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Effect of intraoral scanner and fixed partial denture situation on the scan accuracy of multiple implants: An in vitro study

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Abstract

Background: Accuracy of intraoral implant scans may be affected by the region of the implant and the type of the intraoral scanner (IOSs). However, there is limited knowledge on the scan accuracy of multiple implants placed for an implant-supported fixed partial denture (FPD) in different partially edentulous situations when digitized by using different IOSs.

Purpose: To investigate the effect of IOS and FPD situation on the scan accuracy of two implants when partial-arch scans were performed.

Materials and Methods: Tissue level implants were placed in 3 maxillary models with implant spaces either at right first premolar and right first molar sites (Model 1, 3-unit FPD), at right canine and right first molar sites (Model 2, 4-unit FPD), or at lateral incisor sites (Model 3, 4-unit FPD). Reference standard tessellation language (STL) files of the models were generated by using an optical scanner (ATOS Capsule 200MV120). Two IOSs (CEREC Primescan [CP] and TRIOS 3 [TR]) were used to perform partial-arch scans (test-scans) of each model ($n = 14$), which were exported in STL format. A metrology-grade analysis software (GOM Inspect 2018) was used to superimpose test-scan STLs over the reference STL to calculate 3D distance, inter-implant distance, and angular (mesiodistal and buccopalatal) deviations. Trueness and precision analyses were performed by using bootstrap analysis of variance followed by Welch tests with Holm correction ($\alpha = 0.05$).

Results: Trueness of the scans was affected by IOS and FPD situation when 3D distance deviations were considered, while inter-implant distance, mesiodistal angular, and buccopalatal angular deviations were only affected by the FPD situation ($p < 0.001$). Scan precision was affected by the interaction between the IOSs and the FPD situation when 3D distance and buccopalatal angular deviations were concerned, while IOSs and FPD situation were effective when all deviations were concerned ($p \leq 0.001$). When 3D distance deviations were considered, CP scans had higher accuracy TR scans in Models 1 and 3 ($p \leq 0.002$), and the Model 1 scans had the highest accuracy ($p < 0.001$). When inter-implant distance deviations were considered, Model 1 scans had the highest accuracy with CP and higher accuracy than Model 2 when TR was used ($p \leq 0.030$). When mesiodistal angular deviations were considered, Model 1 scans had the highest accuracy ($p \leq 0.040$). When buccopalatal angular deviations were considered, Model 1 scans had the highest accuracy among models when CP was used ($p \leq 0.020$).

Conclusions: Posterior 3-unit fixed partial denture implant scans, CP scans, and combination of these two factors had accuracy either similar to or better than their tested counterparts.

KEYWORDS
fixed partial denture, implant, intraoral scanner, precision, trueness

Summary Box

What Is Known

Intraoral scanner use in implant prosthodontics is increasing given their steadily improving scan accuracy. However, scan accuracy may still vary across scanners and in different partial edentulism situations depending on the span length in a given region of the arch or due to the region of the arch when the span length is similar. In this respect, the knowledge on the combined effect of intraoral scanner and fixed partial denture situation on the accuracy of implant scans is limited.

What This Study Adds

CEREC Primescan (CP) scans had accuracy that was either similar to or higher than those performed by using TRIOS 3 (TR). Scans of the implants placed for a posterior 3-unit fixed partial denture had accuracy that was either similar to or higher than that of the implants placed for a posterior 4-unit or an anterior 4-unit fixed partial denture. Partial-arch scans of 2 implants placed for a posterior 3-unit fixed partial denture performed by using CP may lead to more accurately fitting restorations than those of other tested intraoral scanner-fixed partial denture situation pairs.

1 | INTRODUCTION

Direct digital workflow eliminates shortcomings with conventional impressions,[1] using intraoral scanners (IOSs) and scan bodies (SBs) to acquire the 3-dimensional (3D) position of the implants.[2–5] However, scan accuracy of IOSs has always been questioned[6] as inaccurate impressions may result in misfit[7] that could lead to screw loosening, screw fracture, chipping of the veneering material, gingival inflammation, bone loss, and implant or prosthesis loss.[8] Therefore, IOS scans should have at least similar accuracy to that of a conventional impression to be routinely used.[9]

Trueness (closeness of a measurement to the actual dimensions) and precision (closeness of repetitive measurements to each other) define the accuracy of a scan.[10–12] Different factors have been reported to affect the scan accuracy of IOSs,[9,13] one of which is the IOS itself.[10] Extent of the edentulous area is another factor as previous studies have shown that increased span length reduced scan accuracy.[1,14–18] Region of the scan (anterior or posterior) was also shown to affect scan accuracy, however, contradicting results have been reported.[19,20]

