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ORIGINAL ARTICLE

Accuracy, scanning time, and patient satisfaction of stereophotogrammetry systems for acquiring 3D dental implant positions: A systematic review

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Abstract

Purpose: To evaluate accuracy, scanning time, and patient satisfaction of photogrammetry (PG) systems for recording the 3D position of dental implants.

Material and Methods: A literature search was completed in five databases: PubMed/Medline, Scopus, Embase, World of Science, and Cochrane. A manual search was also conducted. Studies reporting the use of commercially available PG systems were included. Two investigators evaluated the studies independently by applying the Joanna Briggs Institute critical appraisal. A third examiner was consulted to resolve any lack of consensus.

Results: A total of 14 articles were included: 3 in vivo, 6 in vitro, and 6 case report manuscripts. One clinical study evaluated trueness, another one tested precision, and the third one assessed impression time and patient and operator satisfaction. All the in vitro studies evaluated the trueness and precision of a PG system. Additionally, all the reviewed studies investigated completely edentulous conditions with multiple implants. The number of placed implants per arch among the reviewed clinical studies varied from 4 to 8 implants, while the number of implants placed on the reference casts included 4, 5, 6, or 8 implants. Not all the studies compared the accuracy of PG systems with conventional impression methods, using intraoral scanners as additional experimental groups. For the PIC system, trueness ranged from 10 to 49 μm and precision ranged from 5 to 65 μm. For the iCam4D system, trueness ranged from 24 to 77 μm and the precision value ranged from 2 to 203 μm.

Conclusions: PG systems may provide a reliable alternative for acquiring the 3D position of dental implants. However, this conclusion should be interpreted carefully, as one study reported a mean precision value of one PG system higher than the clinically acceptable discrepancy. Lower scanning time and higher patient and operator satisfaction have been reported when compared with conventional techniques. Further studies are needed to increase the evidence regarding the accuracy, scanning time, and patient and operator satisfaction of the commercially available PG systems.

KEYWORDS
accuracy, digital impression, prosthodontics, stereophotogrammetry

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TABLE 1 Boolean search terms for the different databases explored.

Database	MeSH terms and search terms
Medline/PubMed and Cochrane	(“Photogrammetry”[MeSH] OR “stereophotogrammetry”) AND (“implant dentistry” OR “Dental Prosthesis”[Mesh] OR “Implant digital impression” OR “IMPLANT DIGITAL SCAN”) AND (“Dental Impression Technique”[Mesh] or “implant impression” OR “conventional implant impression” OR“ Coordinate measure machine” OR “Dental laboratory scanner” OR “dental lab scanner” OR “Intraoral scanner” OR “Intraoral scanners”) AND (“Accuracy” OR “trueness” OR “precision” OR “Patient Satisfaction”[Mesh] OR “Patient Preference”[Mesh] OR “scanning time” OR “efficiency” OR “reliability”)
Embase and Scopus	(“Photogrammetry”[MeSH] OR “stereophotogrammetry”) AND (“implant dentistry” OR “Dental Prosthesis”[Mesh] OR “Implant digital impression” OR “IMPLANT DIGITAL SCAN”) AND (“Dental Impression Technique”[Mesh] or “implant impression” OR “conventional implant impression” OR“ Coordinate measure machine” OR “Dental laboratory scanner” OR “dental lab scanner” OR “Intraoral scanner” OR “Intraoral scanners”) AND (“Accuracy” OR “trueness” OR “precision” OR “Patient Satisfaction”[Mesh] OR “Patient Preference”[Mesh] OR “scanning time” OR “efficiency” OR “reliability”) NOT MEDLINE

Photogrammetry (PG) is a technology developed to obtain measurements by using reference points within photographs.[1] PG has been widely employed in different fields such as cartography, anthropometric data,[2] archeology optics,[3] automotive, and mining industries.[4] PG is able to calculate the three-dimensional (3D) position of points by analyzing photographs taken from different angles. In dentistry, PG technology has been adapted for capturing the 3D position of dental implants.[5,6]

PG may provide a digital alternative to intraoral scanners (IOSs) for recording the 3D position of dental implants.[7,8] Dental literature has assessed the accuracy of complete-arch intraoral implant scans by using IOSs reporting contradictory results.[9–12] Additionally, operator- and patient-related factors that can reduce the scanning accuracy of IOSs have been identified,[13,14] such as scanning pattern,[15,16] ambient illuminance conditions,[17,18] rescanning techniques,[19,20] and edentulous areas with mobile tissue and lack of anatomical landmarks.[21,22] PG systems may not be influenced by these influencing factors due to their operating mechanism, easing the digitizing method. Furthermore, PG eliminates the need for overlapping captured images such as those performed by IOS software programs for obtaining intraoral digital scans.[5,6] Stitching techniques have been identified as a possible source of errors or scanning inaccuracies of IOSs, especially in long-span or complete-arch intraoral digital implant scans.[13,14]

PG requires the use of optical or fiducial markers that are specific to the PG system elected.[7,8] The optical markers usually have specific geometries that are identified by the PG software program and used to calculate the 3D implant position. These optical markers are placed on each dental implant.[7,8] Additionally, the optical markers are available in different materials, including polymer and metal.[7,8] Similarly, IOSs necessitate the use of implant scan bodies positioned on each dental implant for intraorally capturing the 3D implant position, which after some computer-aided design (CAD) procedures, the implant position is virtually transferred to the definitive implant cast. Dental literature is unclear regarding the optimal ISB design,[23-25] clinical scan body height,[26-28] and geometry bevel position[29] for maximizing the accuracy of intraoral digital implant scans, which difficult the operator’s decision-making process. PG systems provide an advantage regarding optical marker selection when compared with IOSs, as there are no multiple optical marker designs available.

PG methods do not capture adjacent teeth or soft tissues; therefore, an additional impression method is still needed.[5,6] Currently, there are different PG systems available in the market to capture the position of the implants present in a dental arch.[7,8] Dental literature has analyzed the accuracy of these PG systems. However, a systematic approach to assess the trueness and precision, scanning time, and patient satisfaction of the dental PG systems is needed.

The purpose of the present systematic review was to evaluate the accuracy (trueness and precision), scanning time, and patient satisfaction of the commercially available photogrammetry systems that record the 3D position of implants. The null hypothesis was that there would be no significant difference in the trueness and precision, scanning time, and patient satisfaction of the commercially available PG systems compared with conventional impression methods and intraoral digital implant scans.

