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RESEARCH AND EDUCATION

Feasibility of using an intraoral scanner for a complete-arch digital scan

Gun-Hong Park, MSD,[a] KeunBaDa Son,[b] and Kyu-Bok Lee, DDS, PhD[c]

ABSTRACT

Statement of problem. The introduction of intraoral scanners has increased the use of digital technology in dental procedures. However, research on the extent of clinically recommended scans is lacking.

Purpose. The purpose of this in vitro study was to compare 3D arch distortion according to the distance from the tooth at the beginning of a complete-arch scan made using an intraoral scanner.

Material and methods. An industrial scanner was used to digitize a master model for a computer-aided design (CAD) reference model. In addition, the master model was digitized using 4 intraoral scanners (TRIOS2, TRIOS3, CS3500, and CS3600) and 1 dental laboratory scanner (FREEDOM HD) to make the CAD test model (N=20). The scanned teeth were divided using an inspection software program (Geomagic control X), and overlapping and 3D analyses of the CAD reference model and CAD test model were performed. The presence or absence of normal distribution in the root mean square (RMS) values of all divided teeth was assessed and evaluated with the Kruskal-Wallis test (α=.05), and post hoc comparison was performed using the Mann-Whitney U-test and Bonferroni correction method (α=.005).

Results. The overall RMS value was significantly different for all scanners (P<.001). The dental laboratory scanner showed the lowest value (47.5 ±1.6 µm), whereas TRIOS2 showed the highest value (343.4 ±56.4 µm). TRIOS3 (9.6 ±1.2 µm) showed the best trueness in those teeth where the scan started. However, the larger the scan range, the lower the RMS value difference between TRIOS3 and CS3500. The RMS values of the dental laboratory scanners were higher than those of the intraoral scanners in the narrow scan range. CS3600 showed an RMS value less than or equal to that of the dental laboratory scanner at 5 teeth scan ranges. However, the wider the scan range, the lower the RMS values of all the intraoral scanners.

Conclusions. Current complete-arch scanning is not sufficiently accurate for fabricating fixed prostheses. However, intraoral scanners are useful for short scans, such as those for single (TRIOS2, TRIOS3, and CS3500) or short-span prostheses (CS3600). (J Prosthet Dent 2019;121:803-10)

The introduction of intraoral scanners has enabled a digital workflow for dental prosthetic processes.[1,2] The first step in the preparation of a restoration in a dental laboratory computer-aided design and computer-aided manufacturing (CAD-CAM) system is to make an impression of the mouth and pour a definitive cast. This process is prone to errors and relies on the experience of the practitioner and proper usage of materials, such as impression material and gypsum.[3] In contrast, with a chairside CAD-CAM system, a virtual definitive cast can be acquired using an intraoral scanner. The virtual cast thus obtained can be used to make an actual cast through 3D printing or milling. Although the digital scan may be more accurate and efficient than the conventional impression technique,[4] its accuracy in recording a wide area (such as a complete arch) for fabricating a fixed prosthesis is limited.[5]

The accuracy of an intraoral scanner is greater than that of the conventional method over a narrow range,[6-8] but it decreases as the range of the scan increases.[5,8-12] Moreover, there is a difference in the accuracy of the

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[a]Graduate student, Department of Dentistry, Graduate School, Kyungpook National University, Daegu, Republic of Korea.
[b]Graduate student, Department of Dental Science, Graduate School, Kyungpook National University, Daegu, Republic of Korea.
[c]Professor, Department of Prosthodontics, School of Dentistry, Kyungpook National University, Daegu, Republic of Korea.

Clinical Implications

The degree of distortion of the virtual model differs depending on the type of intraoral scanner. The recommended scan range for intraoral scans is essential guidance for achieving ideal clinical outcomes for fixed prostheses.

scan depending on the order and the point from which scanning of the complete arch is initiated.[13,14] As errors tend to accumulate from the starting point over the course of the scan, accuracy is reduced as the scan range increases. However, the accuracy of an intraoral scanner has been reported to be greater than that of an irreversible hydrocolloid complete-arch impression for planning and monitoring orthodontic treatment.[11,15-17]

Recent studies have evaluated the accuracy of complete-arch scans using an intraoral scanner in several ways.[15,18,19] The distance to a reference point or shape has been measured,[20-22] or a 3D analysis was performed by superimposing the CAD reference model (CRM) and CAD test model (CTM).[11,23,24] An important aspect of the 3D analysis is the alignment process that overlaps the CRM with software. In general, the overlapping process has been studied through best-fit alignment.[25-27] However, with this method, if a large discrepancy in one part is autocorrected through the best-fit alignment process, errors can result in other parts.[28,29] Furthermore, the results of the best fit alignment process may vary depending on the type and version of the inspection software[30-33] because of differences in alignment protocols. Therefore, in this study, a 3D analysis method that compared the distortion of the complete arch based on the scan-initiated teeth was used.

