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Comparison of Accuracy of Intra-oral Scanners according to Scanning Distance

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<Abstract>

Comparison of Accuracy of Intra-oral Scanners according to Scanning Distance

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Objectives: The aim of this study was to evaluate the factors affecting intra-oral scanner accuracy by analyzing variation in measurements of a dental model according to scanning distance.

Methods: A dental cast, including a prepared left mandibular first molar, was used as a reference model. Rectangular resin frames measuring 20 mm × 30 mm with heights of 2.5 mm, 5.0 mm, and 7.5 mm were made with a three-dimensional (3D) printer to achieve uniform scanning distances between the teeth and the scanner tip. The model was scanned 10 times with a laboratory reference scanner (Identica Hybrid; Medit, Seoul, Korea) to obtain the true value. Scanning was performed 10 times at four distances of 0 mm, 2.5 mm, 5.0 mm, and 7.5 mm with the frame of each height using the following three different intra-oral scanners: TRIOS (3Shape, Copenhagen, Denmark); CS 3500 (Carestream Health, NY, USA); and PlanScan (Planmeca, Helsinki, Finland). The linear distance measurement method (2D) and the best-fit alignment method (3D) were used to analyze and evaluate the accuracy of the intra-oral scanners. In the linear distance measurement method (2D), the scan image was aligned to the same position using the Rapidform 2004 software (INUS Technology, Seoul, Korea). Measurements were taken at five different parameters (i.e., between the canines [3D], the first molars [6BD and 6LD], and the canine and the first molar [46D and 36D]) and the results were compared. In the best-fit alignment method (3D), using the Geomagic Control X 2017 (3D Systems, Rock Hill, SC, USA) program, the root mean square (RMS) values of the two scan images were calculated. Differences were analyzed using a Friedman test and post hoc Wilcoxon signed-rank test ($p < 0.05$).

Results: In the 2D comparison, the different from the reference value was the smallest at 2.5 mm and 5.0 mm. In the 3D comparison, 2.5 mm and 5.0 mm were the most accurate, and 0 mm was the least accurate among the four distances. The two methods showed similar results. The accuracy of the scanners used from most accurate to least accurate was as follows: Identica Hybrid, TRIOS, CS 3500, and PlanScan.

Conclusions: To our knowledge, this study was the first to evaluate the accuracy of scanning distances, and found a difference between the accuracy of the scanning distance and the accuracy of the scanner. Moreover, the results of this study indicated that the scanning distance was a variable affecting accuracy. Therefore, the results of this study will improve the accuracy of intra-oral scanners in various oral environments, and provide guidelines for developing new intra-oral scanners.

Keywords: intra-oral scanner, scanning distance, accuracy, trueness, precision

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Comparison of Accuracy of Intra-oral Scanners according to Scanning Distance

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CONTENTS

I. INTRODUCTION

Since the introduction of computer-aided design/computer-aided manufacturing in the 1980s, a new range of techniques and materials have been introduced into dentistry since the elimination of the stone model-making process [1-5]. Digital impression is superior to conventional impression in the aspects of improved diagnosis and treatment planning, reduced storage requirements, faster laboratory return, enhanced workflow, and lower inventory expense. Moreover, digital impression can be a powerful marketing tool because it provides more comfortable and safe treatment and reduces chair time [6-8]. These advantages clearly show that the digital impression method is a better alternative to the conventional impression method [9].

Intra-oral scanners are very popular due to these advantages, and, notably, the latest digital impressions can scan the full arch at clinically acceptable levels [9-13]. Many studies were conducted to evaluate the accuracy among various intra-oral scanners. These studies primarily compared the parameters between conventional impressions and digital impressions [9, 11, 14, 15], as well as between intra-oral scanners and extra-oral scanners [12, 16-18].

Interestingly, these studies showed that the factors affecting scan accuracy included scanning technique, technique-related errors, hand movement during the scanning process, patient movement, the teeth and saliva as adjacent structures, the presence of blood and reflection, elapsed time between measurements, the intra-oral environment (e.g., temperature and humidity), the type of scan material, the shadow of undercut structures, and spatial limitations [12, 13, 17, 19-26].

There are two ways of evaluating the accuracy of the intra-oral scanners: linear distance measurement (two-dimensional [2D]) and best-fit alignment (three-dimensional [3D]). The linear distance measurement method is common because it is the easiest way to measure linear distance in a 3D program. However, this method can only be valid for certain geometric forms, does not have clear reference points, and cannot measure repeatable reference points [27-32]. In order to remedy these shortcomings of 2D measurements, many recent studies compared and analyzed accuracy using 3D comparative analysis programs. These programs used the best-fit algorithm, which superimposes and compares the discrepancies between 3D datasets [10-13, 15, 33].