MATERIALS AND METHODS

A systematic literature search was completed by using five different databases: PubMed/Medline, Scopus, Embase, World of Science, and Cochrane. The search was based on a PICO question composed of the following terms: P (problem or population), which included the use of photogrammetry or stereophotogrammetry technology; I (intervention), which comprised implant dentistry, implant digital scans and dental prosthesis (MeSH term); C (comparison), that comprehended the analogic and digital impression techniques: “dental impression technique” (MeSH), implant impression, conventional implant impression, and intraoral digital scans; and other devices frequently employed to obtain reference models, such as coordinate measure machine (CMM) or dental laboratory scanner; and O (outcome), that involved the accuracy (trueness and precision), scanning time, and patient satisfaction (MeSH term) or preference (Table 1). The search was completed in March 2023.

TABLE 2 Items for the Joanna Briggs Institute critical appraisal checklist for quasi-experimental studies (non-randomized experimental studies).

Question		Answer
1	Is it clear in the study what is the 'cause' and what is the 'effect' (i.e., there is no confusion about which variable comes first)?	Yes, No, Unclear, or Not applicable
2	Were the participants included in any comparisons similar?	
3	Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?	
4	Was there a control group?	
5	Were there multiple measurements of the outcome both pre- and post-the intervention/exposure?	
6	Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?	
7	Were the outcomes of participants included in any comparisons measured in the same way?	
8	Were outcomes measured in a reliable way?	
9	Was appropriate statistical analysis used?	

The titles and abstracts of the selected articles were analyzed for the inclusion criteria that comprised clinical or in vitro studies evaluating the trueness or precision, scanning time, and patient satisfaction of digital scans employing photogrammetry systems; and case report articles that described the use of a commercially available photogrammetry system for digitally recording the 3D implant position. The exclusion criteria included studies that used non-commercial photogrammetry systems/systems not available for clinical use. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed for the performance of the present systematic review.[30]

In the second phase of the review process, all the full-text articles that complied with the inclusion criteria were examined by two calibrated reviewers (M.G.-P. and M.R.-L.). The examiners collected the data into structured tables. Discrepancies were resolved by consensus and a third examiner (R.O.) was consulted.

With respect to the selection of articles through reviewing their titles and abstracts, there was a significant agreement between the two reviewers (Cohen's Kappa = 0.93, $p < 0.001$). With respect to the selection of articles through reviewing the full text, there also was a significant agreement between the two reviewers (Cohen's Kappa = 1, $p < 0.001$).

The quality of the included manuscripts was assessed by the same two examiners by applying the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Quasi-Experimental Studies (non-randomized experimental studies) (Table 2).[31] The two examiners discussed their findings to come to a consensus on the quality of the investigations. When there was a disagreement between the two reviewers, a third examiner was consulted to resolve the disagreement (Figure 1).

RESULTS

The search strategy yielded 23 studies: 13 articles from PubMed/Medline, 10 from Scopus, 0 from Embase, and 0 from Cochrane. Seven additional articles were included by manual search. After the analysis of title and abstract, 9 articles were excluded. The 9 excluded studies were classified as "non-photogrammetry" studies. One duplicate article was identified and eliminated. In the full-text assessment phase, 5 additional manuscripts were considered ineligible for using non-commercialized photogrammetry systems.

A total of 15 articles were included in the present systematic review (Tables 3 and 4).[5–8,32–42] The selected studies were classified based on the type of investigation:[37] 3 in vivo studies,[32,36,42] 6 in vitro experiments,[7–8,33–35] and 6 case reports.[5,38–41] Although there are 4 PG systems currently available in the market, only 2 of these PG systems were identified among the reviewed studies namely the PIC System from PIC Dental and ICam 4D from Imetric (Table 5). Two in vivo[32,36] and 4 in vitro studies[7,34,35,37] evaluated the PIC system, while 2 in vitro[8,33] and 1 in vivo study[52] used the ICam 4D system. Additionally, all 6 case reports recorded implant positions using the PIC system.[5,6,38–41]

Six case report publications were identified.[5,6,38–41] Among all the reviewed case report studies, 3 of them described implant placement with immediate loading with an implant-supported interim prosthesis.[5,39,40] The other 3 studies described conventional loading protocols.[6,38,41] Additionally, all of the reviewed case reports employed the same PG system (PIC system from PIC dental) combined with an irreversible hydrocolloid conventional impression technique for capturing the soft tissues and adjacent teeth.

Among the reviewed studies, only 3 clinical studies analyzed the performance of the PG systems. One clinical study[32] evaluated impression time, patient and operator satisfaction, implant success, prosthesis survival, and marginal bone loss, but not accuracy. Completely edentulous patients (maxillary, mandibular, or both arches) were selected.[32] The other 2 in vivo studies assessed precision, but not trueness[36]; or trueness, but not the precision of the PG system tested.[42] The study assessing precision was performed on a completely edentulous patient using both maxillary and mandibular arches.[36] Meanwhile, the clinical study analyzing trueness

TABLE 3 Characteristics of the clinical and in vitro studies included in the systematic review.

Reference	Study type	Cast/patients	PG system	Groups/PG system/reference model /Comparisons	Methodology	Operator/s experience-Ambient conditions	Results	Conclusions
(Peñarrocha-Diago et al., 2017)[32]	In vivo RCT	18 complete-arch participants, 131 dental implants (InHex; Ticare, Mozo-Grau). Immediate loading. Implant-level. Two participants lost (PG group)	PIC System; PIC Dental	- PG group (test group) - Conventional impressions: (control group): open-tray splined technique. - Working times from removal to replacement of healing abutments (minutes) - Patient and dentist satisfaction: visual analog scale. - Implant success: Buser success criteria. Prosthesis survival: presence of the prosthesis, without screw loosening or fracture. - Marginal bone loss: Marginal bone loss was measured using the imaging software, establishing two arbitrary points at the platform interface to trace a straight line. 2 lines traced perpendicular to this line (mesial and distal), to 1st bone-implant contact. The highest value was selected. - Minimum follow up: 1 year after loading.	- PG group (test group): eight participants, 66 implants. Register of soft tissues with irreversible hydrocolloid. Impressions poured with Type 4 gypsum. Digitalized with a 3D scanner (Rexcan Ds3; Solutionix). Merged of files by using a computer program (DentalCAD; exocad) by best-fit automatic adjustment - Conventional impressions: (control group): 10 participants 65 implants: impression copings splinted with autopolymerizing acrylic resin (Pi-Ku-Plast; Bredent). Polyether material open tray direct technique. Cast digitized to manufacture a CAD-CAM framework.	No experience data or ambiental conditions provided.	- Accuracy not evaluated. - Impression time (mean ± SD): PG: 15.6 ± 1.2 min; Conventional impression: 27.1 ± 1.3 min (Student t test, $p < 0.001$). - Participant satisfaction score (mean ± SD): PG: 8.8 ± 0.6; Conventional impression: 7.9 ± 0.8 (Mann-Whitney U test, $p = .028$). Professional satisfaction score (mean ± SD): PG: 9.1 ± 0.5; Conventional impression: 8.5 ± 0.5 (Mann-Whitney U test, $p = 0.03$). Follow-up (mean ±SD): 14.7 ± 5.2 months. Peri-implant marginal bone loss of 0.6 ± 0.5 mm in the experimental group.	- Less time for impression making with PG technique. - Greater patient and dentist satisfaction with the PG technique. - No differences in implant survival, marginal bone loss, or prosthesis survival after 1 year of follow-up.

