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RESEARCH AND EDUCATION

Scanning accuracy and scanning area discrepancies of intraoral digital scans acquired at varying scanning distances and angulations among 4 different intraoral scanners

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ABSTRACT

Statement of problem. The accuracy of intraoral scanners (IOSs) can be affected by operator handling; however, the scanning area and accuracy discrepancies acquired at different scanning distances and angulations among IOSs remain uncertain.

Purpose. The objective of this in vitro study was to compare the scanning area and scanning accuracy of the intraoral digital scans obtained at 3 scanning distances with 4 different scanning angulations among 4 different IOSs.

Material and methods. A reference device (reference file) was designed with 4 inclinations (0, 15, 30, and 45 degrees) and printed. Four groups were created based on the IOS: i700, TRIOS4, CS 3800, and iTero scanners. Four subgroups were generated depending on the scanning angulation (0, 15, 30, and 45 degrees). Each subgroup was divided into 3 subgroups based on the scanning distance: 0, 2, and 4 mm (N=720, n=15). The reference devices were positioned in a z-axis calibrated platform for standardizing the scanning distance. In the i700-0-0 subgroup, the 0-degree reference device was positioned in the calibrated platform. The wand of the IOS was positioned in a supporting framework with a 0-mm scanning distance, and the scans were acquired. In the i700-0-2 subgroup, the platform was lowered for a 2-mm scanning distance followed by the specimen acquisition. In the i700-0-4 subgroup, the platform was further lowered for a 4-mm scanning distance, and the scans were obtained. For the i700-15, i700-30, and i700-45 subgroups, the same procedures were carried out as in the i700-0 subgroups respectively, but with the 10-, 15-, 30-, or 45-degree reference device. Similarly, the same procedures were completed for all the groups with the corresponding IOS. The area of each scan was measured. The reference file was used to measure the discrepancy with the experimental scans by using the root mean square (RMS) error. Three-way ANOVA and post hoc Tukey pairwise comparison tests were used to analyze the scanning area data. Kruskal–Wallis and multiple pairwise comparison tests were used to analyze the RMS data (α=.05).

Results. IOS (P<.001), scanning distance (P<.001), and scanning angle (P<.001) were significant factors of the scanning area measured among the subgroups tested. A significant group×subgroup interaction was found (P<.001). The iTero and the TRIOS4 groups obtained higher scanning area mean values than the i700 and CS 3800 groups. The CS 3800 obtained the lowest scanning area among the IOS groups tested. The 0-mm subgroups obtained a significantly lower scanning area than the 2- and 4-mm subgroups (P<.001). The 0- and 30-degree subgroups obtained a significantly lower scanning area than the 15- and 45-degree subgroups (P<.001). The Kruskal–Wallis test revealed significant median RMS discrepancies (P<.001). All the IOS groups were significantly different from each other (P<.001), except for the CS 3800 and TRIOS4 groups (P>.999). All the scanning distance groups were different from each other (P<.001).

Conclusions. Scanning area and scanning accuracy were influenced by the IOS, scanning distance, and scanning angle selected to acquire the digital scans. (J Prosthet Dent 2023;■:■-■)

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Clinical Implications

The skill of the operator handling the IOSs tested can affect the outcome of an intraoral digital scan, including the scanning accuracy (trueness and precision) and scanning area captured. Therfore, the operator handling the IOS has an impactful influence on the accuracy and scanning area captured.

The implementation of intraoral scanners (IOSs) in dental care has increased in recent years.[1] IOSs provide a digital option for acquiring virtual diagnostic casts,[2] manufacturing tooth- and implant-supported dental prostheses,[3-7] digitizing existing complete dentures,[7-9] and assessing volumetric changes over time.[10-13] However, the performance and accuracy of the IOSs can be reduced by operator skill and decision making, as well as the intraoral conditions of the patient being scanned.[14,15] Among the operator factors, inadequate handling[16-18] of the IOS, including the scanning distance[19,20] used to acquire the data, can reduce scanning accuracy. Scanning distance has been defined as the distance between the scanning tip and the surface being digitized.[14] Although the optimal scanning distance is based on the IOS hardware, the handling of the operator affects the scanning distance used while acquiring the intraoral digital scans. Intraoral scanning accuracy has been reported to affect the scanning distance.[19,20] However, the IOSs assessed were limited and the scanning angulation was not considered. Additionally, the scanning area and accuracy discrepancies acquired at different scanning distances and angulations among IOSs remain unknown.

The aim of this in vitro study was to compare the scanning area captured and accuracy (trueness and precision) at 3 scanning distances (0, 2, and 4 mm) with 4 different angulations (0, 15, 30, and 45 degrees) of 4 different IOSs. The null hypotheses were that no difference would be found in the scanned area captured among the intraoral digital scans acquired at different scanning distances with varying scanning angulations and IOSs and that no difference would be found in the scanning accuracy (trueness and precision) among the intraoral digital scans acquired at different scanning distances with varying scanning angulations and IOSs.

MATERIAL AND METHODS

A square device (60×60 mm) was created by using an open-source computer-aided design (CAD) software program. The coronal surface of the reference device was designed with a grid pattern texture and served as the reference file. The device design was prepared with 4 different angulations: 0, 15, 30, and 45 degrees. The 4 designs were exported in a standard tessellation language (STL) file format and manufactured by using a 3-dimensional polymer printer (Nexdent 5100; 3D Systems) and a cast resin material (Model Resin 2.0; Nexdent) according to the manufacturer's recommended protocol.[21] The printer had been previously calibrated according to the manufacturer's protocol. After printing, the reference device was removed from the build platform with the removal tool provided by the manufacturer. The reference devices were fully submerged in an ultrasonic bath with isopropyl alcohol (IPA) (Isopropyl alcohol 99%; Cumberland Swan) for 3 minutes and subsequently submerged in a second bath with clean 99% IPA for 2 minutes. Specimens were placed on a paper towel and dried in ambient air. Specimens were then placed in the UV-polymerization machine (LC-3DPrint Box; Nexdent) for 10 minutes at 60 °C according to the manufacturer's recommendations. The support material was removed with a removal tool provided by the manufacturer (Fig. 1A).

Figure 1. A, Printed reference devices (0, 15, 30, and 45 degrees) for scanning angulation standardization. B, Representative image of 0-degree printed reference device positioned on calibrated platform for scanning distance standardization.

Four different groups were created based on the IOS selected: i700 (Medit i700, wireless, v.3.0.3; Medit),

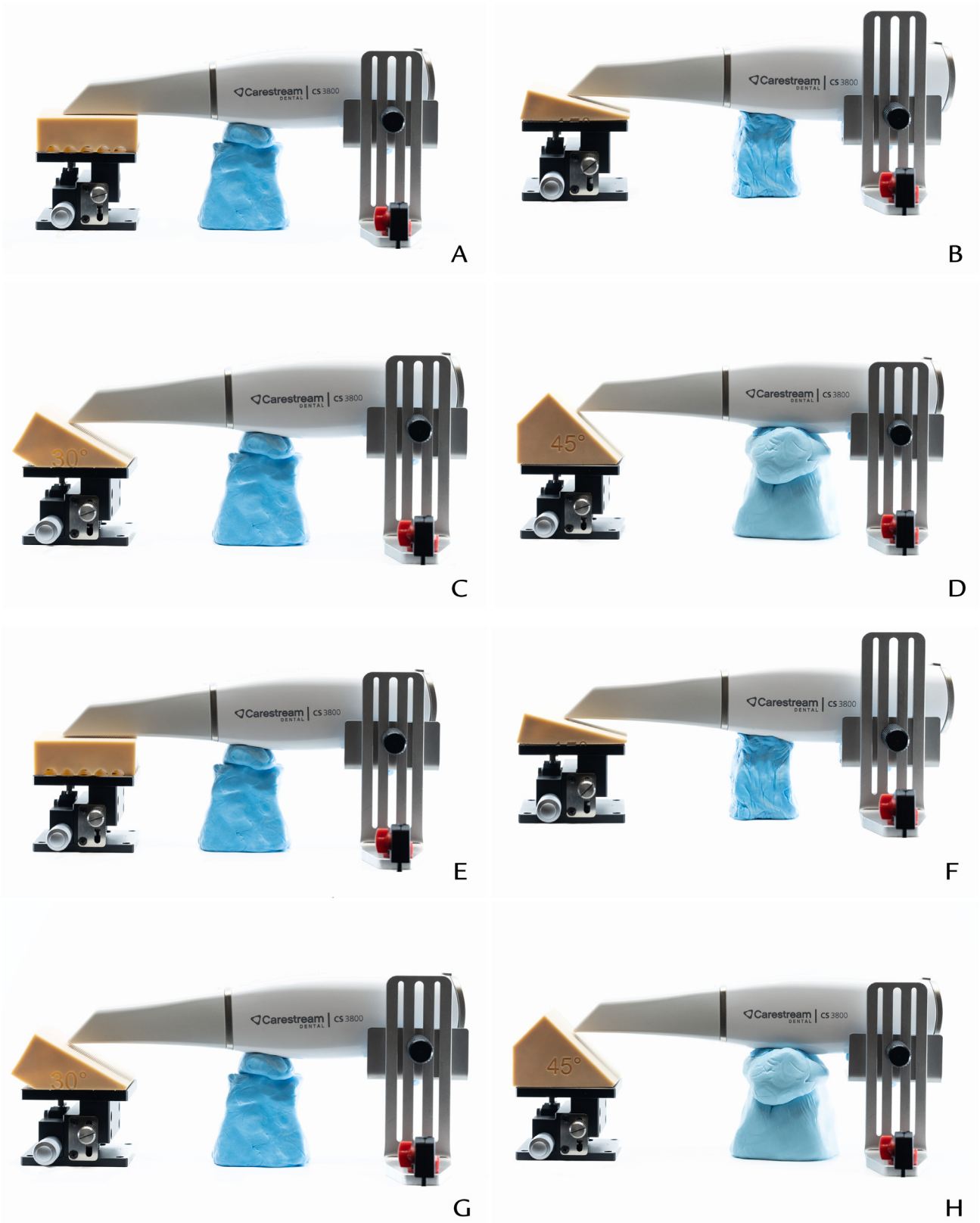


Figure 2. Representative setting for data acquisition procedures by using CS 3800 IOS. A, CS 3800-0-0 subgroup. B, CS 3800-0-15 subgroup. C, CS 3800-0-30 subgroup. D, CS 3800-0-45 subgroup. E, CS 3800-2-0 subgroup. F, CS 3800-2-15 subgroup. G, CS 3800-2-30 subgroup. H, CS 3800-2-45 subgroup.