The number of studies focusing on the scan accuracy of implants placed for a fixed partial denture (FPD) is limited.[1,15,17,21–24] In addition, among those studies, only one has evaluated the scan accuracy of anterior implants for an FPD when complete-arch scans were performed.[24] However, higher trueness has been reported for partial-arch scans compared with complete-arch scans.[19,25] Therefore, the aim of the present study was to evaluate the effect of two IOSs and three different FPD situations (two implants placed at maxillary right first premolar and first molar sites, at maxillary right canine and first molar sites, or at maxillary lateral incisor sites) on the accuracy of

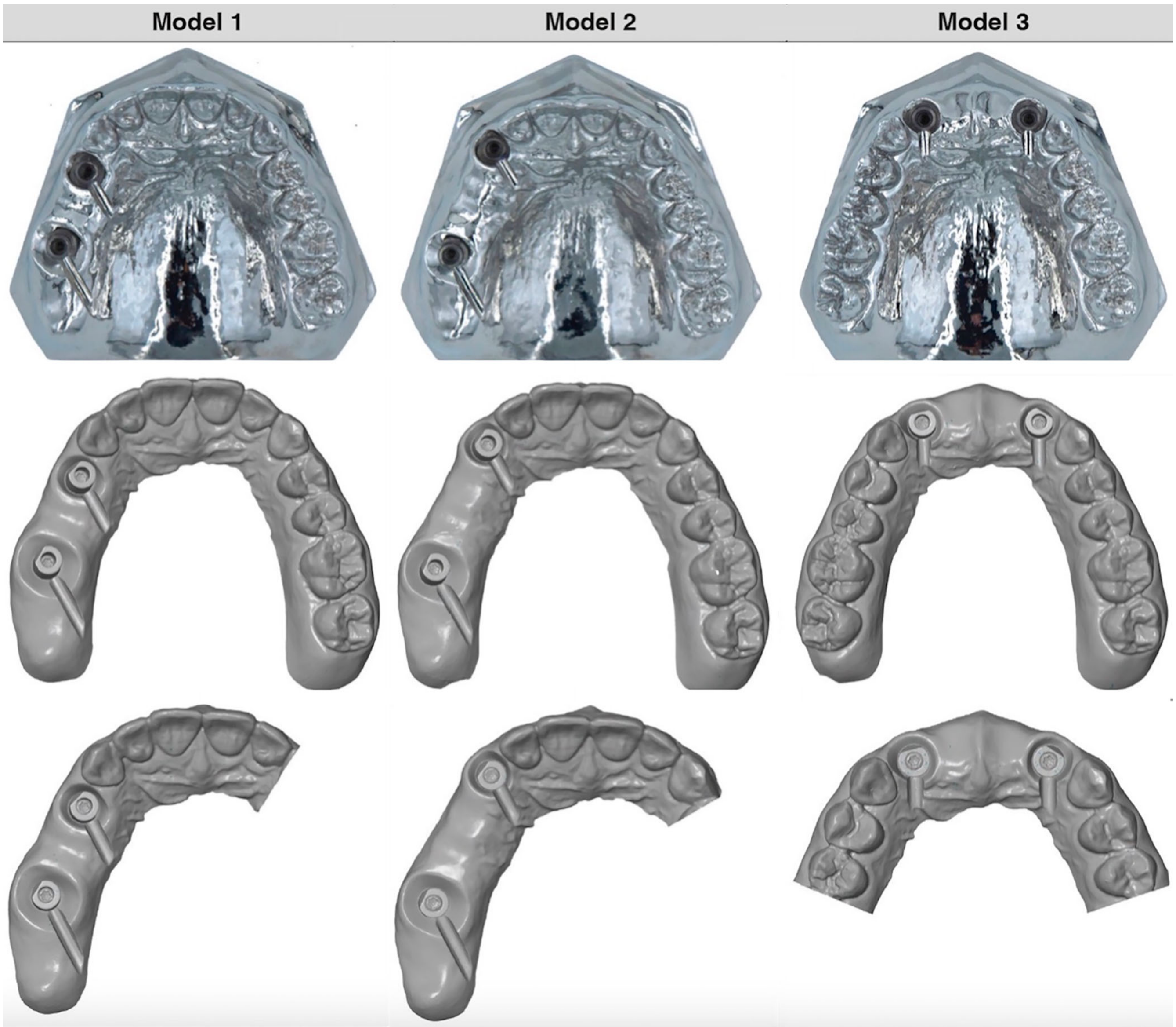

FIGURE 1 Master implant-supported fixed partial denture models, complete-arch reference scans, and partial-arch test scans.

partial-arch implant scans. The null hypotheses were that (i) the type of IOS and FPD situation would not affect the trueness of implant scans and (ii) the type of IOS and FPD situation would not affect the precision of implant scans.

