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RESEARCH AND EDUCATION

Comparative study of the accuracy of an implant intraoral scanner and that of a conventional intraoral scanner for complete-arch fixed dental prostheses

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ABSTRACT

Statement of problem. Most of the available digital systems are designed to image teeth and soft tissue rather than dental implants. However, although some are marketed specifically to record implant position, whether these products are better for implant scanning is unclear.

Purpose. The purpose of this in vitro study was to compare the accuracy of an implant intraoral scanner (PiC camera) with that of an intraoral scanner (TRIOS3) for 6 implants placed in completely edentulous arches.

Material and methods. Two maxillary master models with 6 external hexagonal Ø5.1-mm implants were used, one with parallel and the other with angled implants. The reference values were obtained with a coordinate measuring machine. Ten scans were made per model (parallel and angled) and system (intraoral and implant) (n=10), after which the 3-dimensional coordinates for each implant were determined with a computer-aided design software program and compared with the linear and angular reference values. Statistical significance was determined with the Student *t* test (α=.05).

Results. Statistically significant differences (P<.001) were found in both precision and trueness. The overall errors relative to the reference in the parallel implant-supported casts based on the implant scanner were 20 μm (P=.031) and 0.354 degrees (P=.087) compared with 100 μm (P<.001) and 1.177 degrees (P<.001) in the cast based on conventional digital scans. The global errors in the angled implant casts were 10 μm (P=.055) and 0.084 degrees (P=.045) for the implant digital scans and 23 μm (P=.179) and 0.529 degrees (P<.001) for the conventional digital scans.

Conclusions. The implant intraoral scanner delivered greater precision and trueness than the conventional instrument for imaging complete-arch implant-supported prostheses. (J Prosthet Dent 2021;■:■-■)

Implant-supported dental prostheses have been used successfully for decades to treat partially or completely edentulous patients.[1] An essential consideration when preparing prosthetic frameworks with a passive fit to the implants is their accuracy.[2-4] Tolerances of 10 μm to 150 μm have been proposed as acceptable discrepancies for defining passive fit,[4-11] with the present consensus for complete-arch FDPs ranging between 50 μm and 100 μm.[2]

For implant-supported fixed prostheses, digital scanning systems must deliver suitable accuracy to ensure the reliability of the images recorded. Accuracy can be determined by precision, defined as the variation under specific conditions between different scans of the same object and by trueness, defined as the degree of agreement between the value measured and the actual dimensions of the object.[12-14]

Different digital systems have been marketed for imaging implant-supported prostheses, implants being scanned by attaching scan bodies. One of the various technologies available is based on confocal

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Clinical Implications

The implant intraoral scanner appears to deliver more accurate implant imaging than conventional intraoral scanners in edentulous arches, especially in terms of precision. Conventional intraoral scanners showed greater deviations, with values sometimes beyond the accepted clinical range, which might lead to misfit in complete-arch implant-supported fixed dental prostheses.

microscopy.[15-18] The most modern systems scan in color and need no powder,[7] while some feature telecentricity in the scan field of the target object.[17] One possible problem with intraoral scanners (IOSs) is that the small wand size necessitates subsequent stitching of the fields scanned, a procedure prone to accumulating errors.[10,12,19-29] That is particularly the case for large edentulous spaces where there are fewer references for stitching fields. Nevertheless, this is not the only factor that can affect the accuracy of dental scans.[5,29-54]

Extraoral scanners have been designed and marketed specifically for scanning implant positions in which interimplant distances and angles are calculated as vectors. These scanners avoid the need to stich the images, thereby lowering the likelihood of error.[55,56] As such systems require an implant as a reference, they are not suitable for single implants,[57] and as they image neither teeth nor soft tissue, additional conventional impressions or intraoral scans are required and the data files subsequently merged digitally to generate the definitive cast.[55-61]

This study compared the accuracy, trueness, and precision of the coordinates for 6 implants in 2 completely edentulous arches (one with parallel and the other with angled implant replicas) recorded by an implant (iIOS) and a conventional IOS with the respective reference measurements determined by a coordinate measuring machine (CMM). The null hypothesis was that the trueness and precision of the longitudinal and angular measurements made with the 2 systems and those recorded with CMM in either the parallel or angled implant casts would be similar.