(Continues)

TABLE 3 (Continued)

Reference	Study type	Cast/patients	PG system	Groups/PG system/reference model /Comparisons	Methodology	Operator/s experience-Ambient conditions	Results	Conclusions
(Revilla-León et al., 2021)[7]	In vitro ($n = 10$)	Maxillary completely edentulous cast with six implant abutment analogs (RC analog for screw-retained abutment; Institute Straumann AG). Different depths and angulations: right first M: 3 mm, 0 degrees; right first PM: 2 mm 10 degrees (mesial(M)); right C 3 mm, 4 degrees (M); left C: 2 mm, 4 degrees (distal(D)), Left first PM: 3 mm, 10 degrees (D); and left first M: 3 mm, 0 degrees.	iCam4D; Imetric	- Conventional impression technique (CNV group). - PG technology (PG group) (Icam4D; Imetric). - 2 IOSs: IOS-1 (iTero Element; Align technology) and IOS-2 (TRIOS 3; 3Shape A/S). - 3D linear (x-, y-, and z-axes) directions of the center point displacement calculated. Angular discrepancy measurement: axis of each implant abutment replica versus the definitive implant cast. - 3D discrepancies calculated by a mathematic formula: $\sqrt{(media\ x-axis)^2 + (media\ y-axis)^2 + (media\ z-axis)^2}$ - Reference coordinates (interimplant distances and angulations) from obtained by using CMM (CMM Contura G2; Zeiss)	- CNV group: AM polymer open-custom tray. Open tray impression copings (Impression Post for open tray, TAN, for Screw-retained Abutment; Institute Straumann AG). 35 Ncm tightened. Coping splinted to AM Co-Cr framework using an autopolymerizing acrylic resin (Pattern Resin; GC). Polyether impression. Impressions poured with type IV dental stone. - PG: PG system (Icam4D; Imetric). Optical markers (IcamBody; Imetric) hand tightened. - IOS groups: ISBs (CARES Mono Scan body for screw-retained abutment; Institute Straumann AG). Hand tightened.	One operator. 9 years of IOS experience. Controlled room lighting conditions (1003 lux)	Trueness: average distortion of implant abutment positions between definitive cast and scanned models. Precision: SD of average absolute discrepancies between all scanned specimens and definitive cast. - Lineal: No significant difference in linear discrepancy on x- and z-axes. PG group obtained a significantly higher discrepancy on the y-axis compared with all the remaining groups ($p = 0.004$). x-axis (median (IQR)) = CNV: 7.3(17.9) μm, PG:23.8(308.7), IOS1: 4.1(16.6), IOS2: 9.7(54.6) μm y-axis (median (IQR)) = CNV:8.9(17.5) μm, PG: 73.7(273.6) μm, IOS 1: 17.5 (48.9) μm, 18.0(54.) μm z-axis (median (IQR)) = CNV: 1.8 (4.6), PG:−4.7(27.2), IOS1:−4.1(37.3), IOS2: −4.9 (20.7) μm 3D discrepancy: CNV:11.7 μm, PG: 77.6 μm, IOS1: 18.4 μm, IOS2: 21.1 μm - Angular PG group presented significantly higher XZ and YZ angles compared with all the groups ($p < 0.001$): XZ angle (median (IQR)): CNV: 0.1(0.4) degrees, PG:0.1(0.6) degrees, IOS1:−0.1(0.1) degrees, IOS2: −0.2 (0.4) degrees YZ angle (median (IQR)): CNV: −0.1(0.3)degrees, PG:0.3(0.6) degrees, IOS1:−0.1(0.3) degrees, IOS2: 0.2 (0.4) degrees	- CNV method obtained the lowest accuracy values among the groups tested. -PG system tested obtained the highest 3D discrepancy for the implant abutment position translation. - PG system tested obtained the lowest precision values among the groups tested. - The 2 IOSs tested provided a reliable digitizing procedure as no significant differences were found between the linear discrepancy compared with the conventional impression technique.

(Continues)

TABLE 3 (Continued)

Reference	Study type	Cast/patients	PG system	Groups/PG system/reference model /Comparisons	Methodology	Operator/s experience-Ambient conditions	Results	Conclusions
(Ma et al., 2021)[33]	In vitro ($n = 10$)	Completely edentulous cast. with six implant abutment analogs (RC 4.6 mm repositionable analog for screw retained abutments; Institute Straumann AG). Different angulations (0, 7 degrees distal, 9 degrees distal, 2 degrees distal, 11 degrees distal and 7 degrees distal) and gingival depths (3 mm, 2 mm, 1 mm, 2 mm, 2 mm, and 1 mm).	iCam4D; Imetric	- PG system (PG group). - IOS: (IOS group) -Conventional impression (CNV group). Digitization by using an extraoral laboratory scanner (E4; 3Shape A/S) Quantification of deviations of implant replicas positions. Alignment by 3D best fit.	- PG group: PG scan bodies (IcamBody; Imetric4D). Hand tightened. 10 scans. - IOS group: IOS (TRIOS3; 3Shape A/S). Scan bodies (CARES Mono Scan body for screw-retained abutment; Institute Straumann AG). Hand tightened. 10 scans. - CNV group: abutment-level impression copings (RC 4.6 mm impression coping for screw retained abutments; Institute Straumann AG). Hand tightened. Impressions copings splinted by using autopolymerized acrylic resin (Pattern Resin; GC)). Sectioned and reconnected. Custom light-cured open-tray. Polyether impression. Poured with type IV dental stone. STL files imported to dental CAD software (DentalCAD; Exocad). ISBs converted to implant abutment (Geomagic Control X; 3D systems)	One operator. 5 years' experience.Ambient conditions: ambient light conditions not specified. Temperature range of 22−25°C (for CNV impressions; not specified for PG and IOS groups).	Trueness: RMS for 3D deviations of implant replicas positions with reference file. Significant differences ($p < 0.001$). Medians: PG: 24.45 (IQR 0.73),[a] IOS: 43.45 μm (IQR 6.17 μm),[b] CNV 28.70 μm (IQR 7.90 μm).[c] Precision: RMS for 3D deviations of implant replicas´ positions of the pairwise comparison of files within the test groups. Significant differences ($p < 0.001$). Medians: PG: 2.00 μm (IQR 1.65 μm),[a] IOS: 36.00 μm (IQR 9.95 μm),[b] CNV: 29.40 μm (IQR 4.80 μm).[c]	PG obtained the lowest 3D discrepancy in terms of trueness and precision values among the groups tested.

