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CLINICAL RESEARCH

Precision of stereophotogrammetry in complete arch implant recordings: A clinical study

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ABSTRACT

Statement of problem. Stereophotogrammetry has been proposed as an alternative to intraoral scanners for recording the location of multiple dental implants. Most studies evaluating its accuracy have been in vitro, and clinical studies are lacking.

Purpose. The purpose of this clinical study was to evaluate the precision of a stereophotogrammetry system for complete arch prostheses supported by 6 implants.

Material and methods. A total of 10 participants with a completely edentulous maxilla with 6 multiunit implant abutments were recruited. For each participant, 5 recordings were made using a stereophotogrammetry device (PIC system; PIC dental). From the resulting standard tessellation language (STL) files, linear and angular Euclidean distances were recorded. A statistical analysis of the measurements obtained was used to determine their repeatability and to identify maximum discrepancy values. A comparative analysis of the standard deviation values was performed with the Kruskal-Wallis and Sidak statistical tests. (α=.05).

Results. For linear distances, the mean ±standard deviation precision was 14.71 ±12.2 µm, with a maximum discrepancy of 61 µm. For the angular measurements, the mean ±standard deviation precision was 0.072 ±0.064 degrees, with a maximum discrepancy of 0.345 degrees. Statistically significant differences ($P<.05$) were found among the different implant spans.

Conclusions. The results suggested that the stereophotogrammetry device was sufficiently precise for recording implant locations in complete arch prostheses supported by 6 implant abutments. (J Prosthet Dent 2025;133:1242-1249)

An accurate recording, in terms of trueness and precision, is essential to ensure the passive fit of complete arch implant-supported prostheses.[1] The 3-dimensional (3D) implant position must be registered accurately, since the tolerance for poor fit in complete arch implant restorations decreases with the increased number of implants.[2]

Quantifying the clinically acceptable level of fit in implant supported-prostheses is challenging.[3] A vertical misfit tolerance ranging from 30 µm to 160 µm and up to 150 µm horizontally has been suggested to avoid mechanical complications and up to 1 mm vertically and 345 µm horizontally to prevent biological complications.[4–8] Ranges between 0.4 and 1 degree have been proposed for angular discrepancies.[9–12]

With the transition to digital workflows, intraoral scanners (IOSs) have been proposed for acquiring 3D implant positions. However, in complete arch implant-supported prostheses, their accuracy remains unclear, as long edentulous spans, implant depth, implant angulation, interimplant distance, scan body design, ambient light, sensor size, scanning strategy, and software

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Clinical Implications

Stereophotogrammetry should be a reliable digital acquisition method for recording the 3-dimensional implant positions in complete arch implant-supported prostheses.Clinical intraoral scanning with this technology provides repeatability values that would ensure an implant-supported prostheses with passive fit.

programs have been reported to interfere with image stitching.[13–28]

Stereophotogrammetry (SPG) has been proposed as an alternative to an IOS in recording restorations supported by multiple implants.[29–32] SPG is capable of measuring the 3D implant positions through the spatial intersection of 2-dimensional (2D) photographs obtained with a stereoscopic camera.[32] These photographs are captured from different angles to obtain the position and angulation of the implants. SPG requires specific scan bodies screwed onto the implants and recognized by the system's software programs.[31,32]

Although photogrammetry (PG) and SPG have been described interchangeably, SPG is a variation of PG.[29,30,33,34]

The accuracy of the Precise Implant Capture (PIC) system (Precise Implants Capture; PIC dental), which uses SPG to record the implant positions, has been evaluated in vitro,[30,32,35–42] with trueness values of 10 to 49 µm and precision values of 5 to 65 µm being reported.[30,32,35,37,38] These studies evaluated both parameters of accuracy, but their clinical relevance was limited because of their in vitro design. In contrast, in most clinical studies, it is not possible to analyze trueness because of the absence of a criterion standard. Analyzing precision clinically is essential to compare the results obtained in previous studies.[10]

The concept of accuracy encompasses the terms trueness and precision, as specified in the International Organization for Standardization (ISO) 5725–1 standard.[43] For the analysis of SPG, trueness is described as the ability of this technology to transfer the position of the implants as closely as possible to their actual position. Precision is described as the repeatability of the implant position recordings under the same conditions.[32]

The purpose of this clinical study was to determine the precision of the PIC system in recording the position of 6 implant abutments supporting a complete arch prosthesis. The effect of the interimplant distance on the precision of the SPG system was also evaluated. The research hypotheses were that the PIC system would be precise for recording implant positions in complete arch prostheses supported by 6 implants and that interimplant distance would not affect the repeatability of measurements.

