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Original Article

Evaluating the accuracy of three intraoral scanners using models containing different numbers of crown-prepared abutments

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Abstract *Background/purpose:* The scanning accuracy of intraoral scanners' data collection plays a key role in the success of the final treatment. However, few studies start from scanning technology itself to directly evaluate it. The aim of this study was to evaluate the scanning accuracy of three intraoral scanners, to provide a reference for relevant research and clinical applications.

Materials and methods: Six types of resin models containing different numbers of crown-prepared abutments were three-dimensionally printed, and a model scanner, as well as three intraoral scanners, were used to digitally scan the six models. The obtained data were uploaded to three-dimensional reverse software for registration and comparison, and the accuracy of the models were analyzed.

Results: When scanning the six groups of models, the Omnicam outperformed both the TRIOS and iTero in terms of accuracy in all groups except the second molar group. The TRIOS and iTero scanners also exhibited decreased degrees of accuracy when scanning the long dental arch. The accuracy decreased as the scanning scope increased; however, the Omnicam scanner exhibited a relatively high degree of accuracy when scanning the three-unit fixed bridge and anterior areas. All scanners exhibited the lowest degree of accuracy when scanning the full-arch model. Certain deviations were observed, and the scanning areas at the incisal edges of the anterior teeth and end of the dental arch exhibited relatively large deviations.

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Conclusion: With the model scanner data as reference, the scanning accuracy of the three scanners exhibited differences and certain deviations, which were within clinical tolerance.

Introduction

Impressions demand highly accurate duplication of oral conditions.[1] Intraoral scanners have undergone rapid development and popularization, which nowadays demonstrate several advantages when compared with traditional impression techniques, such as higher accuracy,[2–4] real-time visualization,[5,6] improved comfort, and safety of patients;[7] however, there are also some difficulties that arise with their use. The enamel is semitransparent and in the wet, intraoral environment, is highly reflective, exhibiting a low degree of scanning accuracy.[8] Evaluating the data accuracy of scanners is therefore required.

Scanning accuracy during measurement includes two aspects: accuracy and precision. Accuracy reflects systematic error, whereas precision reflects random error. Currently, the average accuracy of intraoral scanners is approximately 20 μm; however, the scanning accuracy described by manufacturers is the value obtained when small objects are scanned,[9] and may differ from the accuracy factor when scanning large objects, such as full dentition. Previous studies were primarily conducted to evaluate the accuracy of intraoral impressions by measuring the marginal adaptation of final restorations.[10,11] To accurately analyze the devices themselves, it is more favorable to directly compare the data generated by these scanners.[12]

At present, three types of scanners-the TRIOS (3 Shape, Copenhagen, Denmark), iTero (Align Technology, San Jose, CA, USA), and CEREC Omnicam (Dentsply Sirona, York County, PA, USA)-are primarily used. The aim of this experiment was to evaluate the scanning accuracy of these three intraoral scanners using the in vitro research method, with the scanning data of the model scanner used as reference values. The results of this study are expected to serve as a reference for relevant research and clinical applications.

Materials and methods

A dental research model (Nissin Dental Products, Inc., Kyoto, Japan) that covers full crown restoration abutments (right angle shoulder) was chosen, and divided into six groups according to the abutment distribution (Fig. 1). The scans of six plaster models were obtained using a D1000 scanner (3 Shape), and six experimental models were obtained using a three-dimensional printer (Perfactory-ddp4 photocuring 3D printer, Envision TEC, Gladbeck, Germany).

Collection of digital impressions

The scanner was first calibrated, and the six groups of reference scanning models were scanned by the same proficient operator according to the scanning methods and sequences recommended by the manufacturer. The impressions of the control group (R group) were obtained using the D1000 scanner; all models in reference Groups 1–6 were scanned 10 times, and the scanning procedures were repeated to verify the reliability of the scanner (R' group). The impressions of the models in Groups 1–6 were scanned 10 times ($n = 10$) using the three types of intraoral scanners. A scanning flowchart of this experiment is shown in Fig. 2.