(Continues)

TABLE 3 (Continued)

Reference	Study type	Cast/patients	PG system	Groups/PG system/reference model /Comparisons	Methodology	Operator/s experience-Ambient conditions	Results	Conclusions
(Sallorenzo et al., 2022)[34]	In vitro ($n = 10$)	Completely edentulous cast with six external hex implant analogs (Ø5.1-mm external hexagon implant analogs, IPD/ BA-AW-00; IPD dental). 2 models: parallel (PIMP) and angled (AIMP) implant analogs (degrees): first right M = 20 (Distal); first right PM = 10 (Mesial); lateral right and lateral left incisors = 0; first left PM = 15 (Mesial); first left M = 30 (Distal).	PIC System; PIC Dental	- IOS group: TRIOS3, v.1.4.7.5.3; 3Shape A/S - PG (SPG group). PIC system; PICdental. - Reference coordinates (interimplant distances and angulations) from obtained by using CMM (Global Evo 09.15.08, serial No. 906; Hexagon Manufacturing Intelligence) under controlled conditions (21.3°C, 37.9% humidity). - Euclidean distances among central points of implants and relative angulations among implants' vectors were calculated.	- IOS group: ISBs (Elos Accurate IO Scan; Elos Medtech AB). - PG group (iIOS): PG markers (PiC transfer; PiC dental). Tighten at 15Ncm. 3 abutments marked as reference. Implants digitally splinted with a virtual Ackerman bar for each scan (Exocad v.2.2; Align Technology). Files exported to a 3-dimensional analysis software program (Geomagic; 3D Systems) to determine geometrical center (coordinates) and vector of each implant.	- One operator. No experience in use details provided. - Controlled ambient conditions: 21.5°C and room lighting of 1000 lux in both groups.	Trueness:- PIMP overall errors: Distances: PG = 20 μm / IOS = 100 μm (P<.001), Angulations: PG = 0.354 degrees / IOS = 1.177 degrees (P<.001). - AIMP overall errors: Distances: PG = 10 μm / IOS = 23 μm (P = 0.480). Angulations: PG = 0.084 / IOD = 0.529 degrees (P = .008). Precision: - PIMP overall errors: Distances: PG = ±32 μm / IOS: ±292 μm (P<.001). PG = ±0.280 degrees / IOS = ±0.474 degrees. (P<.001). - AIMP overall errors: Distances: PG = ±65 μm / IOS = ±205 μm. (P = .08) Angulations: PG = ±0.246 degrees / IOS = ±0.841 degrees (P<.001).	PG had higher accuracy values than IOS, particularly in terms of precision, except in distance deviation in the AIMP cast.

(Continues)

TABLE 3 (Continued)

Reference	Study type	Cast/patients	PG system	Groups/PG system/reference model /Comparisons	Methodology	Operator/s experience-Ambient conditions	Results	Conclusions
(Kosago et al., 2022)[35]	In vitro ($n = 5$)	Completely- edentulous mandibular cast with five implant abutment analogs (RC Screw-ret. Abut., TAN-straight, 4.6 mm in diameter, GH 2.5 mm, Institute Straumann AG). 3 parallel (anterior), 2 angulated (17 degrees) (posterior implants). 0° in anterior implants, 17° in posterior implants. No depth specified.	PIC System; PIC Dental	- Conventional impression, CO (open-tray splint impression coping). - 3 IOSs groups: TS (TRIOS 4), IT (iTero Element 2), and PS (Primescan). - PG group. Digitization by an extraoral scanner (E4; 3Shape A/S) Quantification of deviations of ISBs´ positions. Alignment by 3D bestfit.	- 5 CO (open-tray splint impression coping, Polyether, dental floss+ low shrinkage modeling resin (Pattern Resin LS; GC). Once polymerized, the splint was sectioned by using a diamond disk. Double pouring technique with type IV gypsum. - IOS groups: PEEK ISBs (CARES Mono Scan body Straumann). 5 previous scans discarded to avoid inaccuracies by operator learning curve. Scan strategy "recommended by the manufacturer for each IOS". - PG group: PIC transfer; PIC Dental. All the files transformed to STL format. Superimposition to the reference cast identifying 3 fixed points in the ISBs and best-fit alignment (Geomagic Control X; 3D System).	One operator- no experience data pro-vided.Ambient conditions: ambient light conditions not specified. Temperature between 18 and 25°C.	Trueness: RMS for 3D deviations of scan bodies' positions with reference scans: Significant differences ($P<.05$). PG (48.74 ± 1.80 μm),[b] Trios 4 (52.14 ± 3.88 μm),[b] Primescan (57.24 ± 2.05 μm),[b] iTero (67.72 ± 7.18 μm),[c] CO (141.86 ± 5.58 μm).[a] Precision: RMS for 3D deviations of scan bodies' positions, intragroup comparisons: Significant differences ($P<.05$). PG (5.46 ± 1.10 μm),[c] Trios 4 (19.39 ± 3.61 μm),[b] Primescan (28.58 ± 8.03 μm), [b] iTero (36.84 ± 12.64 μm), [a,b] CO (49.40 ± 13.39 μm).[a]	PG showed the best results, especially in terms of precision. In trueness, PG did not show significant differences with Trios 4 and Primescan. Conventional splint open-tray impression with polyether showed less trueness and precision than PG and IOSs.

(Continues)

TABLE 3 (Continued)

