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EPA Consensus Project Paper: Accuracy of Photogrammetry Devices, Intraoral Scanners, and Conventional Techniques for the Full-Arch Implant Impressions: A Systematic Review

Keywords

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ABSTRACT

Purpose: The objective of this systematic review was to evaluate and compare the accuracy of digital impression techniques and conventional methods for full-arch implant impressions. Methods: An electronic literature search in the databases Medline (Pubmed), Web of Science, and Embase was performed to identify in vitro and in vivo publications (between 2016 and 2022) directly comparing digital and conventional abutment-level impression techniques. All selected articles passed through the data extraction procedure according to defined parameters in inclusion and exclusion criteria. Measurements on linear, angular and/or surface deviations were performed in all selected articles. Results: Nine studies met the inclusion criteria and were selected for this systematic review. 3 articles were clinical studies and 6 studies were in vitro. Accuracy difference mean values of the trueness up to 162+/-77µm between digital and conventional techniques were reported in the clinical studies and up to 43µm in laboratory studies. Methodological heterogeneity was observed in both, in vivo and in vitro studies. Conclusions: Intraoral scanning and photogrammetric method showed comparable accuracy for registering implant positions in the full-arch edentulous cases. A tolerable implant prosthesis misfit threshold and objective misfit assessment criteria (for linear and angular deviations) should be verified in clinical studies.

INTRODUCTION

Digital approach has become an alternative to conventional techniques to restore completely edentulous cases with fixed implant prostheses. Therefore, full-arch digital impression accuracy is extensively investigated in clinical[1,2] and laboratory studies.[3,4]

Trueness and precision are well-described standardized measures to evaluate the accuracy of digital and conventional impressions. While trueness represents the test group compared with the true reference, precision describes the repeatability of a procedure.[5] Most commonly trueness

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and precision are evaluated for linear, angular,[3] and surface[6] deviations. Reference data can be conveniently obtained in laboratory studies by coordinate measuring machines (CMM),[4] industrial[3] or laboratory scanners[6] with a very high level of accuracy of up to only a few 4 microns.[6–8] For this reason, most of the studies on implant impression accuracy are mainly done *in vitro*, which limits the applicability of the results in clinical practice. Attaining the reference scan in clinical conditions still remains a major methodological issue.[9] There is a lack of clinical studies with an objective evaluation of the fit of full-arch implant-supported fixed restorations produced from digital impressions.[10] Therefore, open-tray conventional implant impressions with splinted impression copings are still the most documented technique in clinical studies and, therefore, can be regarded as a reliable positive control.[11]

There are two main digital techniques to capture the spatial position of the dental implants for full-arch cases: intraoral scanning (IOS) and photogrammetry (PG)[12,13] Contradicting results and conclusions have been reported by several systematic reviews evaluating the accuracy of full-arch digital implant impressions with intraoral scanners.[12,14] This can be explained by the methodological differences of the selected studies. Also, the accuracy of the intraoral scanners can be affected by multiple factors.[15] The size of the edentulous area negatively affects the accuracy, as the lack of natural reference objects compromises the quality of stitching of the images. For this, different types of artificial reference objects have been suggested to improve the quality of a digital implant impression.[16–20] Modern intraoral scanners were found to demonstrate high trueness,[21] however, intraoral scanning for full-arch implant-supported prostheses still needs further clinical validation.[22]

Photogrammetry serves as an alternative to intraoral scanning when 3D (Three dimensional) coordinates of implant position are captured with a special camera. Instead of multiple registrations as with intraoral scanners, it takes a limited number of images of special screw-retained transfers. With this technique, only implant positions are registered, while soft tissue surface or bite registrations are done with intraoral scanners or conventional impression techniques. Many studies have reported the reliability of photogrammetry, however, others demonstrated poorer accuracy than the conventional technique.[8,23,24]

The diversity of the results from different systematic reviews, could be explained by the inclusion of less controlled studies (case series, case reports),[25] using different reference models and techniques to obtain reference data, presence or absence of the remaining teeth in the dental arch, comparing different types of impressions (implant- vs abutment-level),[26] high variability of number of the implants in the arch, usage of very limited sample size, different user experience, different generations of digital devices, and other factors.[12,27] Yet, the main limitation remains that indirect comparisons between different types of digital devices and conventional techniques are being made.

Therefore, the aim of this systematic review was to evaluate the accuracy of the full-arch dental implant impressions taken with intraoral scanners and photogrammetry devices of the latest generation, by including only studies of high methodological quality, which investigated clinically relevant scenarios (abutment-level full-arch impressions from 4 or more implants) and directly compared the accuracy of digital and conventional impressions (CI).

METHODS

This systematic review was performed according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The review was registered on the PROSPERO register (registration number: CRD42021288679).

The focused PICOS (Population, Intervention, Comparison, Outcome, Study design) question (*Table 1*) was defined: "What are the accuracy outcomes of implant position registration in full-arch edentulous cases using intraoral scanners and/or photogrammetric devices compared to conventional impressions?"