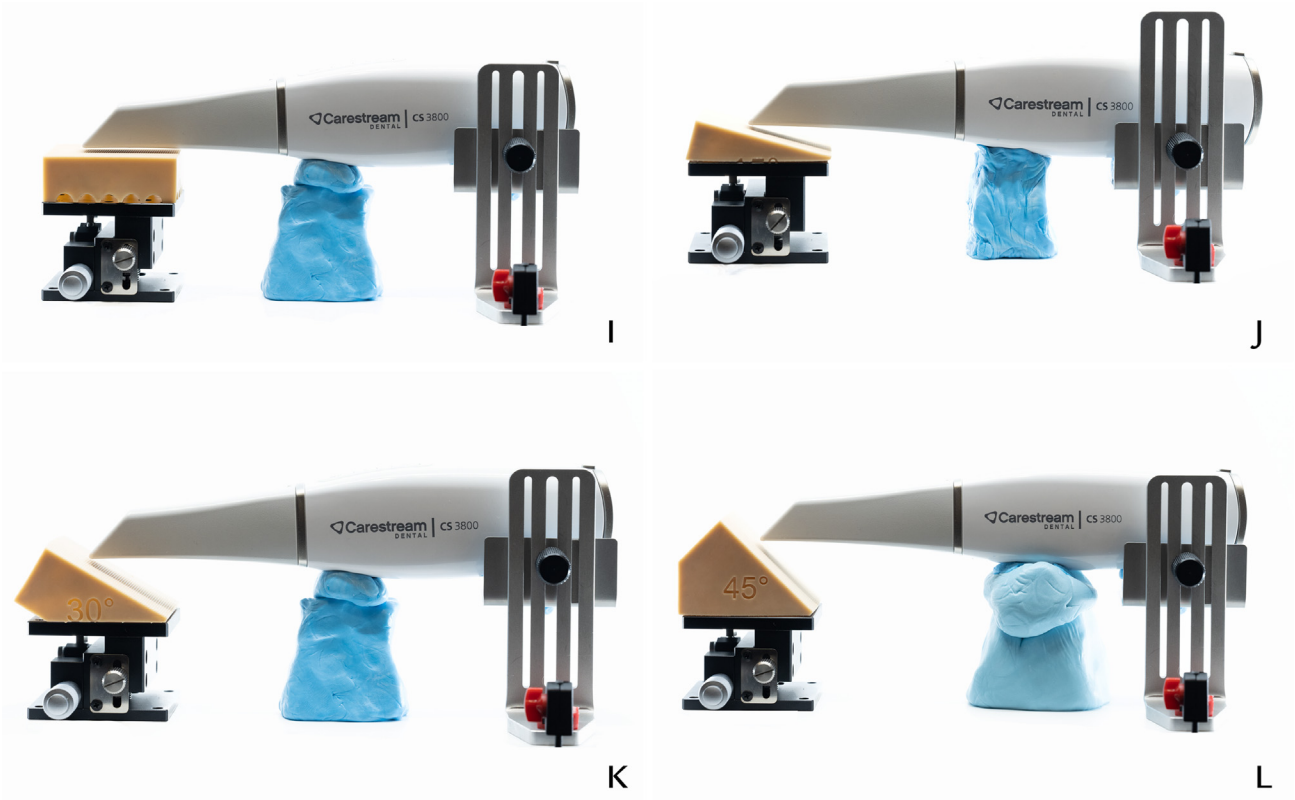


Figure 2. *(Continued).* I, CS 3800-4-0 subgroup. J, CS 3800-4-15 subgroup. K, CS 3800-4-30 subgroup. L, CS 3800-4-45 subgroup.

TRIOS4 (TRIOS 4, wireless, v.1.7.31.1; 3Shape A/S), CS 3800 (CS 3800, CS Imaging v.8.0.5.10; Carestream), and iTero (iTero Element 5D, v.2.7.9.601; Align Technologies) groups. The scanning depth of the i700 device was determined at the maximum focal length (23 mm) using the IOS software program; the other IOSs tested did not allow any modification of the focal length of the system. All the intraoral digital scans were acquired under 1000-lux ambient illumination conditions[22-25] standardized by using a meter (LX1330B Light Meter; Dr.Meter Digital Illuminance). Additionally, the i700, TRIOS4, and CS 3800 devices were calibrated before starting the data collection and after every 10 intraoral digital scans. The calibration was completed by using the specific calibration devices according to the calibration protocol recommended by the IOS manufacturer.[26] The iTero IOS device did not allow calibration by the operator but incorporated a self-calibration system.

Each group was divided into 4 subgroups depending on the scanning angulation (0, 15, 30, and 45 degrees). The scanning angulations were standardized by using the respective reference device, which reflected the tested 0-, 15-, 30-, or 45-degree inclinations of the surface being scanned. Additionally, each subgroup was subdivided into 3 additional subgroups depending on the scanning

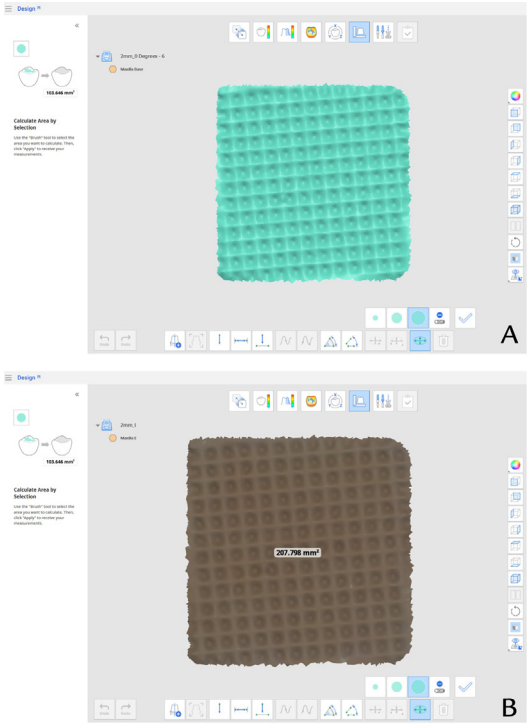


Figure 3. Representative area measurement procedures. A, Entire scan selection. B, Automatic area calculation.

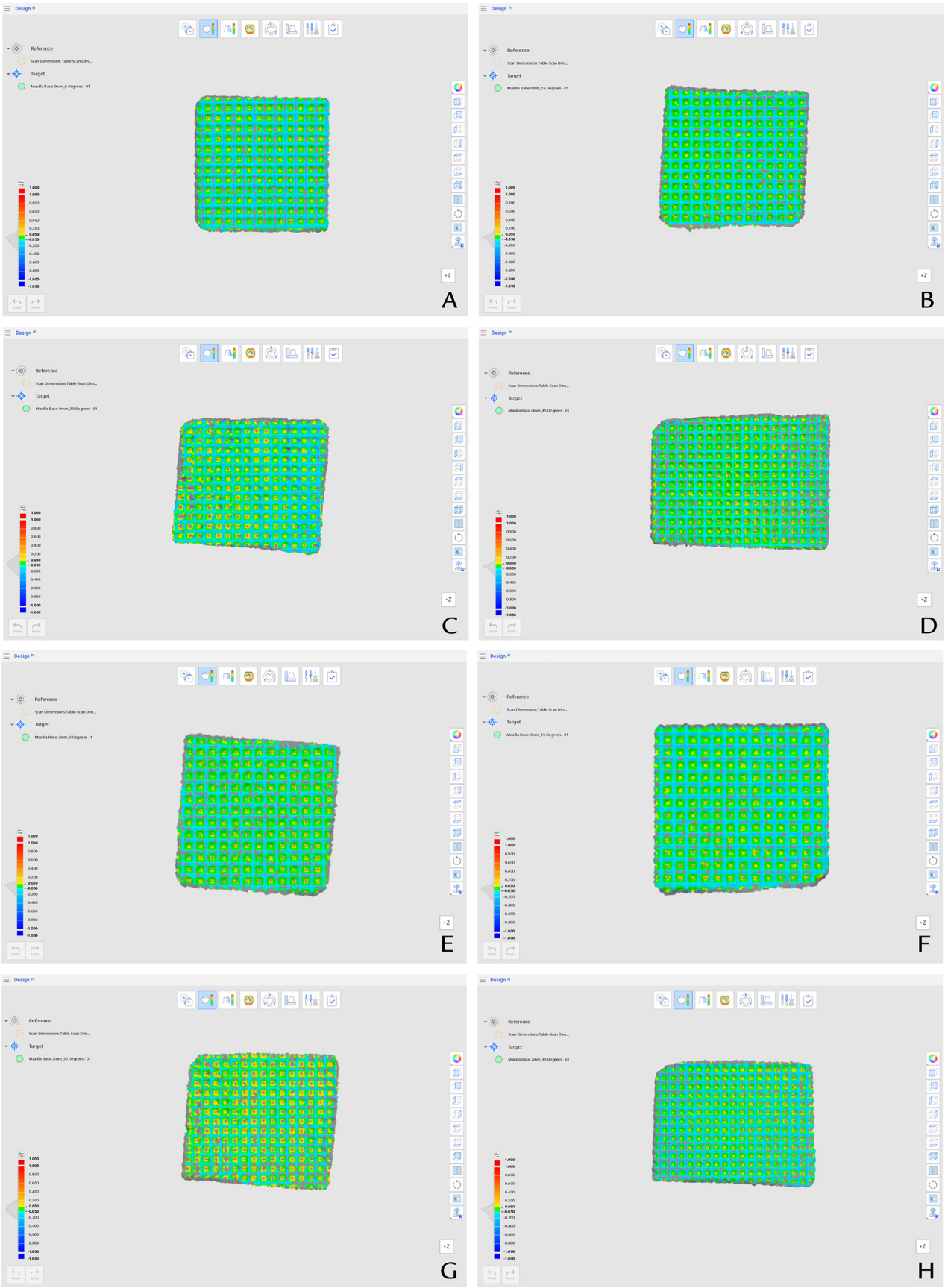


Figure 4. Representative color map of accuracy discrepancies measured among i700 subgroups tested. A, i700-0-0 subgroup. B, i700-0-15 subgroup. C, i700-0-30 subgroup. D, i700-0-45 subgroup. E, i700-2-0 subgroup. F, i700-2-15 subgroup. G, i700-2-30 subgroup. H, i700-2-45 subgroup.

