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RESEARCH AND EDUCATION

Influence of implant reference on the scanning accuracy of complete arch implant scans captured by using a photogrammetry system

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ABSTRACT

Statement of problem. Photogrammetry has been reported to be a reliable digital alternative for recording implant positions; however, the factors that may impact the accuracy of photogrammetry techniques remain unknown.

Purpose. The purpose of this in vitro study was to assess the influence of the implant reference on the accuracy of complete arch implant scans acquired by using a photogrammetry system.

Material and methods. An edentulous cast with 6 implant abutment analogs (MultiUnit Abutment Plus Replica) was obtained and digitized by using a laboratory scanner (T710; Medit). A photogrammetry system (PIC System) was selected to obtain complete arch implant scans. An optical marker (PIC Transfer, HC MUA Metal; PIC Dental) was positioned on each implant abutment of the reference cast. Each optical marker code and position was determined in the photogrammetry software program. Three groups were created based on the implant reference selected before acquiring the photogrammetry scans: right first molar (IPR-3 group), left canine (IPR-11 group), and left first molar (IPR-14 group) (n=30). Euclidean linear and angular measurements were obtained on the digitized reference cast and used to compare the discrepancies with the same measurements obtained on each experimental scan. One-way ANOVA and the Tukey tests were used to analyze the trueness data. The Levene test was used to analyze the precision values (α=.05 for all tests).

Results. One-way ANOVA revealed significant linear (P=.003) and angular (P=.009) trueness differences among the groups tested. Additionally, the Tukey test showed that the IPR-11 and IPR-14 groups had significantly different linear (P<.001) and angular trueness (P<.001). The Levene test showed no significant precision linear (P=.197) and angular (P=.235) discrepancies among the groups tested. The IPR-3 group obtained the highest trueness (P<.001) and precision (P<.001) values among the groups tested.

Conclusions. Implant reference impacted the accuracy of complete arch implant scans obtained by using the photogrammetry system tested. However, a trueness ±precision linear discrepancy of 6 ±3 μm and an angular discrepancy of 0.01 ±0.01 degrees were measured among the groups tested; therefore, the impact of the discrepancy measured should not be clinically significant. (J Prosthet Dent 2025;133:252-257)

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Clinical Implications

The selection of the reference implant does not impact the accuracy of the photogrammetry system tested; however, marking the implant placed on the right and most posterior tooth location as the implant reference is recommended to maximize the accuracy of the photogrammetry system tested.

Photogrammetry (PG) systems provide a digital alternative for acquiring the 3-dimensional (3D) implant positions.[1–3] These dental PG devices require system-specific markers to be placed on each dental implant.[1–3] PG systems register the 3D position of optical markers and their interrelated spatial positions from photographic images.[1–3]

The accuracy of dental PG systems has been analyzed.[4–10] Among the 4 PG systems currently available, 2 of them, namely PIC system from PIC Dental and iCam4D from Imetric, have been evaluated in most of the in vitro and in vivo studies.[11] For the PIC system, trueness ranged from 10 to 49 μm and precision ranged from 5 to 65 μm.[6–8,10,11] For the iCam4D system, trueness ranged from 24 to 77 μm and the precision value ranged from 2 to 203 μm.[4,5,9,11] These 2 PG may provide a reliable digital alternative for capturing implant positions.[4–11]

While PG systems are capable of recording implant positions, this PG technology does not capture soft tissue information or teeth.[1–3] Therefore, an additional recording method is needed, such as an intraoral scanner (IOS). Multiple factors have been identified that can impact the accuracy of IOSs[12–14]; however, the factors that can impact the accuracy of PG techniques remain unknown.

The purpose of the present in vitro study was to assess the influence of the implant reference on the accuracy (trueness and precision) of complete arch implant scans by using a PG system (PIC system; PIC Dental). The null hypotheses were that no significant difference would be found in the trueness and precision of the complete arch implant scans captured by using the PG system tested in which a different implant reference was marked.

