THE JOURNAL OF PROSTHETIC DENTISTRY

SYSTEMATIC REVIEW

Techniques to improve the accuracy of complete-arch implant intraoral digital scans: A systematic review

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ABSTRACT

Statement of problem. The best method of optimizing the accuracy of complete-arch intraoral digital scans is still unclear. For instance, the location of the scan bodies can be significantly distorted with respect to their actual positions, which would lead to a nonpassive fit of the definitive prosthesis.

Purpose. The purpose of this systematic review was to analyze available techniques for improving the accuracy of digital scans in implant-supported complete-arch fixed prostheses.

Material and methods. Three databases (Medline, Embase, and Google Scholar) were searched, and the results obtained were supplemented by a hand search. Specific descriptors identified techniques whose objective were to increase the accuracy of digital scans in implant-supported complete-arch fixed prostheses. Titles and abstracts were screened by 2 independent reviewers, and unclear results were discussed with a third independent reviewer. A qualitative analysis based on procedural parameters was used. The interexaminer agreements of both were assessed by the Cohen kappa statistic, and the Risk of Bias Tool was used to assess the risk of bias across the studies.

Results. A total of 17 techniques matching the inclusion criteria were evaluated. Higher accuracy but also differences regarding the need for supplementary devices, number of intraoral scans, and time consumption of clinical and software program steps were observed compared with the conventional digital scanning protocol. The use of a splinting device was common to most of the studies. The outcome variables for the evaluation of the effectiveness of these protocols were heterogeneous.

Conclusions. The use of additional techniques during intraoral scanning can improve accuracy in implant-supported complete-arch fixed prostheses. However, higher complexity for those procedures should be expected. (J Prosthet Dent 2021;■:■-■)

The fixed prosthodontic workflow has been transformed by the introduction of digital technologies.[1-3] The conventional nondigital methodology for fabricating complete-arch implant-supported fixed prostheses requires abutments, impression materials, and custom trays and techniques such as splinting of the implant transfers.[4] The introduction of intraoral scanners (IOSs) has enabled a completely digital workflow.[5] Advantages include reduced patient discomfort, simplified clinical procedures and disinfection protocols, no need to pour dental stone casts, and better communication with the dental laboratory technician and patient.[6-10]

The effectiveness of IOSs can be reduced by the presence of saliva,[11] mobile tissues,[12] or reflecting materials.[13] These factors together with the stitching procedure, the absence of reference points in edentulous areas, or the geometry of the scan

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Clinical Implications

Optimizing complete-arch implant intraoral digital scans is essential for achieving a flawless digital workflow in implant prosthodontics. This analysis of the techniques devised for improving digital scanning for implant-supported complete-arch fixed prostheses should help dental clinicians.

bodies (SBs) have been reported to affect the accuracy of digital scans of long-span implant-supported fixed prostheses.[14-17] All these factors make scanning these prostheses one of the more challenging situations for obtaining an accurate intraoral scan file.[8,18-20] With this in mind, special devices based in photogrammetry have been designed explicitly to improve scanning accuracy for implant prostheses. Nevertheless, their acquisition requires an additional cost for dental clinicians.[21-24]

An accurate transfer of the position of the implants from the patient's mouth to a gypsum or virtual cast is essential for passive fit and, subsequently, for the long-term success of implant-supported prostheses.[25,26] Although the use of IOSs has been recommended for complete-arch scanning,[27,28] others have reported a lack of accuracy and, therefore, the unsuitability of the completely digital workflow.[29,30] Different solutions have been proposed to improve accuracy, including different scanning techniques or devices.[15] The present systematic review aimed to identify and summarize the current techniques for improving the accuracy of digital scans for complete-arch implant-supported fixed prostheses. Furthermore, additional information about these techniques was analyzed, particularly their advantages and disadvantages, the need for extra resources, and the scientific evidence for their effectiveness.

MATERIAL AND METHODS

The following population, intervention, comparison, outcome, study type (PICOS) question was formulated: P, complete-arch implant-supported fixed prostheses; I, intraoral digital scanning techniques with novel protocols, supplementary devices, or merging with other digital files; C, digital intraoral scanners without additional techniques, methods, devices, or software programs; O, accuracy, trueness, or precision of the digital files and fit of the prostheses; S, in vivo studies, ex vivo studies, description of dental techniques, or in vitro studies.