Accuracy consists of trueness and precision (ISO 5725-1) [34], and high accuracy is essential for fabricating precise prosthetic appliances [35]. Trueness indicates how much a measurement deviates from the actual object, while precision describes how close repeated measurements are to each other [24]. In order to evaluate the trueness of an intra-oral scanner, a reference model scanned at an accuracy below 5 μm is required [8]. Consequently, a reference scanner that meets these criteria. Notably, many previous studies examined the trueness of an intra-oral scanner using a reference scanner [8, 10, 13, 19, 36].

The scanning principles and measurement methods of intra-oral scanners vary by manufacturer, with considerable measurement errors when an inappropriate method is used. Moreover, new and improved products are released to the market every year, and it can be difficult for users to actually use them. Some scanner types recommend attaching the tip of the intra-oral scanner to the teeth or maintaining a certain distance during scanning. However, it may not be possible to put the tip in close contact with the patient or to maintain the desired distance. Flügge at al. [24] examined the accuracy of various intra-oral scanners using various distances and angles between implant scanbodies, which are often used clinically. However, scanning distances were not known and all measurements were linear distances, which were limitations of that study.

To date, no study has evaluated the distance between the teeth and an intra-oral scanner. Therefore, the objectives of this study were to analyze the changes in measurements by distance between the dental model and the scanner tip, and to evaluate the effects of the scanning distance on the accuracy of the intra-oral scanners.

II. MATERIALS AND METHODS

Reference model

A mandibular typodont (M-tech Korea, Gyeonggi, Korea) with a prepared left first molar was used as an original model. This model was duplicated using alginate (Aroma Fine Plus; GC, Tokyo, Japan) with a stainless steel impression tray and poured with type IV stone (Neo Plum stone; Mutsumi Chemical Industries Co., Mutsumi, Japan). One stone cast was made as a reference model in this study (Figure 1).

Rectangular resin frames with 3D printing

Frames of different heights were designed using the computer-aided design software Solidworks 2016 (Dassault Systemes, Waltham, MA, USA) to achieve uniform scanning distances between the teeth and a scanner tip. The area of the frames was 20 mm × 30 mm, and the heights were 2.5 mm, 5.0 mm, and 7.5 mm. A 3D printer (Perfactory Micro XL; Envisiontec, Dearborn, MI, USA) was used to print the rectangular resin frames (Figure 2).

Figure 1. The reference dental model.

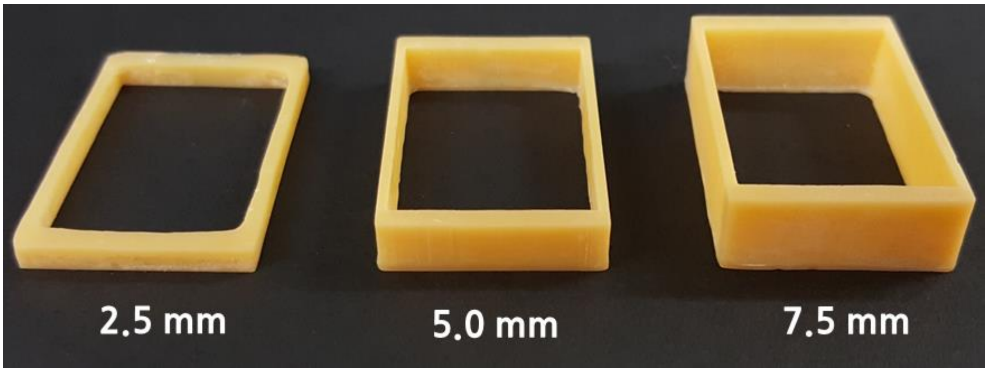

Figure 2. 3D printed rectangular resin frames.

Digital impressions

A true value was obtained with a high-accuracy laboratory reference scanner (Identica Hybrid; Medit, Seoul, Korea). The stone model was scanned with the reference scanner 10 times along different axes. The model was scanned with the frames of each height on a scanner tip (Figure 3) using the following three different intra-oral scanners: TRIOS (3Shape, Copenhagen, Denmark), CS 3500 (Carestream Health, NY, USA), and PlanScan (Planmeca, Helsinki, Finland). The scanning process using the intra-oral scanners was repeated 10 times at four distances of 0 mm, 2.5 mm, 5.0 mm, and 7.5 mm, and a total of 120 datasets were obtained. The scanned datasets were exported into standard tessellation language (STL) data formats. Scanning was performed by a single trained investigator, following the manufacturer's instructions. The main specifications of all scanners are summarized in Table 1.

Figure 3. Scanning with an intra-oral scanner.