Table 1. Inclusion criteria of studies into systematic review based on PICOS guides.

	Systematic review
Patients/ Population	Completely edentulous dental arch or replica with implants
Intervention	Taking full-arch conventional and digital (IOS or photogrammetry) implant impressions with commercially available intraoral scanner or photogrammetric devices, using scan bodies.
Comparison	Accuracy (trueness and precision or trueness only) of digital implant impression directly compared to the model produced from the conventional implant impression
Outcomes	Quantitative estimation of accuracy: linear, angular, or surface deviations
Study design	*In-vivo* and *in-vitro* experimental studies

SEARCH STRATEGY AND SEARCH TERMS

A literature search in the electronic databases Medline (PubMed), Web of Science, and Embase was conducted to receive publications from January 1, 2016, to the date of search (February 4, 2022), resulting in a time period of about 6 years. Six year period was chosen to include the latest and most relevant hardware and software of the digital devices.

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English- and German- language articles were selected using the following search terms: implant* AND (impression* OR scan* OR IOS OR digital impression* OR photogrammetry [MesH Term] OR photogrammetric OR optical OR intraoral scan* OR stereophotogrammetry [MesH Term] OR stereophotogrammetric) AND (full arch OR edentulous OR edentate OR complete arch) AND (trueness OR precision OR accuracy).

The decision criteria for including or excluding the studies are shown in Table 2.

Table 2. Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
English and German literature	Articles reporting on impression accuracy for tooth-supported or removable prostheses
At least 4 implants per dental arch	Partially edentulous situations, implant-level impressions
Minimum sample size: 5	Only qualitative evaluation of impression or/and model accuracy
Peer-reviewed *in vitro* and *in vivo* articles published from 2016	Digital impression device is not commercially available or not available on the market
Digital and conventional impression groups available in the study	Expert opinions, case reports, reviews

DATA EXTRACTION

Three reviewers (S.H., I.M, A.G.) conducted the primary literature search in the databases and independently screened the titles for abstract revision. There was only one disagreement, that was resolved by discussion. The selected abstracts had been revised independently for further full-text screening according to the inclusion and exclusion criteria *(Table 2)*. The full texts had been selected and the final consensus for inclusion was reached by all the authors. The extracted data was arranged in an online spreadsheet (Google Sheets, Google LLC), according to the following categories: identification of the article (year, authors); study type (*in vitro*, *in vivo*), implants (system, number, angulation, connection type), location (mandible, maxilla), study groups (impression type, material, and device, reference group), number of samples or performed interventions, accuracy assessment (assessment methods, results, outcomes). There was one disagreement regarding the number of implants used in the study. After discussion, the decision to exclude the article was taken, as it was clarified that less than 4 implants per arch were used for the measurements. An assessment of the quality and risk of bias for the included studies was performed according to the Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) tool.[28] Meta-analysis was not conducted due to the methodological differences of the selected studies.

RESULTS

A total of 805 studies were identified after the initial literature search in the databases. Removal of duplicates and title revision resulted in 117 abstracts for screening. Twenty-five full-text articles were considered to be eligible. After the exclusion of sixteen full-text articles with reason, nine studies fulfilled the inclusion criteria and were selected for further synthesis. *(Figure 1)*

The main findings of the systematic review are presented in Table 3.

STUDY TYPE

The majority of the selected articles were *in vitro* studies.[4,6–8,24,29] All of them were assessed with a low risk of bias *(Table 4)*. Three studies were done in an *in vivo* setting.[1,2,22] Two of them showed a high risk of bias, whereas the risk was rated as unclear for the study by Carneiro Pereira *et al*.

STUDY GROUPS AND CONTROLS

All analyzed articles were characterized by the presence of a "conventional impression group"(positive group).

Four studies compared the accuracy of conventional impressions and digital impressions gained from different intraoral scanners.[2,4,6,22] In the four publications a single intraoral scanner was tested.[2,4,6,22] Two studies evaluated the accuracy of the conventional impression technique in comparison with the impressions captured by photogrammetric imaging devices.[1,24] In the remaining three articles all three impression groups were investigated and analyzed against each other, namely conventional methods vs. digital impressions from IOS vs. PG.[7,8,29] In one of these studies two different intraoral scanners were applied.[8]

In regard to the clinical studies, two of them compared the accuracy of conventional impressions and IOS impressions,[2,22] while one study evaluated conventional impressions and implant position registrations obtained by photogrammetry.[1]

Concerning the control group, in the clinical studies casts obtained from conventional impression methods were considered as controls for the accuracy measurements.[1,2,22] In all *in vitro* settings control reference models were produced with coordinate measuring machines or scanned with industrial optical or laboratory scanners.[4,6–8,24,29]

The number of scans per examined group varied from 1 scan[1,2,22] to 10[4,6–8,24] or 15 scans[29] per group. *(Table 3)*