A literature search was developed on 3 different databases by implementing the search strategy displayed in Table 1. No time or language limitations were applied to the results. For the literature search on the Google Scholar database, only the first 300 results were

Table 1. Search strategy

Database	MeSH Terms and Search Terms
MEDLINE/PubMed, EMBASE, Google Scholar	("complete arch" OR "complete-arch" OR "fullarch" OR "full-arch" OR "full arch" OR "edentulous" OR "Toronto" OR "all on four" OR "all-on-four" OR "all on 4" OR "all on six" OR "all-on-six" OR "all on 6") AND ("intraoral scanner" OR "intraoral scanning" OR "digital impression" OR "optical impression" OR "scanning device" OR "CMA" OR "custom made measuring device" OR "CSD" OR "custom scanning device" OR "implant scanning" OR "guided implant scanning" OR "CSS" OR "Continuous scanning strategy" OR "continuous scan strategy" OR "auxiliary geometric device" OR "digital scan" OR "optical scan" OR "scanning" OR "scan abutment" OR "scan body") AND ("technique" OR "accuracy" OR "improving" OR "precision" OR "reliability").

considered.[31] Based on the Sci-Mago journal ranking (www.scimagojr.com), the 5 dental journals with the highest rating related to implant prosthodontics (Dental Materials, Journal of Prosthodontic Research, Journal of Prosthodontics, Journal of Prosthetic Dentistry, and International Journal of Prosthodontics) were hand-searched for relevant articles. A hand search was carried out for articles published between January 1, 2016, and November 25, 2020. This short timespan was considered appropriate because of the rapidly changing nature of digital dentistry.[32] This systematic review followed the Preferred Reported Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[33] Furthermore, reference lists of the studies identified were screened for additional material. Titles and abstracts were screened by 2 independent reviewers (A.P., S.V.), who identified articles matching the following inclusion criteria: only in vivo or in vitro studies considering the use of IOSs for definitive scans for complete-arch implant-supported fixed prostheses, and only studies where the intraoral scan protocol was different from the conventional, that is, using different scanning strategies, supplementary devices, materials, or radiographic, optical, or clinical methodologies to improve the accuracy of the definitive digital cast.

Disagreement for this preliminary phase of the screening process was recorded by means of the Cohen kappa statistic, and unclear results were discussed with a third independent reviewer (M.G.-P.). The full text of the identified studies was analyzed by 2 reviewers (A.P., S.V.), and disagreements were discussed with a third reviewer (M.G.-P.). The interexaminer agreement for this secondary phase of the screening process was assessed by the Cohen kappa statistic. Procedure-related variables were recorded from the resulting studies, and a qualitative assessment was carried out. An evaluation scale (Table 2) was used for assessing the identified scanning techniques, including the following items: need for additional exposure to X-rays, need for a supplementary device, need for a previous intraoral scan or impression for fabricating the scanning device, number of complete-

Table 2. Criteria for comparison with conventional intraoral scanning protocol

Item	Favorable	Acceptable	Unfavorable
Need for additional X-ray exposure	No	NA	Yes
Need for supplementary device	No	Prefabricated	Custom
Need for previous intraoral scan for fabricating scanning device	No	Obtained during previous clinical steps	Yes
Number of intraoral scans	1	2	>2
Difficulty and time consumption of clinical steps	Comparable with conventional intraoral scan technique	Requires additional low-level skills demanding steps	Requires additional high-level skills demanding steps
Difficulty and time consumption of software program steps	Comparable with conventional technique	Requires one additional digital procedure	Requires more than one additional digital procedure
Scientific evidence supporting technique	Quantitative information regarding accuracy of intraoral scan or regarding fit of definitive prosthesis	Qualitative assessment regarding accuracy of intraoral scan or regarding fit of definitive prosthesis	No assessment provided
Reported accuracy of technique	Intraoral scan accuracy or marginal fit of definitive prosthesis better than conventional technique	Intraoral scan accuracy or marginal fit of definitive prosthesis equivalent to conventional technique	Intraoral scan accuracy or marginal fit of definitive prosthesis less accurate than conventional technique or no information provided

NA, not applicable.

arch intraoral digital scans, difficulty and time consumption of the clinical steps, difficulty and time consumption of the software program steps, and scientific evidence (quality and quantity) supporting the technique. An assessment of the success and survival complete-arch implant-supported fixed prostheses fabricated by modified complete-arch intraoral digital scanning protocols was developed.