2 | MATERIALS AND METHODS

Three partially edentulous maxillary models simulating different FPD situations with 2 implant spaces located either at right first premolar and right first molar sites (Model 1, posterior 3-unit gap), right canine, and right first molar sites (Model 2, posterior 4-unit gap), or right and left lateral incisor sites (Model 3, anterior 4-unit gap) were designed by using a CAD software (Zirkonzahn.Modellier; Zirkonzahn GmbH, Gais, Italy). Models were milled from cobalt-chromium-molybdenum alloy[26] with a 5-axis milling unit M5 (Zirkonzahn GmbH, Gais, Italy). After milling, tissue-level titanium implants (Straumann S RN 4.1 $\times$ 10 mm; Straumann AG, Basel, Switzerland) were screwed in their respective threaded spaces, 2 mm submucosally, and fixed with a dental metal adhesive (Adesso Split Justierkleber; Baumann Dental GmbH, Remchingen, Germany). Each model was digitized by using an industrial-grade optical scanner (ATOS Capsule 200MV120; GOM GmbH, Braunschweig, Germany) after tightening scan bodies (SBs; CARES Mono Scanbody; Straumann AG, Basel, Switzerland) to the implants with 15 Ncm torque and applying an anti-reflective scan spray (IP Scan Spray; IP-Division, Haimhausen, Germany) on each model. A reverse engineering software (Pro 8.1; GOM GmbH, Braunschweig, Germany) was used to generate the reference standard tessellation language (STL) file of each model (Figure 1).

After reference scans, a single operator (A.M.) digitized each model by using 2 different IOSs (CEREC Primescan; Dentsply Sirona, Bensheim, Germany [CP] and TRIOS 3; 3Shpae, Copenhagen,

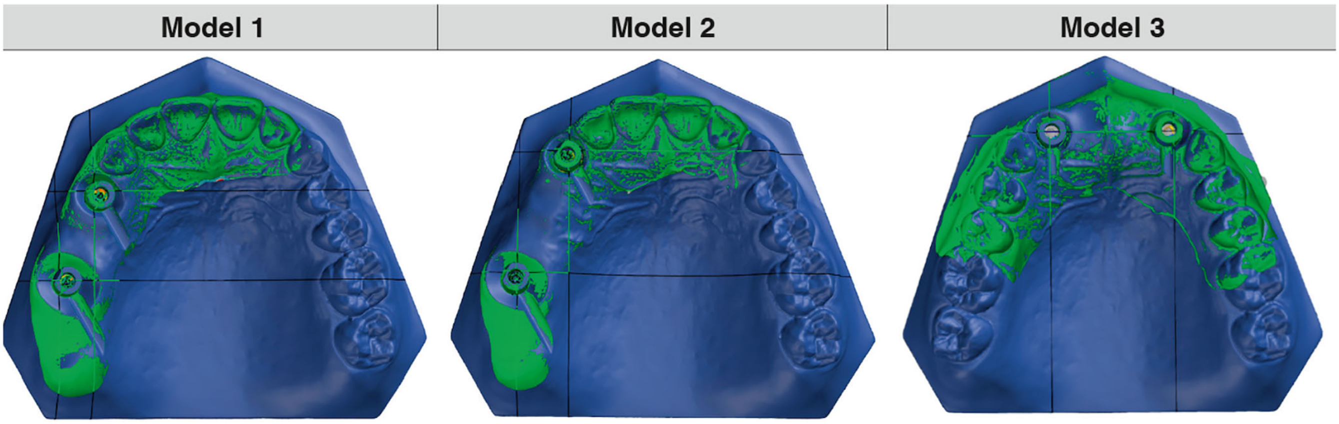

FIGURE 2 Color maps generated by superimpositions and planes used for angular deviation analyses.