The purpose of this in vitro study was to evaluate 3D arch distortion from the start tooth when a complete-arch scan was made using an intraoral scanner. The null hypothesis was that when the scan-initiated teeth were aligned, no difference would be found in the root mean square (RMS) values between each tooth in the virtual complete-arch model obtained using 4 intraoral scanners and 1 dental laboratory scanner.

MATERIAL AND METHODS

This study involved developing a reference model for CRM production and digitizing it by using an industrial scanner; digitization of the reference model using 4 intraoral scanners and a dental laboratory scanner for CTM production; and CRM and CTM overlap with inspection software and 3D analysis (Fig. 1). Pilot experiments were performed 5 times to determine the sample size of 20,

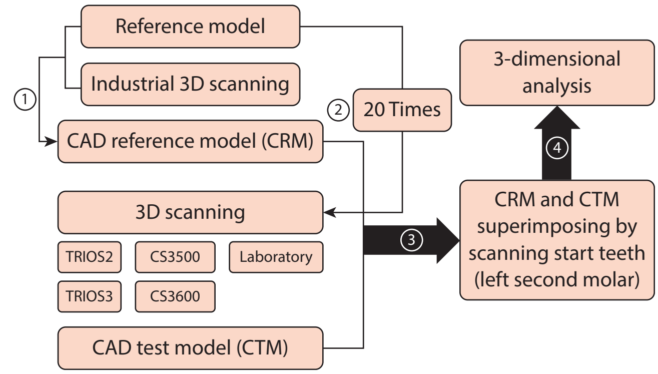

Figure 1. Experimental design.

which was calculated using a power analysis software program (G*Power v3.1.9.2; Heinrich-Heine-Universität Düsseldorf) on each scanner (actual power=96.1%; power=95%; α=.05).

A master model (ANA-4; Frasaco GmbH) made of dental stone was selected. The master model was used to produce the CRM file using an industrial 3D scanner (Solutionix C500; MEDIT) with a resolution of 2×5 megapixels and a blue LED light.

Four intraoral scanners (CS3500 [Carestream Dental], CS3600 [Carestream Dental], TRIOS2 [3Shape], and TRIOS3 [3Shape]) and 1 dental laboratory scanner (FREEDOM HD; DOF) were used to obtain the digital scan of the master model. The scan sequence was determined according to the manufacturer's instructions for the complete scan and from published literature on scan strategies for optimal results.[13] The scan was initiated from the occlusal surface of the left second molar, and a complete-arch scan was performed in the counterclockwise direction (Fig. 2). According to ISO-12836 specifications,[34] each scan was performed at an ambient temperature of 23 ±2°C. One investigator (K.S.) performed a total of 30 scans with each intraoral scanner. To reduce the accuracy difference according to the proficiency of the intraoral scanner, the first 10 scans were deleted, and the following 20 scans were used for evaluation. The standard tessellation language (STL) files were subsequently obtained for 3D analysis.

The 3D analysis can vary as each 3D inspection software program is based on different protocols. The 3D inspection software used in this study was Geomagic's 3D inspection software (release 2018.0.0; Geomagic control X; 3D Systems) recommended in ISO-12836.

First, the CRM file for 3D analysis of the teeth was split (Fig. 3). In addition, to evaluating the movement of the dentition, a plane based on a hypothetical line connecting the central incisor and half of the second molar in the sagittal plane was formed. After preparing the CRM file, the CTM file was loaded, and the initial alignment was performed. To compare the

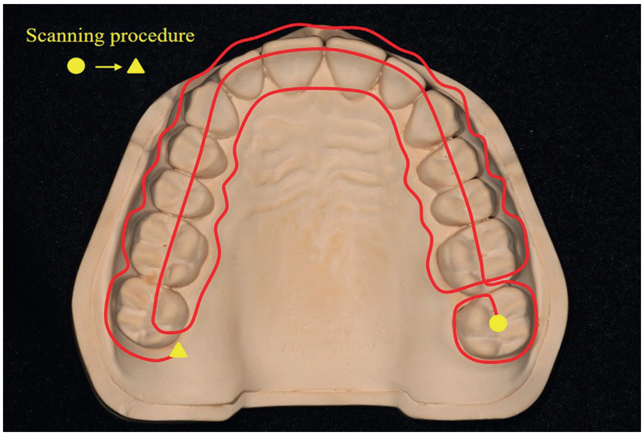

Figure 2. Strategies of complete-arch scanning.

