vitro*. The clinical significance was still inconclusive.

Span length of restorations is one factor that influences the accuracy of intraoral scanners.[17,18] In digital implant impression, the studies reported that the larger the span of the implant-supported prosthesis was, the greater inaccuracy of intraorally scanned data was observed.[4,21,25-28] Although most of the studies had the experiment, few studies reported the length of inter-implant distance used to measure the accuracy of the scanners.[4,26,28] Fukazawa *et al*.[26] studied the accuracy of intraoral scanners with a laboratory scanner and coordinate measuring machine. Two models, with inter-implant distances of approximately 9.6 and 18.4 millimeters apart, were used to compare the trueness and precision. The large-span model revealed less accuracy than that of the shorter one under intraoral scanners.

Similarly, Vandeweghe *et al*.[28] studied different inter-implant distances: 9.51, 6.61, 10.28, 7.28, and 5.70 millimeters apart. Six implants on an edentulous mandible were measured to compare the trueness and the precision of four intraoral scanners. The data showed greater inaccuracy when the span length was 9.51 mm or longer, especially in the posterior region. Various angulation of implants may affect the inconsistency of the data. Another clinical study showed a wide range of distance error and some scanning failures.[4] The inter-implant distance in the study ranged between 13 and 26 mm. The results by the distances caused -0.6 to 0.5 mm distance error. The reasons for errors and failures of scanning were reported as incorrect scanning strategy and less amount of keratinized tissue. Therefore, the movement of the oral mucosa may affect the accuracy of intraoral scanners. However, in the previous studies, there was no emphasis on the effect of inter-implant distance on the accuracy of intraoral scanners. Thus, the purpose of this study was to investigate the effect of inter-implant distanc-

es on the accuracy of intraoral scanners.

MATERIALS AND METHODS

A brief experimental workflow was illustrated in Fig. 1. Firstly, three models were designed and prepared via Meshmixer™ (Autodesk Inc., San Rafael, CA, USA), a computer-aided design software. A fully dentate three-dimensional replica model was made into STL file format. In model 1, the right maxillary canine (13) and first premolar (14) were removed by utilizing the "Select" tool, and 5-mm-diametral and 15-mm-deep cylindrical holes were prepared parallelly for two-implant analogs where the center of holes was 7 mm apart. The model was printed by using the Form2™ SLA 3D printer (Formlabs, Somerville, MA, USA) as printing hardware. Tooth 13 was replaced by the Straumann® (Straumann Holding AG, Basel, Switzerland) Regular CrossFit™ implant analog and a scan abutment. The analog was placed approximately 3 - 4 mm under the crest in the hole and fixed by using dental wax. In the same manner, the 14 was also replaced by the Straumann® Regular CrossFit™ implant analog and a scan abutment. The inter-implant distance was 7 mm apart, measured from the central axis of the two scan abutments by utilizing a digital vernier caliper. Similarly, in the model 2 and 3, the holes were prepared by the software with 14 mm and 21 mm apart, respectively. In the same manner, the scan abutments and implant analogs were then stabilized (Fig. 2).