MATERIAL AND METHODS

In this controlled, nonrandomized clinical study, a total of 50 optical recordings were made with the PIC system. The study protocol was approved by the Research Ethics Committee of the European University of Madrid (CIPI213006.16) and by the Research Ethics Committee of the Jiménez-Díaz Foundation (PIC 129–21_OTROS). The study was conducted at the dental clinic of the European University of Madrid between February and May 2022.

The inclusion criteria were participants with a completely edentulous maxilla and with 6 osseointegrated implants and implant abutments (MultiUnit Abutment; IPD Dental Group). Participants with limited mouth opening or fewer implants were excluded. All participants gave written consent to the study before inclusion.

A total of 5 recordings (n=5) were made per participant (n=10). Manufacturer's scan bodies, PIC transfers (PIC Transfer; PIC dental), were screwed onto each implant abutment located along the edentulous arch at 10 Ncm of torque (Fig. 1). PIC transfers were positioned to be visible to the 2 lenses of the system's stereoscopic camera. Each PIC transfer was coded in the system before making the 5 recordings per participant.

The PIC camera (PIC dental) is an extraoral stereoscopic camera capable of making up to 64 photographs per second per pair of implants. This process was performed until the position of all the implants was located and they were interrelated in 3 dimensions. With the associated software program (PIC V2.3.7; CamSoft Corp), the longitudinal axis of the implant abutments was used to calculate the linear and angular Euclidean distances among the implant scan bodies.

Five recordings were made per participant with the PIC camera positioned at a 20- to 30-cm scanning distance and 30- to 45-degrees scanning angle (Fig. 2).[39] Three PIC transfers were selected as implant reference: 1

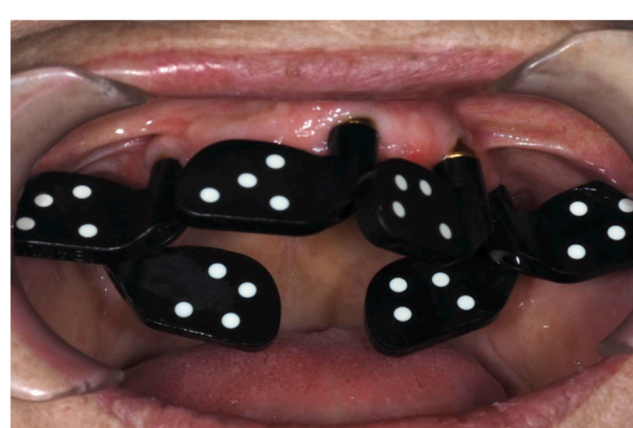

Figure 1. Precise Implant Capture (PIC) abutments screwed onto implant abutments for recording.

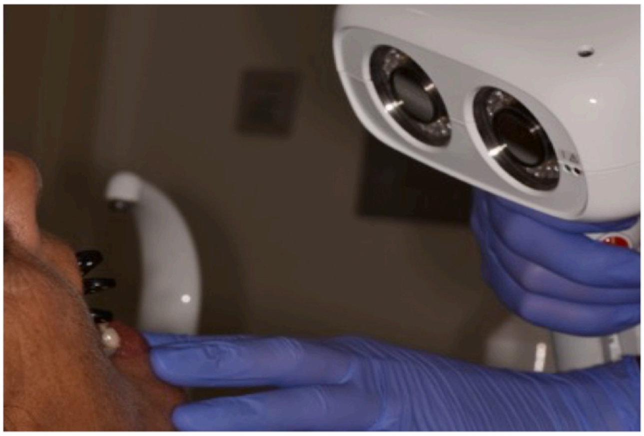

Figure 2. Clinical scenario for recording digital 3-dimensional position of specific stereophotogrammetry scan bodies.

in each posterior zone and 1 in the anterior zone of the arch (Figs. 3 and 4A).[42] The PIC transfers were not removed during the 5 recordings. One experienced operator (M.E.R.) made all the recordings under room light conditions (500 lux) measured with a light meter (LX1330B Light Meter; Dr.Meter Digital Illuminance).