Figure 3. Splitting of CRM file for 3D analysis of teeth. CRM, CAD reference model.

scan-initiated teeth, the divided left second molar was superimposed with the best-fit alignment. The sampling rate was set at 100%.

The dimensional differences of the CRM and CTM files were calculated for all data points of the divided teeth. The data point was calculated by RMS value, and the following formula was used:

$$RMS=\frac{1}{\sqrt{n}}\cdot\sqrt{\sum_{i=1}^{n}\left(X_{1,i}-X_{2,i}\right)^{2}},$$

where $X_{1,i}$ is the measurement point of i of the CRM, $X_{2,i}$ is the measurement point of i of the CTM, and n is the number of all points measured in each analysis.

The RMS value can be used to determine how the deviation between 2 different sets of data is different from zero. Thus, a low RMS value represents a high degree of 3D conformity of the superimposed data.[35] The 3D comparison was shown as a color difference map at a specified range of ±100 μm (20 color segments) and a tolerance range of ±10 μm (green). Each divided tooth yielded 3D analysis values. All the divided teeth were analyzed together to obtain the overall RMS values.

All data were analyzed using a statistical software program (IBM SPSS Statistics, v23.0; IBM Corp). First, the normal distribution of data was investigated through the Shapiro-Wilk test. In non-normal distribution, differences between groups were analyzed using the Kruskal-Wallis test (α=.05) and post hoc test using the Mann-Whitney U-test and Bonferroni correction method (α=.005).

RESULTS

The RMS values of the 4 intraoral and 1 dental laboratory scanners are shown in Table 1. A significant difference was found among the scanners in all teeth (P<.001). Best trueness of the tooth from where the scan was initiated was found for TRIOS3 (9.6 ±1.2 μm) (P<.001). However, the larger the scan range, the lesser the difference in the RMS values between TRIOS3 and CS3500 (P<.001; Table 1).

The RMS value of the dental laboratory scanner was higher than that of the intraoral scanner in a narrow range (left second molar, left first molar, left second premolar) of the scan but was lower than that of all the intraoral scanners as the scan range increased. CS3600 showed an RMS value less than or equal to the dental laboratory scanner at 5-teeth scan ranges (left second molar, left first molar, left second premolar, left first premolar, and left canine) (Table 1).

With respect to the overall RMS value, the dental laboratory scanner had the lowest value (47.5 ±1.6 μm), and TRIOS2 had the highest value (343.4 ±56.4 μm) (P<.001; Table 1). In general, the RMS value increased sharply as the scan range of all the intraoral scanners increased (Fig. 4). In contrast, the dental laboratory scanner showed a relatively small change in the overall scan range (Fig. 4).

On comparing the color difference map in terms of the scanner, all 4 intraoral scanners, but not the dental laboratory scanner, revealed many displacements as the range of scanning increased (Fig. 5). In addition, Figure 6A shows that the anterior part scanned in TRIOS2 was displaced lingually, and as the range of scan widened, the posterior part scanned was displaced buccally. However, TRIOS3, CS3500, and CS3600 did not show lingual displacement, and a buccal displacement was observed as the scan range is widened (Fig. 6).

DISCUSSION

The present study compared 3D arch distortion across 4 types of intraoral scanner and 1 dental laboratory scanner in terms of the distance from the tooth at the beginning of the scan for a complete-arch impression. It was hypothesized that there would be no difference in the tooth

Table 1. Comparison of RMS values from scan of start tooth by using 4 intraoral scanners and 1 dental laboratory scanner