MATERIAL AND METHODS

A maxillary completely edentulous stone cast with 6 implant abutment analogs (MultiUnit Abutment Plus Replica; Nobel Biocare) was obtained. The implant abutment analogs were located at the right and left first molar, right and left first premolar, and right and left canines. A new[15] 2-piece PEEK[16,17] implant scan body (ISB) (Scan Abutment Non Engaging, Ø4.8 mm, H10 mm; IPD) was tightened to 10 Ncm[17] on each implant abutment of the reference implant cast as per the manufacturer's instructions. Subsequently, the reference implant cast was digitized by using a laboratory scanner (T710; Medit) according to the manufacturer's recommendations. The scanner had been previously calibrated by following the manufacturer's instructions. The manufacturer of the laboratory scanner reports a scanning accuracy of 4 μm according to the International Organization for Standardization (ISO) 12836 standard.[18] The reference standard tessellation language (STL) file was exported. Afterwards, the ISBs were removed from the reference implant cast.

A PG system (PIC System; PIC Dental) was selected to obtain complete arch implant scans. An optical marker (PIC Transfer, HC MUA Metal, Ø4.8 mm; PIC Dental) was positioned on each implant abutment of the reference implant cast according to the manufacturer's recommendations. Each optical marker code and position was marked in the PG software program (Table 1). The optical markers remained in the same position during all the digitizing procedures (Fig. 1).

Three groups were created based on the implant reference selected before acquiring the PG scans: right first molar (IPR-3 group), left canine (IPR-11 group), and left first molar (IPR-14 group). A total of 30

Table 1. Optical marker (PIC Transfer; PIC Dental) codes and positions determined

Implant Position	Optical Marker Code
Right first molar	88MUA5
Right first premolar	88MUA4
Right canine	88MUA6
Left canine	88MUA9
Left first premolar	88MUA0
Left first molar	88MUA3

Figure 1. Reference cast.

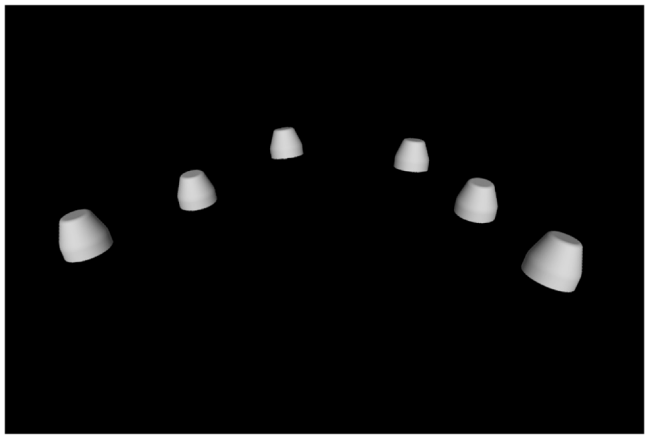

Figure 2. Representative photogrammetry scan.

consecutive PG scans per group were acquired (n=30) by following the ISO 20896–1:2019 standard.[19,20] The PG system captured the implant scans at a 30-cm scanning distance between the most anterior optical marker and the camera of the PG device. The STL files were exported (Fig. 2).

The manufacturer of the ISB (Scan Abutment Non Engaging, Ø4.8 mm, H10 mm; IPD) selected provided the corresponding CAD file. The reference STL file and the CAD file of the selected ISB were imported into a reverse engineering software program (Geomagic, Control X; 3D Systems). In the reference STL, the z plane was located at the most coronal surface of each ISB, followed by the location of the longitudinal axis of each ISB.[21] The z plane marked on each ISB was moved 10 mm apically, which corresponded to the height of the selected ISB. Then, the point located at the intersection between the z plane and the longitudinal axis of each ISB was used to measure the Euclidean linear distances among the 6 ISBs (Fig. 3A).[20] Additionally, the longitudinal axes of the implant scan bodies were used to calculate the Euclidean angular distances among the ISBs.[21]

The same CAD procedures were completed on each experimental scan. First, each scan was imported into the same reverse engineering software program. Then, the z plane was located at the apical base of each implant abutment, followed by the longitudinal axis of