Three fabricated models were scanned using the

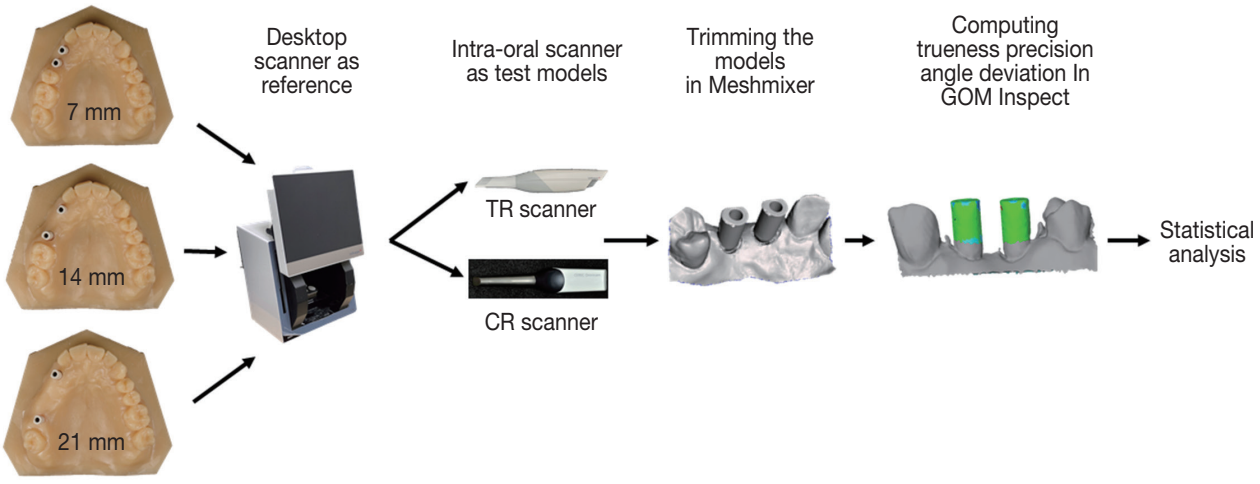

Fig. 1. A brief experimental workflow.

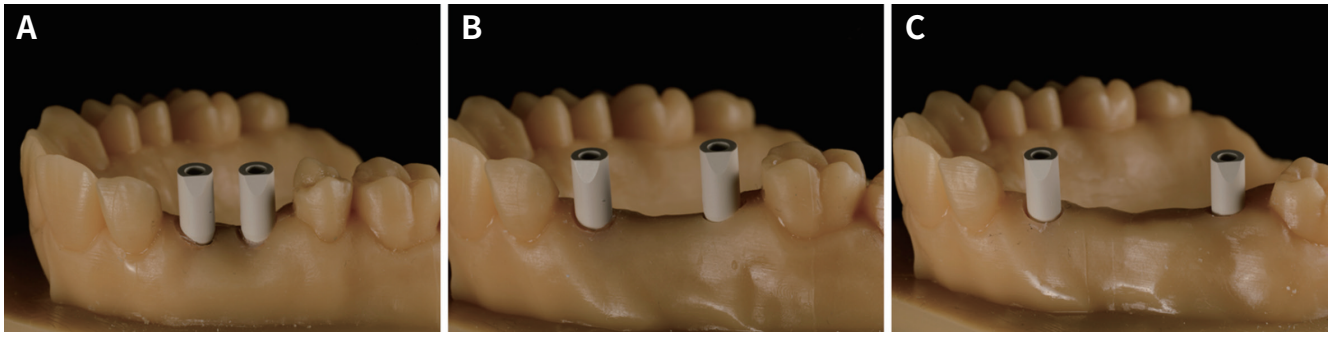

Fig. 2. Models used in the study, (A) Model 1, two scan abutments are placed at tooth 13, and 14, 7 mm apart (B) Model 2, two scan abutments are placed at tooth 13 and 15, 14 mm apart (C) Model 3, two scan abutments are placed at tooth 13 and 16, 21 mm apart.

https://doi.org/10.4047/jap.2021.13.2.107

3shape® D900L dental laboratory scanner (3Shape, Copenhagen, Denmark), a highly precise non-contact optical scanner. The scanner was reported as having an accuracy of 8 μm for implant bar restoration. This reference model preparation was also performed in other studies.[6,29-32] The scanned models were imported to STL file format as reference models for model 1, 2, and 3. Afterward, two intraoral scanners, 3Shape® TRIOS3™ (3Shape, Copenhagen, Denmark) and Dentsply Sirona® CEREC™ Omnicam (Dentsply Sirona, Charlotte, NC, USA) were used to scan the three models as test models. Fifteen scans of each model were performed for one scanner following the company's protocol.

Before computing trueness, precision, and angle deviation of the test models generated by intraoral scanners, model trimming was performed in Meshmixer to limit the area of measurement. Superimposition of the reference and test models was, then, done in GOM Inspect™ software (GOM GmbH, Braunschweig, Germany), a reverse-engineering software, via "prealignment" function together with "best-fit alignment" setting. The second alignment was consequently processed with "local best-fit alignment" to align the flat surfaces on the scan abutments. The parallelism of two implants was confirmed by GOM Inspect software prior to the trueness, precision and angular error analysis.