Reference	Study type	Cast/patients	PG system	Groups/PG system/reference model /Comparisons	Methodology	Operator/s experience-Ambient conditions	Results	Conclusions
(Orejas et al., 2022)[36]	In vivo ($n = 5$)	Completely edentulous arches. (1 maxilla and 1 mandible in the same patient.). Implant level. Eight external hex implants maxilla, eight external hex implants mandible (Medical Precision Implants MPI)	PIC System; PIC Dental	- 2 groups of intraoral scanners (IOS): T (TRIOS 3; 3Shape A/S), TD (True Definition; 3 M ESPE). - PG group. Euclidean distances among implant platform central points and relative angulations among implants' vectors were calculated.	- IOS group: Group T and Group TD. ISBs (Elos Accurate 6A-B Scan Body'' Brånemark System RP). Tighten at 10Ncm. Titanium dioxide powder coating used in TD group. - PG. PIC transfers; PIC dental. - ISBs substituted by digital ISBs from digital library In IOS files (Dental CAD; Exocad GmbH). - A suprastructure (8 rotatory abutments and 7 Ackerman segments with 3 mm sections) was designed for each digital working cast.	Same operator. 3 years of experience.-Ambient conditions: NA.	Only assessed precision. Overall data of all distances not provided. Significant differences in Euclidean distances when comparing PG (14 segments maxilla / 11 mandible) with both IOS systems. Linear measurements: Greatest difference between measurements: maxilla: PG = 108.2 μm, T = 220.6 μm, and TD = 342.9 μm. Mandible: PG = 104.4 μm, TD = 269.0 μm, and T = 476.4 μm. Angulation. Greatest difference (degrees) between measurements. Maxilla: PG = 0.44, TD = 1.01, Mandible: PG = 0.24, TD = 1.61, T = 2.57.	PG system obtained better precision than the evaluated IOS systems.
(Revilla-León et al., 2023)[8]	In vitro ($n = 10$)	Completely edentulous cast with six implant abutment replicas (RC analog for screw-retained abutment straight; Institute Straumann AG).	PIC System; PIC Dental	-Conventional impressions (CNV group). - PG scanning (PG group). - CMM to obtain references (CMM Contura G2; Carl Zeiss Industrielle Messtechnik GmbH). -Linear discrepancies on x, y, and z axes computed in micrometers by using best-fit algorithm (Calypso; Carl Zeiss Industrielle Messtechnik GmbH). - Angular discrepancy. Two projections of each axis: X axis (XZ angle); Y axis, (YZ angle). - 3D discrepancies calculated by a mathematic formula: $\sqrt{((X_1-X_2)^2+(Y_1-Y_2)^2+(Z_1-Z_2)^2)}$	- CNV group: AM polymer open-custom tray. Open tray impression copings (Impression Post for open tray, TAN, for Screw-retained Abutment; Institute Straumann AG). 35Ncm tightened. Impression abutments splinted to Co-Cr AM splinting framework by using an autopolymerizing acrylic resin (Pattern Resin; GC). Polyether impressions poured with Type IV dental stone. - PG group: PG scan bodies (PIC transfer; PIC dental). Hand tightened.	- No operator details provided.-Ambient conditions: ambient light conditions not specified. Temperature range of 23°C (for CNV impressions; not specified for PG groups).	Trueness: mean discrepancies positions of implant abutments with reference cast. Precision: SD discrepancies positions of implant abutments with reference cast. Significant differences (P<.001) in linear discrepancies on x and z axes (medians ±IQR), X-axis: CNV 11.18 ±6.56 μm; PG, 13.36 ±18.63 μm (Z-axis: CNV 2.82 ±2.74 μm; PG 8.05 ±7.62 μm. 3D discrepancy (median ± IQR) for CNV 18.40 ±6.81 μm and PG 20.15 ±25.42 μm. Significant differences (P<.001) in angular discrepancies on XZ (CNV, 0.22 ±0.32 degrees; PG 0.03 ±0.12 degrees and YZ angles CNV, 0.26 ±0.30 degrees; PG 0.08 ±0.08 degrees.	- CNV obtained higher overall accuracy than PG system (trueness difference of 3 μm; precision difference of 18 μm). - Smaller angular discrepancies on the PG group than the CNV group.

(Continues)

TABLE 3 (Continued)

Reference	Study type	Cast/patients	PG system	Groups/PG system/reference model /Comparisons	Methodology	Operator/s experience-Ambient conditions	Results	Conclusions
(Tohme et al., 2023)[37]	In vitro (n = 15)	Complete arch. Abutment-level. Edentulous maxilla. Four implants. (“All-on-four simulation”) RC Bone Level Implant Analog; Institut Straumann AG)- 2 parallel (anterior), 2 angulated (17 degrees) (posterior implants). Implant angulation corrected by angled screw-retained abutments). (RC Screw-ret. Abut., TAN-straight, 4.6 mm in diameter, GH 2.5 mm, Institut Straumann AG) 0° in anterior implants, 17° in posterior implants. No depth specified.	PIC System; PIC Dental	- Conventional impressions (CI group). - IOS (DIS group): TRIOS3; 3Shape A/S - PG scanning (SPG group). - Digitization of reference cast by using an extraoral laboratory scanner (E3; 3Shape A/S) - 3D deviations of 1. Whole scan bodies (WSB); 2. Flat angled surface (FAS) alone. (Geomagic Control X; 3D System)	- CI group: abutment-level impression copings (Impression post for open tray, TANdfor screw-ret. Abut. Abut. Level, 0°, D 4.6 mm; Institut Straumann AG). 15Ncm tightened. Impressions copings not splinted. Custom light-polymerizing acrylic resin. Impression material: impression plaster powder (Snow white; Kerr Corp). Type IV plaster. Digitization by using an extraoral laboratory scanner (E3; 3Shape A/S). STL files imported to dental CAD software (DentalCAD; exocad). - DIS group: ISBs (CARES Mono Scanbody for screw-retained abutment level; Institut Straumann A/S). Tightened to 15Ncm. - SPG group: PG scan bodies (PIC transfer; PIC dental). Hand tightened. PIC camera placed 15 to 30 cm, and 45 degrees with respect to the transfers.	- No operator details provided.- Ambient conditions: ambient light conditions not specified. Temperature range temperature environment of 25°C with a relative humidity of 50% (for CNV impressions; not specified for PG groups).	Trueness, alignment of STL file to its corresponding reference by best fit. Linear deviation: - RMS 3D Deviation WSB (P<.001): PG: 0.088 ±0.006 mm,[a] CI: 0.115 ±0.037 mm,[a,b] DIS: 0.148 ±0.061mm[b] - RMS 3D Deviation FAS (P <.001): PG: 0.213 ±0.064 mm,[b] CI: 0.166 ±0.038 mm,[a,b] DIS: 0.112 ±0.032mm[a] Angular Deviation (P<.001): PG: 0.809 ±0.005 degrees,[a] CI: 0.922 ±0.194 degrees, [a,b] DIS: 1.081 ±0.348 degrees [b] Precision, STL files were overlapped within each group. Linear deviation: - RMS 3D Deviation WSB (P<.001): PG: 0.002 ±0.001 mm,[a] CI: 0.103 ±0.024 mm,[c] DIS: 0.063 ±0.035 mm[b] - RMS 3D Deviation FAS (P <.001): PG: 0.002 ±0.003,[a] CI: 0.166 ±0.033,[c] DIS: 0.067 ±0.030[b] Angular Deviation (P<.001): PG: 0.010 ±0.011 degrees,[a] CI: 1.142 ±0.296 degrees,[c] DIS: 0.221 ±0.088 degrees [b]	PG showed the lowest scan body 3D discrepancy and global angular deviation in terms of trueness and precision. However, the flat angled surface of this group was not close to that of the reference.