Evaluated Tooth	TRIOS2	TRIOS3	CS3500	CS3600	Laboratory	*P*
	RMS (μm), Mean ±Standard Deviation					
LSM	15.0 ±2.5[a]	9.6 ±1.2[b]	14.9 ±2.1[a]	14.9 ±2.8[a]	14.6 ±0.5[a]	<.001
LFM	34.0 ±6.8[a]	21.3 ±4.3[bc]	35.8 ±12.0[a]	19.7 ±2.9[b]	22.5 ±1.1[c]	<.001
LSP	75.3 ±15.4[a]	48.7 ±11.5[b]	71.4 ±28.4[ab]	24.3 ±7.3[c]	29.8 ±1.6[d]	<.001
LFP	124.1 ±23.6[a]	80.3 ±18.7[b]	118.5 ±47.6[ab]	31.6 ±9.7[c]	35.1 ±2.1[c]	<.001
LC	185.0 ±35.6[a]	123.5 ±31.7[b]	147.7 ±54.1[ab]	45.8 ±16.1[c]	42.4 ±2.4[c]	<.001
LLI	269.0 ±58.5[a]	166.8 ±44.4[b]	201.9 ±73.5[b]	65.5 ±26.3[c]	38.3 ±2.3[d]	<.001
LCI	311.7 ±67.5[a]	207.9 ±55.6[b]	238.8 ±80.5[ab]	83.2 ±34.0[c]	42.9 ±2.4[d]	<.001
RCI	359.8 ±78.0[a]	240.2 ±65.7[b]	255.1 ±81.6[b]	103.7 ±43.5[c]	48.8 ±2.5[d]	<.001
RLI	367.3 ±75.7[a]	238.6 ±66.0[b]	258.9 ±83.0[b]	120.0 ±49.8[c]	55.9 ±2.3[d]	<.001
RC	348.1 ±72.0[a]	222.1 ±62.2[b]	253.8 ±83.1[b]	125.7 ±52.8[c]	60.9 ±2.2[d]	<.001
RFP	398.4 ±65.6[a]	212.9 ±57.1[b]	217.3 ±83.4[b]	131.6 ±53.4[c]	59.9 ±2.5[d]	<.001
RSP	405.5 ±73.3[a]	208.2 ±62.3[b]	214.5 ±93.7[b]	151.2 ±62.6[b]	59.0 ±2.3[c]	<.001
RFM	451.9 ±97.3[a]	212.9 ±72.0[b]	234.0 ±90.4[b]	177.3 ±73.3[b]	59.5 ±2.0[c]	<.001
RSM	532.4 ±130.1[a]	226.6 ±88.4[b]	302.7 ±95.0[c]	204.9 ±80.0[b]	67.3 ±1.7[d]	<.001
Overall RMS value	343.4 ±56.4[a]	183.9 ±49.7[b]	209.9 ±53.7[b]	118.9 ±42.1[c]	47.5 ±1.6[d]	<.001

LC, left canine; LCI, left central incisor; LFM, left first molar; LFP, left first premolar; LLI, left lateral incisor; LSM, left second molar; LSP, left second premolar; RC, right canine; RCI, right central incisor; RFM, right first molar; RFP, right first premolar; RLI, right lateral incisor; RMS, root mean square; RSM, right second molar; RSP, right second premolar. Significant by Kruskal-Wallis test; *P*<.05. Different letters indicate significant differences (*P*<.005) by Mann-Whitney U-test and Bonferroni correction method.

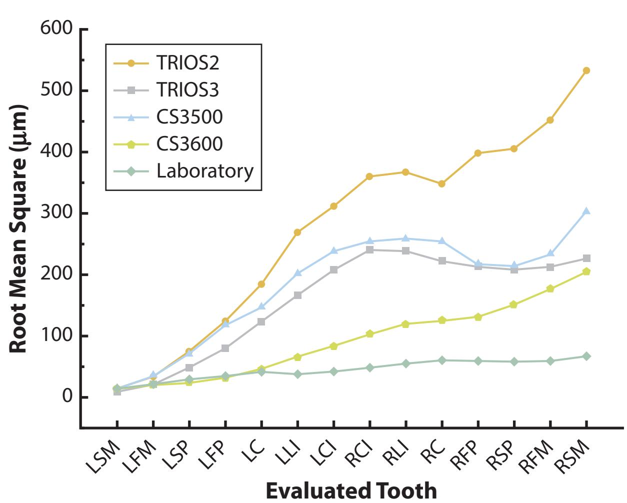

Figure 4. Comparison of RMS value per tooth according to scanner. LC, left canine; LCI, left central incisor; LFM, left first molar; LFP, left first premolar; LLI, left lateral incisor; LSM, left second molar; LSP, left second premolar; RC, right canine; RCI, right central incisor; RFM, right first molar; RFP, right first premolar; RLI, right lateral incisor; RMS, root mean square; RSM, right second molar; RSP, right second premolar.