For trueness, the function "surface comparison on CAD" was used to compute surface distortion to the reference data (Fig. 3). Without the reference models, precision was evaluated from the test models by using the surface comparison function. The areas of measurement were located only on the scan abutments. Next, to evaluate each scan abutment's angle deviation, the axis of the abutments was generated from the axis of cylindrical shape of abutments. The cylinders were generated by Gaussian fitting element. The "angle" function was utilized to compare the angle of the test abutment to the reference abutment three-dimensionally (Fig. 4). Therefore, one scan of each model provided two angle comparison. These angles were averaged as the angle deviation for one model.

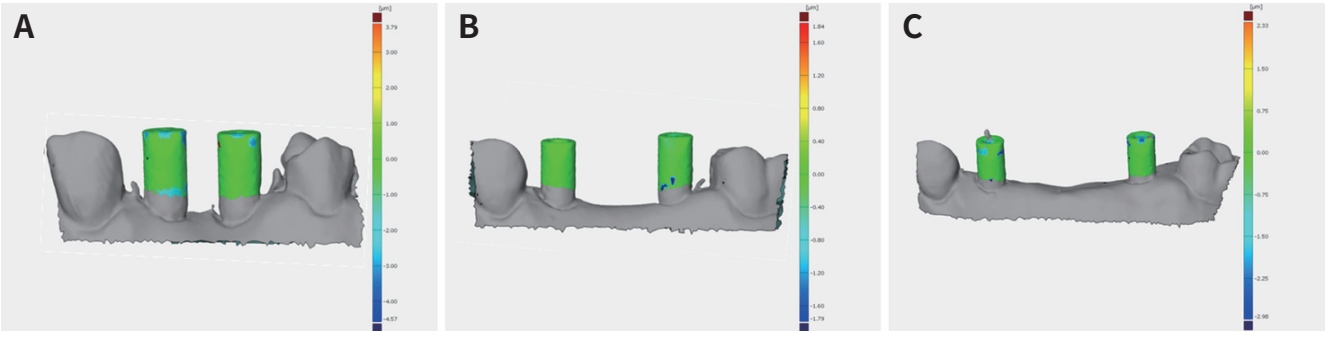

Fig. 3. Analysis of trueness and precision. (A), (B) and (C) were the measurements of 7-, 14-, and 21-mm inter-implant distance, respectively.

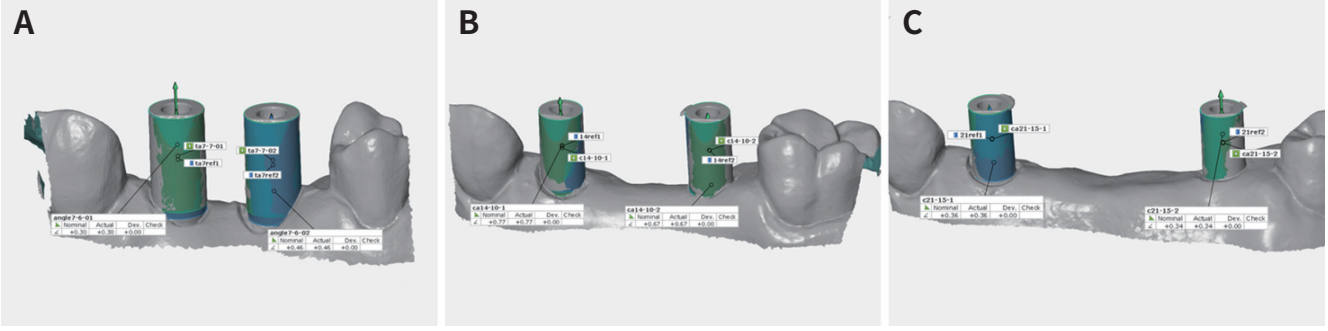

Fig. 4. Analysis of angle deviation. (A), (B) and (C) demonstrate angle deviation measurements of 7-, 14-, and 21-mm inter-implant distance, respectively.

The data of trueness, precision, and angle deviation of each test sample were recorded and analyzed in IBM SPSS 18 (IBM SPSS Statistics for Windows, IBM Corp, Armonk, NY, USA). Statistical estimation of data distribution and comparison were performed using Kruskal-Wallis and Mann-Whitney U test.