MATERIAL AND METHODS

Six Ø5.1-mm external hexagon implant analogs (ref. IPD/BA-AW-00; Implant Protesis Dental 2004 SL) were screwed onto 2 maxillary arch acrylic resin master models at the lateral incisor, first premolar, and first molar positions. One cast was designed with parallel (PIMP, 0 degrees angle) and the other with angled (AIMP) (Fig. 1) implants with the first right molar 20 degrees distally; the first right premolar, 10 degrees mesially; the lateral right incisor, 0 degrees; the lateral left incisor, 0 degrees; the first left premolar, 15 degrees mesially; and the first left molar, 30 degrees distally.

The reference coordinates for calculating interimplant distances and angulations were measured under controlled conditions (21.3 °C, 37.9% humidity) using a CMM (Global Evo 09.15.08, serial No. 906; Hexagon Manufacturing Intelligence). Lighting conditions were not taken into account because it was a tactile device. The head type was Hexagon HH-AS8-T2.5 with a sensor type TP200 and a Ø0.5-mm ruby stylus. The machine settings and calibration were as expressed in UNE EN ISO10360-2:2010.[62] The measurements of the coordinates of the 6 implants in each cast were carried out directly on the implant platform, without any type of abutment. The axis of the implant replica was obtained with the CMM sensor by contacting the external circumference of the implant replica at 3 different points. After that, using the same approach, the CMM found the references of the implant replica connection plane. The intersection between the implant replica connection plane and its circumferential axis, which is perpendicular to the same plane, gives the center point of that implant replica. The coordinates of the 6 center points were calculated by the CMM's software program based on a center coordinate system chosen by the operator. The maximum permitted longitudinal error was defined as 1.3+3L/1000 μm.

Ten scans (n=10) were recorded per cast and imaging system, based on previous studies with similar experimental designs and supported by a sample size calculation.[12,63] The Student *t* test (G*power v.3.1; Universität Düsseldorf) was used for analysis power for (n=10 ×15) for a normalized size of the effect of 0.5 (Cohen effect size), providing a power of 0.85 at α=.05.

The IOS (TRIOS 3 v.1.4.7.5.3; 3Shape A/S) was used by the same experienced operator (A.S.) throughout. Scanning was consistently begun at the implant in the first maxillary right molar position. The IOS was calibrated before starting the scanning session by following the manufacturer instructions. Six high-precision scan bodies (Elos Accurate IO Scan; Elos Medtech AB) were used (Fig. 2). This confocal microscopy–based IOS system features high-speed scanning (3000 images per second) and visible white light that beams oscillating illumination on the object. Major advantages include that the system recognizes variations in the focal plane across a range of plane positions while maintaining a fixed spatial relationship with the object imaged and that powder is not required.[15-18] The software program then converted the information collected into a 3-dimensional surface.

The iIOS (PiC Camera; PiC Dental) used was fitted with an extraoral, 2-charge-coupled device camera that located implant positions with white polka-dotted black transfer abutments (PiC transfer; PiC dental) (Fig. 3). The camera was configured to make 50 to 60 photographs in 2 dimensions per each pair of implants at a speed of 64

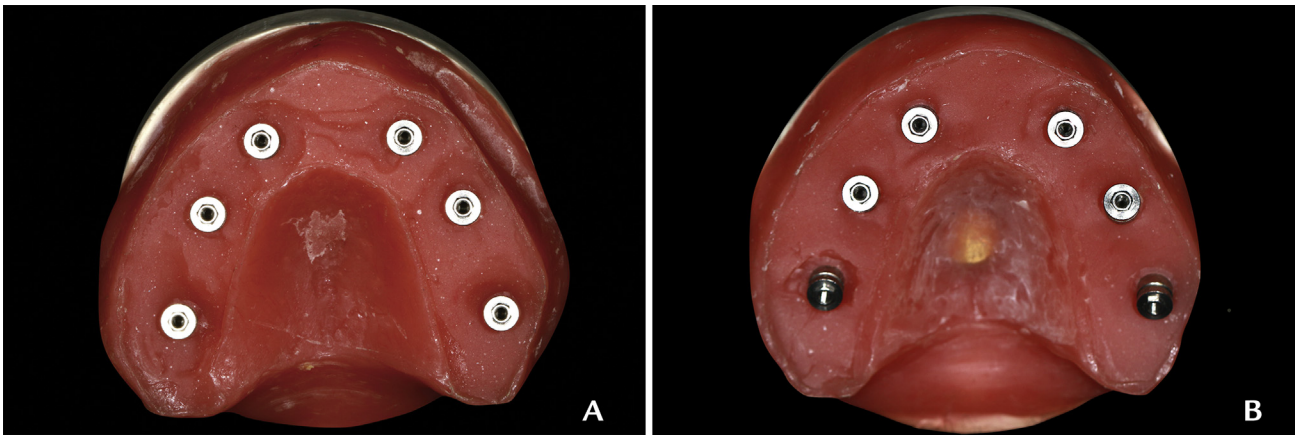

Figure 1. Master models. A, Parallel implant cast (PIMP). B, Angled implant cast (AIMP).