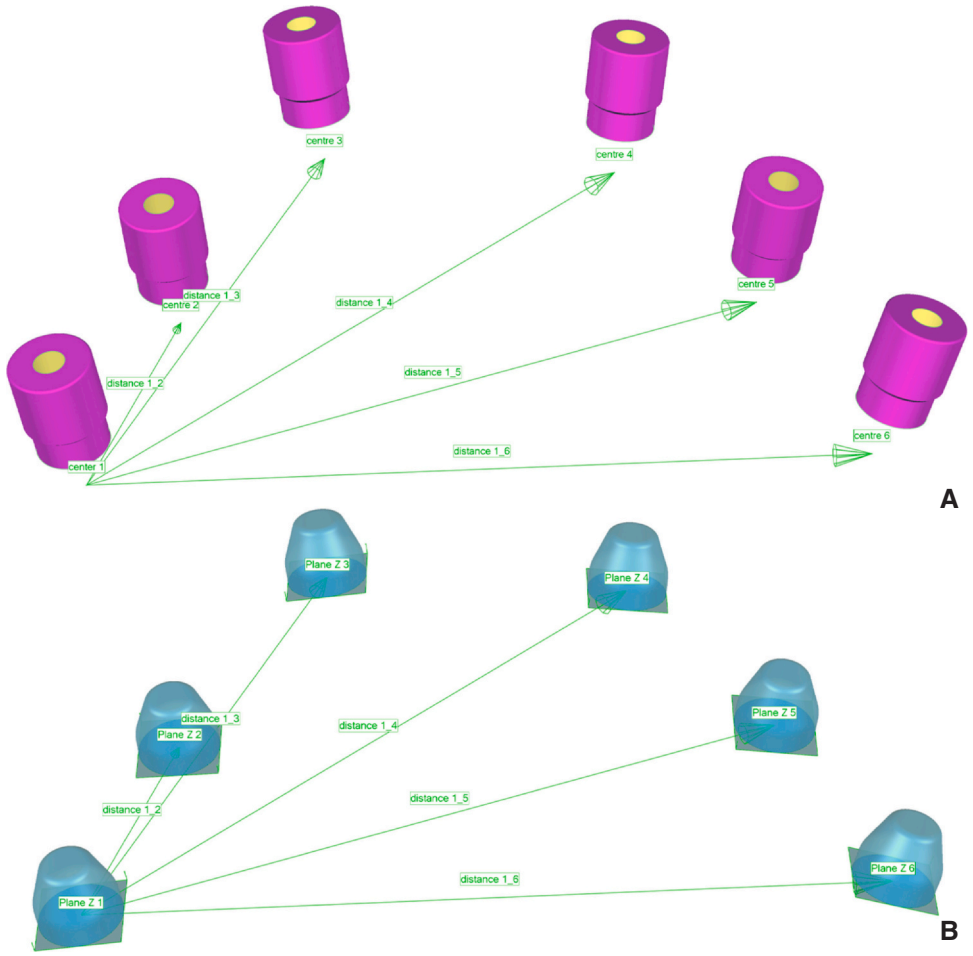

Figure 3. Representative measurement method. A, Linear measurements of reference cast. B, Linear measurements of experimental file.

Table 2. Descriptive statistics of overall linear and angular measurement discrepancies computed in groups tested

Group	Mean ±SD Linear Measurement Discrepancies (Trueness ±Precision) (μm)	Mean ±SD Angular Measurement Discrepancies (Trueness ±Precision) (Degrees)
IPR-3	24 ±6	0.13 ±0.01
IPR-11	28 ±3	0.13 ±0.01
IPR-14	30 ±6	0.14 ±0.01

IPR, implant reference; SD, standard deviation.

each implant abutment. Similarly, as in the reference file, the point located at the intersection between the z plane and the longitudinal axis of the implant abutment was used to measure the Euclidean linear distances among the 6 implant abutments (Fig. 3B).[21] Additionally, the longitudinal axes of the implant abutments were used to calculate the Euclidean angular distances among the ISBs.[21]

The linear and angular measurements obtained in the reference file were used as a reference to calculate the scanning distortion with each experimental scan. Trueness was defined as the average linear and angular measurement discrepancies between the reference and experimental scans.[19–21] Precision was described as the linear and angular measurement variations per each group or standard deviation (SD).[19–21] The Shapiro-Wilk and Kolmogorov-Smirnov tests revealed that the data were not normally distributed ($P>.05$). One-way ANOVA analysis of variance followed by the pairwise comparison Tukey test were used to analyze the trueness data. The Levene test was used to analyze the precision values. All the statistical analysis was completed by using a statistical software program (IBM SPSS Statistics for Windows, v26; IBM Corp) ($\alpha=.05$).