RESULTS

During the scanning procedure following the manufacturer's protocol, one scan model from the CEREC Omnicam (CR) intra-oral scanner failed to form one measurable model in the 21-mm inter-implant distance group. The incident occurred due to the wrong stitching of the scanned surfaces. Therefore, one sample was excluded from a 21-mm inter-implant distance scanned by the CR scanner.

Analyzed data of trueness among inter-implant distances were recorded in Table 1. The data were presented in median, minimum and maximum value. The trueness of each inter-implant distance of the TRIOS3 (TR) intra-oral scanner showed a significant difference ($P < .001$), which 21-mm distance showed the greatest error ($P < .05$). For the CR intra-oral scanner, there was a significant difference among the inter-implant distances ($P < .001$); 14- and 21-mm inter-implant distances had greater error than the 7-mm inter-implant distance group ($P < .05$). To compare between two intra-oral scanners, there was no significant difference between the two scanners except for the 14-mm inter-implant distance group, in which the value of the trueness error of the TR group was less than that of the CR group ($P = .003$).

Table 2 illustrates the data of the precision error of the TR and CR scanners in different inter-implant distances. Both intra-oral scanners showed significant differences in the precision error among the inter-implant distance groups ($P < .001$); 21-mm distance scanned by the TR scanner had the greatest error ($P < .05$). For the CR intra-oral scanner, there were significant differences in the errors among the inter-implant distance groups. The greatest error was also reported in the 21-mm group. To compare two intra-oral scanners, the TR scanner had lower precision error than the CR scanner ($P < .05$).

Table 3 demonstrates the angle deviation from the inter-implant distance and the scanner. There were significant differences in angle deviation among in-

Table 1. Median (Min, Max) (μm) of the trueness of TRIOS3 (TR) and CEREC Omnicam (CR) among the inter-implant distance of 7, 14, and 21 mm

		Inter-implant distance			
		7 mm	14 mm	21 mm	*P*
Scanner	TR	12.22 (3.15, 13.86)[a]	10.91 (6.72, 20.19)[a]	19.68 (8.25, 23.27)[b]	< .001*
	CR	13.63 (4.09, 15.41)[c]	17.06 (8.99, 19.31)[d]	18.26 (11.99, 38.47)[d]	< .001*
	P	.161	.003*	.847	

* Significant by Kruskal-Wallis test. The same superscript indicates no significant difference by Mann-Whitney U test ($P > .05$).

Table 2. Median (Min, Max) (μm) of the precision of TRIOS3 (TR) and CEREC Omnicam (CR) among the inter-implant distance of 7, 14, and 21 mm

		Inter-implant distance			
		7 mm	14 mm	21 mm	*P*
Scanner	TR	5.91 (3.06, 9.35)[a]	6.36 (3.00, 52.50)[a]	15.79 (12.92, 23.52)[b]	< .001*
	CR	7.68 (4.96, 8.04)[c]	13.23 (6.00, 22.37)[d]	34.31 (16.77, 47.70)[e]	< .001*
	P	.019	.007	< .001	

* Significant by Kruskal-Wallis test. The same superscript indicates no significant difference by Mann-Whitney U test ($P > .05$).

https://doi.org/10.4047/jap.2021.13.2.107

Table 3. Median (Min, Max) (degree) of the angle deviation of TRIOS3 (TR) and CEREC Omnicam (CR) among the inter-implant distance of 7, 14, and 21 mm

		Inter-implant distance			
		7 mm	14 mm	21 mm	*P*
Scanner	TR	0.385 (0.165, 0.515)[a]	0.445 (0.270, 0.620)[a]	0.235 (0.075, 0.34)[b]	< .001*
	CR	0.310 (0.135, 0.525)[c]	0.550 (0.305, 1.2)[d]	0.338 (0.160, 0.505)[c]	.001*
	P	.486	.250	.003*	

* Significant by Kruskal-Wallis test. The same superscript indicates no significant difference by Mann-Whitney U test ($P > .05$).

ter-implant distances of both TR and CR scanners ($P < .001$). For the TR scanner, the angle deviation of the 21-mm group was 0.235 degrees, which was lower than those of the other distances ($P < .05$), while there was no significant difference between 7- and 14-mm groups ($P = .215$). In the CR scanner, the angle deviation of the 14-mm group was 0.550 degrees, which was the greatest ($P = .004$). Considering between 2 intra-oral scanners, statistical difference was only observed in the 21-mm group ($P = .003$).