The PIC system software program used mathematical formulas to convert the 3-dimensional implant coordinates into unique values for each linear measurement (in µm) and each angular measurement (in degrees) among the interimplant spans[31,32,35]:

$$d = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2 + (Z_1 - Z_2)^2}$$

$$\alpha = \tan^{-1}\sqrt{\frac{x^2 + y^2}{z^2}}.$$

All the possible combinations (n=15) of interimplant linear and angular deviations were analyzed in each recording (Figs. 4B, 5). A total of 50 standard tessellation language (STL) files were obtained containing linear (n=750) and angular measurements (n=750) (Fig. 6).

A threshold of 75 µm for linear distances and 0.6 degrees for angular measurements was established to assess discrepancies between successive measurements of each variable. This threshold was based on a clinical study analyzing the precision of various IOSs in complete arch implant-supported restorations.[10]

Precision was described as the mean absolute value of discrepancies between the successive measurements of each linear and angular Euclidean distance among all possible interimplant spans of the 50 recordings. Based on previous clinical studies where the PIC system showed a precision of ≥95% for measuring linear Euclidean distances and 100% for angular measurements among implants,[10] a minimum of 520 and 126 measurements was calculated for each variable to determine the clinical precision of this SPG system with a precision error of less than 3% and a confidence level of 95%.

A descriptive analysis was performed with the mean error, the standard deviation (SD), and the minimum and maximum discrepancies among all possible interimplant spans of all the recordings for both variables (n=1500). The same descriptive analysis from spans 1 to 2 to 1 to 6 (n=500) was done to determine the effect of the interimplant distance on the repeatability of the PIC system.

The Kruskal-Wallis and the pairwise Sidak test were used for the comparative analysis from span 1 to 2 to 1

Figure 3. Linear and angular Euclidean measurements obtained in 1 recording with 3 implant references.

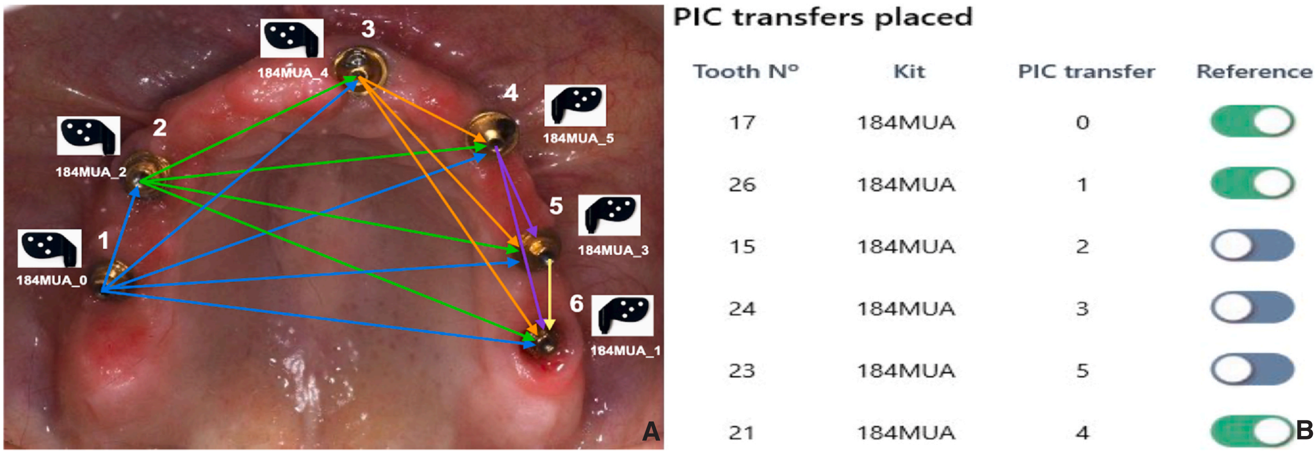

Figure 4. A, Precise Implant Capture (PIC) transfer codes with corresponding implant abutment positions. B, Intraoral view of completely edentulous maxilla with 6 implant abutments and measurements made to analyze linear discrepancies.