The Risk of Bias Tool v2 (RoB tool) was adopted to assess the risk of bias across the studies.[34] As different study designs were included and this resource was intended specifically for randomized clinical trials, the assessment tool was adapted. Where the answer to at least 1 of the items was considered not applicable or more than 3 items were answered as medium risk or at least 1 item as high risk, the overall potential for bias of the study was classified as high risk. Where all items were answered, and no high-risk items were identified, but more than 1 and fewer than 4 items were classified as medium risk, the overall potential for bias was classified as medium risk. Where all items were answered, and only 1 was classified as medium risk, the overall potential for bias was classified as low risk.

RESULTS

A total of 2004 scientific articles (779 from PubMed, 925 from EMBASE, 300 from Google Scholar) emerged from the database search. The hand search resulted in the retrieval of 4697 articles (998 from Dental Materials, 677 from the Journal of Prosthodontic Research, 1736 from the Journal of Prosthetic Dentistry, 804 from the International Journal of Prosthodontics, and 482 from the Journal of Prosthodontics). From the web search, 22 articles were selected for full-text analysis on PubMed, 11 on EMBASE, and 0 on Google Scholar. From the hand search, a total of 6 studies were selected from the Journal of Prosthetic Dentistry and 2 articles from the Journal of Prosthodontics. Disagreements had been resolved by a third reviewer (M.G.-P.). After eliminating duplicates and full-text analysis, a total of 15 studies,[5,8,27,35-46] describing 17 different techniques, were selected for qualitative analysis. A total of 28 studies[1,4,19,29,47-70] were excluded for the reasons shown in Figure 1. During the screening of the abstracts identified through the online and hand search, a kappa value of 0.85 for interexaminer agreement was calculated, and a kappa value of 0.92 for the full-text analysis. Figure 1 presents the PRISMA flow diagram for identification of the studies.

Different study designs were identified, of which 7 (46%) were clinical studies,[5,8,27,36,37,45,46] of which only 1 had a controlled design.[37] Four articles (27%) were in vitro research,[35,40,41,44] and the other 4 articles (27%) were dental technique manuscripts.[38,39,42,43] The variables registered for each technique in comparison with the conventional intraoral scanning protocol are shown in Table 3. In addition, Figures 2, 3 show the percentages of favorable, acceptable, and unfavorable qualifications for each variable and technique, respectively. The protocols described were partly supported by clinical reports where the accuracy of the scanning technique was assessed by passive fit evaluation through clinical or radiographic examination.[5,36,46] Those studies involving prospective observation of multiple restorations also relied on clinical and radiographic examination of the framework-to-implant fit.[27,37,45] The success and survival rates of complete-arch implant-supported fixed prostheses fabricated by modified complete-arch intraoral digital scanning protocols were reported at 12 months[8,37] and 24 months.[45] All studies described 93% or higher success and survival rates, but no differences were observed with respect to conventional analog techniques or no detailed information was provided about differences in accuracy.[37]