Table 1. Specifications of the Scanners

Scanner	Light Source	Data capture mode	Data capture principle	Tip Size (mm)	Accuracy (μm)	Manufacturer's recommended scanning distance (mm)
Identica Hybrid	Blue LED light	-	-	-	7	-
TRIOS	LED	Video sequence	Confocal	18 × 21	20	0 to 5
CS 3500	Amber, blue, green, UV LED	Individual images	Confocal	16 × 22	30	− 2 to 13
PlanScan	Blue laser	Video sequence	Triangulation	15 × 20	30	Rest the tip of the scanner

LED: light-emitting diode; UV: ultraviolet

Two-dimensional measurements

For 2D comparison of the digital model, we selected the five measurement parameters used by Creed et al. [37], which were between the canines (3D), the first molars (6BD, 6LD), and the canine and the first molar (46D, 36D) (Figure 4). All scanned images were aligned in the same position, and the five measurement parameters were measured using the Rapidform 2004 software (INUS Technology, Seoul, Korea). Five parameters were obtained per scan image, and the mean and standard deviation (SD) of each parameter were calculated at each scanning distance.

Three-dimensional measurements

The obtained STL datasets were used to evaluate the trueness and precision of the scanners. One of the 10 reference datasets obtained from the reference scanner was randomly selected as the reference data (R1) to evaluate the trueness of the intra-oral scanners. All datasets were loaded into the 3D inspection software Geomagic Control X 2017 (3D Systems, Rock Hill, SC, USA). For the evaluation of trueness, the R1 and each scanned image of the intra-oral scanners were superimposed using the best-fit algorithm. The differences between datasets were analyzed, and the root mean square (RMS) values were calculated. For the evaluation of precision, the first dataset of each scanner and scanning distance datasets were used as a reference dataset of precision. The RMS values were calculated by superimposing the reference dataset and each scanned dataset.

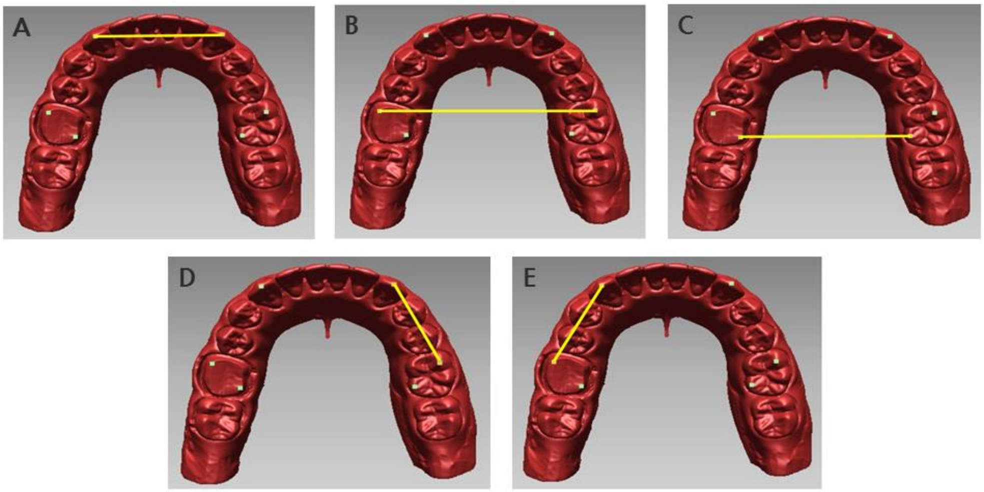

Figure 4. Linear measurement parameters on the digital models. **A:** 3D; **B:** 6BD; **C:** 6LD; **D:** 46D; **E:** 36D. (3D: the distance between the right and left canine cusp tips; 6BD: the distance between the mesiobuccal cusp tips on the right and left first molars; 6LD: the distance between the distolingual cusp tips on the right and left first molars; 46D: the distance between the mesiobuccal cusp tip on the left first molar and the left canine tip; 36D: the distance between the mesiobuccal cusp tip on the right first molar and the right canine tip).

Statistical analysis

To measure the trueness and precision of intra-oral scanners at four scanning distances, all RMS values were analyzed statistically using software (IBM SPSS Statistics 23; SPSS Inc., Chicago, IL, USA). The datasets were tested for a normal distribution using the Kolmogorov–Smirnov and Shapiro–Wilk tests. The nonparametric Friedman test was used to compare the three intra-oral scanners and the four scanning distances. Post hoc analysis was also performed using the Wilcoxon signed-rank test to compare accuracy among the scanners at each scanning distance. All values are presented in the format of mean ± standard deviation (*$p < 0.05$, **$p < 0.01$).

III. RESULTS

Two-dimensional Comparisons

The Friedman test showed that the four scanning distances in 6BD (TRIOS), 6LD and 46D (CS 3500), and 6LD and 46D (PlanScan) were significantly different. All mean ± SD results are presented in Tables 2-4. To investigate the mean difference from the reference scanner, the difference value of each mean was calculated. The difference values were converted into absolute values (Table 5). The absolute values of parameters at 2.5 mm or 5.0 mm distance were lower than those of the other scanning distances.