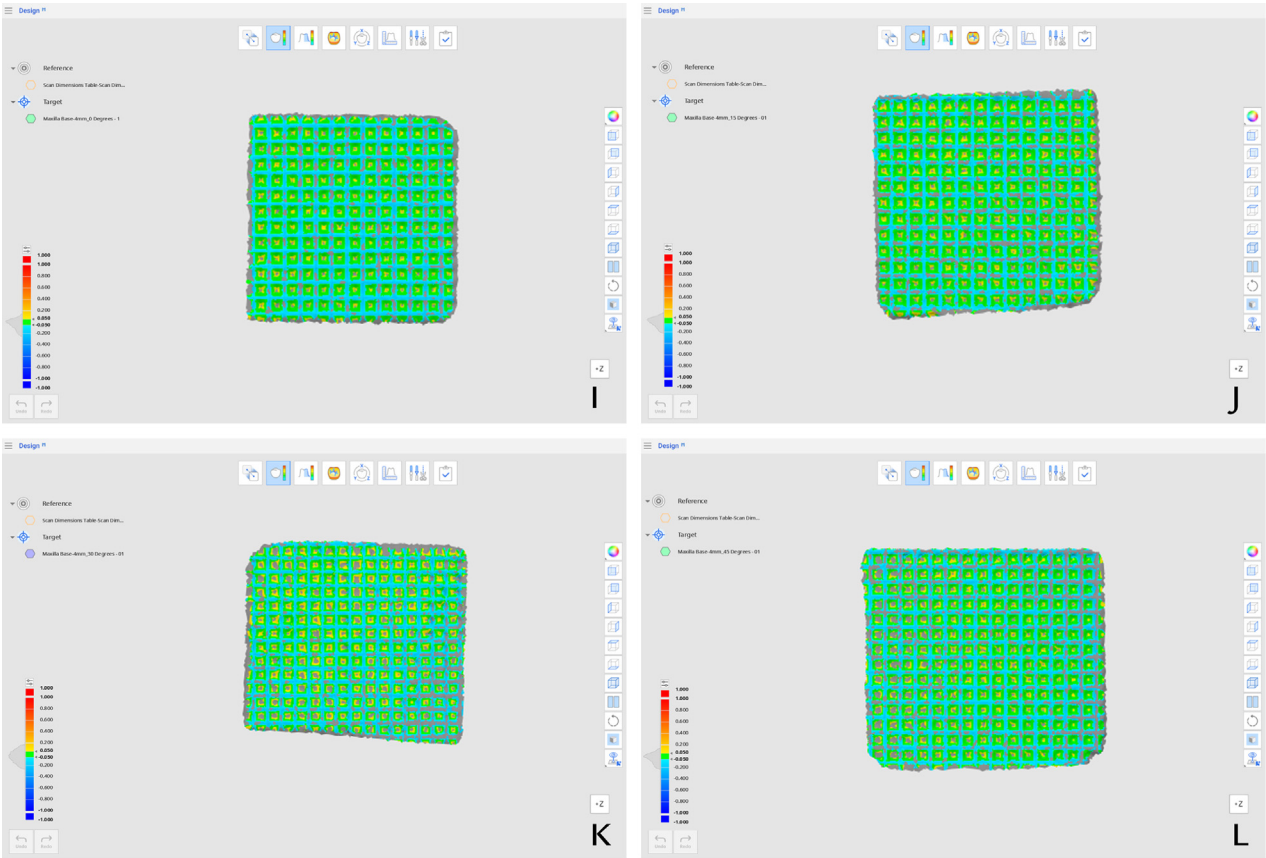


Figure 4. *(Continued).* I, i700-4-0 subgroup. J, i700-4-15 subgroup. K, i700-4-30 subgroup. L, i700-4-45 subgroup.

distance (distance between the scanning tip and the surface being digitized) at which the scans were obtained: 0 (subgroup 0), 2 (subgroup 2), and 4 mm (subgroup 4). To standardize the scanning distance, the reference devices were positioned on a z-axis calibrated platform (MPositioning T60Z-10A; MPositioning Co) that controlled the vertical movement of the platform in millimeters (0, 2, or 4 mm) (Figs. 1B,2).

In the i700-0-0 subgroup, the 0-degree reference device was positioned on the calibrated platform. The IOS wand was positioned in a supported framework by using polyvinyl siloxane material (Panasil Lab Puty; Kettenbach Dental) attached to a table with a bar clamp (6-inch Bar Clamp; Tekton). The scanning distance or the distance between the surface of the 0-degree reference device and the surface of the scanning tip was established at 0 mm. A digital scan was then acquired without any operator intervention other than turning the IOS on and off. The total scanning time per scan was 5 seconds. The digital scan was postprocessed automatically by the IOS program without operator intervention and exported in an STL file format (n=15).

In the i700-0-2 subgroup, the calibrated platform was lowered to determine a scanning distance of 2 mm. The remaining setting was maintained intact. The same scanning procedures as in the i700-0-0 subgroup were completed to acquire all the specimens. In the i700-0-4 subgroup, the calibrated platform was further lowered to determine a scanning distance of 4 mm, maintaining the remaining settings. The same scanning procedures as in the i700-0-0 subgroup were completed to acquire all the specimens.

For the i700-15, i700-30, and i700-45 subgroups, the same procedures as in the i700-0 subgroups were completed respectively, but with the 10-, 15-, 30-, or 45-degree reference device. Similarly, the same procedures were completed for all the groups with the corresponding IOS (N=720, n=15). Two analyses were completed: total scanned area and scanning accuracy. For the total scanned area, the area of each intraoral digital scan was measured in mm^2. Each STL file was imported into a CAD software program (Medit Link, Medit Design App, v.3.0.3; Medit). Each STL file was selected, and the area of each scan was obtained (Fig. 3).

For the scanning accuracy assessment, the reference file was used to measure the difference with the experimental scans obtained among the different subgroups tested by using a CAD software program (Medit

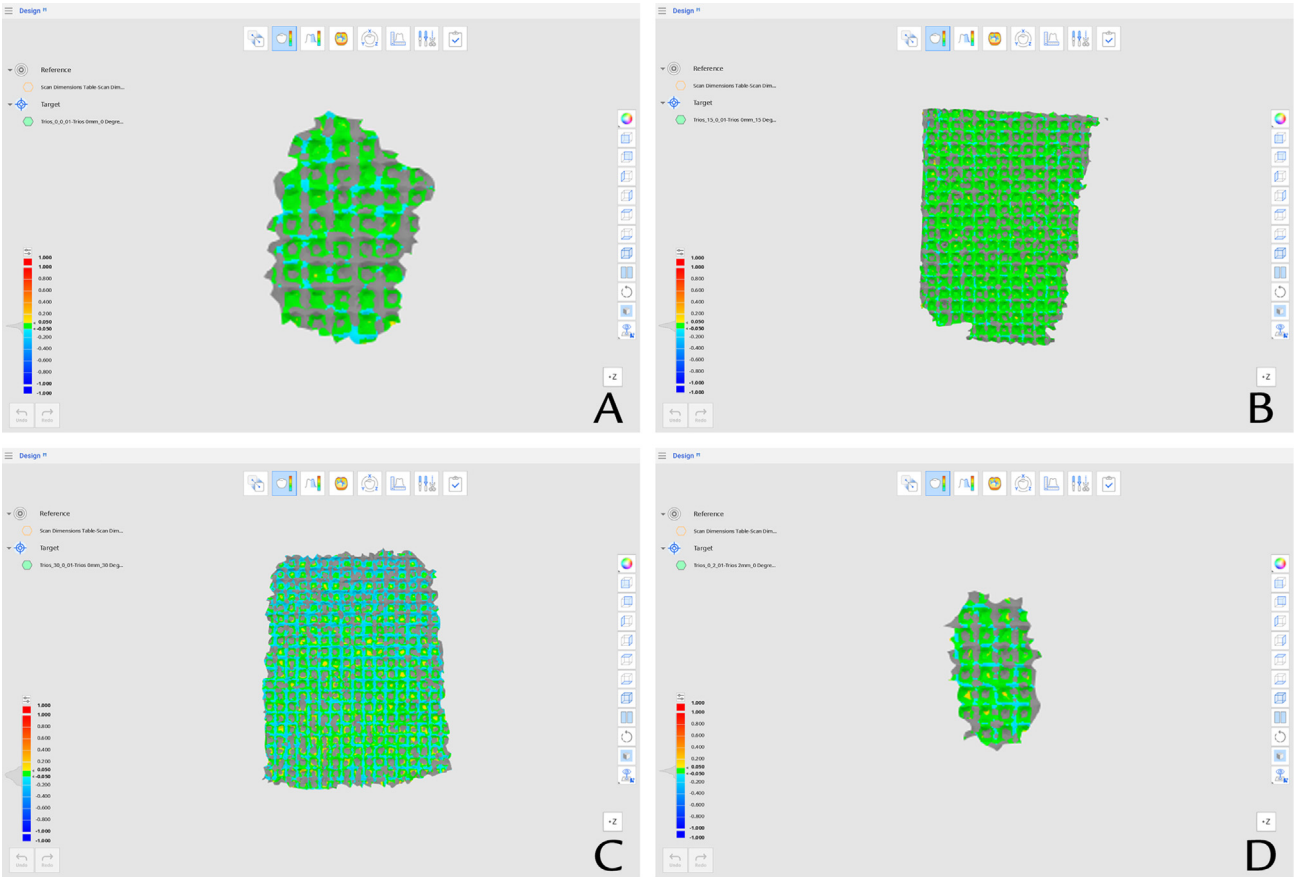


Figure 5. Representative color map of accuracy discrepancies measured among TRIOS4 subgroups tested. A, TRIOS4-0-0 subgroup. B, TRIOS4-0-15 subgroup. C, TRIOS4-0-30 subgroup. D, TRIOS4-2-0 subgroup.