DISCUSSION

Intra-oral scanning is an important step to collect data on the oral cavity in digital implant dentistry. Because of the long-term success of implant treatment, the accuracy of the scanned model should be indicated. Previous studies reported that the edentulous span length between implants influenced the accuracy of intra-oral scanners.[4,21,25-28] The longer the edentulous length, the more inaccuracy may be found. However, few studies reported the length of inter-implant distance in number.[4,26,28] Therefore, this study was designed to investigate the relationship between the length of the edentulous span and the error of intra-oral scanners after forming three-dimensional models. Although the group of 21-mm inter-implant distance was rarely seen in clinical situation, the authors aimed to investigate the impact of the length of edentulous span between two implants.

To measure the accuracy of the devices, reference data should be prepared using high-precision scanners. According to the experiment, the reference data were prepared by the D900L dental laboratory scanner, the highly precise dental laboratory optical scanner. Although several studies employed engineering-grade optical scanners related to digital scanning devices,[8,15,18,19,21,27,28] the dental laboratory scanners were also considered as acceptable reference scanners.[6,8,29-32] Moreover, it was reported that the accuracy of dental desktop scanners was unaffected when they were used to scan two scan bodies.[33] Therefore, a D900L dental laboratory scanner was used to generate reference three-dimensional scanned models in this study.

The jaw curve in the anterior region may be one of the factors that affect the scanning error.[4,17-22] In this study, the authors proposed to measure the error generated from the straight-line span. Thus, the implant analogs and scan bodies were positioned at the maxilla's posterior region, where the arch is relatively straight. This was to avoid the curve of the arch that may create errors from the stitching process. Beside the factor of jaw curve, the scan body's design in this study was chosen following the study of Motel *et al*.[34] This design of scan bodies reduces errors that occurs mostly at the sharp edges. The sharp-edge shape geometry was also mentioned in some studies that it could affect the accuracy of the scanned models.[35-37] Therefore, to control this influencing factor, the posterior region and the scan body's design was selected to evaluate the effect of inter-implant distance.

Another critical aspect of measuring the accuracy is the superimposition of the test and reference models or data alignment. Correct model alignment indicates the test objects' translation error compared to the reference objects, which impacts the result estimation of the software. Because best-fit alignment or local best-

fit alignment produced minimal errors from aligning models,[38] this study started from "prealignment" to approximate the closest alignment. Then, "local best-fit alignment" was followed to ensure the fitness of aligning objects. Furthermore, a small portion of models from the scan was also recommended to promote proper alignment accuracy.[38] This was also observed in five studies that trimmed the scanned data to the area of interest to improve accuracy of models' alignment.[18,21,27,28,39]

Passive fit on the implant prostheses is essential for the long-term stability of treatment, reducing fatigue in the implant.[2,3] This is related to the density of surrounding bone or prosthetic component fit that leads to the various value of framework misfit.[2,5] Because scan bodies represent the implant position and will later be generated to simulate implant fixtures in CAD software, capturing precise scanned data of the scan abutments is significant to provide correct angularity and surface characteristics. It could influence the passive fit of prostheses. Therefore, to avoid scanning defects from other structures, surface comparison areas were located only on the scan abutments to investigate the error of scan abutments, which was related to framework passive fit.

For trueness, considering at least 22 μm was called misfit,[4,5] the error of trueness in this study were within the acceptable range for the passive fit, except for the 21-mm group in which the maximum trueness error was over 22 μm. Additionally, the trueness error in this study were not as high as the trueness of other studies.[21,23,26-28,40] They reported the error of the intra-oral scanners up to 100 μm. It was because the trueness was measured from the larger surface of scanned models. This experiment's error of trueness was relatively small because the small area of scan abutment was selected to evaluate the passiveness. Comparing trueness among intra-oral scanners, although only the 14-mm group's trueness was statistically different between the TR and the CR groups, the difference of errors was limited to 15 μm. These differences may not be clinically significant, and these values were also found in other studies.[21,27,28,40]