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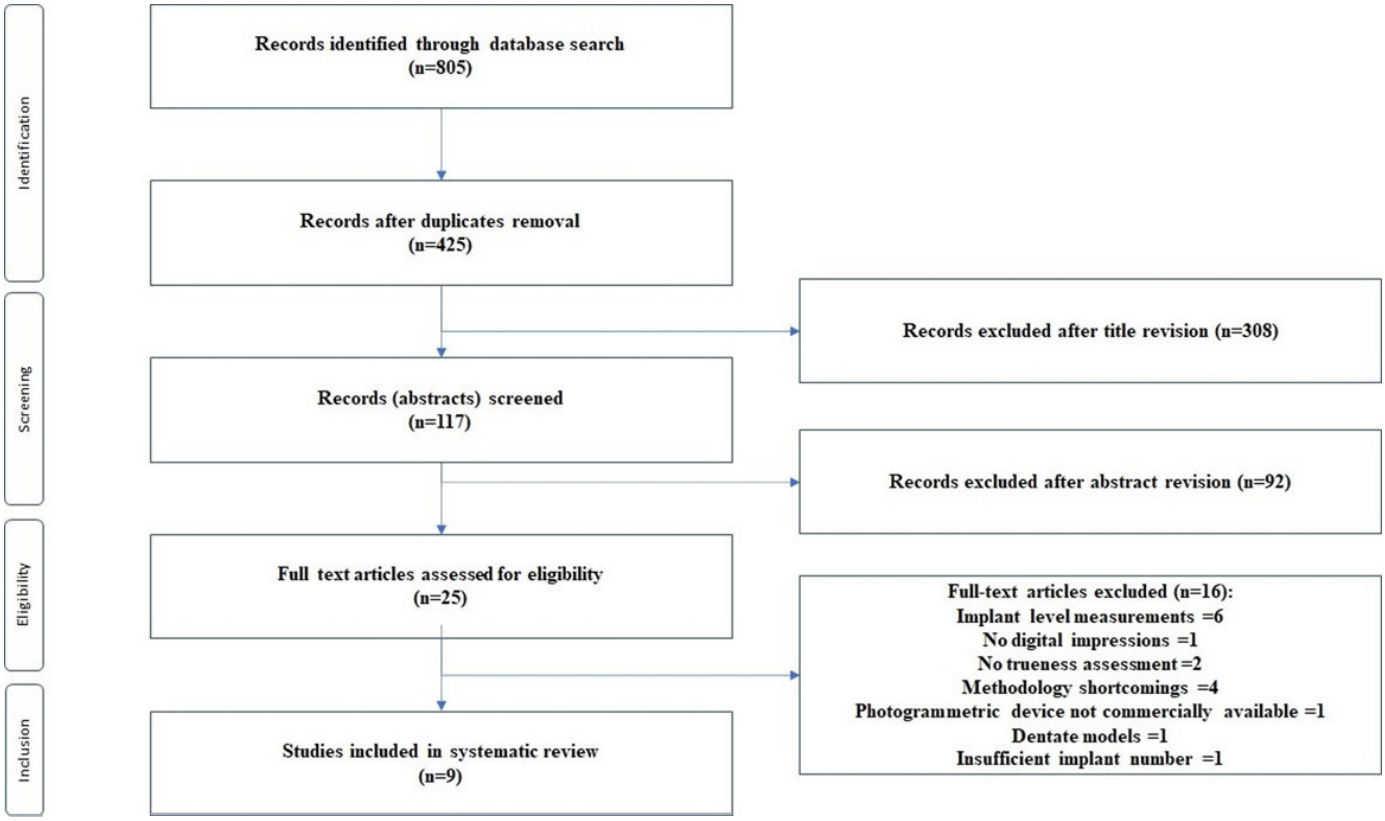

Figure 1: Search strategy.

SAMPLE SIZE AND IMPLANT PARAMETERS

Majority of publications presented full-arch situations with 4 - 6 implants or implant replicas for accuracy measurements. In one clinical study, the number of implants varied among the patient cases from 4 to 7.[1]

Five studies were related to the maxilla,[7,8,22,24,29] two to the mandible.[2,6] In one study the implants were distributed over both jaws[1] and one study used a simplified cast for the reference model. [4]

Among the included studies, four integrated tilted implants in their study-set up,[7,8,22,29] in one article only parallel implants were used[6] and in the remaining 4 studies no statement regarding implant angulation was made.[1,2,4,24]

Implant abutment replicas were chosen for the implant position measurements by four authors,[4,7,8,24] while in the other five studies internal connection implants fitted with multi-unit abutments were investigated.[1,2,6,22,29]

IMPRESSION DETAILS

In regards to the impression level, in all analyzed studies impressions and measurements were performed at the abutment level, which was in accordance with the inclusion criteria.