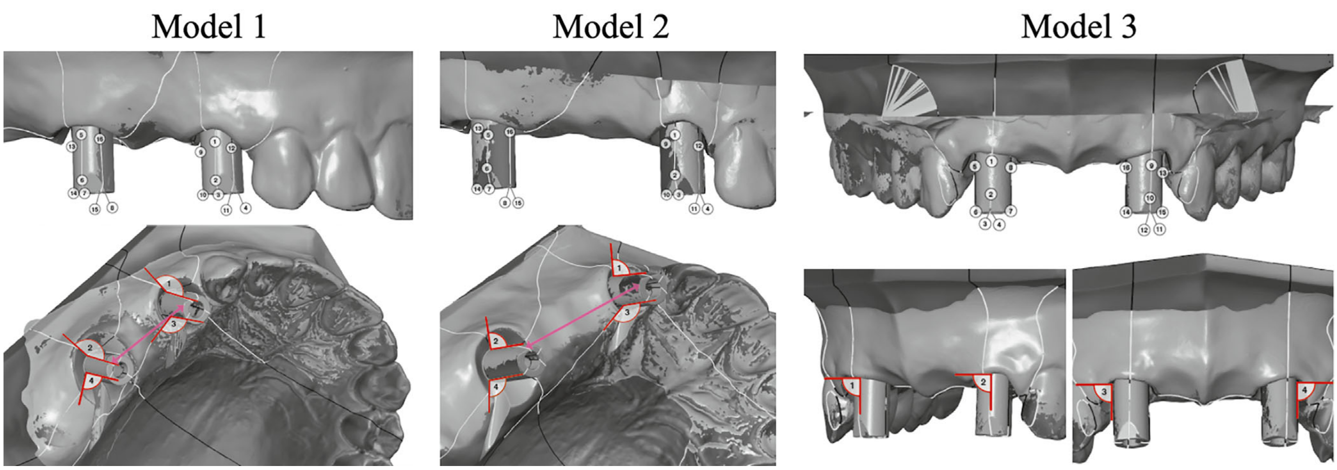

FIGURE 3 Overview of points 1–16 (upper images), and angles (lower images) used for accuracy analyses. Analyses of buccopalatal angular deviations were performed by using angles 1 and 2, while analyses of mesiodistal angular deviations were performed by using angles 3 and. Violet vectors demonstrate inter-implant distances.

Denmark [TR]) that had the most recent software versions. Welch-tests based on the results of previous studies ($\alpha = 0.05$ and $1 - \beta =$ above 80%) deemed 14 scans sufficient,[27,28] which resulted in a total of 84 scans. IOSs were calibrated according to their manufacturers' recommendations before each set of scans and 5-min breaks were taken between each set of scans to minimize any fatigue-related inaccuracies.[2]

An antireflective spray was used to spray the surface of each model and the SBs after mounting the models to phantom heads with face masks by using two-sided adhesive tape. Model surfaces were not contacted until all scans were performed. A dentate mandibular training model (typodont) was also mounted as the opposing jaw. Scans were initially performed by using CP, which was decided with a coin toss. Regardless of the IOS, scans of Models 1 and 2 involved the area starting from right second molar to the midline, while the scans of Model 3 involved the area starting from right first premolar to the left first premolar. All scans were performed in the same room (23°C) under approximately 1000 lux illuminance.[29]

All STL files were trimmed approximately 2 mm below the gingival zenith of remaining teeth by using a design software program (Meshmixer; Autodesk Inc, San Rafael, USA) for standardization and imported into a metrology-grade 3D analysis software program (GOM Inspect 2018; GOM GmbH, Braunschweig, Germany). IOS scan STLs were superimposed over the reference scan STLs after automatic pre-alignment and global best-fit excluding only the SB surface data for each model (Figure 2).[25] Eight points were generated on each SB of the reference scan STL and their coordinates were recorded, which allowed a standardized selection of the points throughout the analyses.[30] The points were projected onto the IOS scan, and the 3D distance deviations of these points were automatically calculated and then averaged for each scan. The distance between two of the previously defined points (one on each SB) for reference and IOS STLs was measured for inter-implant distance deviations. To calculate the angular deviations between the reference and the IOS STLs, two vectors (one in mesiodistal direction and one in buccopalatal direction) passing through two points on each SB were generated (Figure 3).

TABLE 1 Median and interquartile range (25%–75%) values of measured deviations (trueness) for each scanner-model pair.

Model	Scanner	Distance deviations (μm)		Angular deviations (°)	
		3D	Inter-implant	Mesiodistal	Buccopalatal
Model 1	CP	8.75^{aA} (6.97–10)	1.27^{aA} (1–2.81)	0.04^{aA} (0.03–0.06)	0.06^{aA} (0.04–0.09)
	TR	22.81^{bA} (18.91–25.35)	3.14^{aA} (1.32–4.75)	0.10^{aA} (0.07–0.20)	0.06^{aA} (0.04–0.08)
Model 2	CP	119.42^{aB} (99.42–136.56)	24.94^{aB} (2.08–36.95)	0.32^{aB} (0.22–0.46)	0.34^{aB} (0.03–0.06)
	TR	112.15^{aB} (99.40–148.75)	20.78^{aB} (1.45–36.27)	0.56^{aB} (0.29–0.70)	0.09^{aA} (0.04–0.46)
Model 3	CP	155.53^{aC} (152.04–162.66)	15.57^{aB} (6.41–22.60)	0.17^{aB} (0.11–0.34)	0.27^{aB} (0.11–0.38)
	TR	172.17^{bC} (169.39–180.69)	8^{aAB} (2.25–24.53)	0.27^{aB} (0.20–0.60)	0.14^{aA} (0.04–0.38)

Note: In each column, different superscript lowercase letters indicate significant differences between scanners within each model, while superscript uppercase letters indicate significant differences between models within each scanner ($p < 0.05$).