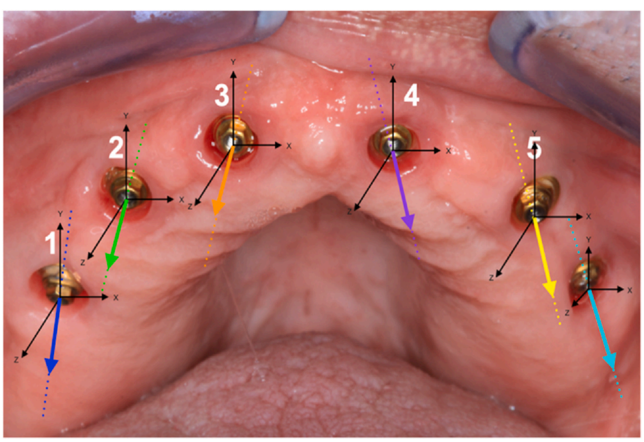

Figure 5. Intraoral view of completely edentulous maxilla with 6 implant abutments and representation of rotational axis of each implant abutment.

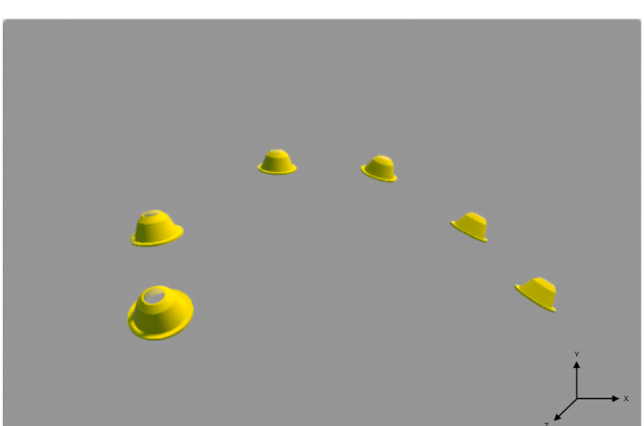

Figure 6. Multiunit implant abutment standard tessellation language file containing 3-dimensional implant position obtained by using stereophotogrammetry system tested.

to 6 to analyze statistically significant differences among spans. All statistical analysis was completed using a statistical software program (STATA BE v.17; Stata Corp) (α=.05).

RESULTS

Ten participants with a completely edentulous maxilla with 6 osseointegrated implants and with multiunit implant abutments were recruited.

Regarding the linear measurements, the mean ±standard deviation precision obtained was 14.71 ±12.21 µm. Discrepancies ranged from 0 to 61 µm, with the largest difference in span 2 to 4 (Table 1). The Kruskal-Wallis test indicated statistically significant differences from span 1 to 2 to span 1 to 6 ($P<.05$) (Fig. 7A). The Sidak test revealed statistically significant differences ($P<.05$) in linear measurements between spans 1 to 2 and 1 to 5, 1 to 2 and 1 to 6, 1 to 3 and 1 to 5, 1 to 3 and 1 to 6, and 1 to 4 and 1 to 6 (Table 2).

Table 1. Descriptive linear measurements of individual and total Euclidean distances

Euclidean Distances	Mean (µm)	SD (µm)	Min (µm)	Max (µm)
Overall	14.71	12.21	0	61
1 – 2	16.20	11.85	0	42
1 – 3	15.90	12.12	1	47
1 – 4	12.66	10.49	0	52
1 – 5	1.03	8.90	0	43
1 – 6	7.80	6.69	0	27
2 – 3	16.24	12.37	0	45
2 – 4	19.12	15.43	0	61
2 – 5	15.12	12.34	0	55
2 – 6	12.38	9.55	0	4
3 – 4	12.72	11.68	0	54
3 – 5	16.38	13.76	0	5
3 – 6	15.44	13.41	0	45
4 – 5	15.28	11.46	0	49
4 – 6	16.44	12.80	0	47
5 – 6	1.88	12.97	0	49

Max, maximum; Min, minimum; SD, standard deviation.