The majority of studies conducted the splinted open-tray impression technique for producing conventional stone casts.[1,6–8,24] In two articles the conventional impressions were done with the open-tray non-splinted method.[22,29] Menini *et al.* analyzed various conventional impression techniques e.g. open-tray splinted and non-splinted and additionally the closed-tray approach.[4] Carneiro-Pereira *et al.*, however, used no trays for impressions but splinted the impression copings intraorally with acrylic resin and poured it directly into the dental stone.[2]

Regarding the impression material in three studies polyvinyl siloxane (PVS) was utilized,[1,6,22] in three studies polyether (PE) was the material of choice[7,8,24] and in one article impression plaster (type I) was used for the conventional impressions.[29] Menini *et al.* performed the impressions with polyether and plaster material and as already mentioned previously, in the study of Carneiro-Pereira *et al.* no impression material was used.[2,4]

A variety of different intraoral scanners were chosen for performing digital impressions. The most frequently used IOS was the TRIOS 3(3Shape, Copenhagen, Denmark)[2,6–8,29] followed by the True Definition scanner (3M, Saint Paul, Minesota, USA).[4,22] An exact list of all intraoral scanners is shown in Table 3. For obtaining digital impressions by photogrammetric imaging in three articles the Icam4D system (Imetric4D Imaging Sàrl, Courgenay, Switzerland) was selected,[1,7,8] while in the other two studies the PIC camera (PIC Dental, Madrid, Spain) was applied.[24,29]

Apart from the study of Huang *et al.*, where custom CAD/CAM scan bodies were fabricated in addition, in all other articles the original scan bodies were used for the abutment level assessments.

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Table 3. The main findings of this systematic review.

Author	Study type	Number of implants	Types of impressions compared	Conventional impression technique	Impression material	IOS/ photogrammetry device	Type of scan body (height, original, custom made)	Results Trueness	Results Precision	Outcome / Conclusion
Menini et al, 2018	***in vitro***	4	IOS vs CI	1. OT, PE 1; 2. OT splinted PE 1; 3. CT PE 1; 4. OT PE 2; 5. OT splinted PE 2; 6. CT PE 2; 7. OT Plaster	1. PE 1; 2. PE 2; 3. Plaster	True Definition (3M ESPE)	Createch Medical (Createch Medical S.L.); 8mm	IOS: distance error: - 12 ± 26 µm; angle error: 0.257±0.242°	NA	Statistically significant differences were reported between IOS and CI both for distance and angle errors. IOS showed better reproducibility than conventional techniques.
Chochlidakis et al, 2020	***in vivo***	4, 5, 6 (16 cases)	IOS vs CI	OT, nonsplinted	PVS	True Definition (3M ESPE)	CARES Mono scan bodies (Straumann)	3D deviations for 4 implants: mean 139±56 µm; 5 implants: mean 146±90 µm; 6 implants: 185±81 µm.	-	Overall 3D deviation between virtual casts and CI casts was 162±77µm. Positive, but not significant correlation between implant number and 3D deviation.
Huang et al, 2020	***in vitro***	4	IOS vs CI	OT, splinted	PVS	TRIOS 3 (3Shape)	IOS 1: Original scan bodies (Straumann) 9 mm height; IOS 2: CAD/ CAM scan bodies (Gialloy Ti-5; SRL Dental GmbH), 9 mm height; IOS 3: CAD/ CAM scan bodies (Gialloy Ti-5; SRL Dental GmbH), 9 mm height; 20 mm extensional structure	The median of trueness of 3D surface for IOS varied from 28.45 µm to 35.8 µm and 25.55 µm for CI.	The median of precision of 3D surface for IOS varied from 27.3 to 48.9 µm and 19 µm for CI.	Design of the extensional structure of SB improved scanning accuracy; CI were more accurate than IOS.
Carneiro Pereira et al, 2021	***in vivo***	4 (10 cases)	IOS vs CI	Splinted impression copings poured into dental stone without tray	Splint with acrylic resin	Trios (3Shape)	Neodent (Straumann); scanning device: with patented CAD software program	Total linear 3D displacements varied from 2.28 µm to 4.39 µm. Median angular displacements varied from -4.48° to 6.37°.	-	Scanning device improved trueness of linear and angular displacements.
Revilla-Leon et al, 2021	***in vitro***	6	CI vs PG	OT, splinted (additively manufactured Co-Cr framework splinted with copings)	PE	PIC camera (PIC dental)	PIC Transfer (PIC Dental)	3D discrepancy for CI 18.4 µm, for PG system 20.15 µm.	3D discrepancy for CI 6.81µm, for PG system 25.41µm.	Trueness values were similar, precision varied. CI showed significantly higher accuracy values than PG.

Table 3 continued overleaf...

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Table 3. The main findings of this systematic review - continued....