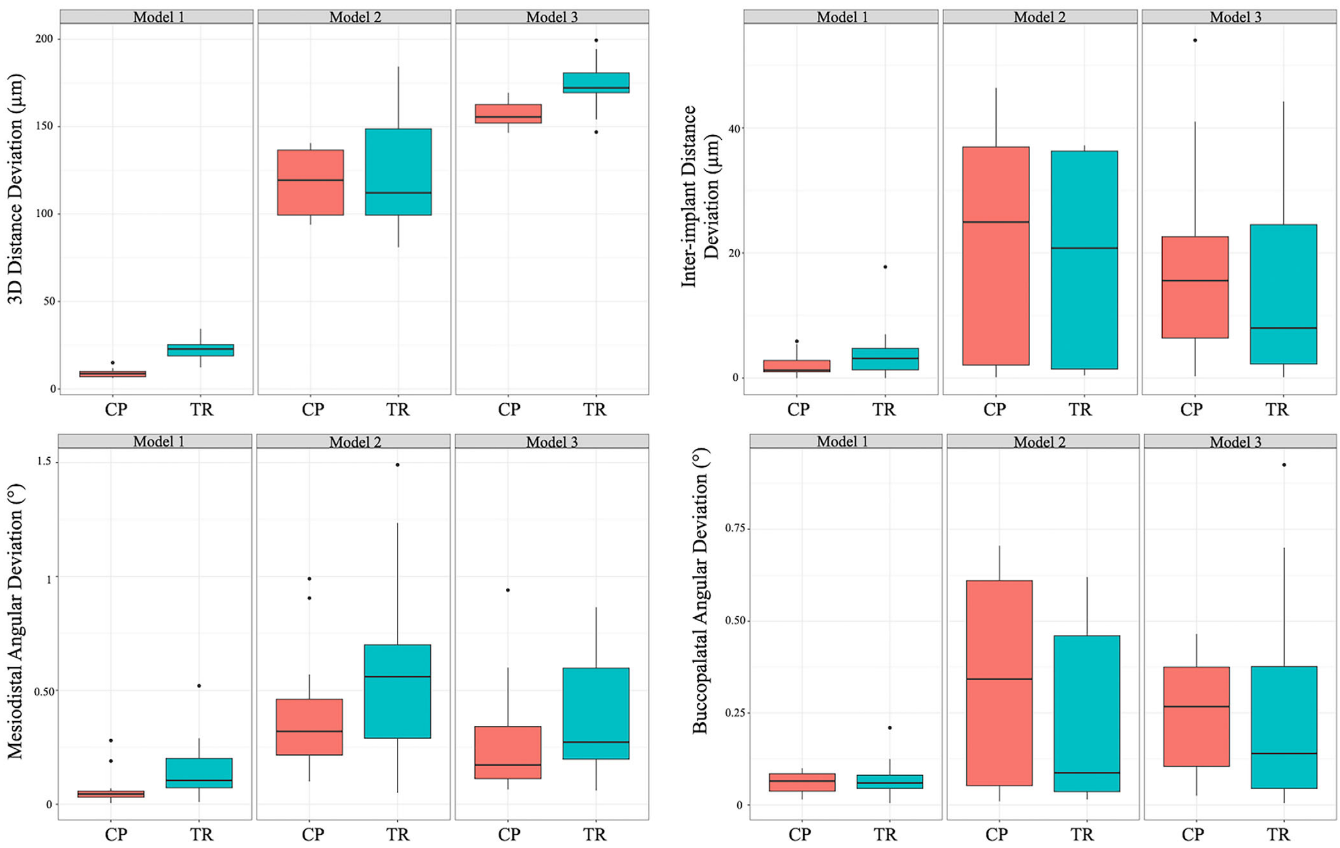

FIGURE 4 Box-plot graphs of measured deviations for each intraoral scanner-model pair. CP, CEREC Primescan; TR, TRIOS 3.

Median values and interquartile ranges for 3D distance deviations, inter-implant distance deviations, and angular deviations (mesiodistal and buccopalatal) were calculated for trueness (distance between test and reference scans) and precision (variance between scans) analyses. Levene's test was used to analyze the homogeneity of variances and group data showed strong heteroscedasticity (differences in variances); thus, parametric bootstrap analysis of variance tests, which included IOSs and FPD situation as the main factors as well as the interaction between these factors were performed. Significant differences were further resolved by using post-hoc Welch tests with Holm correction. All analyses were performed by using a software (R v4.0.2; The R Foundation, Vienna, Austria; $\alpha = 0.05$).