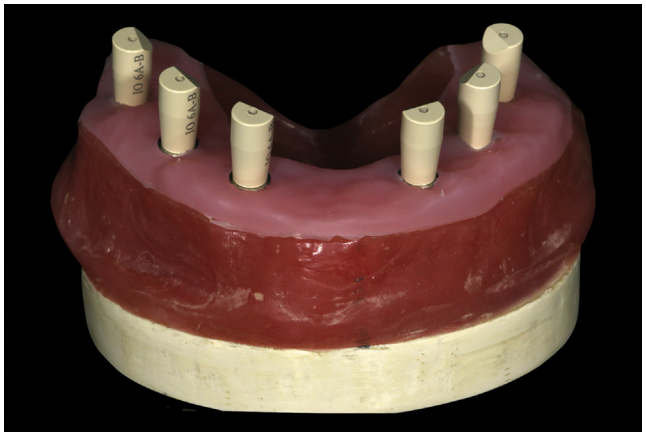

Figure 2. Cast with parallel implants and scan bodies.

Figure 3. Parallel implant cast with PiC abutments (iIOS system). iIOS, implant intraoral scanner.

images/s to determine their position.[55] As for the IOS, the iIOS was calibrated before the scanning session. The abutments were screwed onto the implants at the manufacturer-recommended torque of 15 Ncm in the same order in the 2 casts. Scanning was preceded by entering the implant brand and diameter and the serial number of each abutment. Three implants were marked as references before the scanning procedure as required by the software program of the iIOS system. These implants references were independent of the reference system used during the analysis phase with the reverse engineering software program (Geomagic; 3D Systems). Scanning was conducted by the same experienced operator (A.S.) with the camera at a distance of 15 cm to 30 cm, and the images for the 2 groups were subsequently exported in standard tessellation language (STL) format. In both iIOS and IOs scanning sessions, the ambient conditions were controlled, with a temperature of 21.5 °C and room lighting of 1000 lux, as suggested in a previous study.[49] The implants were digitally splinted with a virtual Ackerman bar designed for each scan with a software program (exocad v.2.2; Align Technology). The aim was to export this design to a 3-dimensional analysis software program (Geomagic; 3D Systems) to determine the coordinates of the center of the connection surface of each implant. The center point was obtained from the intersection of the symmetry axis of each implant (obtained from the cylinders of the Ackerman bar), perpendicular to a plane that included the implant connection surface. Subsequentially, a vector perpendicular to the same plane was generated, in which a random point was chosen, having 2 points for each vector. The next step was to define the implant in the first maxillary right molar position as the origin of the coordinates, corresponding to the starting point of the IOS scan (Fig. 4). Based on the new origin of the 3-dimensional system, the coordinates (x, y, and z) of the 12 points of the 6 implants were determined. This methodology was selected to capture the cumulative potential errors registered during the scanning stitching process.

The coordinates were exported to a spreadsheet (Microsoft Excel; Microsoft Corp) used to calculate the

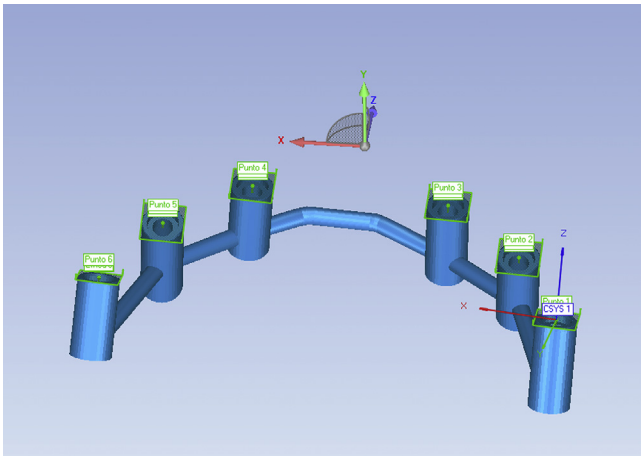

Figure 4. Determination of coordinates for center of each implant relative to maxillary right molar position with Geomagic software program.

distances and convert the angles from radians to degrees with the following equations:

$$D = \sqrt{(x_a - x_b)^2 + (y_a - y_b)^2 + (z_a - z_b)^2}$$

$$\alpha = \tan^{-1} \sqrt{\frac{x_v^2 + y_v^2}{z_v^2}}$$

All the possible combinations (15) of interimplant linear and angular deviations were analyzed in each scan (Fig. 5).