RESULTS

The linear and angular mean ±SD discrepancies obtained in the groups tested are presented in Table 2. Regarding the analysis of the linear measurements, the

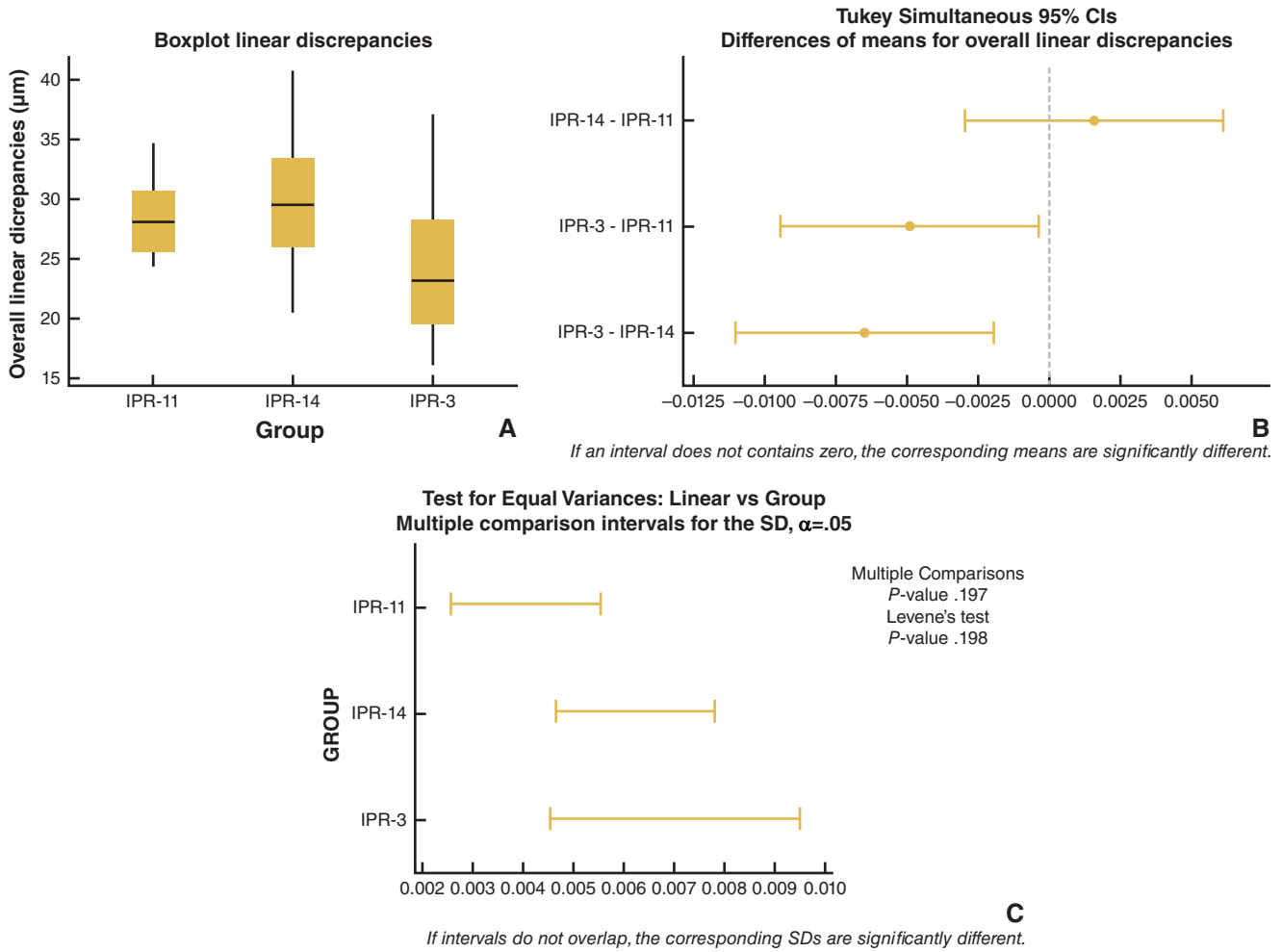

Figure 4. Linear measurement discrepancies. A, Boxplot of linear measurement discrepancies measured among groups tested. B, Tukey simultaneous 95% CIs differences of means for overall linear discrepancies. C, Test for equal variances: linear versus group.