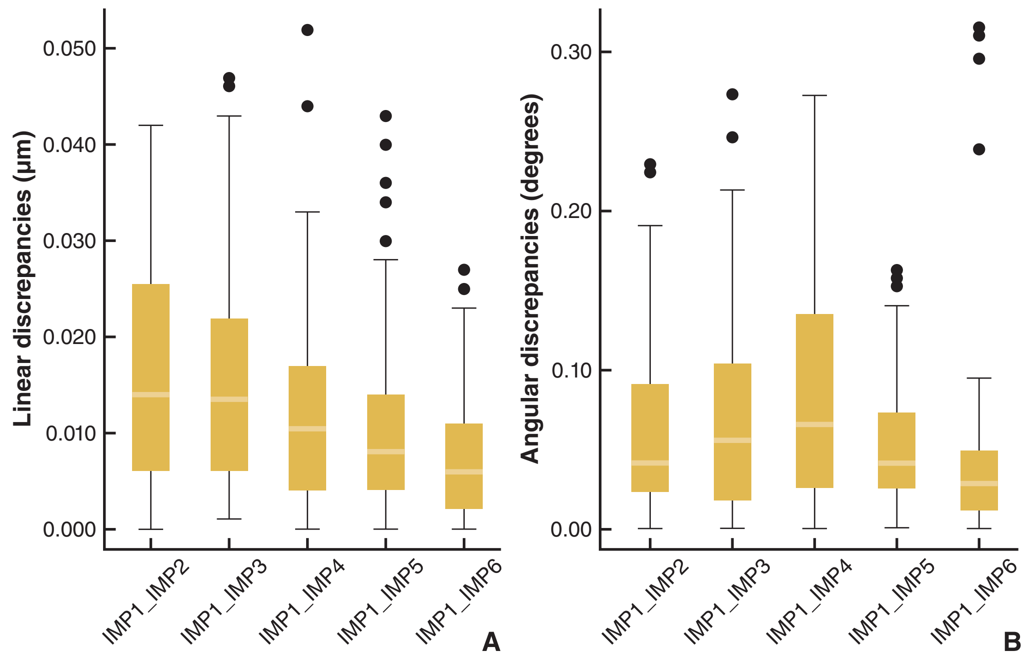

Figure 7. Box plot of linear measurements discrepancies. A, Measured from span 1 to 2 to span 1 to 6. B, Measured from span 1 to 2 to span 1 to 6.

Table 2. Statistical analysis of precision values (linear measurements) from distance 1 to 2 to distance 1 to 6. Statistically significant differences in bold (*P*<.05)

Euclidean Distances	1 – 2	1 – 3 1	1 – 4	1 – 5
1 – 3	>.999			
1 – 4	.137	.226		
1 – 5	**<.001**	**<.001**	.663	
1 – 6	**<.001**	**<.001**	**.008**	.585

Regarding the angular measurements, the mean ±standard deviation precision obtained was 0.072 ±0.064 degrees. Discrepancies ranged from 0 to 0.345 degrees, with the largest difference in span 3 to 6 (Table 3). The Kruskal-Wallis test revealed statistically significant differences from span 1 to 2 to span 1 to 6 (*P*<.05) (Fig. 7B). The Sidak test revealed statistically significant differences (*P*<.05) in angular measurements between spans 1 to 2 and 1 to 4, 1 to 3 and 1 to 6, 1 to 4 and 1 to 5, and 1 to 4 and 1 to 6 (Table 4).

Table 3. Descriptive angular measurements between implants and total Euclidean angular distances

Angulations	Mean (Degrees)	SD (Degrees)	Min (Degrees)	Max (Degrees)
Overall	0.072	0.064	0.000	0.345
1 – 2	0.064	0.057	0.000	0.230
1 – 3	0.069	0.059	0.000	0.273
1 – 4	0.088	0.076	0.000	0.273
1 – 5	0.055	0.040	0.001	0.165
1 – 6	0.041	0.056	0.000	0.315
2 – 3	0.076	0.061	0.000	0.243
2 – 4	0.073	0.063	0.000	0.270
2 – 5	0.081	0.064	0.001	0.290
2 – 6	0.065	0.055	0.000	0.211
3 – 4	0.062	0.050	0.001	0.275
3 – 5	0.078	0.064	0.004	0.283
3 – 6	0.086	0.081	0.000	0.345
4 – 5	0.085	0.068	0.000	0.341
4 – 6	0.082	0.075	0.003	0.334
5 – 6	0.077	0.068	0.001	0.287

Max, maximum; Min, minimum; SD, standard deviation.