Author	Study type	Number of implants	Types of impressions compared	Conventional impression technique	Impression material	IOS/ photogrammetry device	Type of scan body (height, original, custom made)	Results Trueness	Results Precision	Outcome / Conclusion
Zhang et al, 2021	***in vivo***	4, 5, 6, 7 (14 cases)	CI vs PG	OT, splinted (metal bars splinted with impression copings)	PVS	ICam4D (Imetric4D Imaging Sarl)	For PG: custom scan bodies ICamBody (Imetric4D Imaging Sarl). For digitization of verified casts: desktop scan bodies IO 2C-A (Nobel Biocare)	PG overall linear distance deviation 70±57 µm, angular deviation 0.43±0.35°	NA	PG positive correlation of distance deviations with interimplant distance, but no angular deviation correlation.
Ma et al, 2021	***in vitro***	6	IOS vs CI vs PG	OT, splinted	PE	ICam4D (Imetric4D Imaging Sàrl), TRIOS 3 (3Shape)	PG: ICamBody (Imetric4D, Imaging Sarl); IOS: CARES Mono scan bodies (Straumann)	Median trueness of 3D surface deviations: PG: 24.45 µm; IOS: 43.45 µm; CI: 28.7 µm;	Median precision of 3D surface deviations: PG: 2 µm; IOS: 36 µm; CI: 29.4 µm.	The PG system obtained the lowest 3D discrepancy in terms of trueness and precision for the implant abutment positions. The IOS tested represented the least accuracy among the three impression techniques tested.
Revilla-Leon et al, 2021	***in vitro***	6	IOS vs CI vs PG	OT, splinted (additively manufactured Co-Cr framework splinted with copings)	PE	ICam4D (Imetric4D Imaging Sarl), iTero Element (Cadent), Trios 3 (3Shape)	For PG: optical marker ICamBody (Imetric4D Imaging Sarl). IOS: CARES Mono scan body (Straumann)	The median linear trueness for CI varied from 1.8 to 8.9 µm, for IOS 1 varied from -4.1 to 17.5 µm, for IOS 2 varied from -4.9 to 18 µm. For PG group varied from -4.7 to 73.7 µm.	Linear precision for CI group varied from 4.6 to 17.9 µm, for IOS 1group varied from 16.6 to 48.9 µm, for IOS 2 group varied from 20.7 to 54.9 µm. For PG group varied from 27.2 to 308.7 µm	CI demonstrated the lowest 3D discrepancy, IOS showed the most stable results. PG system was the least accurate.
Tohme et al, 2021	***in vitro***	4	IOS vs CI vs PG	OT, nonsplinted	Plaster	Trios 3 (3Shape); PIC camera (PIC dental)	CARES Mono scan body (Straumann)	Global whole scan body 3D surface deviation for CI group 120 µm, for IOS group 150 µm, for PG group 90 µm	Global whole scan body 3D deviation for CI group 103 µm, for IOS group 63 µm, for PG group 2 µm.	The PG technique demonstrated the highest accuracy in terms of trueness and precision for the intraoral scan bodies of all the techniques evaluated.

IOS – intraoral scanning, CI – conventional impression, OT – open tray, CT – closed tray, PE – polyether, PVS – polyvinylsiloxane, NA – not available

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Table 4. Risk of bias evaluation according to Quadas-2 domains.

Study	Risk Of Bias			
	Patient Selection	Index Test	Reference Standard	Flow And Timing
Menini et al	+	+	+	+
Caneiro Pereira et al	?	?	?	+
Chochlidakis et al	-	-	-	?
Huang et al	+	+	+	+
Ma et al	+	+	+	+
Revilla-Leon et al	+	+	+	+
Revilla-Leon et al	+	+	+	+
Tohme et al	+	+	+	+
Zhang et al	-	-	-	-

+ Low Risk; - High Risk; ? Unclear Risk

In the clinical study of Carneiro Pereira *et al*. an additional digital experimental group was examined, where the scanning process was conducted with a CAD/CAM produced scanning device that was attached over the scan bodies, and therefore a splinting of the scan bodies was obtained. A similar procedure was reported in the article of Huang *et al*. They used CAD/CAM scan bodies with extensional structures as an auxiliary device for the scanning procedure. Chochlidakis *et al*. performed the IOS scanning with palatal fiducial markers.

There was no information available about the number of operators and their experience in the three articles.[22,24,29] In five studies a single operator conducted all digital impressions,[1,2,6–8] while the operator number was three in the study of Menini *et al*. Regarding the operator experience, four studies reported that they had operators with a long experience,[1,2,7,8] while in two studies un-experienced operators performed the scannings.[4,6] No inter- and intra-observer reliability had been reported in the selected studies.