(Continues)

TABLE 3 (Continued)

Reference	Study type	Cast/patients	PG system	Groups/PG system/reference model /Comparisons	Methodology	Operator/s experience-Ambient conditions	Results	Conclusions
(Zhang et al., 2021)[42]	In vivo (n = 14)	Completely edentulous arches. Abutment-level. Minimum four implants. 14 patients (5 maxillary, 9 mandibular)	iCam4D; Imetric	- PG group -Conventional impression (CNV group). Conventional impression verification: titanium frameworks manufactured on preliminary cast obtained. With splinted open-tray technique. Fit of frameworks was evaluated intraorally. Tactile evaluation combined with one-screw test. With all screws tightened, radiography with paralleling device. Verified definitive casts scanned by using a laboratory scanner of 4-mm accuracy (LS3; Nobel Biocare) to export virtual models in STL format. STL files were imported into a reverse engineering program (Geomagic Studio 2014; 3D Systems, Inc).	PG group: PG scan bodies with superficial target points and titanium interfaces (ICamBody; Imetric4D). After image processing by using the software program (ICam4D; Imetric4D), virtual healing caps attached to virtual abutments and exported STL. Conventional splinted: impression copings splinted by metal bars and autopolymerizing resin (Pattern resin; GC Corporation). Open tray with PVS impression material. Double-pour technique with type IV gypsum	No experience data or ambient conditions provided.	Only trueness evaluated, not precision. PG overall mean ±SD distance deviation: 70 ±57 μm. PG overall mean ±SD angular deviation: 0.432 ±0.348	-PG deviations within the clinically acceptable range of errors (150 μm). - PG distance deviations increased with greater interimplant distances. Angular deviations not significantly affected. - Interimplant angulations and jaw had no significant effect on PG trueness.

Abbreviations: AM, additively manufactured; C, canine; CAD, computer-aided design; CAM, computer-aided manufacturing; CMM, coordinate measurement machine; Co-Cr, cobalt-chromium; IOS, intraoral scanner; IQR, interquartile range; ISB, implant scan body; NA, not available; M, molar; PG, photogrammetry; PM, premolar; PVS, polyvinyl siloxane; RCT, randomized clinical trial; RMS, root mean square.

TABLE 4 Characteristics of the case report articles included in the present systematic review.

Article	Clinical case	Number of implants	PG system	Teeth and soft tissues registration method	Loading type/ Prosthesis material	Conclusions
(Peñarrocha-Diago et al., 2014)[38]	Partially edentulous maxilla (posterior region)	Three implants (Euroteknika Iberia, Barcelona, Spain). Implant level (right first premolar, right second premolar, right second-molar)	PIC System; PIC Dental	Alginate impression. Sone cast scanned with a 3D scanner in open STL format. Digitized cast and implants positions aligned by using a software program (Exocad GmbH, Darmstadt, Germany) (three-point method and subsequently improved by *Best-fit)*	Conventional loading. 4-units bridge. Metal (Cr-Co)- porcelain design.	PG system allowed the rehabilitation of a patient with extreme maxillary free end edentulism. The prosthetic fabrication process was feasible, fast, and simple for the dentist and comfortable for the patient.
(Agustín-Panadero et al., 2015)[6]	Completely- edentulous maxilla	Six implants (additional information not provided)	PIC System; PIC Dental	Hydrocolloid material. Poured with type IV plaster cast. Stone cast was digitized by using an extraoral scanner to create STL file.	Porcelain fused to metal.	PG allowed the registration of the 3D position and angulation of multiple implants placed in the maxillary arch. However, PG cannot capture soft tissue information.
(Peñarrocha-Diago et al., 2015)[39]	Completely- edentulous maxilla	Eight implants (External Hex; Mozo Grau) (right first molar, right first and second premolar, right central incisor, left lateral incisor, left first premolar, and left first and second molar positions)	PIC System; PIC Dental	Irreversible hydrocolloid impression material. The stone cast was scanned with an extraoral 3D scanner (PICscan). The PICfile and the digitized cast were aligned using PICpro (PICdental), dental CAD software based on Exocad (Exocad GmbH, Darmstadt, Germany) with three-point registration, and subsequent enhancement using best-fit alignment.	Immediate loading. acetalic resin (TSM Ac- etal Dental; Pressing Dental Srl, Falciano, Republic of San Marino). Material of the definitive prostheses: NP.	PG allowed the recording of the 3D position and angulation of multiple implants, converting all the clinically relevant information directly from the patient to a digital file, and eliminating the need for impression posts, implant analogs, trays, and impression materials.
(Sánchez-Monescillo et al., 2016)[40]	Completely edentulous mandible.	Seven implants (TSV; Zimmer Dental). Implant positions not provided.	PIC System; PIC Dental	Irreversible hydrocolloid impression. Stone cast scanned with extraoral 3D scanner (PICscan). Implants postions´ file and STLfile of digitized cast integrated using a best-fit algorithm.	Immediate loading. Provisional restoration (material used: NP).	PG systems facilitated implant impression making and reduced manufacturing time. However, PG system did not reproduce soft tissue information.
(Gómez-Polo et al., 2017)[5]	Partially edentulous maxilla (anterior region)	Three implants (Biohorizons Tapered Internal). Implant level. Immediate implants (first right premolar, right canine, right lateral incisive). Immediate loading.	PIC System; PIC Dental	Conventional alginate impression (Cavex CA 37; Cavex Hollan BV)	Immediate loading. 6-units bridge. Interim restoration: CAD-CAM milled poly- oxymethylene (Acetal resin; Delrin; Dupont USA)	PG was a useful and effective tool for producing immediate prostheses with a predictably correct passive fit. It does not reproduce soft tissue, so a conventional cast must be performed, digitized, and merged to supplement the implant positions' information.
(Sánchez Monescillo et al., 2019)[41]	Completely- edentulous mandible.	Four implants (TSV; Zimmer Dental)	PIC System; PIC Dental	Conventional alginate impression. Digitally scanned (D71O3D Scanner; 3Shape)	Conventional loading. Co-Cr framework with acrylic resin denture teeth.	PG provided an alternative method for digitally capturing implant position. It did not reproduce information for soft and hard tissue, so an additional impression was needed.

Abbreviations: 3D, 3-dimensional; CAD-CAM, computer-aided design and computer-aided manufacturing; Co-Cr, cobalt-chromium; NP, not provided; PG, photogrammetry; STL, standard tessellation language.