Statistical analysis

All the scanning data were entered into the Geomagic Studio 2014 software (Raindrop Geomagic, Development Triangle, NC, USA), and were checked and trimmed again to ensure that all data overlapped with the same edges and accuracy. A deviation analysis function was used to visualize the differences between the control and experimental groups in a three-dimensional direction, with the results displayed in standard 15-fragment deviation chromatogram to visualize the differences in a three-dimensional direction. The data obtained in deviation analysis covered maximum distance positive and negative values, average distance positive and negative values, SD, and root mean square (RMS), and meanwhile report was created for display. Then, all data were analyzed using SPSS software (IBM SPSS Statistics version 22, IBM, Armonk, NY, USA). To evaluated the accuracy of the three types of intraoral scanners, Kolmogorov-Smirnoff was used to verify the normal distribution of each group of values, and Levene's test was used to check the homoscedasticity. If it conformed to the normal distribution and homoscedasticity, one-way analysis of variance SNK verification would be conducted; if not, Friedman analysis was applied. To verified the reliability of model scanner, t-test was used to compare the differences of the same model in scanning the data in R and R′ groups; if not, Kruskal–Wallis would be adopted. The results were considered significant if the P-value was less than 0.05.

Results

The statistical results for the accuracy of the three scanners when scanning the six different types of models are presented in Table 1. The boxplot for the accuracy of the three types of scanners, as well as the same scanner, in groups 1–6 when scanning the six groups of models is shown in Fig. 3.

Table 2 shows the results for the comparison of accuracy and precision values for the three types of scanners, while Tables 3 and 4 show the results when using the same, single scanner to scan models with different numbers of

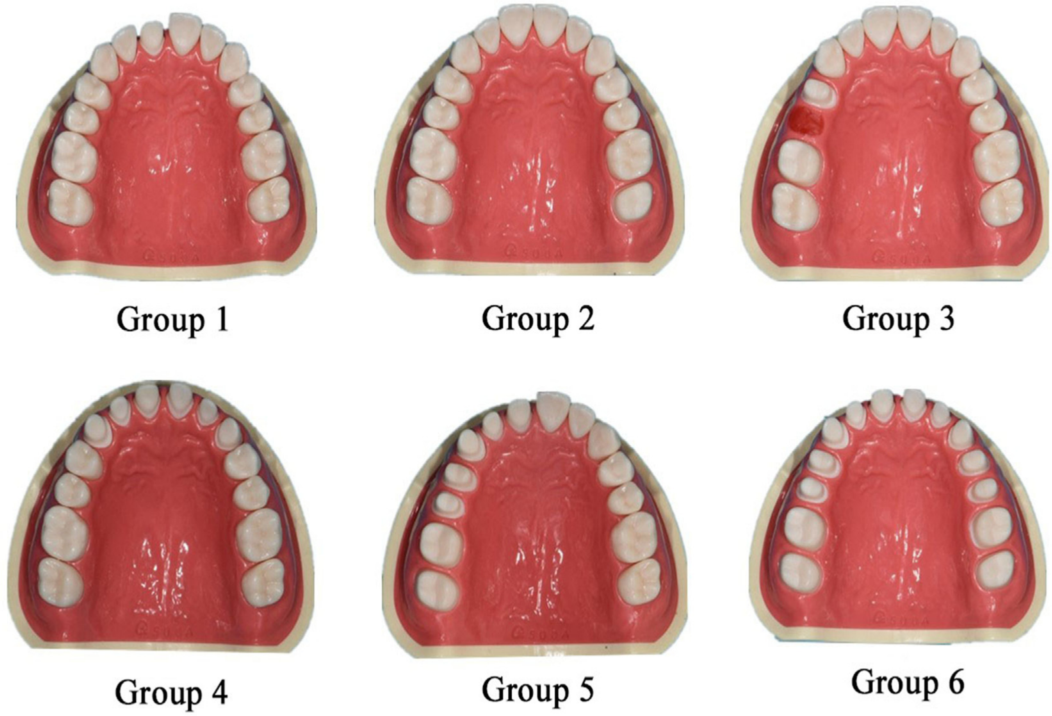

Figure 1 Standard model grouping. Group 1: The right maxillary central incisor as the abutment, with the remaining teeth complete; Group 2: The second left maxillary molar as the abutment, with the remaining teeth complete; Group 3: The first right maxillary premolar and first right maxillary molar as the abutment, with the missing second right maxillary premolar filled with wax, and the remaining teeth complete; Group 4: The right to left maxillary cuspid as the abutment, with the remaining teeth complete; Group 5: All of the right maxillary side teeth as the abutment, with the teeth on the left side complete; Group 6: All of the maxillary teeth as the abutment.