Link, Medit Design App, v.3.0.3; Medit).The reference STL file and the experimental file were defined and aligned by using the best fit technique.[27] The root mean square (RMS) error calculation was computed in the same area using the following formula: $RMS = \sqrt{\frac{\sum_{i=1}^{n}(X_{1,i}-X_{2,i})^2}{n}}$, where X_1,i is the reference data, X_2,i is the scan data, and n indicates the total number of measurement points measured in each analysis (Figs. 4-7). The discrepancy calculations for each subgroup were used to analyze the data. Trueness was defined as the average RMS error discrepancy between the reference file and experimental scans, while precision was described as the RMS error variation per each group or standard deviation.[28,29]

The Shapiro–Wilk and Kolmogorov–Smirnov tests indicated that the scanning area data had a normal distribution (P>.05). Three-way ANOVA and post hoc Tukey pairwise comparison tests (α=.05) were used to analyze the data. Also, the Shapiro–Wilk and Kolmogorov–Smirnov tests indicated that the RMS error data were not normally distributed (P<.05). Kruskal–Wallis and multiple pairwise comparison tests (α=.05) were used to analyze the RMS median data. The Kruskal–Wallis test was used to analyze the interquartile range (IQR) for precision evaluation. A statistical software program (IBM SPSS Statistics for Windows, v27; IBM Corp) was used to perform the statistical analysis.

RESULTS

A digital scan could not be acquired with the TRIOS4 IOS at a 45-degree scanning angulation and at 0-, 2-, or 4-mm scanning distances. Similarly, digital scans could not be captured with the CS 3800 and iTero IOSs at a 45-degree scanning angulation with a 2- or 4-mm scanning distance (Table 1). The scanning area and RMS error data were standardized for data comparison (Fig. 8).

Regarding scanning area analysis, 3-way ANOVA revealed that IOS (DF=3, MS=504 353; F value=62.29, P<.001), scanning distance (DF=2, MS=75 268, F-value=9.30, P<.001), and scanning angle (DF=3, MS=197 299; F value=24.37, P<.001) were significant factors of the scanning area measured among the subgroups tested (Fig. 9A, B). Additionally, a significant

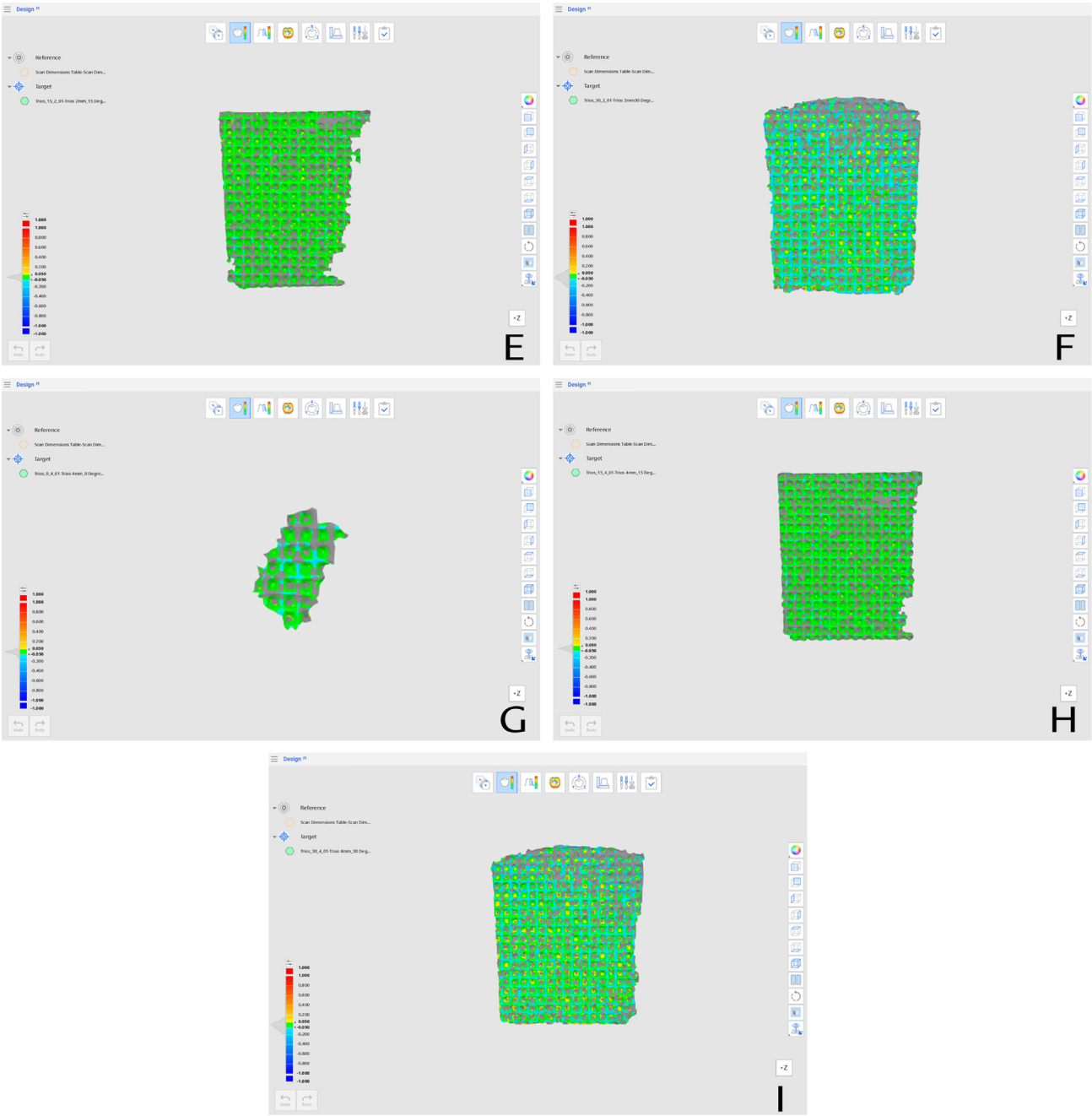


Figure 5. *(Continued).* E, TRIOS4-2-15 subgroup. F, TRIOS4-2-30 subgroup. G, TRIOS4-4-0 subgroup. H, TRIOS4-4-15 subgroup. I, TRIOS4-4-30 subgroup.

group×subgroup interaction was found (DF=6, MS=47 362; *F* value=5.85, *P*<.001).

The Tukey test revealed significant scanning area mean value discrepancies among the different IOSs tested (*P*<.05). When grouping the data of the IOS groups, the iTero (mean area 292.4 mm^2) and the TRIOS4 (mean area 283.6 mm^2) groups obtained significantly higher scanning area mean values than the i700 (mean area: 242.5 mm^2) and CS 3800 (mean area: 162.6 mm^2) groups (Fig. 9C). The CS 3800 obtained the lowest scanning area among the IOS groups tested. When grouping the data of the scanning distance subgroups, the 0-mm subgroups obtained significantly a lower scanning area than the 2-mm and 4-mm subgroups (*P*<.001). When grouping the data of the scanning angle subgroups, the 0-degree and 30-degree subgroups obtained a significantly lower scanning area than the 15-degree and 45-degree subgroups, (*P*<.001). The 30-degree and 45-degree subgroups were not significantly different from each other (*P*=.061).