Table 2. Mean ± SD Values of Five Parameters at Four Scanning Distances in the TRIOS

(unit; mm)

	Identica	0 mm	2.5 mm	5.0 mm	7.5 mm	p-value
3D	26.17 ± 0.10	26.24 ± 0.05	26.18 ± 0.06	26.25 ± 0.11	26.21 ± 0.12	0.359
6BD	46.67 ± 0.07	46.60 ± 0.15	46.63 ± 0.11	46.71 ± 0.08	46.62 ± 0.14	0.026*
6LD	36.28 ± 0.34	36.54 ± 0.40	36.56 ± 0.42	36.57 ± 0.43	36.58 ± 0.46	0.230
46D	20.98 ± 0.08	20.90 ± 0.13	20.94 ± 0.06	20.95 ± 0.06	20.95 ± 0.10	0.516
36D	21.68 ± 0.08	21.88 ± 0.39	21.77 ± 0.10	21.81 ± 0.10	21.89 ± 0.38	0.361

Differences between parameters examined using the Friedman test.
(*p < 0.05, **p < 0.01)

Table 3. Mean ± SD Values of Five Parameters at Four Scanning Distances in the CS 3500

(unit; mm)

	Identica	**0 mm**	**2.5 mm**	**5.0 mm**	**7.5 mm**	**p-value**
3D	26.17 ± 0.10	26.09 ± 0.12	26.19 ± 0.15	26.18 ± 0.13	26.26 ± 0.13	0.222
6BD	46.67 ± 0.07	46.64 ± 0.43	46.72 ± 0.18	46.70 ± 0.24	46.91 ± 0.37	0.072
6LD	36.28 ± 0.34	36.71 ± 0.70	36.90 ± 0.29	36.45 ± 0.43	37.27 ± 0.48	0.001^{**}
46D	20.98 ± 0.08	20.82 ± 0.13	20.86 ± 0.12	20.85 ± 0.12	20.81 ± 0.14	0.033^{*}
36D	21.68 ± 0.08	21.69 ± 0.09	21.67 ± 0.07	21.68 ± 0.16	21.74 ± 0.09	0.349

Differences between parameters examined using the Friedman test.
($^{*}p < 0.05$, $^{**}p < 0.01$)

Table 4. Mean ± SD Values of Five Parameters at Four Scanning Distances in the PlanScan

(unit; mm)

	Identica	0 mm	2.5 mm	5.0 mm	7.5 mm	p-value
3D	26.17 ± 0.10	26.17 ± 0.14	26.11 ± 0.06	26.20 ± 0.07	26.16 ± 0.17	0.272
6BD	46.67 ± 0.07	47.00 ± 0.46	46.72 ± 0.21	46.93 ± 0.19	46.75 ± 0.21	0.059
6LD	36.28 ± 0.34	37.27 ± 0.50	37.07 ± 0.26	37.16 ± 0.44	37.02 ± 0.35	0.002**
46D	20.98 ± 0.08	20.89 ± 0.13	20.91 ± 0.10	20.96 ± 0.07	20.84 ± 0.05	0.007**
36D	21.68 ± 0.08	22.09 ± 0.48	21.69 ± 0.10	21.64 ± 0.11	21.77 ± 0.43	0.008**

Differences between parameters examined using the Friedman test.
(*p < 0.05, **p < 0.01)

Table 5. Absolute Values of Five Parameters Between Intra-oral Scanners at Four Scanning Distances

(unit; mm)

	TRIOS				CS 3500				PlanScan			
	0	**2.5**	**5.0**	**7.5**	**0**	**2.5**	**5.0**	**7.5**	**0**	**2.5**	**5.0**	**7.5**
3D	0.07	0.01	0.08	0.04	0.08	0.02	0.01	0.09	0.00	0.06	0.03	0.01
6BD	0.07	0.04	0.04	0.05	0.03	0.05	0.03	0.24	0.33	0.05	0.26	0.08
6LD	0.26	0.28	0.29	0.30	0.43	0.62	0.17	0.99	0.99	0.79	0.88	0.74
46D	0.08	0.04	0.03	0.03	0.16	0.12	0.13	0.17	0.09	0.07	0.02	0.14
36D	0.20	0.09	0.13	0.21	0.01	0.01	0.00	0.06	0.41	0.01	0.04	0.09

Three-dimensional Comparisons of Trueness

A total 121 of the R1 (n = 1) and intra-oral scan datasets (n = 40, per scanner) were evaluated to determine the trueness of the intra-oral scanners. In trueness analysis, the Friedman test showed that the scanning distances were not significantly different.