For the assessment of trueness, statistical analysis of the findings was conducted with the 95% significance paired-sample Student *t* test. All the measurements were compared with the CMM reference values. For the assessment of precision, the variance of distance and angular errors between the CMM scans and digital casts of the 2 systems under consideration was analyzed by means of the quadratic Levene test based on ANOVA. Specifically, tests of the variance were performed to establish the value and significance of precision, which was associated with the standard deviation of distance and angular errors. A software package (MATLAB R2019; MathWorks) was used for the analysis.

RESULTS

PIMP cast trueness was studied by comparing the mean error obtained for the 10 scans performed per cast type with the CMM reference values. The iIOS generated fewer distance and angulation errors than the IOS (Table 1, Fig. 6). The overall errors observed with iIOS were 20 μm (P=.031) and 0.354 degrees (P=.087) versus the reference measurements. The analogous values for the IOS system were 100 μm (P<.001) and 1.177 degrees

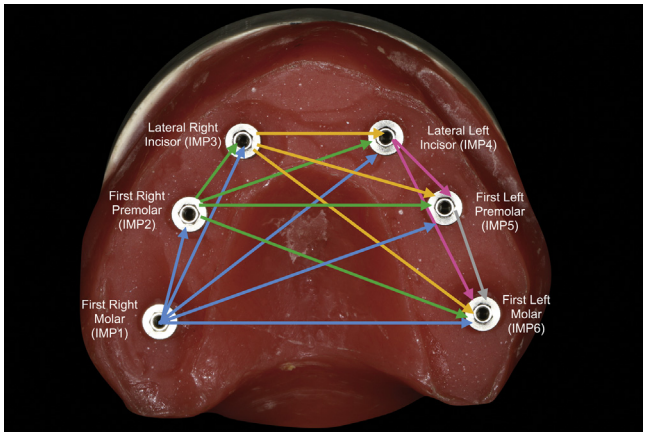

Figure 5. Measurements made to analyze linear deviations. IMP, implant.

(P<.001). The differences were smaller for the AIMP cast, with global errors for iIOS of 10 μm (P=.055) and 0.084 degrees (P=.045) and for IOS of 23 μm (P=.179) and 0.529 degrees (P<.001) when compared with the reference measurements.

Precision for the PIMP cast, measured in terms of the standard deviations for the 10 scans performed, was lower for IOS than for iIOS, with standard deviation ranging over wider intervals in the IOS for both linear (±292 μm) and angular (±0.474 degrees) distances. The respective values observed for iIOS were ±32 μm and ±0.280 degrees. From the Levene quadratic test, precision was significantly better (P<.001) with the iIOS for linear and angular deviations. Standard deviation was also greater (±205 μm, ±0.841 degrees) for the IOS than for the iIOS (±65 mm, ±0.246 degrees), P=.08 for linear and P<.001 for angular distances.

The IOS standard deviation values for both types of casts were significantly greater than the deviations recorded for the reference, taking the center of the first maxillary right molar as the origin (Table 2, Figs. 7, 8). The variations between the iIOS and the reference values were also statistically significantly different, although more narrowly and to a different pattern. The error was not distance dependent.

DISCUSSION

The results of the study led to rejection of the null hypothesis that no statistically significant differences would be found between the CMM-measured longitudinal and angular distances and those obtained with IOS and iIOS. Based on the precision of the 2 systems, the hypothesis that they did not differ significantly was also rejected.