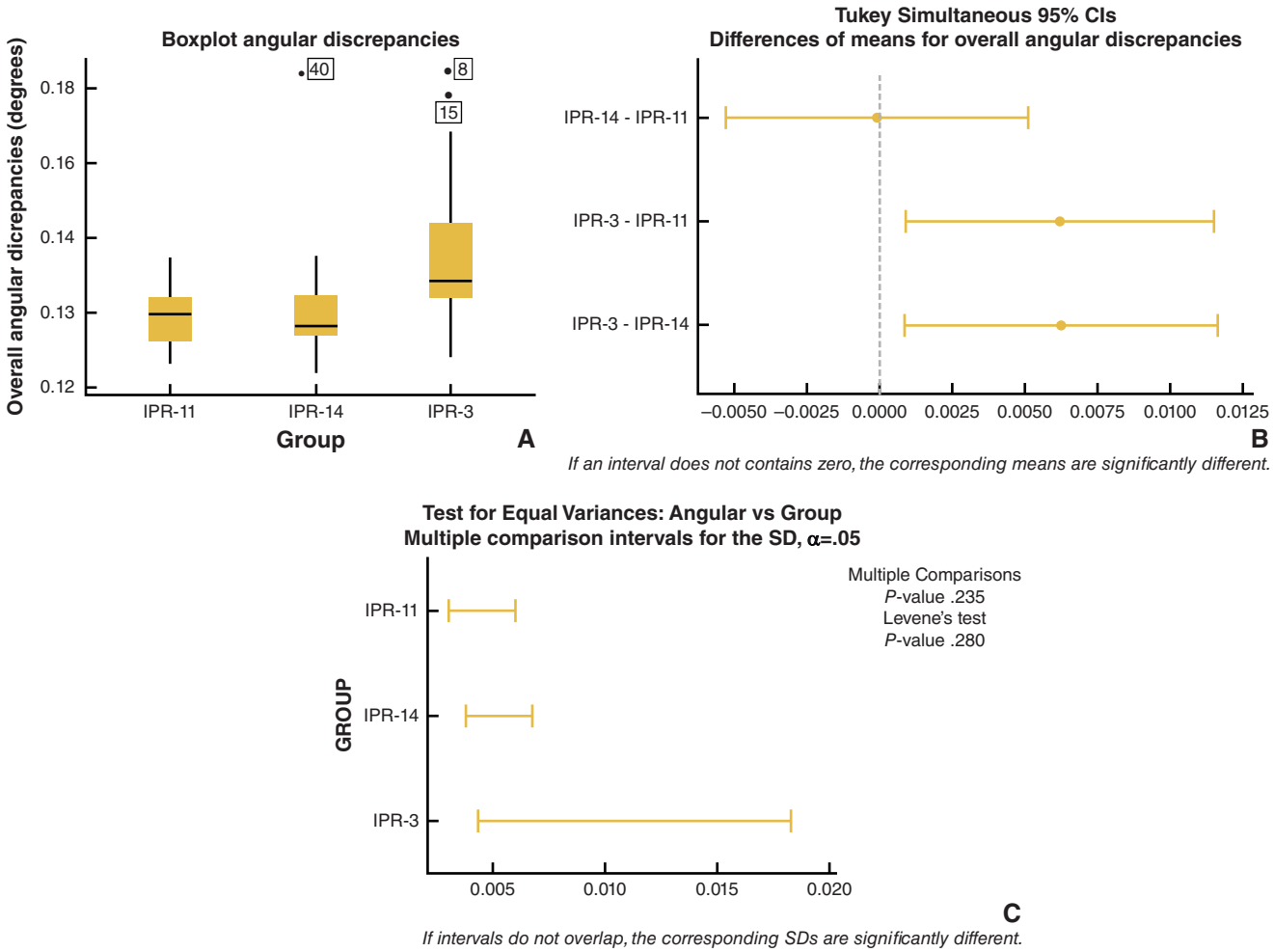

Figure 5. Angular measurement discrepancies. A, Boxplot of angular measurement discrepancies measured in groups tested. B, Tukey simultaneous 95% CIs differences of means for overall angular discrepancies. C, Test for equal variances: angular versus group.

1-way ANOVA test revealed statistically significant mean trueness differences among the groups tested (df=2, MS=0.000171, F=6.51, *P*=.003). Additionally, the Tukey post hoc multiple pairwise comparison test showed that only the IPR-11 and IPR-14 groups were significantly different (*P*<.001). The IPR-3 group obtained the highest trueness value among the groups tested (*P*<.001). Regarding precision, the Levene test showed no significant mean precision discrepancies in the groups tested (*P*=.197) (Fig. 4).

Regarding the analysis of the angular measurements, the 1-way ANOVA test revealed statistically significant mean trueness differences in the groups tested (df=2, MS=0.000174, F=5.30, *P*=.009). Additionally, the Tukey post hoc multiple pairwise comparison test showed that only the IPR-11 and IPR-14 groups were significantly different (*P*<.001). The IPR-3 group obtained the highest precision value of the groups tested (*P*<.001). Regarding precision, the Levene test showed no significant mean precision discrepancies in the groups tested (*P*=.235) (Fig. 5).

DISCUSSION

Based on the results of the present study, the reference implant selected when capturing complete arch implant scans using the PG tested demonstrated a significant effect on the trueness of the virtual definitive implant cast. Therefore, the null hypothesis that no significant difference would be found in the trueness and precision of the complete arch implant scans captured using the PG system tested in which a different implant reference was marked was partially rejected.

The authors are unaware of a previous investigation that analyzed a factor that can impact the accuracy of PG systems. The present study assessed the effect of selecting the implant reference on the accuracy of the PG tested when recording complete arch implant scans. Based on the results, the IPR-3 group obtained the best trueness and precision values of the groups tested. This may indicate that the selection of the implant placed on the right and most posterior tooth location as the implant reference may be recommended for maximizing