The results of the RMS values among the intra-oral scanners are shown in Table 6. The most accurate scanning distance was observed at 5.0 mm in the TRIOS and the CS 3500 and at 2.5 mm in the PlanScan, respectively. The lowest trueness in the intra-oral scanners was observed at 0 mm. The TRIOS showed the lowest RMS values and the highest trueness, followed by the CS 3500 and the PlanScan.

A color difference map of representative trueness data for the intra-oral scanners is presented in Figure 5. In the 3D comparison results, the 0 mm distance showed higher negative (blue) and positive (red) values than did the other distances. Additionally, the TRIOS scanner showed more normal values (green) versus the other intra-oral scanners, whereas the PlanScan scanner showed higher negative (blue) and positive values (red).

Table 6. RMS Values of Trueness Between Intra-oral Scanners at Four Scanning Distances (Mean ± SD)

(unit; mm)

Scanners	0 mm	2.5 mm	5.0 mm	7.5 mm	p-value
TRIOS	0.11 ± 0.02	0.09 ± 0.02	0.07 ± 0.03	0.08 ± 0.01	0.222
CS 3500	0.16 ± 0.09	0.12 ± 0.05	0.12 ± 0.02	0.16 ± 0.11	0.459
PlanScan	0.41 ± 0.09	0.33 ± 0.05	0.37 ± 0.07	0.41 ± 0.09	0.076

Differences between intra-oral scanners examined using the Friedman test.

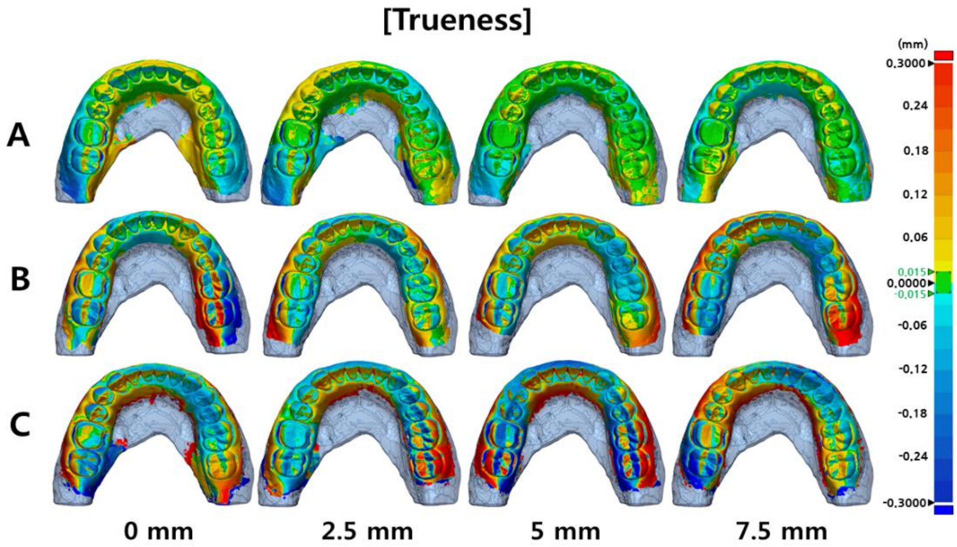

Figure 5. Color-coded images of trueness of each intra-oral scanner at four scanning distances. **A:** TRIOS; **B:** CS 3500; **C:** PlanScan. The color spectrum was set for 20 segments. Critical tolerance values were set to − 0.3 mm (blue) and 0.3 mm (red), while nominal tolerance values were set to ± 0.015 mm (green). The yellow to red spectrum indicates positive values and expansion parts as compared with the reference data, while light-to-dark blue indicates negative values and contraction parts as compared with the reference data.

Three-dimensional Comparisons of Precision

A total 130 of reference scan datasets (n = 10) and intra-oral scan datasets (n = 40, per scanner) were used to determine precision of the intra-oral scanners. In precision analysis, the Friedman test showed that the scanning distances were significantly different. The mean RMS value of the Identica Hybrid scanner was 0.04 ± 0.07 mm.

RMS values among the intra-oral scanners are shown in Table 7. The most accurate scanning distance was observed at 7.5 mm in the TRIOS, at 5.0 mm in the CS 3500, and at 2.5 mm in the PlanScan, respectively. The lowest precision of the intra-oral scanners was observed at 0 mm. The Identica Hybrid showed the lowest RMS values and the highest precision, followed by TRIOS, CS 3500, and PlanScan.

A color difference map of representative precision data for the intra-oral scanners is given in Figure 6. The 0 mm group had more negative (blue) and positive (red) parts as compared with the other distances, and the TRIOS scanner had more green parts as compared with the other intra-oral scanners. In comparison with the 3D comparison results of trueness, similar results were obtained.