In spite of studies analyzing digital intraoral system accuracy, the ongoing evolution of such systems, the appearance of new technologies, and the variety of factors that may affect the end result all drive the pursuit of further information on the subject. Such factors may be intraoral (gingival thickness, oral mucosa and tongue

Table 1. Mean error (μm and degrees), standard deviation, and statistical significance relative to CMM reference and statistical significance of differences between 2 scanning systems (n=10)

Variable		iIOS-CMM			IOS-CMM			(iIOS-IOS) (Mean)	(iIOS-IOS) (Standard Deviation)
		Mean	Standard Deviation	*P*	Mean	Standard Deviation	*P*	*P*	*P*
Distance (μm)	Parallel	20	32	.031	100	292	<.001	<.001	<.001
	Angled	10	65	.055	23	205	.179	.480	.08
Angulation (degrees)	Parallel	0.354	0.280	.087	1.177	0.474	<.001	<.001	<.001
	Angled	0.084	0.246	.045	0.529	0.841	<.001	<.001	<.001

CMM, coordinate measuring machine; iIOS, implant intraoral scanner; IOS, intraoral scanner.

movement, saliva, and blood) and environment- or operator-, or system-related (wand, technology, and scan bodies).[30,31,48-52] However, studies that assessed factors that may affect iIOSs are sparse. These extraoral devices should be less sensitive to intraoral factors.[55,56]

Implant angulation affected precision and trueness to a statistically significantly different extent in the 2 systems, although it was not the aim of this study to assess the effect of angulation on the accuracy of the digital cast. While another study reported different results,[10] the present findings are consistent with those of earlier research that concluded that increased angulation might facilitate scan body imaging.[24,27,42,43,63]

In a systematic review and meta-analysis of digital scans and conventional impressions accuracy in implant prostheses, Flügge et al[10] reported that the mean deviation in completely edentulous arches with parallel implants and digital scan was 51.0 μm (confidence interval [CI], 28.0 μm to 74.0 μm) and in partially edentulous arches 11.0 μm (CI, 4.1 μm to 19.9 μm) and 0.4 degrees (CI, 0.3 degrees to 0.4 degrees). The widest discrepancies were reported for a single quadrant study, where mean linear deviation for parallel implants was 304.0 μm (CI, 278.6 μm to 320.4 μm) and angular deviation 1.6 degrees (CI, 1.3 degrees to 1.9 degrees), whereas for angled implants (21 to 45 degrees), linear deviation was 158.0 μm (CI, 102.8 μm to 213.2 μm) and angular deviation 1.2 degrees (CI, 0.8 degrees to 1.7 degrees). The authors of a study of implant scans for completely edentulous arches reported linear deviations of greater than 170 μm and angular deviations greater than 0.5 degrees in all the scanners and techniques analyzed.[32]

Any comparison between the present and earlier studies must consider the lack of uniformity in the methodologies used, in spite of the similarity of the objectives pursued. Some studies reported smaller discrepancies, suggesting that certain IOSs were suitable for scanning completely edentulous arches with 4 to 6 implants.[7,44] The differences between the present and earlier findings may be because of variations in the methodology used in terms of master model or mesh overlap measurements, interimplant distance and angulation, absence of fixed reference points, or oral mucosa anatomy and texture.[5]

The iIOS system studied here exhibited mean errors lower than the clinically acceptable thresholds of 100 μm for linear and 0.40 degrees for interimplant angular deviations.[2,5] However, the mean angulation error observed for the intraoral scanner was higher than the reference, and linear deviation exceeded the ceiling for precision although not the accuracy limit.