RMS values between the virtual complete-arch model of 4 types of intraoral scanners and a dental laboratory scanner. However, according to the present findings, the null hypothesis was rejected (*P*<.001; Table 1).

Three-dimensional analysis has been reported that compared a master model using an intraoral scanner,[11-14] but data on an acceptable scan range for fixed prostheses are lacking. Several studies have assessed complete-arch impression for orthodontic treatment.[15,16,36-38] Ender et al[11] analyzed 15 virtual complete-arch casts from each intraoral scanner in a clinical environment, whereas Flügge et al[12] analyzed 10 digital casts through comparison with a definitive cast in a clinical environment. These studies showed that the intraoral conditions (saliva, limited access in the oral cavity) contributed to the inaccuracy of the scan. However, as the present study involved a master model in vitro, the errors from the clinical environment were not considered.

Studies have reported that the speed of learning and results of each experiment vary with the products.[39,40] Even experienced dentists need training in the use of the intraoral scanner, and accuracy improves with practice.[25,40] Therefore, in this study, to reduce the accuracy difference according to the proficiency of the intraoral scanner, the first 10 scans were deleted, and the following 20 scans were used for evaluation.

This research differs from other studies involving 3D analysis. In the studies by Lim et al,[25] Jeong et al,[10] and Ender et al,[11] the accuracy of complete-arch casts was compared by using an intraoral scanner, and best-fit alignment was performed to conduct a 3D analysis. Thus, the overall accuracy was determined; however, if there is a large discrepancy in one part, although the best fit alignment process results in fewer errors, errors can occur in other parts. Therefore, it is difficult to determine whether the partial color mismatch in the color difference map of the 3D comparison reveals a relatively exact discrepancy. In the present study, the 3D analysis was performed by the best-fit alignment with a reference point (scan start tooth), and displacements of all the teeth were compared. In this study, only the initial tooth had