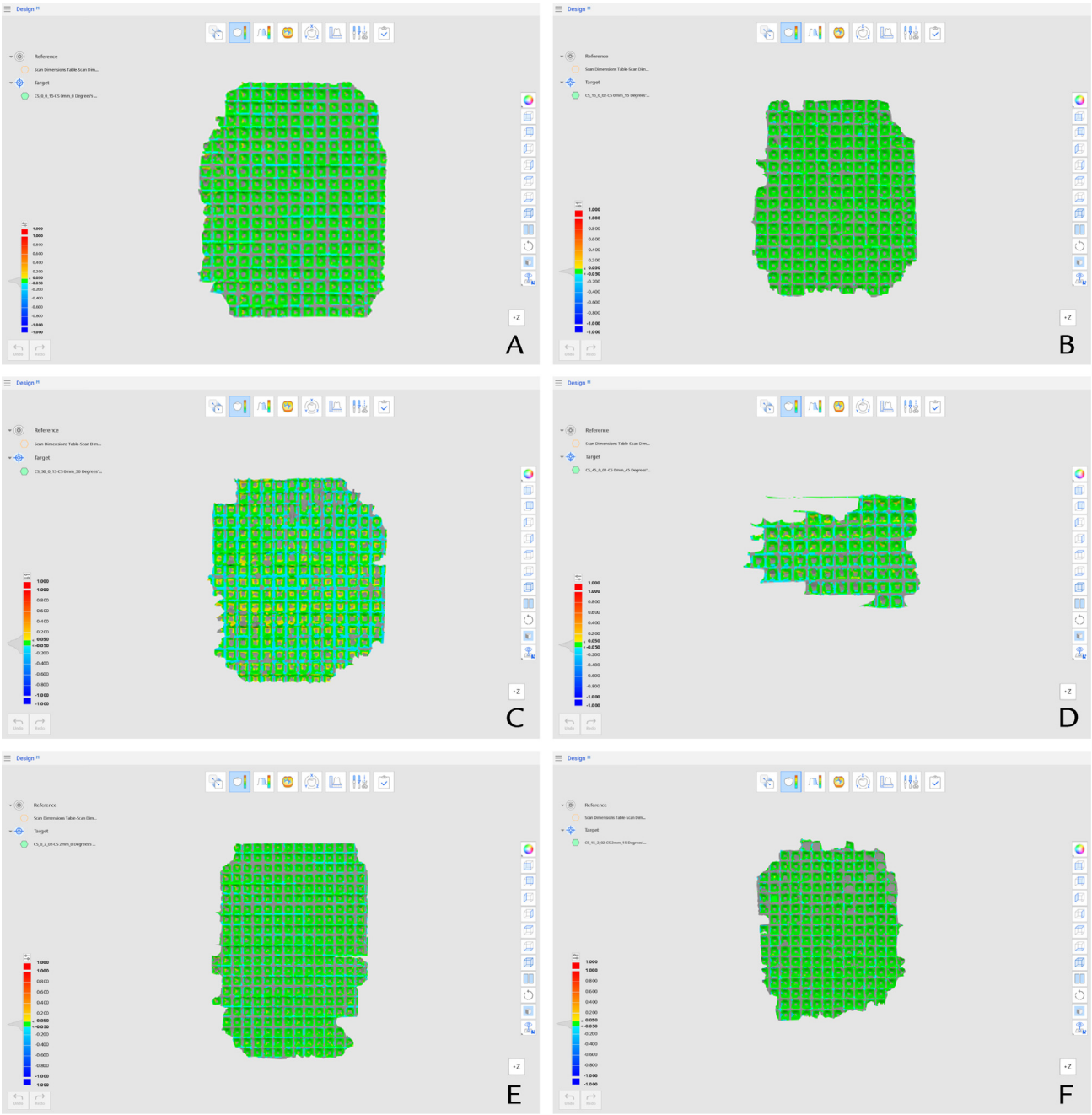


Figure 6. Representative color map of accuracy discrepancies measured among CS subgroups tested. A, CS 3800-0-0 subgroup. B, CS 3800-0-15 subgroup. C, CS 3800-0-30 subgroup. D, CS 3800-0-45 subgroup. E, CS 3800-2-0 subgroup. F, CS 3800-2-15 subgroup.

When grouping the data of the IOS×scanning distance subgroups, the Tukey test revealed significant scanning area discrepancies among the subgroups tested (Table 2). For the TRIOS4, the highest scanning area was obtained at 2 mm, but the 2-mm and 0-mm scanning distance subgroups were statistically similar (P=.076). For the iTero, i700, and CS 3800 groups, the highest scanning area was measured at 2 mm; however, the 0-, 2-, and 4-mm subgroups were statistically similar (P>.05) (Fig. 10).

Regarding RMS error data analysis, the Kruskal–Wallis test revealed significant median RMS discrepancies among the subgroups tested (P<.001). When grouping the data of the IOS groups, multiple pairwise comparisons showed that all the IOS groups

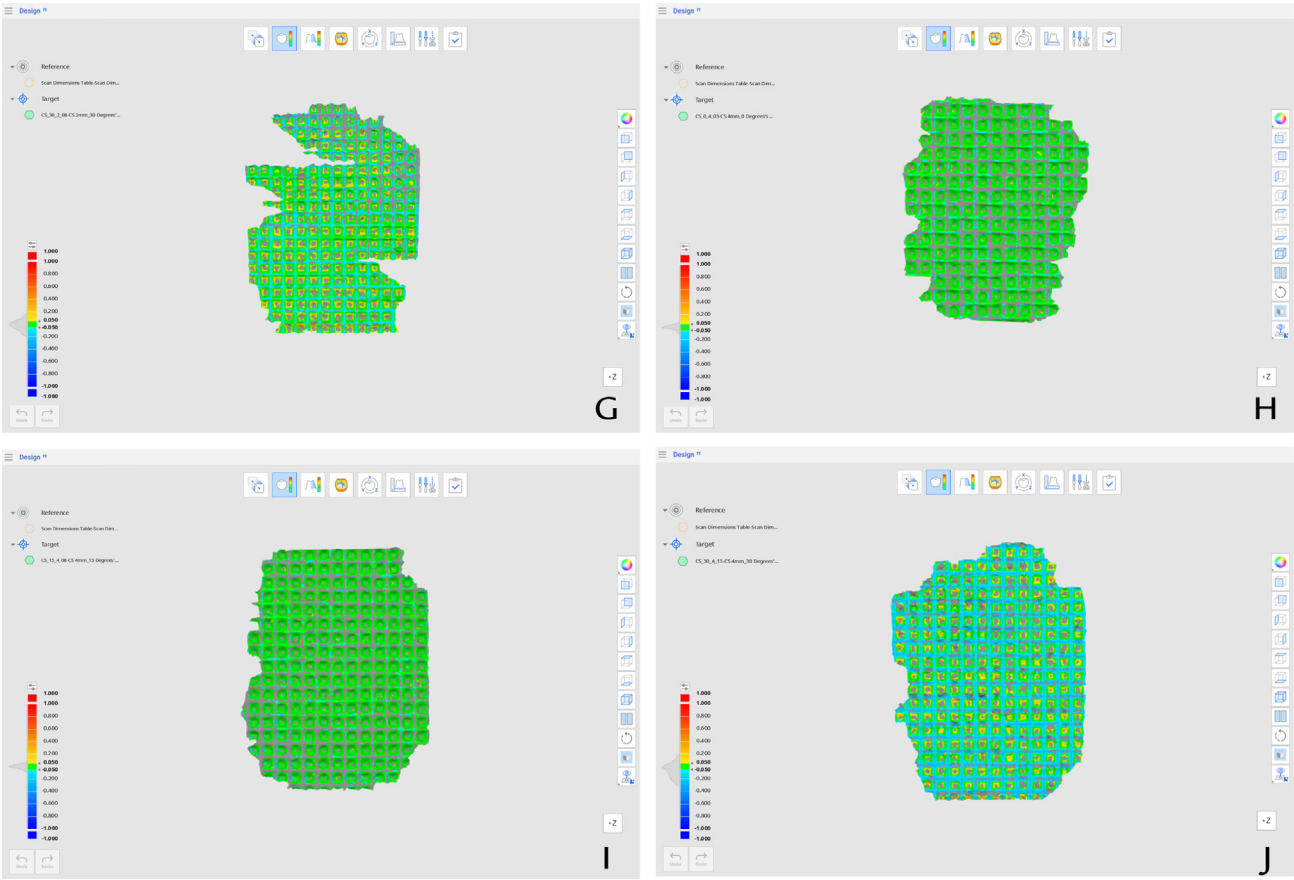


Figure 6. *(Continued).* G, CS 3800-2-30 subgroup. H, CS 3800-4-0 subgroup. I, CS 3800-4-15 subgroup. J, CS 3800-4-30 subgroup.

were significantly different from each other ($P<.001$), except for the CS 3800 and TRIOS4 groups (W=0.0390, $P<.999$). When grouping the data of the scanning distance subgroups, multiple pairwise comparisons showed that all the scanning distance groups were statistically similar ($P>.05$). When grouping the data of the scanning angle subgroups, multiple pairwise comparisons showed that all the scanning distance groups were significantly different from each other ($P<.001$). Regarding precision evaluation, the Kruskal–Wallis test revealed that the IQR values of the groups were statistically similar ($P>.05$).

DISCUSSION

Based on the results obtained in this in vitro study, the scanning area and scanning accuracy were influenced by the IOS, scanning distance, and scanning angle used to acquire the intraoral digital scans. Therefore, the null hypotheses were rejected. The authors are unaware of a previous investigation that evaluated scanning area and scanning accuracy discrepancies among the intraoral digital scans captured with different IOSs with varying scanning distances and scanning angles. Hence, comparisons with previous published studies are not feasible.

The relationship between scanning area and accuracy has not been analyzed in the dental literature. The results of the present study revealed scanning dimensions and scanning accuracy discrepancies among the IOSs when acquiring the digital scans at varying scanning distances and angles. These scanning area and accuracy discrepancies can be explained by the IOS hardware and software differences, as well as the varying sizes of the scanning tips. The mean scanning area discrepancy ranged from 292.44 mm^2 to 162.39 mm^2, representing a mean discrepancy of 130.05 mm^2. Additionally, the trueness ±precision values ranged from 115 ±10 µm to 33 ±4 µm. The results of this study demonstrated the influence of the IOS, scanning distance, and scanning angle on the scanning area, as well as on the accuracy of the IOSs tested. The skill of the operator handling an IOS device can, therefore, impact the outcome of the intraoral digital scan. Additional studies are needed to better understand the relationship among scanning area, scanning distance, scanning depth, and accuracy based on the IOS selected.