TABLE 2 Median and interquartile range (25%–75%) values of measured deviations (precision) for each scanner-model pair.

Model	Scanner	Distance deviations (μm)		Angular deviations (°)	
		3D	Inter-implant	Mesiodistal	Buccopalatal
Model 1	CP	7.48[aA] (6.18–9.46)	1.27[aA] (0.44–4)	0.03[aA] (0.01–0.12)	0.04[aA] (0.01–0.05)
	TR	16.25[bA] (12.50–19.38)	2.77[bA] (1.23–4.93)	0.10[bA] (0.05–0.20)	0.04[bA] (0.01–0.06)
Model 2	CP	55.71[aC] (27.55–66.48)	23.43[aB] (1.75–35.73)	0.23[aB] (0.11–0.46)	0.48[aC] (0.06–0.58)
	TR	66.60[bC] (55.86–81.54)	30.64[aB] (0.80–34.99)	0.41[bC] (0.19–0.66)	0.21[aB] (0.05–0.44)
Model 3	CP	27.84[aB] (23.59–30.90)	13.62[aB] (6.74–21.87)	0.16[aB] (0.06–0.33)	0.17[aB] (0.08–0.28)
	TR	49.87[bB] (43.98–58.30)	14[aB] (5.33–25.64)	0.23[aB] (0.10–0.49)	0.23[bB] (0.07–0.38)

Note: In each column, different superscript lowercase letters indicate significant differences between scanners within each model, while superscript uppercase letters indicate significant differences between models within each scanner ($p < 0.05$).

3 | RESULTS

Table 1 summarizes the descriptive statistics of deviation values within each IOS-FPD situation pair. IOSs and FPD situation had a significant effect on 3D distance deviations of scans ($p < 0.001$). CP scans had higher trueness than those of TR in Models 1 and 3 ($p \leq 0.002$), while Model 1 scans had the highest and Model 3 scans had the lowest trueness regardless of the IOS ($p < 0.001$). FPD situation had a significant effect on inter-implant distance, mesiodistal angular, and buccopalatal angular deviations of scans ($p < 0.001$). When inter-implant distance deviations were considered, Model 1 scans had the highest trueness when CP was used ($p = 0.010$) and had higher trueness than Model 2 scans when TR was used ($p = 0.030$). When mesiodistal angular deviations were concerned, Model 1 scans had the highest trueness regardless of the IOS ($p \leq 0.040$). When buccopalatal angular deviations were concerned, Model 1 scans had the highest trueness when CP was used ($p \leq 0.020$). Figure 4 illustrates the box-plot graph of measured deviations.

The IOSs, the FPD situation, and their interaction were effective on scan precision when 3D distance deviations were concerned ($p < 0.001$). CP scans had higher precision regardless of the model, while Model 1 scans had the highest and Model 2 scans had the lowest precision regardless of the IOS ($p < 0.001$). IOSs and FPD situation had a significant effect on scan precision when inter-implant distance deviations were concerned ($p \leq 0.001$). CP scans had higher precision in Model 1, while the Model 1 scans had the highest precision regardless of the IOS ($p < 0.001$). IOSs and FPD situation affected the precision of scans when angular deviations were considered, while the interaction between these factors was also effective on scan precision when buccopalatal deviations were considered ($p < 0.001$). Scans with CP had higher precision in Models 1 and 2 when mesiodistal angular deviations were concerned ($p < 0.001$). In addition, Model 1 scans had the highest precision regardless of the IOS, while Model 3 scans had higher precision than Model 2 scans with TR ($p < 0.001$). When buccopalatal angular deviations were considered, CP scans had higher precision in Models 1 and 3 ($p \leq 0.020$). In addition, Model 1 scans had the highest precision regardless of the IOS, while Model 2 scans had higher precision than Model 3 scans with CP ($p < 0.001$). Table 2 summarizes descriptive statistics of precision of deviation values within each intraoral scanner-model pair, while Figure 5 illustrates the box-plot graph of precision of measured deviations.