Table 7. The RMS Values of Precision Between Intra-oral Scanners at Four Scanning Distances (Mean ± SD)

(unit; mm)

Scanners	0 mm	2.5 mm	5.0 mm	7.5 mm	p-value
TRIOS	0.23 ± 0.07	0.17 ± 0.04	0.17 ± 0.09	0.14 ± 0.03	0.00003**
CS 3500	0.48 ± 0.09	0.24 ± 0.07	0.19 ± 0.05	0.24 ± 0.14	0.00026**
PlanScan	0.78 ± 0.19	0.57 ± 0.14	0.61 ± 0.21	0.75 ± 0.16	0.00033**

Differences between intra-oral scanners examined using the Friedman test.
(*p < 0.05, **p < 0.01)

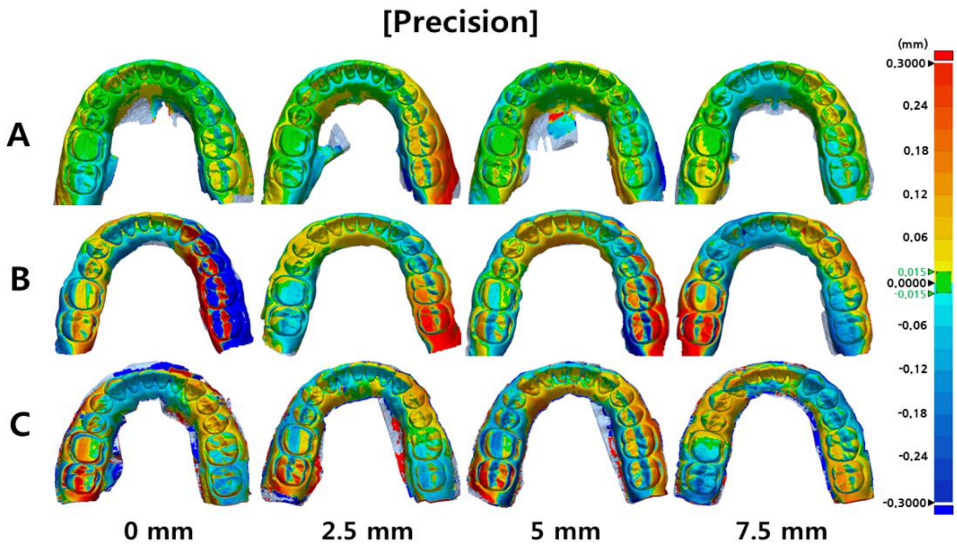

Figure 6. Color-coded images of precision of each intra-oral scanner at four scanning distances. **A:** TRIOS; **B:** CS 3500; **C:** PlanScan. The color spectrum was set for 20 segments. Critical tolerance values were set to − 0.3 mm (blue) and 0.3 mm (red), while nominal tolerance values were set to ± 0.015 mm (green). The yellow to red spectrum indicates positive values and expansion parts as compared with the reference data, while the light-to-dark blue indicates negative values and contraction parts as compared with the reference data.

IV. DISCUSSION

This study assessed factors affecting intra-oral scanner accuracy by analyzing changes in measurements of a dental model according to scanning distance. Four distances were modeled using resin frames, and the accuracy of three intra-oral scanners was evaluated.

The 2D comparison results showed that 6BD of the TRIOS scanner, 6LD and 46D of the CS 3500 scanner, and 4LD, 46D, and 36D of the PlanScan scanner were significantly different. The difference from the reference value was its smallest at 2.5 mm and 5.0 mm. The results obtained were similar to those of the 3D comparison. However, the current linear distance measurement method does not take the dimensional changes existing along the 3D surface of the object into consideration [38]. Therefore, it is not recommended that a 3D model be used to evaluate the accuracy of the digital impression system [11]. The 3D comparison was conducted for multilateral comparisons due to these limitations, and the results obtained were more accurate than those seen with the 2D comparison.

Differences between scanning distances and intra-oral scanners were found by comparing the mean RMS values in the trueness of 3D comparisons, but these differences were not significant. The accuracy was the lowest at the 0 mm distance, which was attributed to insufficient depth of field (DOF) for the 3D laser scanner to obtain accurate images. DOF controls the in-focus area within an image, is not at a fixed distance, and can change. The TRIOS and the CS 3500 scanners operate on the confocal principle. Confocal imaging projects laser light to a target object through a filtering pinhole. It has high scan accuracy because it removes the light that is out of focus (faulty data) among the reflected light. However, when it is out of DOF range, the signal which was out of focus decreases and the noise increases, leading to image blur. The TRIOS scanner can scan a wider range than the specific DOF range because the position of focus changes. The PlanScan scanner uses triangulation, which determines the angle of reflection when the light is reflected from the object, and uses the Pythagorean theorem to calculate the distance from the laser source to the surface of the object. In this case, the focus and the location of image formation changed when the DOF varied. The focus may be blurred and the data inaccurate when the scanning distance is outside the manufacturer's specified DOF range. This can be explained by the technical difference of each company. Each manufacturer has a different range of DOF in which acceptable images can be obtained. The accuracy of the scan data beyond the DOF varies by manufacturer.