ASSESSMENT METHODOLOGY

Articles that measured accuracy in terms of trueness were selected for the systematic review. Precision, the second parameter of accuracy, was evaluated in the majority of *in vitro* studies.[6–8,24,29]

Distance and angular deviations of the scan bodies were measured and calculated in two studies:[1,4] Menini *et al*. and Zhang *et al*. expressed the data for distance and angle parameters in mean values, Zhang *et al*.provided additional information on minimum and maximum values. Three-dimensional discrepancy using the superimposition of the STL files and the best-fit algorithm was assessed by five studies.[2,6,7,22,29] In three articles the 3D surface deviations were measured as root mean squares.[6,7,22] Tohme *et al*. additionally presented means of global angular deviations, whereas Carneiro Pereira *et al*. calculated the median of absolute values and 3D total linear displacements. In two articles linear, angular (mean values and median values respectively), and 3D deviations (median) were measured. (8,24) Additionally, Menini *et al*. measured the framework fit under the stereomicroscope using the Sheffield test. *(Table 3*)

OUTCOME ASSESSMENT

Four articles compared the accuracy of intraoral scanners and conventional impressions.[2,4,6,22] Menini *et al*. reported intraoral scanner superiority to conventional impressions with statistically significant results in linear and angular measurements.[4] The clinical study of Carneiro Pereira *et al*. showed similar results for conventional impressions and intraoral scanning with the scanning device, however, a longer median distance and a higher angular variation were found for the group with scan bodies alone.[2] A comparative prospective study by Chochlidakis *et al*. reported the clinical feasibility of the digital workflow for the fixed complete dentures in the maxilla, as the 3D deviation levels (162±77 μm) of digital scanning lied within the clinically acceptable threshold (<200 μm).[22] However, Huang *et al*.stated the opposite to the previously mentioned findings, reporting better accuracy parameters of conventional splinted open-tray impressions, but noted that the design of the extensional structure of the scan bodies improved scanning accuracy.[6]

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Two articles compared the accuracy of photogrammetric and conventional methods.[14,24] A clinical study by Zhang *et al*. classified photogrammetric imaging as a clinically acceptable method with a distance deviation less than 150 µm, however, 28,6% of measurements showed deviations higher than 150 µm.[1] Revilla-Leon *et al*. reported higher accuracy values for conventional impressions than photogrammetric imaging in a laboratory setting.[24]

Three articles presented accuracy data from conventional impressions, intraoral scanning, and photogrammetric imaging with varying results.[7,8,29] Ma *et al*. evaluated the lowest 3D discrepancy in terms of trueness and precision for the implant abutment positions in the photogrammetric imaging group followed by the conventional impression technique. Both methods showed better accuracy results in comparison to the intraoral scanner, representing the least accuracy among the three tested impression techniques.[7] In contrast, Revilla-Leon *et al*. reported that the photogrammetric imaging system was the least accurate method, while the conventional procedure revealed the lowest 3D discrepancy. The two intraoral scanners showed no significant differences in linear deviations compared to the conventional impressions and hence were regarded as a reliable digitizing procedure.[8] For precision assessment in the study of Tohme *et al*. the smallest deviation values were observed for the photogrammetric imaging group followed by the IOS technique. The conventional group showed the highest precision deviations. In this study in terms of trueness, all results were superior for the photogrammetric method except the flat angled surface region of the scan body, where higher trueness was detected with the IOS technique.[29] *(Table 3)*

DISCUSSION

Digital technologies are helping to continuously improve clinical and research aspects of implant dentistry. Accuracy of the clinical and laboratory procedures is of paramount importance, as it influences the treatment effectiveness, safety, and patient comfort.[15] Besides the advances in CAD/CAM and 3D printing technologies, capturing the exact implant positions using conventional and digital tools still remains a challenge.[12,26,30] Whereas, digital techniques are considered reliable for the short-span fixed implant-supported prosthesis, their accuracy for full-arch cases is still debated. IOS and PG devices have become the most popular for digital registration of implant positions. Few systematic reviews summarized the accuracy of IOS[15,31,32] and PG[23] techniques for the full-arch implant impressions. However, the conclusions and clinical recommendations of these reviews are contradicting due to the methodological differences of the included studies and lack of inclusion of the conventional groups.[12,23,26,27,33] This systematic review aimed at the analysis of the studies which directly compared the current and commercially available digital and conventional techniques using the clinically relevant models and patient populations. As it is widely recommended to use multi-unit abutments for the full-arch implant-supported fixed restoration fabrication, the studies which investigated full-arch implant-level impressions were excluded.

The majority of the studies were *in vitro* studies, which used reference data obtained by CMM or optical scanners. Due to the availability of the reference data, the mean trueness was assessed in these studies and ranged from 2[8] to 263[22] µm in linear deviations. However, the reference data cannot be reliably obtained in the clinical studies and only a comparison between conventional and digital techniques could be made, taking the conventional method as a positive control. The findings from the 2 included *in vivo* studies have indicated that IOS had mean linear deviation values of 2-185 µm as compared with CI.[2,19] One *in vivo* study has shown that this characteristic for PG was 70 µm.[14] The standardization of the impression procedure is more difficult in clinical studies, therefore, the risk of bias was higher as compared to the *in vitro* studies.