Table 4. Statistical analysis of precision values (angular measurements) from distance 1 to 2 to distance 1 to 6

Angulations	1 – 2	1 – 3	1 – 4	1 – 5
1 – 3	.999			
1 – 4	**.040**	.224		
1 – 5	.971	.625	**<.001**	
1 – 6	.077	**.010**	**<.001**	.669

Statistically significant differences in bold (*P*<.05).

DISCUSSION

Based on the results of this study, no measurements of linear and angular Euclidean distances exceeded the established threshold. Therefore, the research hypothesis that the PIC system would be precise for recording implant positions in complete arch prostheses supported by 6 implants was accepted. Although statistically significant differences were observed in the linear and angular Euclidean distances across different spans, increasing the distance between implants did not affect the system's precision. Therefore, the research hypothesis that interimplant distance would not affect the repeatability of measurements was accepted.

The authors are unaware of any previous studies that have used the same methodology and sample size to evaluate the clinical precision of this SPG system for recording implant positions in complete arch implant-supported prostheses. Most studies evaluating the accuracy of IOSs have been conducted in vitro, thus lacking the challenges inherent in clinical studies.[10] The heterogeneity in the design, sample, and methods of accuracy assessment complicates the interpretation of the results and clinical indications of these devices.[10,17,29] Therefore, a clinical study was conducted to determine whether oral conditions could affect the precision of the PIC system.

Based on previous in vitro[31,32,35,40–42,44,45] and clinical studies,[10,46,47] participants with an edentulous maxillary arch with 6 implants were recruited. While 6 is the most common number of implants in SPG accuracy studies, clinical studies have shown variations in the number of implants used ranging from 4 to 8 implants per arch.[10,46,47] In vitro studies typically involve 4 [36,37,39] to 6 implants per cast.[31,32,35,40–42,44,45] The effect of implant connection type, depth, and the use of implant abutments remains controversial in terms of their impact on the accuracy of digital recording techniques.[15–17] Therefore, patients with multiunit abutments on implants were included in this study, consistent with previous in vitro[30–32,37–42,44] and clinical study designs.[46,47]Currently 4 dental PG systems are available: iCam4D (Imetric), Oxo Fit (OXO), PIC system (PIC dental), and MicronMapper (ClaroNav), although only the accuracy of the iCam4D and PIC system has been reported.[29,33,40]

IOSs have a limited field of view and require a large number of images for STL file reconstruction, which complicates the process of image stitching.[10,35] In contrast, the PIC system provides the 3-dimensional position (PIC File; PIC dental) of the implants and is not affected by factors such as operator, scanning pattern, saliva, long edentulous spans without anatomic landmarks and mobile soft tissue,[30,44] aspects that can adversely influence the accuracy of IOSs.[13–28]

Additionally, the PIC camera features an infrared flash system (wavelength 810 nm) and 4 light filters that control light reflection to ensure that ambient light does not affect the accuracy of the system.[33,39] This is in contrast with other IOSs as reported by Revilla-León et al and Ochoa-López et al.[20–22] However, SPG requires a second recording using an IOS or the digitization of a conventional recording for soft tissue registration.[29,31,33,35]

To optimize measurements registration, 3 PIC transfers were selected as implant references.[42] These had to be within the field of view of both camera lenses to start the scan. Those that were visible for simultaneous capture were chosen. The main challenge was the oral opening capacity of each participant and the limitation of the field of view due to perioral tissues such as cheeks or tongue, which increased the scanning time compared with in vitro studies.