abutments. In Group 1, all three scanners exhibited deviations at the shoulder and incisal margin (Fig. 4A—C), whereas in Group 4, the deviations of the three scanners varied. TRIOS exhibited deviations at the axial surfaces of the two cuspids; iTero exhibited deviations at the incisal edges and distal surfaces of two cuspids, as well as at the buccal surfaces of the right maxillary cuspids (Fig. 4D—F). In Group 5, all three scanners exhibited a relative deviation at the mesiodistal shoulder of the central incisor, and distal area of the second molar; iTero also exhibited deviations at the incisal edges of the anterior teeth and dental cusp of the molars (Fig. 4G—I). In Group 6, there were varied deviations in the molar areas. The TRIOS and Omnicam data exhibited horizontal shrinkage distortion at the premolar and molar areas, while Omnicam also exhibited a relatively large deviation at the incisal edges of the anterior teeth. Deviations in the iTero data exhibited vertical distortions, with vertically downward distortions that were azygomorphous along the axis of the right maxillary central incisor, and second left maxillary molar (when compared with the reference model). In addition, there was a vertically upward distortion observed in the axial areas (Fig. 4J—L).

Discussion

With the widespread application of digital models, the use of intraoral scanners to obtain accurate three-dimensional images is crucial. Previous studies have used metal-[13—19] or plaster-based[18,20] reference models; however, owing to deformation and reflection, their results were not ideal. Photosensitive resin materials are reliable, durable, and have no serious optical reflection issues. This study adopted the use of the D1000 intraoral scanner the reference scanner; its accuracy is as high as 5 μm (which has been verified according to the ISO12836 standard), which is much higher than obtained through single abutment scanning in previous studies.[4,12,21] Additionally, Nedelcu et al.[22] observed that the scanning precision of the D1000 averaged at 0.5 μm, which is much higher than that of the intraoral scanner.

This study compared the initial scanning (R) and rescanning (R') datasets with the reference model; no significant differences were observed. With regard to the accuracy of intraoral digital impressions, several studies have evaluated single abutments,[12,23] as well as short-span, fixed, partial dentures;[18,19] some studies have also compared full dental arch model scanning results using different intraoral scanners.[14,15,21] Due to the differences in methodologies, it is difficult to individually compare these studies to draw a general conclusion on the intraoral scanner accuracy. Previous studies that have examined single abutments and quadrant scanning accuracy demonstrated that the accuracy for single abutment scanning ranged from 19.2[23]—27.9[12] μm, whereas the precision was 10.8 ± 1.8 μm.[23] Compared with the previous