Overall, the majority of studies have rated digital techniques as accurate enough for the full-arch edentulous cases.[1,2,4,7,22,29] However, high variability in ranking of the included impression techniques was observed. Three included studies reported that CI was the most accurate technique,[6,8,24] 3 indicated that accuracy was similar[1,2,22] and the rest of the studies preferred DI over CI.[4,7,29]

One group of studies (n=4) compared the accuracy of IOS and CI techniques. Huang *et al*. have reported better accuracy parameters of conventional splinted open-tray impressions, but noted that the design of the extensional structure of the scan bodies improved scanning accuracy. These results can be explained by the use of parallel implants in the study model, large interimplant distances (up to 28 mm), and less experienced operators.[6] Menini *et al*. have found that a more reproducible outcome of IOS compared to CI was achieved, although 3 inexperienced operators were involved in the study. It shows that CI can be more technique sensitive with a steeper learning curve. However, the rest of the studies from this group (both *in vivo*), have stated that the results with IOS were comparable to CI and detected deviations were in the range of clinically acceptable threshold (200 µm). Carneiro Pereira *et al*. reported improved accuracy with a scanning device compared to the situation when only the scan bodies were used without additional device. These findings can be specific to the study, as in the CI group impression dental stone was used. Chochlidakis *et al*. involved patients with edentulous maxilla and mandible with 4-6 implants. The results can be partially explained by the non-splinted CI technique and fiducial markers used in the palatal area.

Another group of studies (n=2) has compared PG and CI for the full-arch implant impressions. Revilla-Leon *et al*. *in vitro* study reported that CI was more accurate than PG. This can be explained by the favorable *in vitro* conditions for the conventional impression making (absence of saliva and mobile soft tissues) and the use of the additively manufactured custom tray and metal framework which was used for splinting of

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the impression copings. However, the statistically significant trueness difference of 1.8 µm and a precision difference of 18.6 µm between both systems is of very limited clinical significance. In vivo study by Zhang *et al*. indicated that the linear measurement difference between CI and PG was up to 127 µm and angular - up to 0.78 degrees. While linear deviation falls in the range of clinically acceptable limits, the angular deviation can be outside of these limits.[34] Yet, due to the absence of a reliable true reference in clinical studies, it is difficult to state which of the impression techniques, conventional or digital, had better overall trueness.

In the third group of studies (n=3) all techniques (PG, IOS, and CI) were compared. All studies were *in vitro* studies, as to do a comparison between 3 impression techniques in a clinical setting would be problematic. In two studies, the CI with splinted impression transfers were used, while Tohme *et al*. did not use the splinting.

Ma *et al*. reported better accuracy for PG than CI and IOS. This is in contrast to the results of Revilla *et al*. study, where CI was rated as the most accurate, followed by IOS and PG.[7,8] Both studies have used the same PG device (iCAM4D, Voxeldental, Magnolia, Texas, USA) on the maxillary model with 6 implants. In one study the true reference data was obtained using the laboratory dental scanner and CMM in another. It can be argued that due to the size and shape of the spherical probe of CMM, it is more challenging to detect complex and undercut areas.[7,8,24] Therefore, using the laboratory scanner could have some advantages for acquiring reference data. These statements need to be investigated further and are of significant importance in accuracy studies. Tohme *et al*. have used a maxillary model with 4 implants, a PIC camera (PG group), and impression plaster for the CI technique. Due to the methodological differences results can not be directly compared to the previous two studies. The PG was found to have the best trueness, followed by the CI and IOS for trueness, as well as for precision, followed by IOS and CI.

Though only the studies with high methodological quality and direct comparison between digital and conventional impressions were included in this systematic review, due to the high variability of the patient population, types of study models, impression techniques and measurement strategies, comparison of the results and providing clinical recommendations is problematic. Many factors can influence the accuracy of the conventional and digital impressions that were used in the included studies. The distance and angulation between implants are one of the most critical factors influencing the accuracy of the impressions. A positive correlation between inter-implant distance and deviations was reported in a few studies.[1,22,35] Also, the use of scan bodies with extensions, auxiliary scanning devices, and fiducial markers showed the tendency to increase the accuracy of intraoral scanners.[2,6,20,22] It was shown that the scanning strategy might significantly affect the IOS accuracy.[18,36–39] However, the majority of studies have not specified the details of the scanning strategy or the number of images obtained.[8,22,24] Majority of the studies reported on the number and experience of the operators. Among those reporting the experience of the operator, impressions in 4 studies were taken by an experienced dentist.[1,2,7,8]

All of the included studies had conventional impression groups as a positive control (*in vitro* studies) or as the best available reference (*in vivo* studies). As digital and conventional techniques are compared between each other, it is important to highlight the variety of the conventional impression groups in different studies. The majority of studies (n=8) have used splinting of the impression copings, however, different splinting techniques were employed. Using prefabricated splinting structures could lead to better accuracy results,[8,24,40] compared to the splinting with acrylic resin without cutting and rejoining.[4] Only two studies (Chochlidakis *et al* and Tohme *et al*) of this systematic review claimed using non-splinted conventional impression copings. 3D accuracy in non-splinted conventional impression group varied from 115 to 162 µm, when in splinted group it varied from 12 to 30 µm. While splinted group demonstrated better results than non-splinted, both were lower than recommended 200 µm clinical threshold.