Precision is a parameter that indicated the reproducibility of the intra-oral scanner. According to the results, increasing precision errors were found with larger inter-implant distances, especially in the CR intra-oral scanner. The error was greater, along with increasing distance. This gradual increase was similar to the other two studies.[21,27] The error of precision was greater when the edentulous span was larger. Moreover, the result showed that the TR scanner was more reproducible than the CR scanner. The errors of the TR scanner were approximately half of those in the CR scanner. It was also consistent with some studies that the CR scanner's precision error was greater than the TR scanner.[21,27] However, in this study, the errors were within the 15 μm range except for the CR scanner at 21-mm inter-implant distance, which may not be clinically significant.

According to different technological principle of two scanners included in the study, the accuracy of the TR scanner was better, approximately twice the CR scanner. The TR scanner is the confocal microscopy. The CR scanner belongs to active triangulation. Active triangulation technique captures the image from two points of view and builds up a 3D model with trigonometric calculation of X, Y and Z coordinates. On the other hand, the confocal microscopy technique is based on the selected focused images. This technique requires larger optical receiver. Therefore, scanning close objects can be an obstacle for light emitting from the intraoral scanners' tip. Capturing details in smaller space between scan bodies faced difficulty. Compared to the CR scanner, smaller wand's tip aids accessibility to the smaller area. Because of this reason, the CR had less difficulty for smaller space accessibility.[41] Only the factor of inter-implant distance was considered. Hence, this reason was used to explain why 14-mm group in the TR scanner had less error than the 7-mm group. On the other hand, the CR scanner had the gradual increase in error. Another reason is the size of the wand's tip that resulted in the differences of the error between the two scanners. The larger size of the tip is superior in gathering images to form a scanned model. A small tip requires more images to be stitched, thus creating more errors.[42] Therefore, greater errors of the CR scanner were reported. The doubled values of the errors were also consistent with some studies.[21,27,35]

Although most of this experiment's error of trueness and precision were within biomechanical ac-

https://doi.org/10.4047/jap.2021.13.2.107

ceptability, the angle deviation seemed unpredictable. In this study, 2 of 6 angles from each scanner and inter-implant distance were greater than 0.388 degrees (0.194 degrees x 2). Most of them rejected authors' hypothesis that 21-mm group may create the greatest error. It is because angle deviation may not directly relate to the error of trueness and precision of the scanners. The angle is generated from two implant axes, reference and test models, while the surface accuracy is analyzed from the closest distance of several point clouds. For instance, one implant may find a small angle error created from the scanner, but trueness and precision may show large errors. This finding was consistent with some studies[4,43] Various range of angle deviation seemed to have an inconclusive relationship to the inter-implant distance and intra-oral scanner.

Since this was an *in vitro* study, other factors related to the accuracy were not included. Therefore, the result might be different when scanning was performed intra-orally. Saliva, moisture, light temperature, or patient movement could impact the accuracy.[4,17-22] Furthermore, 7-mm inter-implant distance may not relate to passive fit of bridgework restoration because it is single unit restoration. However, the accuracy of scanned data is also one factor that indicates proper occlusal and proximal contacts, and path of insertion for implant restoration for the delivery of two single-unit restorations. This study suggested that when inter-implant distances were only considered, the error of trueness and precision was within clinical acceptability. On the contrary, angle deviation that could affect prosthesis may be found when using intra-oral scanners.

CONCLUSION

The TR scanner produced the greatest trueness error at 21-mm inter-implant distance. The CR scanner produced significant error of trueness at 14-mm and 21-mm inter-implant distance. However, the errors were implied as being within biomechanical acceptability under the study's limitation. When measuring precision error, the greater error was reported when the distance between the implants was larger. The TR scanner had approximately two times less precision error than the CR scanner. For angle deviation, clinically significant error can be found in any inter-implant distance and intra-oral scanner while scanning a partially edentulous arch.

Within this study's limitation, it can be concluded that the intra-oral scanner tends to produce more error and less reproducibility at the larger inter-implant distance. The scanner also possibly produces significant angle error at any span length between two implants in the partially edentulous arch.

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