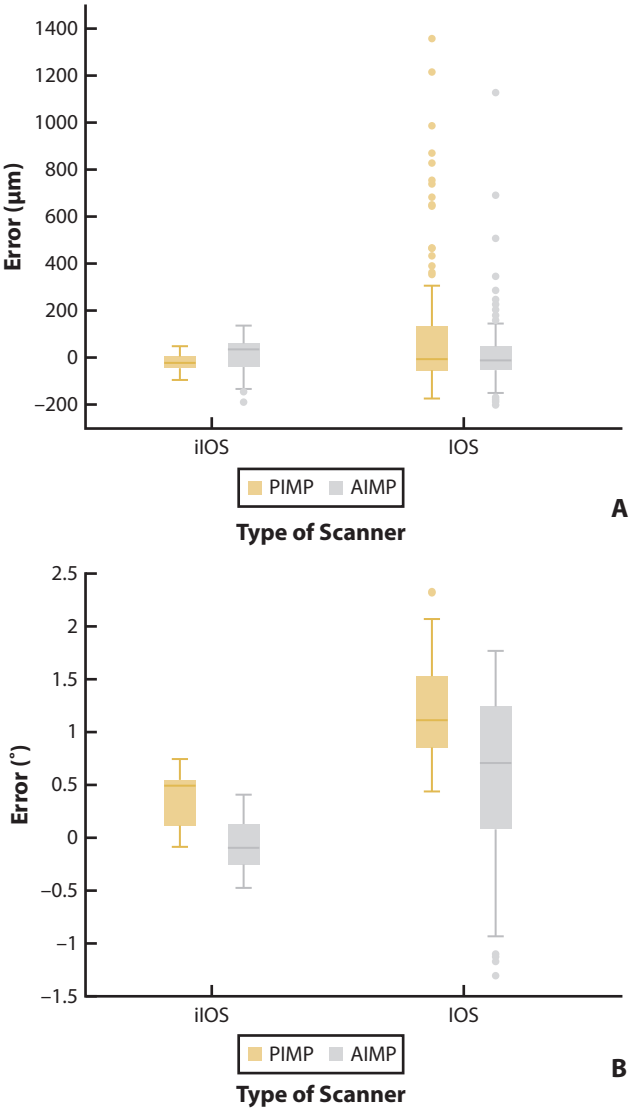

Figure 6. Systems studied by cast type. A, Linear error (μm). B, Angular error (degrees). AIMP, angled implant cast; iIOS, implant intraoral scanner; IOS, intraoral scanner; PIMP, parallel implant cast.

Table 2. Reference angles (degrees) and distances (mm) obtained from CMM from center of coordinate system (IMP1), interimplant mean distance errors (μm) (IMP), and statistical significance relative to reference measurements (n=10)

Cast		CMM Angles (Degrees)	CMM Distance (mm)	iIOS			IOS		
				Mean (μm)	Standard Deviation (μm)	*P*	Mean (μm)	Standard Deviation (μm)	*P*
PIMP	IMP1	0	0	0	0	<.001	0	0	<.001
	IMP2	0.27	16.83	75	16	<.001	265	217	.003
	IMP3	0.39	29.42	72	16	<.001	370	258	<.001
	IMP4	0.46	42.15	122	19	<.001	337	272	.004
	IMP5	0.35	43.84	111	14	<.001	372	290	.003
	IMP6	0.23	45.73	88	18	<.001	785	505	<.001
AIMP	IMP1	0	0	0	0	<.001	0	0	<.001
	IMP2	29.97	16.83	94	12	<.001	55	67	<.001
	IMP3	20.01	29.38	103	7	<.001	72	79	<.001
	IMP4	20.04	42.08	141	7	<.001	107	81	<.001
	IMP5	35.05	43.75	100	6	<.001	46	139	.003
	IMP6	9.90	45.63	124	12	<.001	188	455	.040

AIMP, angled implant cast; CMM, coordinate measuring machine; iIOS, implant intraoral scanner; IMP, implant replica; IOS, intraoral scanner; PIMP, parallel implant cast.

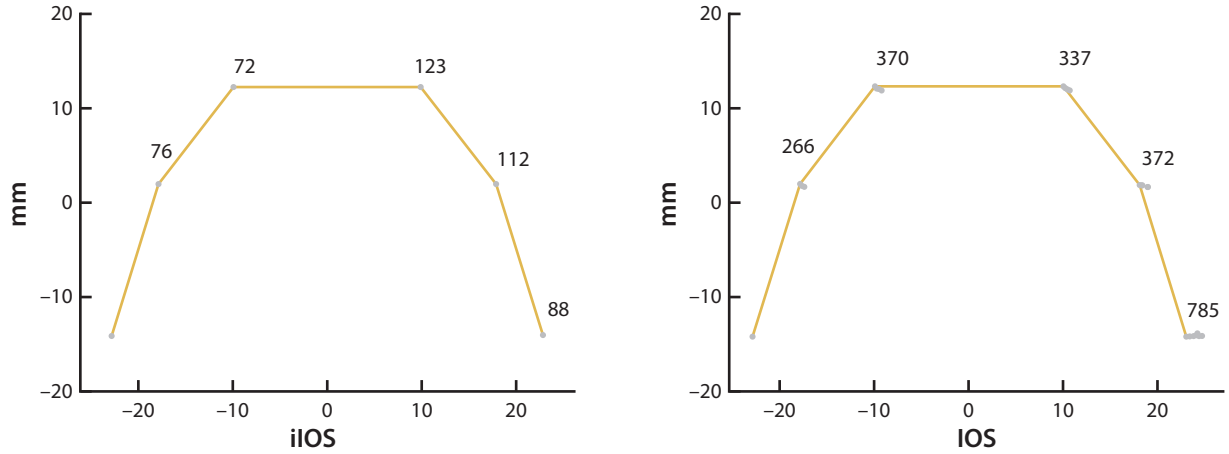

Figure 7. Scatter diagrams for PIMP casts as difference between mean linear measurements and reference value (μm). iIOS, implant intraoral scanner; IOS, intraoral scanner; PIMP, parallel implant cast.