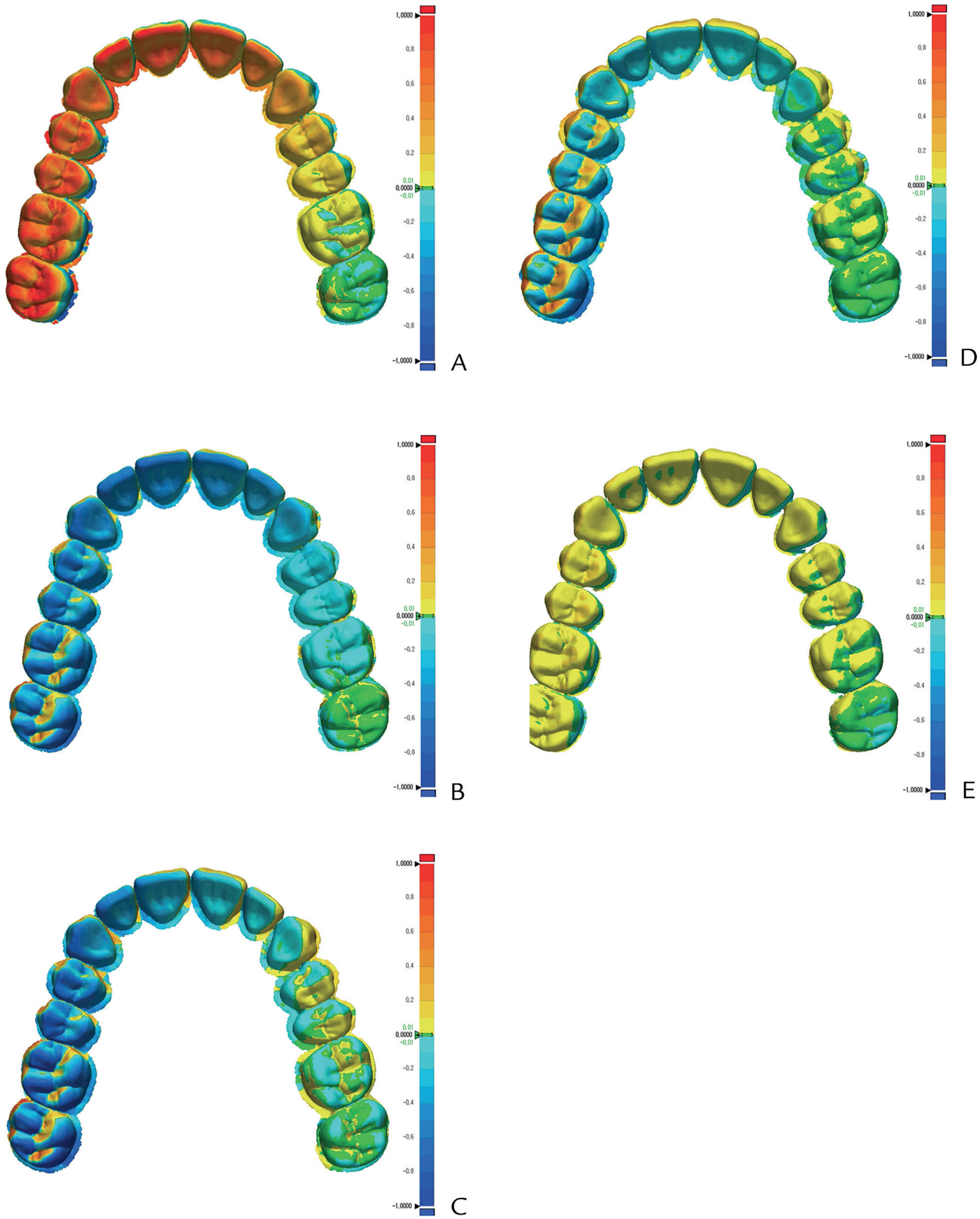

Figure 5. Comparison of color difference map according to scanner. A, TRIOS2. B, TRIOS3. C, CS3500. D, CS3600. E, Laboratory.