In terms of trueness results, distances of 2.5 mm and 5.0 mm showed the highest accuracy among the intra-oral scanners. These results implied that the optimal scanning distance for intra-oral scanners is between 2.5 mm and 5.0 mm. The mean RMS values ranged from 0.07 to 0.11 mm, 0.12 to 0.16 mm, and 0.33 to 0.41 mm for the TRIOS, CS 3500 and PlanScan scanners, respectively. The mean difference among intra-oral scanners was a minimum of 0.03 mm and a maximum of 0.08 mm. Therefore, the scanning distance did not affect the trueness between 0 mm and 7.5 mm. Moreover, the mean RMS values were in the range of 0.11 to 0.41 mm, 0.09 to 0.33 mm, 0.07 to 0.37 mm, and 0.08 to 0.41 mm at distances of 0 mm, 2.5 mm, 5.0 mm, and 7.5 mm, respectively. Interestingly, even though the same model was scanned at the same distance, scan data from each scanner showed a difference between 0.24 mm and 0.33 mm. Our results showed that the trueness varied significantly among different intra-oral scanners.

The precision of the 3D comparisons was significantly different according to the scanning distance. We confirmed that the extra-oral scanner (Identica Hybrid) was more precise than the intra-oral scanners, in accordance with the results of previous studies [10, 12, 17]. The mean RMS values ranged from 0.14 to 0.23 mm, 0.19 to 0.48 mm, and 0.57 to 0.78 mm for the TRIOS, CS 3500, and PlanScan scanners, respectively. The mean difference of the intra-oral scanners was a minimum of 0.09 mm and a maximum of 0.29 mm. We found that the precision levels among the intra-oral scanners were clearly different. Flügge et al. [17] reported that a mean deviation of 10 μm for the laboratory scanner (D250) and 50 μm for the intra-oral scanner (iTero). The intra-oral scanner accuracy of our study was higher than that in previous studies because the three intra-oral scanners used in this study were newer than the conventional scanners used in other studies [12, 17]. However, the overall RMS values of both trueness and precision did not exceed 100 μm, which was in the clinically acceptable range [11], so it could be concluded that all intra-oral scanners regardless of distance had high clinical accuracy.

In terms of trueness and precision, the accuracy of the intra-oral scanners used from most accurate to least accurate was as follows: TRIOS, CS 3500, and PlanScan scanners. The accuracy can vary based on the scanning method used. The TRIOS and the PlanScan scanners used the video sequence method, while the CS 3500 scanner employed individual images. In the individual images method, the 3D surface must be scanned in a way that ensures that more than one-third of the adjacent surface is superimposed [39]. This process is called stitching, and stitching can cause systematic errors [17, 40]. A previous study reported that a video-based system uses a continuous image streaming method that generates surface data with a larger superimposed area, and therefore can create a more accurate image [12, 19].

Superimposed images were compared using the 3D comparison program, and the results showed that the TRIOS scanner had the highest proportion of the green range, which indicated that the TRIOS scanner had higher accuracy than the other two intra-oral scanners. All intra-oral scanners displayed high deviation in the posterior area, which could have been caused by the complex angled surface of the molars and the undercut surfaces of adjacent teeth [17, 41]. Rudolph et al. [41] pointed out that there was a point with a very high discrepancy whenever an object with an irregular surface was scanned [5]. In particular, prior studies found it hard to scan the anterior area because of the lack of geometric information; furthermore, anterior surfaces with a steep angle can require additional scanning at different angles. Error propagation in the anterior area increases the deformation toward the distal side of the dental arch [9, 42].

In the pilot experiment, the scan was performed with a rectangular frame (10 mm in height), but it was difficult to scan the prepared tooth with all intra-oral scanners but the TRIOS scanner. Therefore, a height of 10 mm was excluded. As a result, we determined that the TRIOS scanner could scan at a distance of more than 10 mm. Moreover, it was suggested that the scan range of the CS 3500 and the PlanScan scanners was less than or equal to 10 mm, and that it might be difficult to scan up to

13 mm in height using the CS 3500 scanner, as was recommended by the manufacturer.

There was a limitation to the present study, because it was an in vitro study, and was not conducted in an actual clinical environment. However, in the actual oral environment, diverse factors, including saliva, blood, and body movement can all affect scan accuracy [19]. Therefore, an in vitro approach can provide more accurate results in order to compare the accuracy of various intra-oral impression systems and to detect clinically associated deviations [24]. Another limitation was that it was difficult to scan all teeth at a constant height. In fact, it was very difficult to scan all teeth at a constant height because of the curvature on the surface of the tooth. Therefore, manufacturers need to develop a new intra-oral scanner equipped with a tip height of 2.5 to 5.0 mm, which can improve the scan accuracy as shown in this study, or a device that can complement scanning distance.