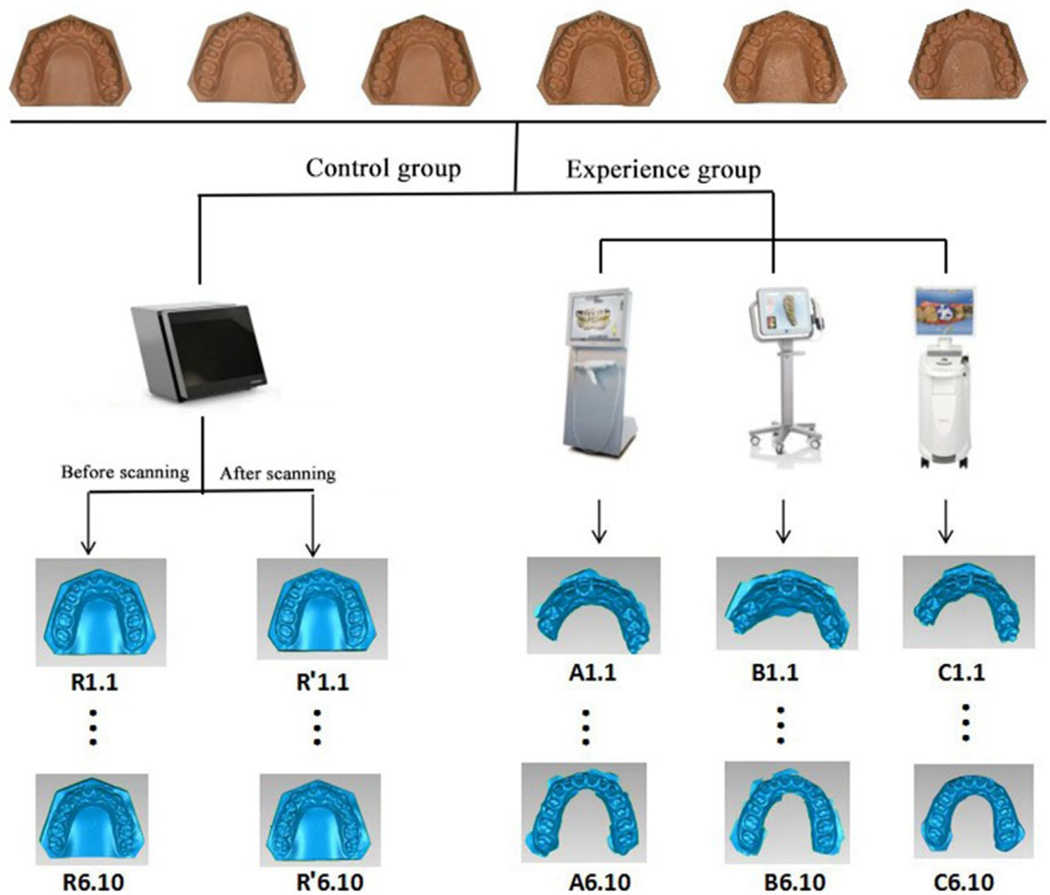

Figure 2 Scanning flowchart.

Table 1 Statistical results of three-dimensional overlapping between scanners in the experiment and control groups (μm).

		Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
A. TRIOS	Mean	14.77	12.82	13.10	18.79	23.2	64.94
	SD	3.69	2.43	3.92	3.58	5.26	15.62
B. iTero	Mean	18.92	13.79	12.06	13.16	23.23	40.87
	SD	4.32	4.09	2.88	2.47	6.17	8.01
C. Omnicam	Mean	13.12	16.01	9.52	11.63	15.65	26.07
	SD	4.11	4.39	2.98	2.72	4.05	7.84

SD: standard deviation.

study,[23] the accuracy and precision values in our study were demonstrated to have significantly improved, which may be related to equipment modifications.

Scholars like Renne et al.[21] demonstrated that the TRIOS 3 (3 Shape) had the worst scanning for single abutments of the first molar; more specifically, the accuracy of the iTero was lower (57.5 μm vs. 56.2 μm), and the precision higher (84.6 μm vs. 89.8 μm) than the Omnicam. This is similar to the trends observed in this study; however, there are considerable differences in the values. This may be because the previous study focused on the maximal positive and negative deviation values, whereas our study used the average positive and negative deviation values.

The accuracy of the digital impression also depends on the data-matching algorithm,[2] which may be crucial for the scanning results of the full dental arch. In fact, intraoral scanners lack a fixed reference; therefore, the first image taken by scanners is used as the reference, while all subsequent images are "sewed" onto the previous image using an optimal fitting algorithm (showing the optimal possible overlap of the two images). There is one fixed error in every overlapping procedure, and the final error increases with splicing; hence, it can be predicted that a larger scanning area will require more splicing processes, ultimately resulting in more considerable errors.[24] The results of this study indicate that an increase in the scanning length leads