Similarly, digital impressions can be affected by various factors. The properties of different scan bodies (geometry, material, optical properties, and machining tolerances) can have a significant impact on the proper registration of the implant positions.[27] Higher than 10 degrees[41] or 15 degrees[12] between implants significantly affects the accuracy of digital implant impression and the fit of the final prosthesis. Repositioning accuracy of the scan bodies can negatively affect the digital impressions.[42] Majority of studies have not declared if the scan bodies were removed and repositioned between each digital registration of the implant positions.

It is also important to discuss different measurement methodologies used in the studies. Some studies have used CAD libraries[1,6,8,29] of the scan bodies and others used meshes obtained after the intraoral scanning to define the planes and axes for the measurements.[2,4,7,22,24] Also, different geometries of the scan bodies dictated the choice of the different planes and axes. The selection of the points for the linear measurements can significantly influence the measurement results and should be standardized in future studies. Different thresholds for the clinically acceptable deviations were mentioned in the studies, ranging up to 200 µm.[43] The 0.4 degree angular deviation threshold is widely used in the studies investigating predominantly implant-level impression accuracy.[34] However, this value is not very well validated and could be significantly different for the abutment-level impressions.

Perimucositis and periimplantitis are common biological complications of osseointegrated implants. Inaccurate fixed implant restoration can be one of the reasons inducing the inflammation of periimplant tissues. Improper design of the prosthesis such as bulky crowns or blocked gingival embrasures prevents good oral hygiene and causes plaque accumulation. Presence of gap at the implant – abutment interface

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leads to microleakage and accumulation of bacteria which can affect the surrounding soft and hard tissue around implants. Single unit implant prosthesis can reach minimal gap of discrepancy: a gap of 10 µm was presented by external connection implant – abutment interface and Morse taper implants demonstrated results with a gap of 2-3 µm in *in vitro* conditions.[44] For screw - retained bridge type restoration marginal gap discrepancy from 25 to 50 microns[45] is also evaluated as accurate fit. Differently, full - arch restorations usually are fixated at abutment level, so the tolerance of micro gap for passive restoration varies from less than 50 to 100 microns.[45] Additional technical issues can also induce periimplant tissue inflammation such as unstable prosthesis and abutment connection,[46] and non-passive prosthesis structure, which can cause tension at implant surrounding bone and its resorption.[47,48] It has been reported, however, that non-passive restoration of implants seems to have no negative impact on marginal bone, because of a possible bone adaptation mechanism.[49] The amount of attached tissue around implants also has an impact to long term implant survival success, despite contrasting data in the literature.[50,51] The recent systematic reviews claimed that the lack of keratinized gingival tissue around implants is associated with higher values of inflammation, plaque accumulation and patients discomfort performing oral hygiene.[52–54]

The included studies and current systematic review have certain limitations. Though only studies reporting on the modern digital devices currently widely used in the clinical practice were included, new hardware and software for IOS and PG devices were released from the onset of this review. The accuracy of full-arch implant impression is of key importance and prerequisite to achieving the final prosthesis with a clinically acceptable misfit. Nonetheless, error propagation of the workflow can occur at the latter clinical and laboratory steps.[55] For the effective treatment, not only accurate digital impressions but also reliable bite registrations are needed. There is a lack of studies, reporting the accuracy of digital bite registration techniques. Although the CAM techniques are reported as very accurate and predictable, the 3D printing of the final prostheses still lacks validation in clinical practice.[56] Furthermore, having accurate registrations of implant positions in 3D space is not enough, as for the finalization of the prosthesis the master model is still recommended. Finally, the clinically acceptable misfit should be more investigated in future research, for the objective evaluation of the fit of the final implant- and abutment-level prostheses produced from different digital and conventional impressions.[57] Only one study[4] investigated the fit of the framework on the model produced from the conventional impressions, however, future studies should evaluate the clinical and laboratory fit of the full-arch prostheses fabricated using digital impression data.[41]

CONCLUSIONS

Within the limitation of this systematic review it can be concluded, that:

1. Intraoral scanning and photogrammetry are reported as having similar accuracy for registering implant positions in the full-arch edentulous situations;
2. Mean values of the linear deviations were of from 2.28 up to 162 µm in the clinical studies and from 4.1 up to 43 µm in laboratory studies were found comparing digital and conventional impression techniques.
3. A wide variety of research methodology (study set-up, reference data collection, scanning, and measurement strategy) compromise comparison of the study results; there is a need to standardize future studies on implant impression accuracy. Minimization of the risks of bias by controlling the patient selection, inclusion of the index test and reference standard should be applied in the future studies.
4. There is a lack of information about digital bite registration accuracy, strategies of model, and prosthesis production, in order to comprehensively assess the error propagation of a specific workflow;
5. Various clinically relevant thresholds for the linear (up to 200 µm) and angular deviations (up to 0.4 degrees) are used in the studies. These values should be validated in the clinical studies and objective misfit assessment criteria adopted for clinical use.

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