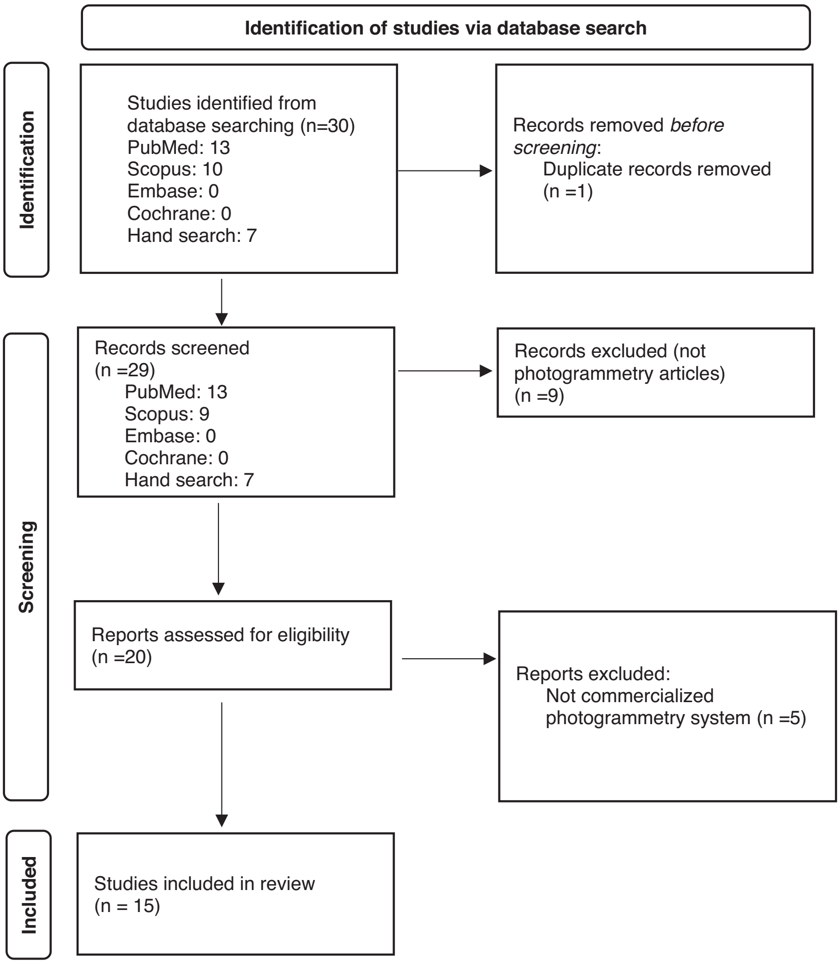

FIGURE 1 PRISMA flowchart of article selection through the several stages of the study.

TABLE 5 Commercially available photogrammetry systems for recording 3D implant positions.

Manufacturer	PG system	Optical markers	Characteristics of the optical markers
Imetric	iCam4D	iCamBodies	Rectangular shape. Back with white dots marker
Oxo	Oxo Fit	Oxo markers	White with grey geometry markers
PIC Dental	PIC System	PIC Transfers	Flag shape marker. Back with white dots marker.
S.I.N. Dental USA	MicronMapper	MicronMapper scan bodies	Cylindrical shape, with a bevel in the occlusal surface. White with black geometry markers

Abbreviation: PG, photogrammetry.

included 14 completely edentulous patients.[42] Additionally, all the reviewed in vitro studies used completely edentulous maxillary casts,[7,8,33,34,37] except one in vitro investigation that selected a completely edentulous mandibular cast.[35]

Accuracy was assessed differently among the included clinical and laboratory studies. Research methodology discrepancies have been found including the number of implants, impression level, impression methods that were compared with the PG systems evaluation methods, and reference measurements. A meta-analysis of the collected accuracy data was not feasible due to the heterogeneity of the data.

Number of implants

The included studies described the use of PG systems for capturing implant positions of varying numbers of implants. In the in vivo studies, the number of implants varied from 4 to 8 per arch.[32,36,42] In the in vitro research, the definitive reference implant casts employed among the studies included four,[37] five,[35] six,[7,8,44,34] and eight[36] implants per cast. Four case reports described the treatment workflow for fabricating implant-supported prostheses on completely-edentulous arches with four,[41] six,[6] seven[40] or eight implants placed by using a PG system for capturing the 3D implant position.[39] The remaining 2 case reports described the treatment workflow on partially edentulous patients with 3 implants (one in the anterior[5] and the other in the posterior region) for fabricating implant-supported fixed dental prostheses, by using a PG technology to record implant position.[38]

Impression level

Considering the impression level where the PG markers, conventional implant impression abutments, or implant scan bodies were connected, two different methodologies were identified among the included studies: abutment- or implant-level impression. Two in vivo studies[32,36] and 1 in vitro study[34] did not use implant abutments; therefore, the impression abutments and implant scan bodies were placed directly into the dental implants or implant analogs. In contrast, the rest of the in vitro studies[7,8,33,35,37] and 1 clinical study[42] were performed at the implant abutment level. One in vitro study[34] discussed the selection of implant impression level aiming to facilitate the accuracy analysis using a coordinate measurement machine (CMM) with a tactile gauge for obtaining the Euclidean reference values (inter-implant distances and angulations).

Impression methods compared with PG systems

Conventional impression methods are still considered today the gold standard for fabricating definitive implant casts. However, not all the reviewed studies compared the PG system tested with conventional impression methods. Some studies included conventional impressions as the control group,[7,8,33,35,37] while other studies selected one or more IOSs[8,34–37] as additional experimental groups.

Evaluation methods

Three different measurement methods for assessing accuracy have been described among the reviewed studies namely (1) linear and angular Euclidean distances,[34,36,42] (2) linear and angular discrepancies for x-, y-, z-axis and 3D discrepancies per implant,[7,8] and (3) root mean square (RMS) error calculation.[33,35,37] Additionally, measurements were performed on the virtual definitive implant casts[7,8,33,35,37,42] or on Ackerman bars designs.[34,36]

Reference measurements

Among the 6 in vitro studies included in this systematic review,[7,8,33–37] two different types of digitizing devices were used to obtain the reference measurements: a CMM[7,8,34] or an extraoral laboratory scanner.[33,35,42] The in vivo study that assessed the precision of a PG did not employ any reference device, as it just evaluated precision, not trueness.[36] The in vivo study that analyzed the trueness of a PG system used the definitive implant cast obtained by using a conventional impression technique with the splinting of the impression copings as a reference.[42]

Accuracy values reported

Among the studies that used conventional impression methods as the control group, varying accuracy values were reported with a trueness value ranging from 12 to 165 μm and with a precision value ranging from 7 to 103 μm.[7,8,33,35,37]

The accuracy of the PG systems tested varied among the reviewed studies.[7,8,33–37,42] Among the in vitro studies, for the PIC system, the trueness value ranged from 10 to 49 μm and the precision value ranged from 5 to 65 μm;[8,34,35,37] for the iCam4D system, the trueness value ranged from 24 to 77 μm and the precision value ranged from 2 to 203 μm.[7,33] One in vivo study analyzed the trueness of the iCam4D system, reporting a mean trueness value of 70 μm,[42] while another in vivo study assessed the precision of the PIC system reporting a maximum precision value of 108 μm.[36]

Scanning time/patient satisfaction results

One clinical study[32] evaluated impression time, patient and operator satisfaction, implant success, prosthesis survival, and marginal bone loss. Authors reported less time for impression and greater patient and dentist satisfaction when using the PG technique when compared with conventional impression methods. Additionally, results revealed no differences in implant survival, marginal bone loss, or prosthesis survival after 1 year of follow-up.