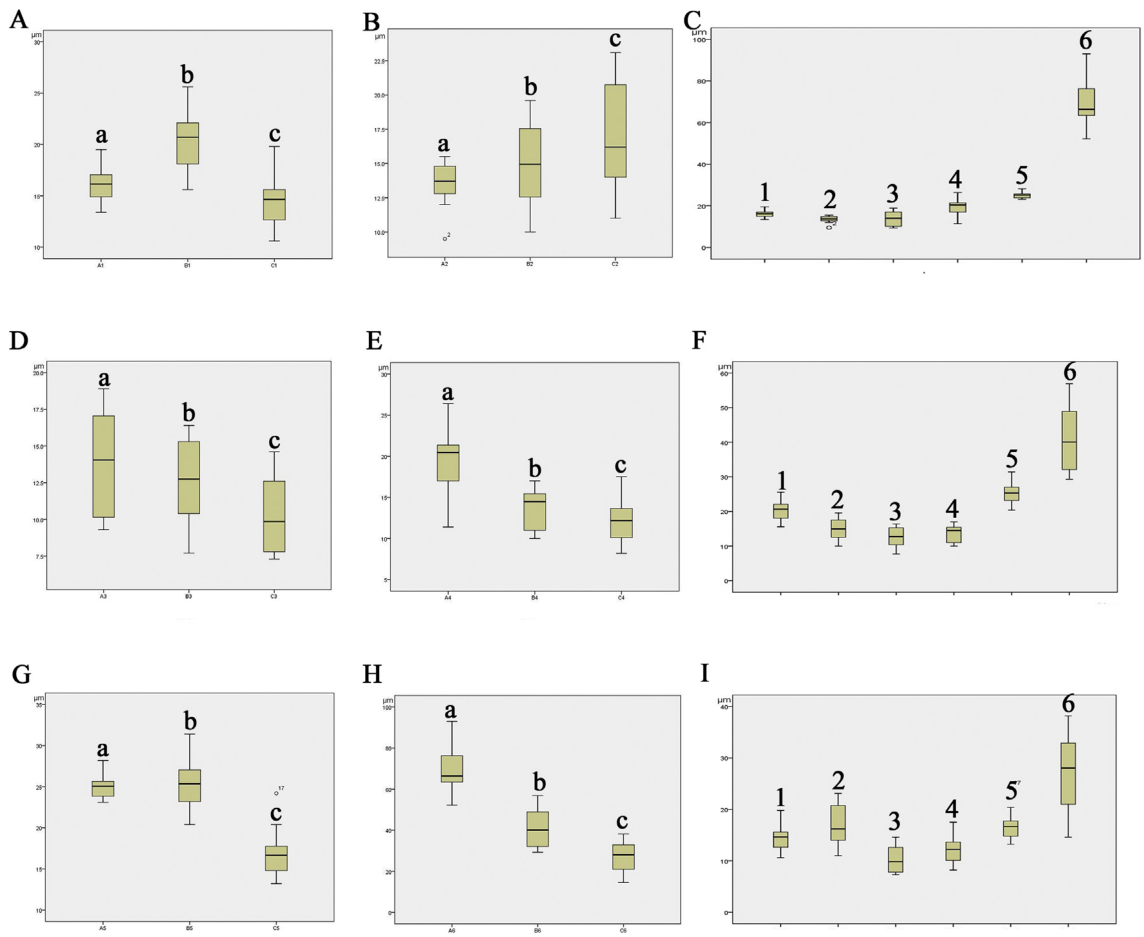

Figure 3 Boxplot for the accuracy of the three types of scanners, as well as the same scanner, when scanning the six groups of models. A: the accuracy of the three types of scanners when scanning the model of Group 1. B: the accuracy of the three types of scanners when scanning the model of Group 2. C: the accuracy of TRIOS when scanning the six groups of models. D: the accuracy of the three types of scanners when scanning the model of Group 3. E: the accuracy of the three types of scanners when scanning the model of Group 4. F: the accuracy of iTero when scanning the six groups of models. G: the accuracy of the three types of scanners when scanning the model of Group 5. H: the accuracy of the three types of scanners when scanning the model of Group 6. I: the accuracy of Omnicam when scanning the six groups of models. a: TRIOS, b: iTero, c: Omnicam, 1: Group 1, 2: Group 2, 3: Group 3, 4: Group 4, 5: Group 5, 6: Group 6.

Table 2 Comparison of accuracy and precision between the three types of scanners.

	A and B		A and C		B and C	
	Accuracy	Precision	Accuracy	Precision	Accuracy	Precision
Group 1	+	+	+	+	+	+
Group 2	+	−	+	+	+	+
Group 3	+	−	+	+	+	+
Group 4	+	+	+	+	−	−
Group 5	−	−	+	+	+	+
Group 6	+	+	+	+	−	+

A:TRIOS; B: iTero; C: Omnicam.

to a decrease in scanning accuracy, particularly with respect to the full dental arch. This is consistent with results from previous studies;[23,25] therefore, the accuracy required by every type of restoration has to be studied. Moreover, the intraoral scanner should be prudently adopted for full dental arch scanning.

According to the information in the color deviation diagram generated by Geomagic, the deviations were mainly

Table 3 Comparison of accuracy for the three types of scanners among the six groups.

	Group 1			Group 2			Group 3			Group 4			Group 5			Group 6		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Group 1				−	−	−	−	−	+	+	+	−	+	+	−	+	+	+
Group 2	−	−	−				−	−	+	+	+	+	+	+	−	+	+	+
Group 3	−	−	+	−	−	+				+	+	−	+	+	+	+	+	+
Group 4	+	+	−	+	+	+	+	+	−				+	+	+	+	+	+
Group 5	+	+	−	+	+	−	+	+	+	+	+	+				+	+	+
Group 6	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			

A:TRIOS; B: iTero; C: Omnicam.
+: Statistically significant difference between the two groups.
−: No statistically significant difference between the two groups.