The present study was, to our knowledge, the first to evaluate the accuracy of intra-oral scanner according to scanning distance. The results indicated that accuracy varied by scanning distance. Moreover, the results of this study showed that the scanning distance is another variable affecting the accuracy. Therefore, the results of this study are believed to contribute to improve the accuracy of the intra-oral scanners in various oral environments, and to provide guidelines for developing new intra-oral scanners.

V. CONCLUSIONS

This study evaluated the effects of scanning distance on scan accuracy using rectangular frames. The results showed that the accuracy was lowest and highest at 0 mm and at a 2.5 to 5.0 mm interval, respectively. These observed differences can be explained by the technical characteristics of each device. However, the results of all three intra-oral scanners were within the clinically acceptable range and these scanners were more accurate than their conventional counterparts. The results of this study imply that scanning distance could be an important factor in determining scan accuracy. Moreover, the results of this study are expected to contribute to the development of high-accuracy intra-oral scanners.

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<국문요약>

스캔 거리에 따른 구내 스캐너의 정확성 비교

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연구목적: 이 연구는 치과 모형과 구내 스캐너 간의 스캔 거리에 따른 측정값의 변화를 분석하여 스캐너의 정확성에 미치는 영향을 평가하고자 하는 것이다.

연구방법: 치과 모형의 하악 좌측 제 1 대구치에 지대치 수복을 위한 삭제를 형성하여 대상으로 사용하였다. 스캐너 팁에 일정한 거리를 주기 위하여, 3D 프린터를 이용하여 넓이 20 X 30mm, 높이 2.5, 5.0, 7.5 mm 의 직사각형 틀을 제작하였다. 대조 스캐너로 모델스캐너인 Identica Hybrid (Medit, Seoul, Korea)를 사용하였고, 연구용으로는 총 3 가지 구내스캐너 ((TRIOS (3Shape, Copenhagen, Denmark), CS 3500 (Carestream Health, NY), PlanScan (Planmeca, Helsinki, Finland))를 사용하였다. 각 스캐너 당 0, 2.5, 5.0, 7.5 mm 높이에서 10 회씩 반복 스캔 후 결과물을 STL (Stereolitho-graphy) 파일로 추출하였다. 구내 스캐너의 정확성을 평가하기 위하여 선형 거리 측정 방법 (2D)과 Best-fit alignment 방법 (3D)으로 나누어 분석하였다. 첫 번째, 선형거리측정 방법 (2D)에서는

Rapidform 2004 software (INUS Technology, Seoul, South Korea)를 사용하여 스캔이미지를 동일한 위치 선상에 정렬 시킨 후, 총 5가지 거리 ((견치 간의 거리 (3D), 제 1 대구치 협측 간의 거리 (6BD), 제 1 대구치 설측 간의 거리 (6LD), 오른쪽 견치와 오른쪽 제 1 대구치 간의 거리 (46D), 왼쪽 견치와 왼쪽 제 1 대구치 간의 거리 (36D))를 계측하고 비교하였다. 두 번째, Best-fit alignment 방법 (3D)에서는 Geomagic Control X 2017 (3D Systems, Rock Hill, SC) 프로그램을 사용, 최소제곱법에 근거하여 오차가 최소화되도록 3차원 중첩 후, 두 모델 간의 RMS (root mean square)값을 비교하였다.

결과: 2D 비교에서 기준스캐너의 평균값에서 가장 가까운 값을 나타내는 거리 항목은 주로 2.5와 5.0 mm이었다. 3D 비교에서 총 4가지 거리 항목 중 가장 정확성이 높은 거리 항목은 2.5 mm와 5.0 mm이고 가장 낮은 항목은 0 mm이어서 두 방법의 결과가 비슷하였다. 모든 거리에서 스캐너들의 정확성 순서는 정확한 기종부터 Identica - TRIOS - CS 3500 - PlanScan 순이었다.

결론: 본 연구는 스캔 거리의 정확도에 관해 처음으로 시행된 연구로서 스캐닝 거리의 정확도와 스캐너 간의 정확도에 차이가 있음을 보여주었다. 또한 스캔 거리가 정확도에 영향을 미치는 또 하나의 변수임을 보여준다. 따라서 이 연구는 다양한 구강 환경에서 구강 내 스캐너의 정확성을 높이고 새로운 구강 내 스캐너를 만들기 위한 지침을 제시하는데 기여할 것이다.

주요어 : 구내스캐너, 스캔 거리, 정확성, 진실성, 정밀도

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