Overall, the IOSs tested captured a higher scanning area under 2- and 4-mm scanning distance and 15-degree and 45-degree scanning angles, and lower

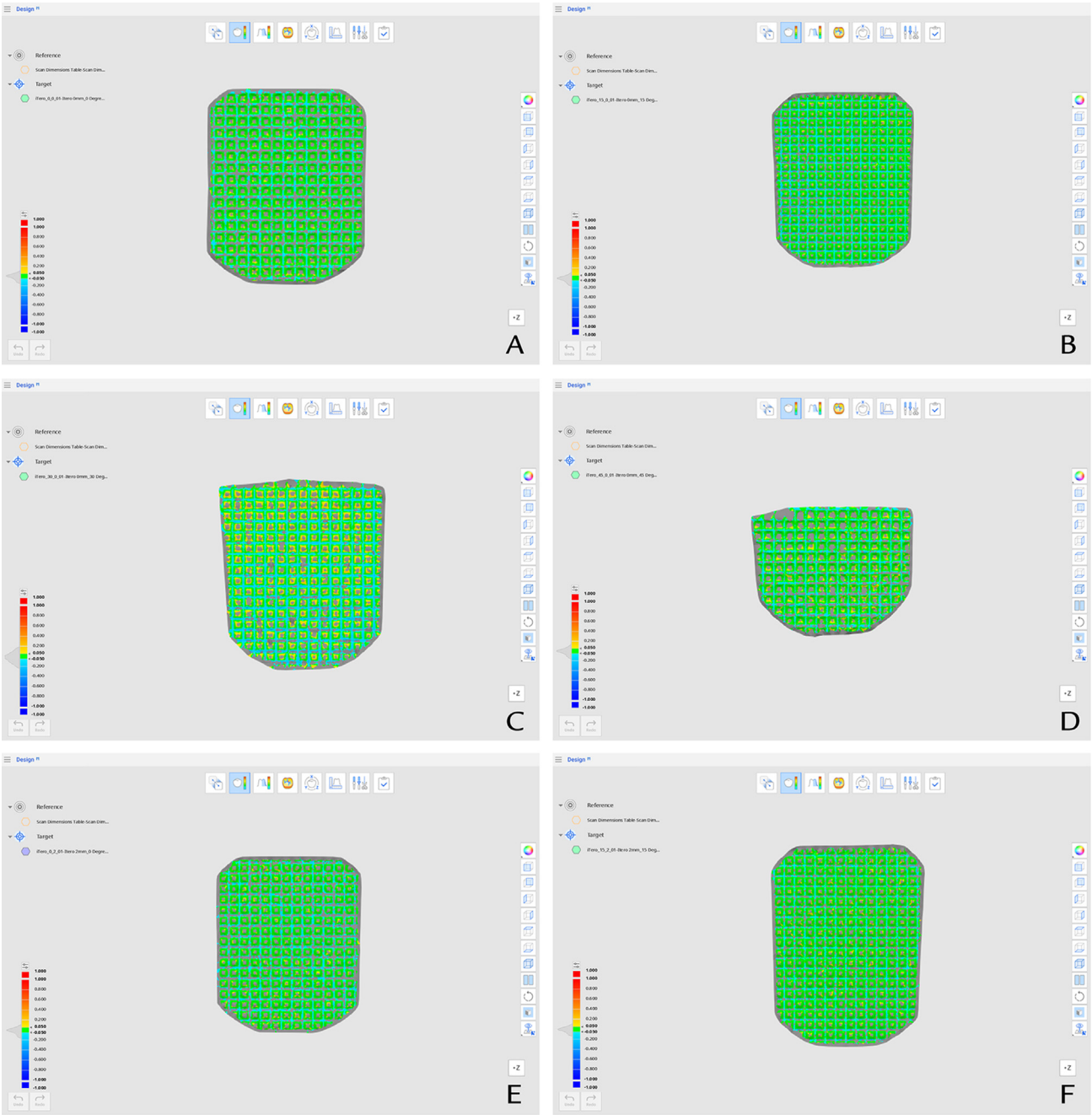


Figure 7. Representative color map of accuracy discrepancies measured among iTero subgroups tested. A, iTero-0-0 subgroup. B, iTero-0-15 subgroup. C, iTero-0-30 subgroup. D, iTero-0-45 subgroup. E, iTero-2-0 subgroup. F, iTero-2-15 subgroup.

scanning discrepancies (higher accuracy values) under 0-degree and a 15-degree scanning angle. In the present study, the i700 system showed the highest scanning area and lowest scanning discrepancy under 0-mm scanning distance with 15-degree scanning angulation. These discrepancies can be explained by the scanning technology and IOS hardware such as sensors, array of the camera, and focal length differences among the systems. The TRIOS4 obtained the highest scanning area and accuracy values under 2-mm scanning distance with 15-degree scanning angulation, and the lowest scanning discrepancies were obtained under 0-, 2-, or 4-mm scanning distance with 15-degree scanning angulation. The CS 3800 showed the highest scanning area and accuracy values under 0-, 2-, and 4-mm scanning distance with 0-degree scanning angulation and under 2-mm scanning distance with 15-degree scanning angulation. Lastly, the iTero recorded the highest scanning area and

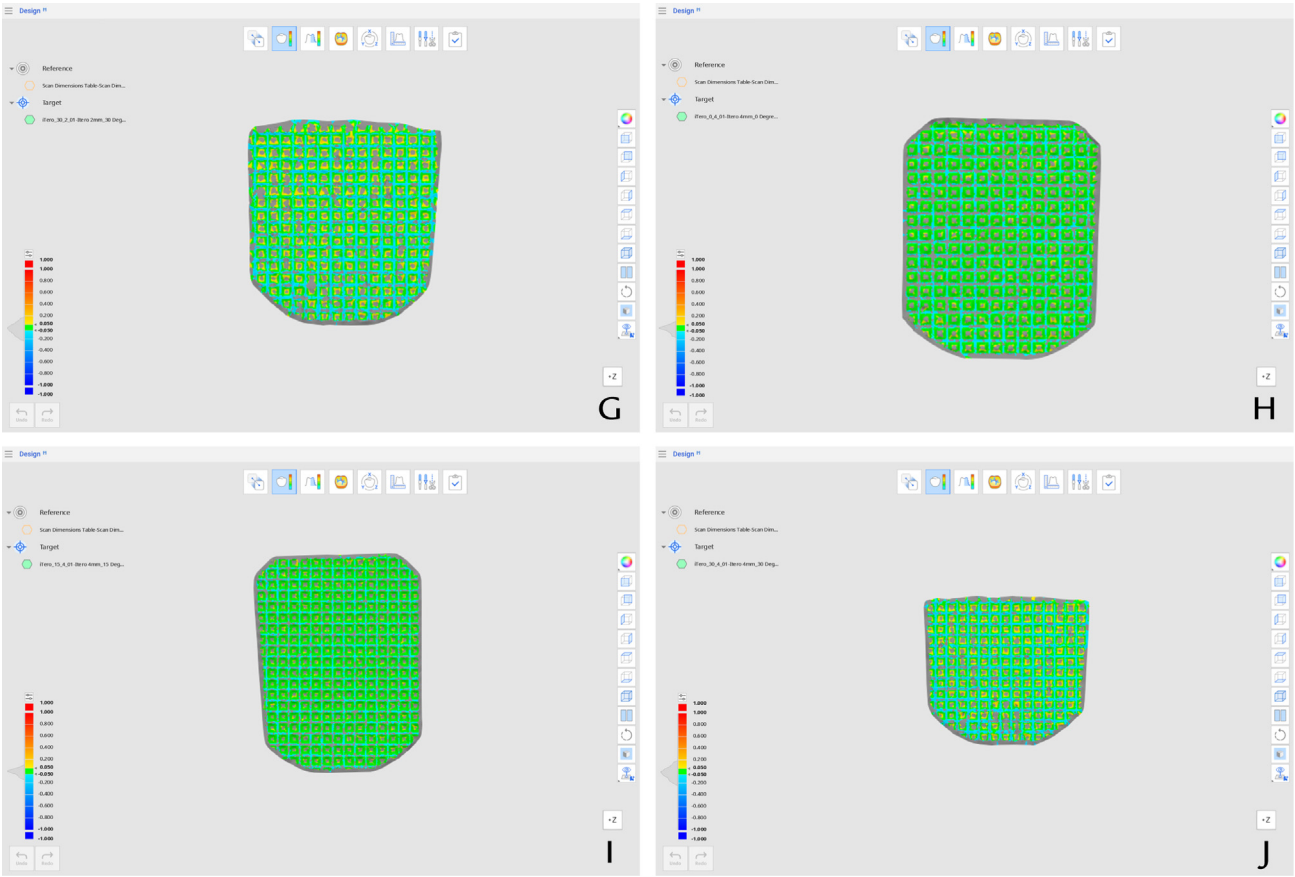


Figure 7. *(Continued).* G, iTero-2-30 subgroup. H, iTero-4-0 subgroup. I, iTero-4-15 subgroup. J, iTero-4-30 subgroup.

lowest scanning discrepancies under 0-, 2-, and 4-mm scanning distance with a 15-degree scanning angulation. Hence, the clinician can influence the outcome of the intraoral scans by altering the scanning distance and scanning angulation when acquiring digital scans.

Previous studies have stated that scanning accuracy can be affected by altering the scanning distance.[19,20] Kim et al[19] evaluated the influence of 4 scanning distances (0, 2.5, 5, and 7.5 mm) on the accuracy of 3 IOSs (CS 3500 from Carestream, TRIOS 3 from 3Shape A/S, and Planscan from Planmenca). Three custom frames were printed that fitted into the scanning tip of the IOS tested to standardize the scanning distance when acquiring complete arch intraoral scans from a conventional stone cast.[19] Scanning discrepancies were assessed by measuring linear distances on the reference and virtual casts and by calculating the RMS error. The results revealed accuracy discrepancies between the scanning distances and IOSs tested. Comparisons with the results of the present study are difficult because of differences in the IOS technology and versions, scanning conditions, reference models, and measurement methods.

Rotar et al[20] assessed the effect of 5 scanning distances (5, 10, 15, 20, and 23 mm) on the accuracy of an IOS (i500; Medit). A typodont with an onlay preparation on the maxillary first molar was used. The scanning pattern started on the occlusal surface of the first molar, continuing toward the occlusal surface of the second molar and the occlusal surface of the second premolar, and ending at the initial starting point. The movement of the typodont was performed in a linear direction and, at all times, rested on the flat surface to standardize the scanning distance. The results showed scanning accuracy discrepancies among the digital scans obtained with varying scanning distances, in which the 10-mm scanning distance obtained the best scanning accuracy values. Comparisons with the results of the present study are challenging because of differences in the research methodology between the studies.