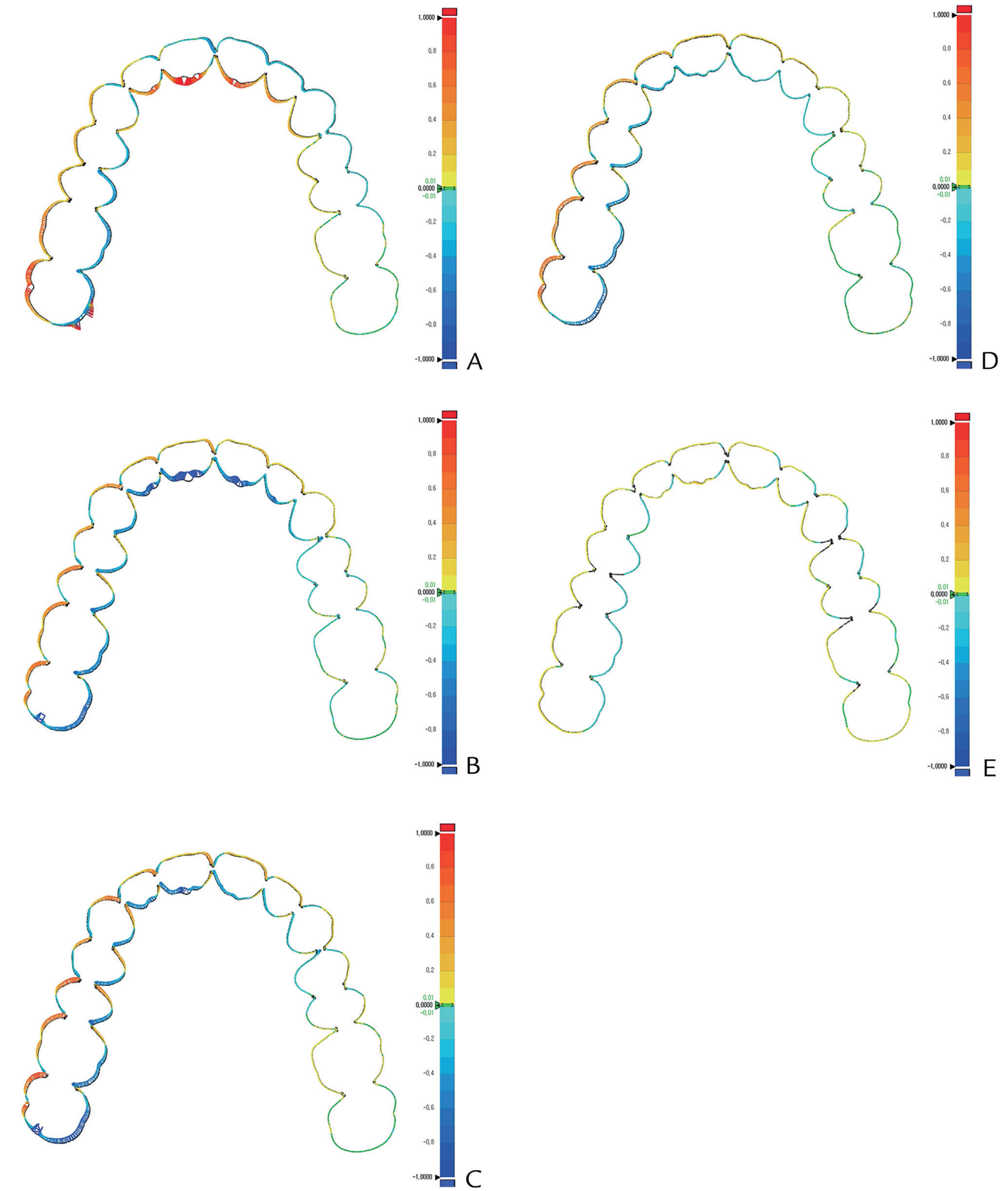

Figure 6. Comparison of distortion score in 2D according to scanner. A, TRIOS2. B, TRIOS3. C, CS3500. D, CS3600. E, Laboratory.

best-fit alignment, and hence, the relative discrepancy could be compared.

In the study by Ender et al,[11] which evaluated the efficacy of complete-arch scanning using an intraoral scanner, the model's trueness was important for the production of fixed prostheses. Therefore, the definitive restoration of the maxillary and mandibular teeth would not fit if it deviates more than 100 μm from the complete arch. Fukazawa et al[41] suggested a permissible range of less than 100 μm, which would accommodate for the cement space of the prosthesis. In the present study, all dental laboratory scans were within the acceptable limits. Trois2 (75.3 ±15.4 μm) and CS3500 (71.4 ±28.4 μm) scans were within the reference range from the beginning of the scan to the third tooth; TRIOS3 (80.3 ±18.7 μm) scans were within the reference range up to the fourth tooth, and CS3600 (83.2 ±34.0 μm) scans were to the range of the half arch.

The RMS is a standard mathematical tool that measures the similarity of two 3D data points and is an established method.[42] Therefore, this calculation method has been used in many dental studies to measure the similarity of 3D data.[11,23-25]

Tooth displacement is caused by the deformation of the tooth itself from scanning error. The reason for this is that the intraoral scanner produces a virtual model by combining the images made by stitching.[43] This means that the errors of the tooth itself when the images are combined markedly affect the distortion of the complete arch. In this study, the RMS value obtained by the tooth-by-tooth difference measurement can be considered the error value of the tooth itself and the resultant tooth displacement. A limitation of this study was that the proposed alignment method affects the accuracy of all other teeth depending on the accuracy of the first scanned tooth. However, considering the acceptable scan range for fixed prostheses, many tooth displacements can occur in the first scanned tooth error. Therefore, the RMS value combined with various errors can be considered reliable for the fabrication of an accurate fixed prosthesis.

In this study, a 2D horizontal displacement was confirmed based on a plane. The plane only evaluated visual horizontal displacement and not rotation and vertical displacement. Only horizontal movements were assessed to investigate the overall horizontal displacement of the complete arch from the tooth where the scan started. 3D measurements were recorded with color maps and RMS values, and the vertical movement was also seen with the color map. In future, horizontal, vertical, and rotational displacements should be accurately measured.

Although this study suggests a range of scans for intraoral scanners for fixed prostheses, the findings have not been confirmed for an actual prosthesis. Future studies are necessary to produce the corresponding prostheses in the scan range and to assess the actual clinical efficacy.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. The distortion of the intraoral scan started from the tooth where the scan started.
2. Complete-arch scans were not found to be appropriate for fabricating fixed prostheses.
3. However, the scan area for single prostheses (TRIOS2, TRIOS3, and CS3500) or short-span prostheses (CS3600) was similar to the RMS value of the dental laboratory scanner; as a result, intraoral scanners may help prepare a fixed prosthesis within the scan range of the half arch.

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Corresponding author:
Dr Kyu-Bok Lee
Department of Prosthodontics, School of Dentistry
Advanced Dental Device Development Institute
Kyungpook National University
2177 Dalgubuldaero, Jung-gu, Daegu 41940
REPUBLIC OF KOREA
Email: kblee@knu.ac.kr

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