4 | DISCUSSION

Tested IOSs and FPD situation had a significant effect on the trueness and the precision of scans. Therefore, the first and the second null hypotheses were rejected. CP scans mostly had higher accuracy TR scans when 3D distance deviations were considered. When inter-implant distance deviations were considered, CP scans had higher precision in Model 1. When angular deviations were considered, CP scans had higher precision in Models 1 and 2 for mesiodistal, and in Models 1 and 3 for buccopalatal angular deviations. Considering that the same operator performed all scans under standardized conditions, this difference between tested IOSs may be related to their digital image acquisition mechanisms as TR uses confocal microscopy and ultrafast optical scanning technology, while CP uses smart pixel sensor.[10] However, these results should be carefully interpreted as the difference between median 3D distance deviation values of CP and TR was 14.06 μm in Model 1 and 16.64 μm in Model 3. When scan precision was considered, maximum difference between median deviation values of tested IOSs was 22.03 μm (3D distance deviations in Model 3) and 0.18° (mesiodistal angular deviations in Model 2). Given that these differences are rather small, it can be speculated that FPDs fabricated by using the scans of tested IOSs may be similar. However, studies based on fabrication trueness, internal adaptation,

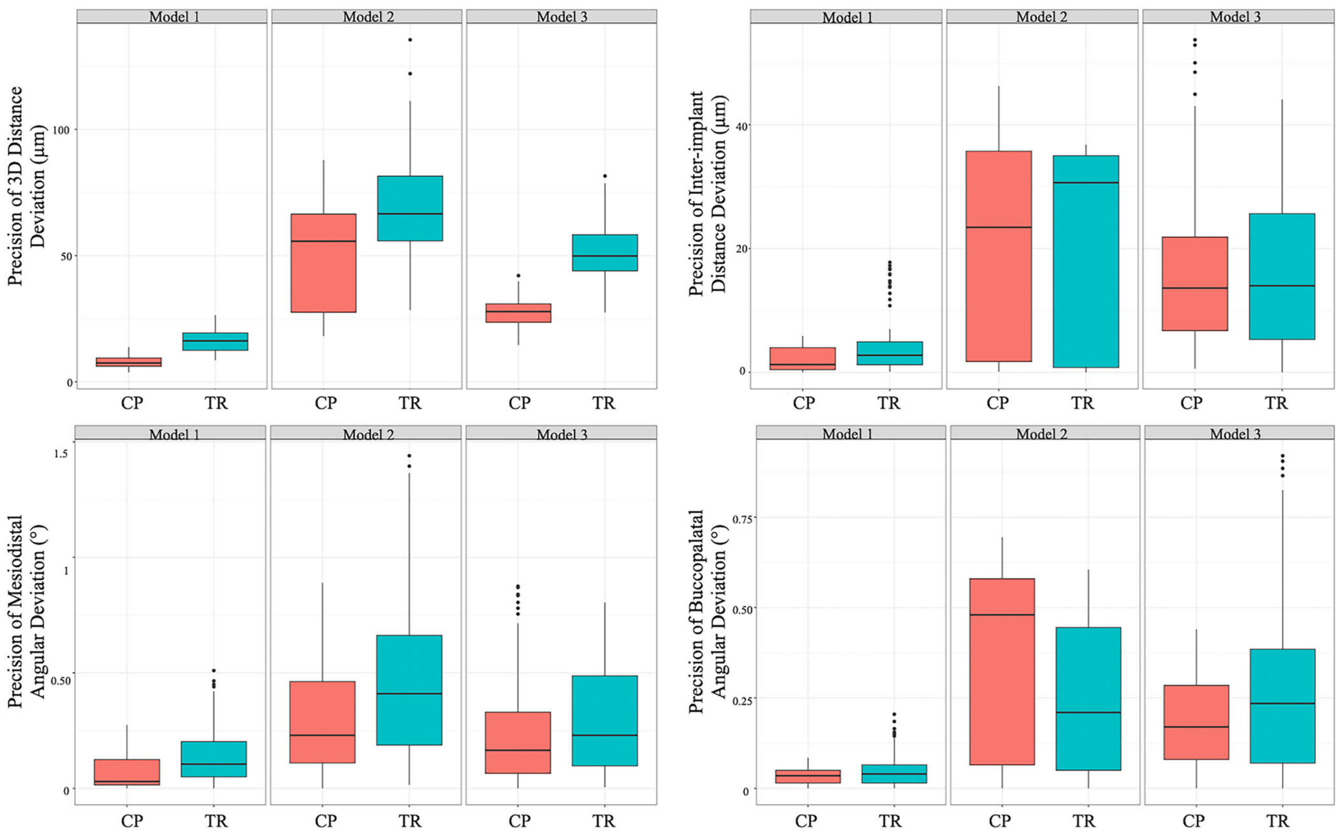

FIGURE 5 Box-plot graphs of precision of measured deviations for each intraoral scanner-model pair. CP, CEREC Primescan; TR, TRIOS 3.

interocclusal and proximal contact adjustment of those restorations are needed to corroborate this hypothesis.