Since a consensus on the acceptable misfit value for implant-supported prostheses is lacking,[3,10,12] clinical guidelines for IOSs remain unclear.[48,49] Significant heterogeneity in materials, methods, and results has been reported when analyzing the accuracy of such devices in restorations supported by 4 to 6 implants. Some studies analyzing SPG accuracy used conventional recordings as the criterion standard,[31,32,37,38,44–47] while others use digital recordings from IOSs as the experimental group for comparison,[10,30,32,35,37–39,41,45,46] complicating the interpretation of the results and conclusions. The passive fit threshold has been established at 200 μm and 0.4 degrees in some studies, while others set it at 150 μm horizontally, 50 μm vertically, and 1degree angularly.[12,48] In some in vitro studies, SPG has shown similar results to those of IOSs in complete arches with 4 to 6 implants, while in others SPG outperforms IOSs.[10,30,32–34,37–39,46,48]

In multiple implant-supported prostheses, analyzing both linear and angular Euclidean measurements is essential as there are infinite possible angular abutment positions that can affect the fit of the framework, even when the distance between implants remains constant.[10] The PIC system directly calculates and provides both linear and angular Euclidean distance measurements without the need for previous image stitching and STL file transformation on the 3-dimensional work cast, thereby avoiding potential errors in implant location.[10,30]

Although trueness was not evaluated in this clinical study because of the lack of a criterion standard, the mean ±standard deviation precision of the PIC system was assessed at 14.71 ±12.21 μm. Since the clinical precision results were consistent with those obtained in vitro,[30,32,35,37–39] it could be inferred that the clinical trueness resembles the in vitro results, which ranged from 10 to 49 μm.[29] Since all measurements were within the established threshold, factors including the oral conditions, patient, implant distribution, and arch length did not affect the precision of the PIC system.

PG and SPG accuracy has been analyzed in previous in vitro studies.[34–42,44,45] The iCam 4D system reported a trueness of 24 to 77 μm and a precision of 2 to 203 μm, while the PIC system presents better values for both parameters according to the literature: 10 to 49 μm for trueness and 5 to 65 μm for precision.[29] In in vitro studies, Sallorenzo et al[35] reported a precision of 32 μm, and Pozzi et al[39] reported a precision of 33 μm, both assessing the PIC system using the same evaluation method. Both of these values were higher than the precision of 14 μm obtained in the present study.

The results of the present study were consistent with those obtained in previous in vitro studies, where the precision ranged were from 5 to 65 μm. These studies used different evaluation methods such as linear and angular discrepancies for the x,y,z axis, the 3-dimensional discrepancies per implant, or the RMS error calculation.[30,32,37–39] The accuracy of IOSs, PG, or SPG has been analyzed by using the best fit alignment technique, which provides a clear and visual representation of discrepancies between structures but can be affected by the amount of mesh in files and the type of software program used.[10]

The authors are aware of only 2 previous clinical studies that analyzed the precision of the PIC system. Orejas-Perez et al[10] reported a maximum discrepancy of 108 µm and 0.44 degrees, while Pozzi et al[46] reported a mean ±standard deviation precision of 87.6 ±74.2 µm and 0.38 ±0.29 degrees and maximum discrepancies of 316.2 µm and 1.92 degrees. The results obtained in the present study showed better precision values with a mean ±standard deviation precision, as with a larger sample, with 14.71 ±12.21 µm and 0.072 ±0.064 degrees, with maximum discrepancies of 61 µm and 0.345 degrees. This improvement may be attributed to advances in hardware and software program development.

The results confirmed that increasing the inter-implant distance did not affect the repeatability of the PIC system. Although statistical differences were observed when comparing measurements from span 1 to 2 to 1 to 6, no increasing pattern of imprecision was observed as implant distance increased. These results were consistent with those of Orejas-Perez et al[10] and Sallorenzo et al.[35] However, as described by Pinto et al,[30] the repeatability of measurements tends to decrease with a higher number of implants.

Limitations of this study included that the trueness of the PIC system was not evaluated because of the absence of a control scan for comparison. Further clinical studies are needed to assess both trueness and precision by using a larger sample size, with different numbers, distributions, and implant connections.

CONCLUSIONS

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

1. The PIC system showed 100% precision in making recordings in maxillary complete arch implant-supported prostheses with 6 implant abutments.
2. Increasing the distance between implants did not affect the precision of the PIC system.

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