Quality assessment

Case report studies could not be assessed using the JBI Critical Appraisal Checklist for Quasi-Experimental studies. For the remaining included studies, questions 2, 5, and 6 of the JBI Critical Appraisal Checklist for Quasi-Experimental were not applicable to the studies reviewed. The risk of bias analysis showed a 100% low risk of bias in all included articles for questions 1, 3, 4, 7, 8, and 9.

DISCUSSION

The purpose of the present systematic review was to evaluate accuracy, scanning time, and patient satisfaction with the commercially available PG systems for recording the 3D position of placed implants. Only 8 included articles (6 in vitro[7,8,33–35,37] and 2 in vivo[36,42]) assessed the trueness and/or precision of these PG systems. Additionally, only 1 clinical study reported the scanning time and patient satisfaction of the PG system tested.[32]

Although there are four different PG systems available in the market, only two of them have been tested in the included studies. This may be explained by the different time development and market implementation of the different PG systems.

Among the reviewed studies, only 3 clinical studies were found.[32,36] One clinical study evaluated the precision of a PG system (PIC system from PIC Dental),[36] another the trueness of a PG system (iCam4D from Imetric),[42] and the third investigation[32] considered other factors such as scanning time or patient and operator preferences. The maximum precision value reported in the described clinical study was 108 μm, which was reported as a better precision value than the other experimental group (IOSs); however, the authors did not include conventional impression methods as a control group.[36] The mean trueness value (70 μm) reported in the clinical study[42] could be considered within the clinically acceptable discrepancy.[43–45] Therefore, clinical data analyzing the accuracy of these two PG systems is very limited, which compromises the generalization of the results reported.

A total of 2 in vitro studies assessing the accuracy of the iCam4D system, reported different accuracy values.[7,33] Revilla-León et al.[7] reported a trueness ± precision of 77 ± 203 μm, where trueness and precision were significantly lower than the conventional and IOSs tested (iTero Element; Align Technologies and TRIOS3; 3Shape A/S). Ma et al.[33] reported a trueness ±precision of 24 ± 2 μm, where trueness and precision values were statistically better than the conventional and IOS tested (TRIOS3; 3Shape A/S). The disparities in the results between both studies could be explained by the different research methodologies (implant abutment analog positions on the reference casts, data acquisition techniques, method for obtaining the reference measurements, and accuracy measurement method). Additional studies evaluating the accuracy of the iCam4D system are needed.

Four in vitro studies assessed the accuracy of the PIC System;[8,34,35,37] 3 of these studies compared the accuracy of the PIC system with conventional impression techniques,[8,35,37] while 1 of them did not include a conventional implant impression method.[48] Revilla León et al.[8] reported a trueness ±precision of 20 ± 25 μm for the PG system, Sallorenzo and Gómez-Polo[34] reported a trueness ±precision of 20 ± 32 μm, Kosago et al.[35] reported a trueness ± precision of 49 ± 5 μm, and Tohme et al.[37] reported a trueness ±precision of 88 ± 2 μm. All the studies reported accuracy values that can be considered within the clinically acceptable discrepancy.[43–45] The reported accuracy discrepancies among these studies may be explained by variations in the research protocol (implant abutment analog positions on the reference casts, data acquisition techniques, method for obtaining the reference measurements, and accuracy measurement method).

Discrepancies in the research methodologies can be identified among the reviewed studies such as measurement methods for assessing accuracy and different impression methods tested. The International Organization for Standardization provides a method for standardizing the accuracy evaluation by adding markers in a cast, followed by performing specific inter-landmark measurements.[46] However, this method may not assist in the evaluation of implant position accuracy of definitive implant casts obtained by different impression methods, including PG systems. Therefore, there is no agreement on the recommended method to assess accuracy. Additionally, the two main impression methods (conventional and digital: IOS, and PG techniques) were not always considered in all the included studies, which may represent a limitation of these studies, as conventional impression methods are still considered the gold standard method for fabricating definitive implant casts.

All the studies identified the need to use an additional impression method for recording the soft tissue information and adjacent teeth such as conventional impression methods or IOSs.[5–8,32–42] PG systems only capture the 3D position of the placed implants.[5–8,32–42] The understanding of the workflow for capturing implant position, soft tissue information, adjacent teeth in the case of partially edentulism, and antagonist dentition is fundamental for the proper execution and implementation of the PG technology.

The unique randomized clinical study that evaluated impression time and patient and operator satisfaction involved 8 participants with completely edentulous arches and 66 placed implants.[32] The results showed that the PG system (PIC system; PIC Dental) needed less data acquisition time and resulted in greater patient and operator satisfaction than the conventional splinted impression technique.[32] Additional studies are needed to further evaluate scanning time and operator/patient satisfaction when using these PG systems.

Dental literature has analyzed the factors that can influence the accuracy of conventional implant impression methods.[47,48] Similarly, different studies have identified different factors that can impact intraoral scanning accuracy.[13,14] However, there is no information if the accuracy of the PG systems can be impacted by different variables such as the design, wear, or torque displacement of the PG markers. Important design differences can be noted among the optical markers needed to capture the 3D implant position among these PG systems, but to the best knowledge of the authors, no study has assessed this factor yet.

Additional studies evaluating the accuracy, scanning time, patient/operator perception and operator satisfaction, and the influence of factors such as environmental or intraoral conditions on the outcomes of these PG systems are needed. Furthermore, all the research articles assessing the accuracy of PG systems were performed on completely edentulous arches with varying numbers of dental implants; therefore, additional information is needed regarding the accuracy of the PG systems in partially edentulous conditions with varying numbers and locations of placed implants.

CONCLUSIONS

Among the four commercially available PG systems, only two of them (PIC system from PIC Dental and iCam4D from Imetric) have been analyzed among the reviewed studies. Further studies are needed to increase the evidence regarding the accuracy, scanning time, and patient and operator satisfaction of the commercially available PG systems.

The accuracy of the two PG systems for complete-arch implant scans varied among the clinical and laboratory studies. For the PIC system, trueness ranged from 10 to 49 μm and precision ranged from 5 to 65 μm. For the iCam4D system, trueness ranged from 24 to 77 μm and the precision value ranged from 2 to 203 μm. These two PG systems may provide a reliable alternative for acquiring implant position. However, this conclusion should be interpreted carefully, as one study reported the mean precision value of one PG system higher than the clinically acceptable discrepancy.

Lower scanning time and higher patient and operator satisfaction have been reported when compared with the splinted conventional impression technique. However, only one study assessed these variables. Additional studies are needed to further evaluate scanning time and operator/patient satisfaction.

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CONFLICT OF INTEREST STATEMENT

The authors did not have any conflict of interest, financial or personal, in any of the materials described in this study.

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