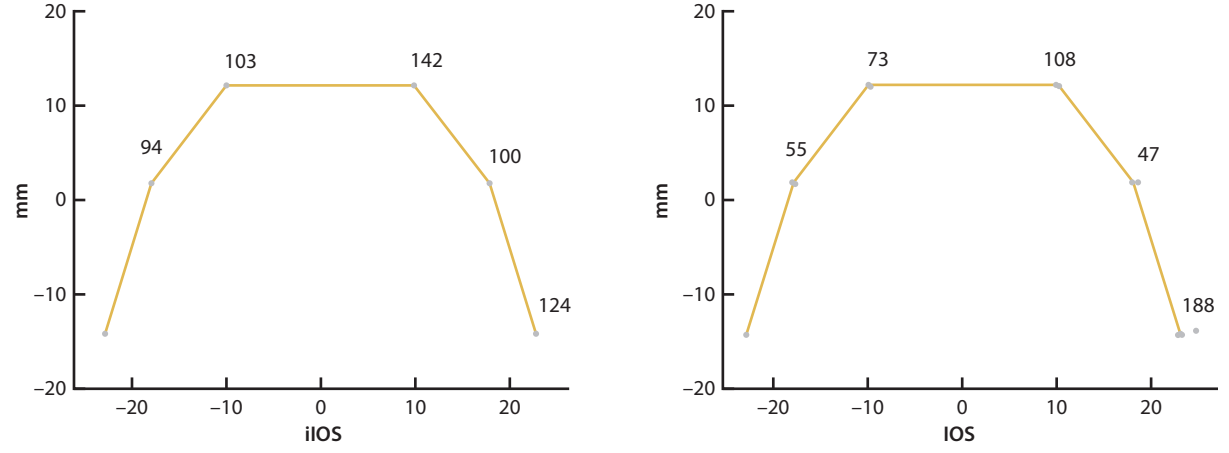

Figure 8. Scatter diagrams for AIMP casts as difference between mean linear measurements and reference value (μm). AIMP, angled implant cast; iIOS, implant intraoral scanner; IOS, intraoral scanner.

Errors in intraoral scanning have been reported to increase with interimplant distance because of image stitching.[10,12,19-21,23-29] That observation was consistent with the present findings for IOS in which, while all interimplant distances differed significantly from the CMM measurements, the

difference widened with distance from the implant defined as the origin.

Proposals to address increased interimplant distance have been made, including altering the edentulous surface to increase the number of reference points for the scanner with techniques such as using an artificial glass pearl reference, splinting the scan bodies, or marking the surface with a mix of pressure-indicating paste and zinc-eugenol cement.[29,33-36] Nevertheless, the use of IOS for imaging fully edentulous arches remains controversial.[5,10,45,51,53,54]

Limitations of this study include its in vitro design that did not fully replicate the clinical conditions, including mucosa or tongue mobility or the presence of saliva, which could affect system accuracy, particularly in the case of the intraoral scanner where the impact of image overlap is greater.[5,37-39] Discrepancies have been reported to be greater and precision lower in clinical studies than in in vitro studies for all the instruments analyzed, including the TRIOS 3.[41] Other authors comparing intraoral and extraoral scans reported up to double the error in the clinical as in the in vitro (25 μm versus 50 μm) evaluation, in all likelihood attributable to moisture, patient movement, and limited oral space.[37] The oral mucosa may also change shape during scanning operations, further hindering image processing.[7] Additional in vitro and clinical studies are needed to corroborate these findings and their clinical implications, as well as to assess factors that may impact both systems.

CONCLUSIONS

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

1. Wider distance and angular deviations ($P<.001$) were observed in the cast with parallel implants in both imaging systems. Therefore, angulation would appear to favor accuracy.
2. The iIOS system delivered more accurate values than IOS, particularly in terms of precision ($P<.001$), except in distance deviation in the AIMP cast.

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