Table 4 Comparison of precision for the three types of scanners among the six groups.

	Group 1			Group 2			Group 3			Group 4			Group 5			Group 6		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Group 1				−	+	−	−	−	−	−	−	−	−	−	−	+	+	+
Group 2	−	+	−				−	−	−	−	−	+	−	+	−	+	+	+
Group 3	−	−	−	−	−	−				−	−	+	−	−	−	+	+	+
Group 4	−	−	−	−	−	+	−	−	+				−	−	+	+	+	+
Group 5	−	−	−	−	+	−	−	−	−	−	−	+				+	+	+
Group 6	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			

A:TRIOS; B: iTero; C: Omnicam.
+: Statistically significant difference between the two groups.
−: No statistically significant difference between the two groups.

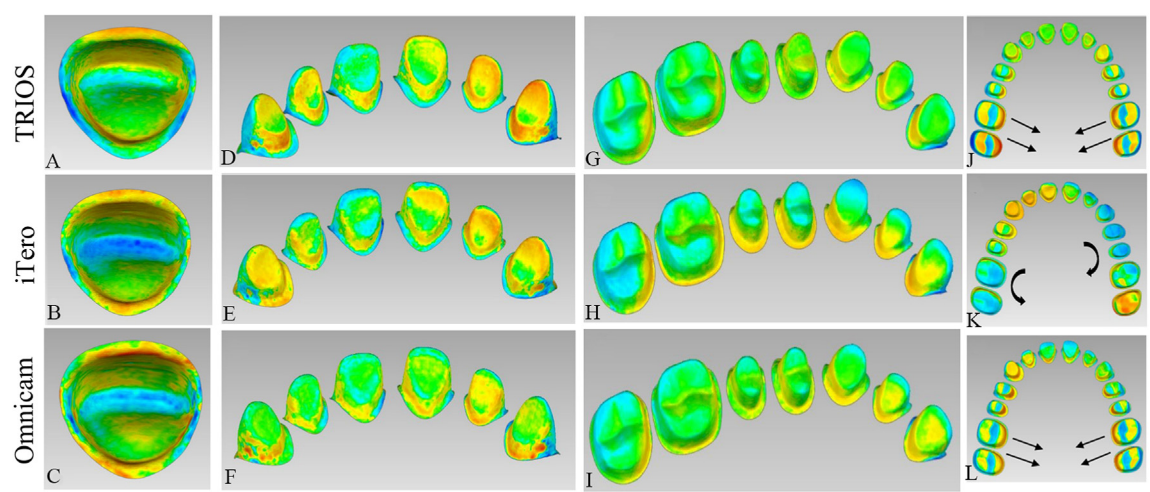

Figure 4 Deviation diagram of three scanners. A–C: Central incisor abutment model. D–F: Premolar abutment model. G–I: Right side half dentition abutment model. J–L: Full dentition abutment model (J and L: arrow pointing to the direction of shrinkage; K: arrow pointing to the direction of distortion).

located at the incisal edges of the anterior teeth, and end of the dental arch, which is consistent with the results reported by Ender and Mehl.[14,16] The deviation at the incisal edges of the anterior teeth may be attributed to their relatively steep structure, as sharp curves allow for an increased likelihood of light scattering. Full dentition digital impressions exhibited different deviations, and all deviations at the distal end of the dental arch increased. The iTero system exhibited a more vertical deviation at the distal end of the dental arch, whereas the Omnicam and TRIOS systems exhibited horizontal compression against the dental arch. These deviations may be attributed to error expansion when the images were spliced; however, the splicing algorithm for the three types of scanners is not yet definite, and the reasons for the different deviations cannot currently be explained. Still, the errors are systemic and can be reduced or avoided via further software modifications.

The drawback of this study lies in the limitation of models' material. The material in this study is photosensitive resin materials. Compared to the metal- and plaster-based materials, the photosensitive resin materials can reduce experimental errors. However, there are some other materials that may resemble the semi-transparency of enamel in a wet environment therefore resemble the intraoral condition, which should be considered in order to mimic the clinical scenario with intraoral scanners better.

In summary, this study suggests that compared with the D1000 scanner data used as a reference, the scanning accuracy of the three included scanners (TRIOS, iTero, and CEREC Omnicam) exhibited certain differences and deviations, all of which remained within clinical tolerance. This study is expected to provide a reference for the selection, research, and improvement of intraoral scanners for different abutments.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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