IOSs have different focal lengths depending on the hardware of the system. With most IOS devices, the focal length cannot be modified by the user.[14] The focal length of the i700 IOS from Medit ranges from 12 to 23 mm. In the present study, the focal length used was 23, aiming to test the influence of the highest focal length of the system on the scanning area and scanning accuracy of the intraoral digital scans obtained at 3 scanning distances

Table 1. Scanning area and RMS error measurements among different subgroups tested

IOSs	Group (Scanning Distance)	Subgroup (Scanning Angulation)	Mean ±SD Scanning Area (mm^2)	Mean ±SD RMS Error (μm)	Median ±IQR RMS Error (μm)
i700	0 mm	0 degrees	196.1 ±2.3	112 ±12	113 ±13
		15 degrees	228.8 ±1.0	81 ±4	81 ±3
		30 degrees	252.2 ±7.5	121 ±13	116 ±12
		45 degrees	321.5 ±7.6	108 ±36	91 ±20
	2 mm	0 degrees	207.6 ±0.9	85 ±3	85 ±3
		15 degrees	220.3 ±0.7	110 ±5	109 ±9
		30 degrees	250.9 ±4.4	109 ±5	107 ±7
		45 degrees	303.6 ±8.0	92 ±15	90 ±13
	4 mm	0 degrees	206.5 ±3.8	100 ±13	98 ±14
		15 degrees	228.3 ±3.7	98 ±20	92 ±13
		30 degrees	256.6 ±10.2	114 ±7	115 ±10
		45 degrees	275.2 ±11.7	91 ±11	90 ±17
TRIOS4	0 mm	0 degrees	69.4 ±69.7	58 ±31	42 ±12
		15 degrees	327.8 ±6.0	38 ±3	37 ±3
		30 degrees	396.9 ±81.8	78 ±5	76 ±8
		45 degrees	NA	NA	NA
	2 mm	0 degrees	208.8 ±139.2	56 ±25	44 ±12
		15 degrees	370.8 ±30.7	36 ±3	35 ±3
		30 degrees	322.5 ±158.9	92 ±34	78 ±12
		45 degrees	NA	NA	NA
	4 mm	0 degrees	116.9 ±130.0	74 ±39	57 ±58
		15 degrees	421.5 ±18.9	43 ±9	38 ±12
		30 degrees	267.5 ±18.9	101 ±39	81 ±30
		45 degrees	NA	NA	NA
CS 3800	0 mm	0 degrees	230.7 ±84.8	53 ±20	46 ±5
		15 degrees	160.2 ±72.7	95 ±115	51 ±49
		30 degrees	66.2 ±89.7	100 ±40	86 ±25
		45 degrees	13.4 ±28.9	138 ±207	53 ±24
	2 mm	0 degrees	210.3 ±95.5	44 ±13	40 ±4
		15 degrees	208.8 ±74.8	39 ±9	34 ±11
		30 degrees	81.6 ±64.8	92 ±35	83 ±11
		45 degrees	NA	NA	NA
	4 mm	0 degrees	246.4 ±46.1	51 ±17	42 ±20
		15 degrees	182.3 ±96.4	36 ±9	33 ±4
		30 degrees	69.4 ±87.7	126 ±77	96 ±44
		45 degrees	NA	NA	NA
iTero	0 mm	0 degrees	259.9 ±17.2	77 ±18	68 ±27
		15 degrees	347.7 ±10.2	64 ±11	60 ±17
		30 degrees	276.8 ±2.7	102 ±11	101 ±20
		45 degrees	194.4 ±4.0	71 ±10	68 ±9
	2 mm	0 degrees	268.1 ±1.0	66 ±8	64 ±8
		15 degrees	356.0 ±7.3	59 ±8	57 ±5
		30 degrees	258.3 ±6.5	95 ±3	94 ±5
		45 degrees	NA	NA	NA
	4 mm	0 degrees	275.3 ±4.1	62 ±3	61 ±4
		15 degrees	361.4 ±4.5	67 ±12	60 ±18
		30 degrees	211.5 ±8.9	96 ±4	94 ±5
		45 degrees	NA	NA	NA

IOS, intraoral scanner; IQR, Interquartile range; NA, not available; RMS, root mean square; SD, standard deviation.

with 4 different scanning angulations. Further studies are recommended to assess the influence of the different scanning depth of this IOS on the scanning accuracy in varying clinical situations.

Limitations of the present study included that, although the scanning position, including scanning distance and angulation, was standardized, the static position tested at which the intraoral digital scans were

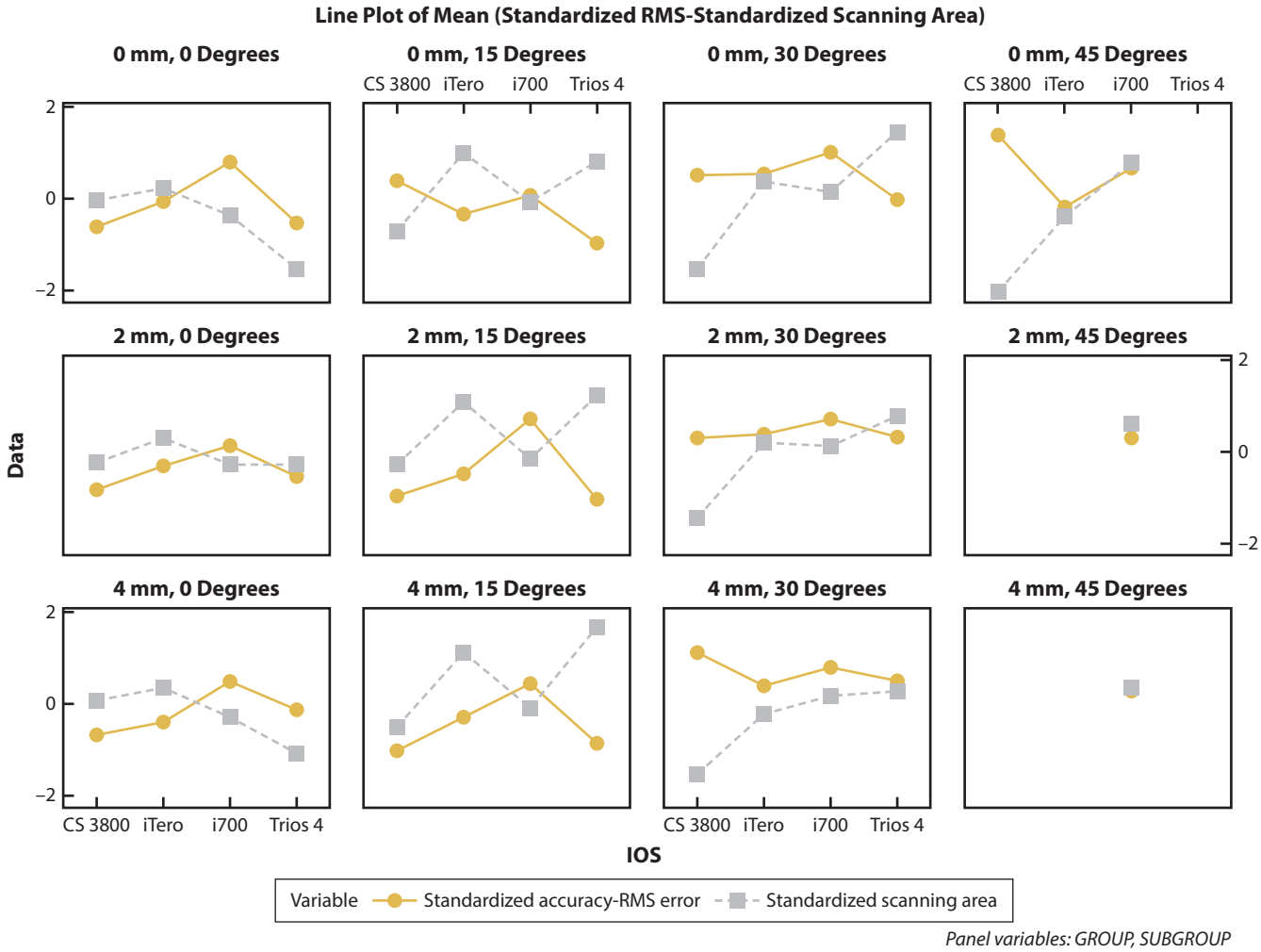


Figure 8. Line plot of mean standardized scanning area and standardized RMS error. RMS, root mean square.