Among tested FPD situations, Model 1 scans (posterior 3-unit FPD) mostly had the highest accuracy, regardless of the IOS. This result is parallel with those in previous studies, which concluded that there was an inverse relation between span-length and scan accuracy,[1,14–18] and could be attributed to the fact that Model 1 had the shortest edentulous span, being the only model designed for a 3-unit FPD. Only nonsignificant difference among tested models was observed when buccopalatal angular deviations in TR scans were concerned, which could be related to the IOS itself.

Even though scan accuracy of implant-supported FPDs has been investigated in previous studies,[1,15,17,21–24] methodological differences complicate possible comparisons of the results of the present study with most of those previous studies.[1,15,17,21–23] However, a recent study by Abou-Ayash et al.[24] used the methodology in the present study. The authors[24] compared the complete-arch scan accuracy of different FPD situations and concluded that the CP scans had accuracy that was either similar to or higher than that of TR scans, which is in line with the results of the present study. CP and TR have also been used in studies on scan accuracy of single implants.[4,5,10–12] Maximum mean 3D distance deviation reported in those studies was 178 µm,[11] which is higher than both maximum median 3D (172.17 µm in Model 3) and inter-implant (24.92 µm in Model 2) distance deviations measured in the present study. A recent systematic review has shown that 160 µm of vertical and 150 µm of horizontal misfit did not cause complications in implant-supported restorations.[8] Inter-implant distance deviation threshold of 100 µm and angular deviation threshold of 0.4° while digitizing 2 adjacent implants have been reported.[7] When the results of the present study were interpreted based on these reported values, it can be hypothesized that FPDs fabricated with tested scans may have clinically acceptable fit, particularly for Model 1. Potential fabrication related errors may increase the risk of misfit more in Models 2 and 3, compared with Model 1. Regardless of the IOS, Model 3 scans had the highest median 3D distance deviations among models, which were also higher than reported values. This might be associated with the curvature of the maxillary arch.[3] Based on reported threshold values, only unacceptable angular deviations were observed in Model 2 scans performed with TR (mesiodistal angular deviations). Curvature of the maxillary arch may also be associated with this result as one of the implants in Model 2 was placed at the canine site, which is the transition between anterior and posterior regions.

The scans were performed on a phantom head with an opposing jaw in a room with previously described ideal conditions.[29] However, absence of patient-related factors such as gag reflex, saliva, and blood[10] can be considered as a limitation. In addition, even though an opposing jaw was used during the scans to simulate clinical conditions, different interincisal openings may affect the results. Tested IOSs were reported to have high accuracy.[17,31] Nevertheless, the effect of IOSs on measured deviations of implant scans has been reported both in the present and previous studies[1,10,17,32]; thus, scan results may differ when scanners other than tested 2 are used. Tested models were fabricated in cobalt-chromium-molybdenum considering its dimensional stability,[26] yet an anti-reflective scan spray had to be used due to the models' reflective surfaces.[6] The authors think that even though it is difficult to standardize the layer thickness of anti-reflective spray used, the effect of layer thickness may be negligible given the fact that the model surfaces were not contacted until all scans were performed. Nevertheless, a different test arrangement with models in different materials that do not require a scan spray may lead to different results. Even though tested FPD situations are commonly encountered, different implant angulations[13] or increased number of implants[1,17] may affect scan accuracy. Superimposing two sets of STLs with the global-best fit algorithm of a metrology-grade 3D analysis software and calculating deviations between these STLs by using RMS method has been reported[33]; but, how deviation is calculated[34] or the algorithm used to calculate RMS[35] may affect the results. Findings of the present study should be elaborated with future in vivo and in vitro studies that focus on the fit and the adjustments needed for the FPDs fabricated by using the scans of tested IOS-FPD situation pairs.

5 | CONCLUSIONS

Within the limitations of the present study, the following conclusions can be drawn:

1. Tested intraoral scanners only affected the 3D distance deviations as CP mostly had higher trueness. Model 1 scans had trueness that was either similar to or higher than that of other models.
2. The interaction between tested intraoral scanners and fixed partial denture situations affected the scan precision when 3D distance and buccopalatal angular deviations were considered. CP scan precision was either similar to or higher than TR scan precision, while Model 1 scans had precision that was either similar to or higher than that of other models.
3. Partial-arch scans of posterior 3-unit fixed partial denture situations with 2 implants performed by using CP may result in higher accuracy when tested implant system is used.

AUTHOR CONTRIBUTIONS

Mustafa Borga Donmez: writing—original draft preparation. **Ayse Mathey:** conceptualization, methodology, investigation. **Fabio Gäumann:** methodology, investigation. **Amber Mathey:** methodology, investigation. **Burak Yilmaz:** supervision, writing—reviewing and editing. **Samir Abou-Ayash:** conceptualization, data curation, formal analysis, funding acquisition, project administration.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest. The authors do not have any financial interest in the companies whose materials are included in this article.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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