the accuracy of the PG system tested. Nevertheless, a trueness ±precision linear discrepancy of 6 ±3 μm and an angular discrepancy of 0.01 ±0.01 degrees were measured in the groups tested. Although statistically significant linear and angular trueness differences were found, the impact of the discrepancy measured may not be clinically significant. Additional studies are needed to further assess the impact of the implant reference selection on the accuracy of different PG systems.

The results of this study were consistent with those reported in the literature on the accuracy of different PG systems.[4–11] However, none of the previous studies reported which implant had been marked as the reference implant on the PG software program; therefore, comparisons of the results obtained in the present study with the results reported previously are not feasible.

Different digitizing methods have been described for capturing the virtual reference model,[11] including a coordinate measurement machine,[4,6,10] industrial scanner,[14] and laboratory dental scanner.[5,7–9] The Euclidean measurement method used in the present study to analyze trueness and precision has been widely used in dental literature.[5,7,10,15]

Limitations of the present study included the in vitro conditions and the single PG device, implant abutment design, and implant manufacturer analyzed. Additionally, a single clinical condition involving 6 dental implants in the maxillary arch was considered. Additional laboratory and clinical studies are recommended to further evaluate the influence of the implant reference on the accuracy of PG systems by considering different numbers and designs of implant abutments and PG systems.

CONCLUSIONS

Based on the results of the present in vitro study, the following conclusions were drawn:

1. Implant reference impacted the accuracy of complete arch implant scans obtained by using the PG tested.
2. A trueness ±precision linear discrepancy of 6 ±3 μm and an angular discrepancy of 0.01 ±0.01 degrees were measured in the groups tested.
3. The impact of the discrepancy measured may not be clinically significant.

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