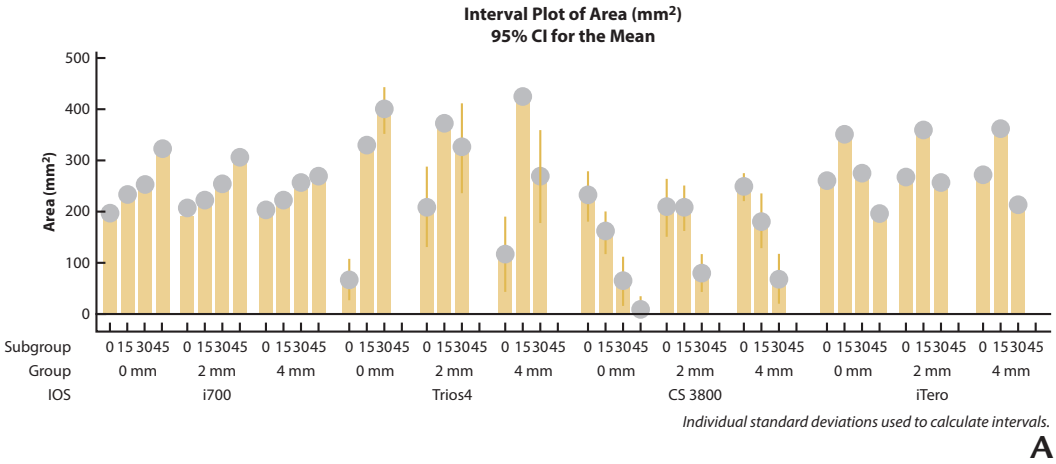
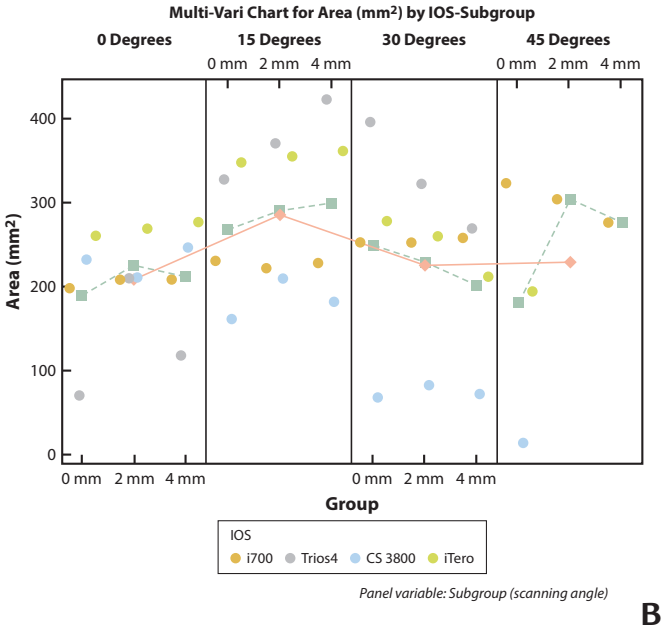
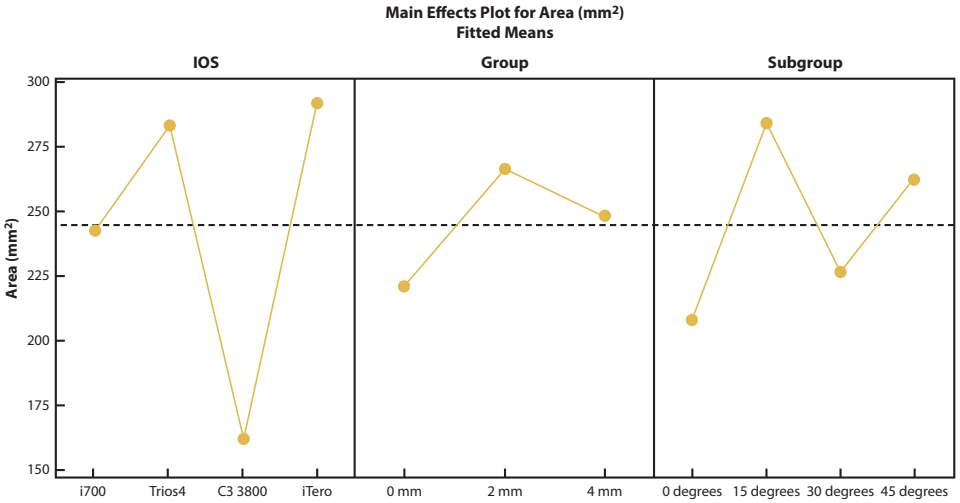


Figure 9. Scanning area analysis. A, Interval plot of scanning area (mm^2).



B



C

Figure 9. *(Continued)*. B, Multi-Vari chart for area (mm^2) by IOS×Subgroup. C, Main effects plot for area (mm^2). IOS, intraoral scanner; CI, confidence interval.

recorded did not represent the IOS movements when obtaining an intraoral digital scan. Additionally, the RMS data were not normally distributed, which limits data interpretation. Further studies are needed to better understand the scanning area and scanning accuracy discrepancies among the IOSs.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Scanning area and scanning accuracy were influenced by the IOS, scanning distance, and scanning angle selected to acquire the digital scans.

Table 2. Tukey pairwise comparisons: IOS×Group. Grouping information using Tukey method and 95% confidence

IOS×Group	Mean Scanning Area (mm^2)
TRIOS4 – 2 mm	319.883^{a}
iTero – 2 mm	313.351^{a,b}
iTero – 4 mm	294.279^{a,b,c}
TRIOS4 – 4 mm	280.169^{a,b,c}
iTero – 0 mm	269.700^{a,b,c}
TRIOS4 – 0 mm	250.778^{b,c,d}
i700 – 2 mm	245.465^{c,d}
i700 – 0 mm	241.530^{c,d,e}
i700 – 4 mm	240.594^{c,d}
CS 3800 – 2 mm	186.046^{d,e,f}
CS 3800 – 4 mm	177.604^{e,f}
CS 3800 – 0 mm	123.509^{f}

IOS, intraoral scanner. Means that do not share letter significantly differ (P<.05).

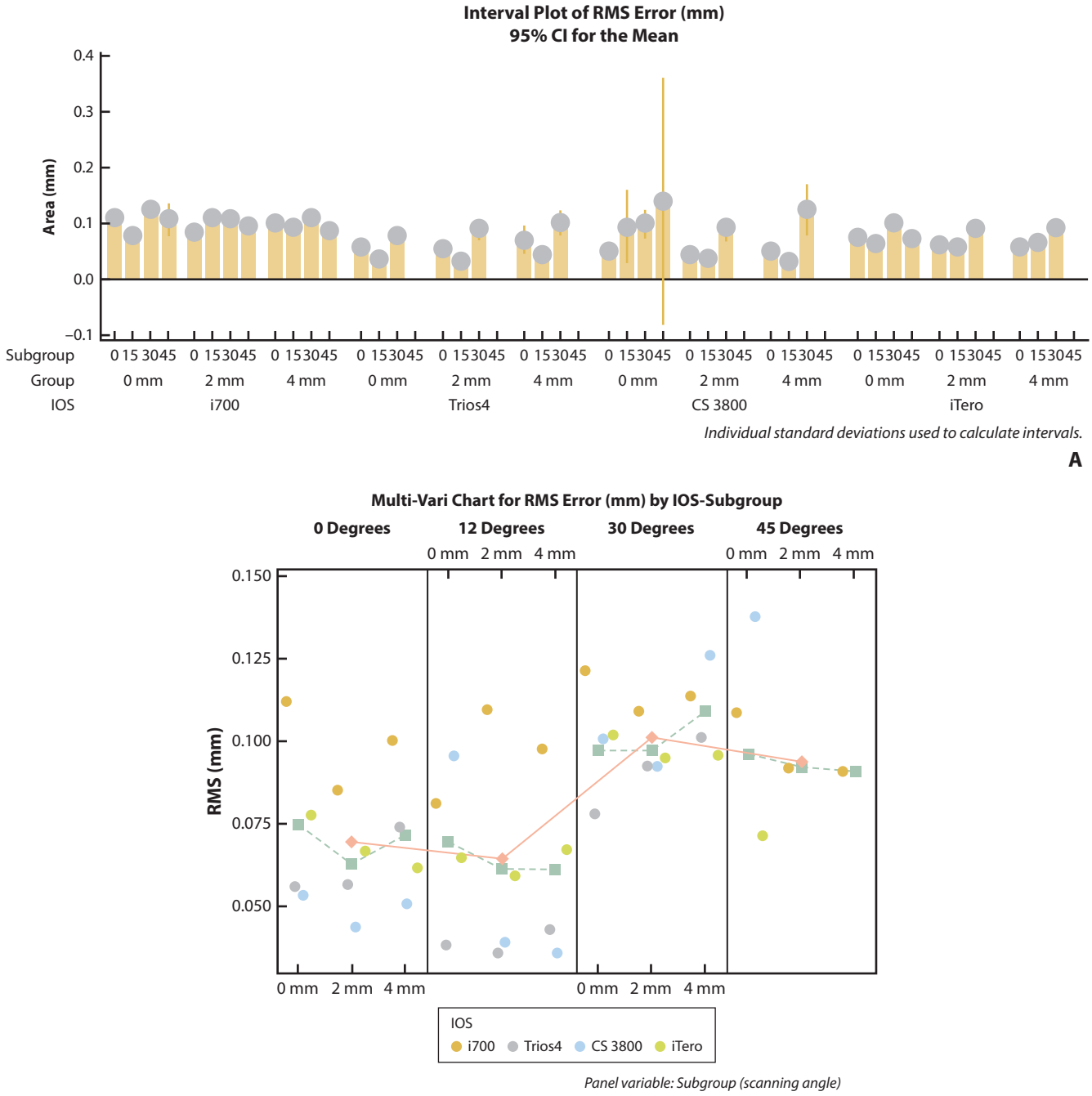


Figure 10. Scanning accuracy analysis. A, Interval plot of RMS error (mm). B, Multi-Vari chart for RMS error (mm) by IOS×Subgroup. IOS, intraoral scanner; RMS, root mean square; CI, confidence interval.

2. With the i700, the highest scanning area was captured under 0-mm scanning distance with 15-degree scanning angulation, while the lowest scanning discrepancies (highest accuracy values) were obtained under 0-mm scanning distance with 15-degree angulation and 2-mm scanning distance with 0-degree scanning angulation.
3. In the TRIOS4, the highest scanning area was obtained under 2-mm scanning distance with 15-degree angulation. Additionally, the lowest scanning discrepancies were measured under 0-, 2-, and 4-mm scanning distance with 15-degree angulation.
4. In the CS 3800, the highest scanning area was shown under 0-, 2-, and 4-mm scanning distance

with 0-degree angulation and under 2-mm scanning distance with 15-degree scanning angulation. The lowest scanning discrepancies were obtained under 0-, 2-, and 4-mm scanning distance with 0-degree scanning angulation and under 2- and 4-mm scanning distance with 15-degree scanning angulation.

5. In the iTero, the highest scanning area was captured under 0-, 2-, and 4-mm scanning distance with 15-degree scanning angulation. Furthermore, the lowest scanning discrepancies were obtained at 0-, 2-, and 4-mm scanning distance with 0-degree angulation and under 0-, 2-, and 4-mm scanning distance with 15-degree scanning angulation.

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