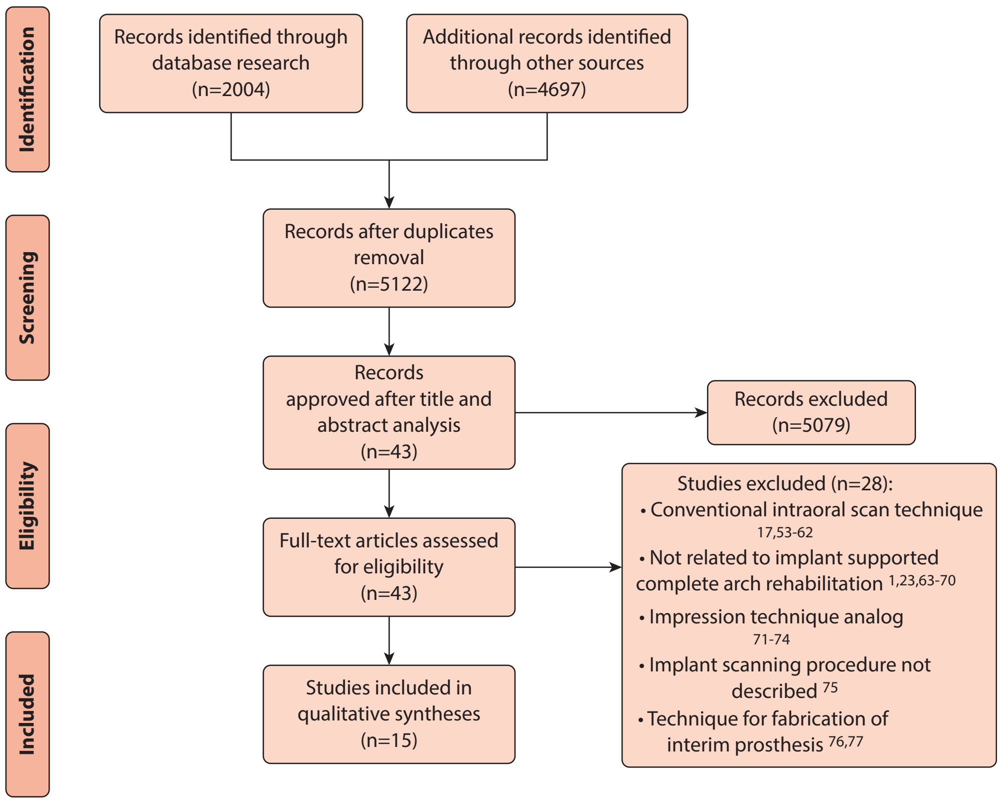

Figure 1. PRISMA flow diagram describing study selection. PRISMA, Preferred Reported Items for Systematic Reviews and Meta-Analyses.

Table 4 reports the results of the risk-of-bias assessment. Four studies were descriptions of dental techniques and, therefore, did not allow the evaluation of any of the items of the RoB v2 evaluation tool.[38,39,42,43]

In 16 of the 17 techniques, additional materials or devices were necessary for improving the accuracy of digital scans for complete-arch implant-supported FDPs. These 16 techniques were grouped in 2 categories: 6 techniques requiring the fabrication of a device by the dental laboratory technician,[5,8,35,36,38,42] while in 9 of them, the supplementary device could be either prefabricated or prepared chairside.[27,37,39,40,44-46] Among the supplementary devices where a dental laboratory technician was needed, resin splint frameworks were the most common (6 of 7 techniques).[5,8,35,36,41,42] Different solutions were used for attaching the scanning templates to the SBs: gypsum[8] or light-polymerizing resin between the template and the SBs,[35,39] and guided surgery pin holes to secure the template to the bone,[5] while 5 of them relied only on mucosal support.[36,38,41,42] Among the techniques that could be made without a custom device, 1 used a prefabricated polymethylmethacrylate (PMMA) milled device where the holes for accommodating the SBs were drilled chairside,[39] 3 used prefabricated fiducial markers adhesively connected to the palatal or interimplant mucosa,[27,40,46] and 2 used commonly available materials such as pressure-indicating paste or dental floss.[40] Dental composite resins were used in 2 studies to splint the SBs with thermoplastic resin or orthodontic wire.[37,45]

The requirement of previous scans for manufacturing the scanning device was present in 8 of the techniques identified.[5,8,27,35,36,38,41,42] The requirement of additional X-ray exposure was present in only 1 of the identified techniques.[43] The number of intraoral scans required for the fabrication of the definitive prosthesis varied among the studies, ranging from 1 to 3. The authors that used a single intraoral scan relied on chairside techniques for improving its accuracy[27,40,44] or matched the intraoral scan with a cone beam computed tomography (CBCT) scan.[43] Eleven needed more than 1 intraoral scan, all of them starting from a scan of commercially available SBs and superimposing it on an additional scan with the splinting device in place.[5,8,35,36,38,39,41,42,45,46] In the only technique where 2 intraoral scans were acquired but no superimposition of splinted and unsplinted SBs took place, the purpose of the second scan was to register additional soft-tissue information.[37] When a third complete-arch intraoral digital scan was acquired, its objective varied from recording additional soft-tissue information,[5,42] recording the retromolar area to facilitate the superimposition of the subsequently acquired standard tessellation language (STL) files,[36] to milling the definitive framework after performing adjustments to a

Table 3. Description and qualitative assessment of included studies

Study	Description	Need for Extra X-ray Exposure	Need for Extra Device	Requirement of Previous Impression for Manufacturing of Extra Device	Number of IO Scans	Difficulty and Time Demand for Clinical Steps	Difficulty and Time Demand of Software Steps	Scientific Evidence of Accuracy
Iturrate et al, 2019[35]	Preliminary IO scan with SBs. Second IO scan of only SBs locations splinted with 3D printed device linked to them with light-polymerizing resin. Digital alignment of both files taking as reference SBs locations in second IO scan.	No	Yes (custom.)	Yes	2	Low-level skills demanding steps (scanning device positioning)	1 additional step	Favorable (in vitro study vs conventional IOs)
Beretta et al, 2021[36]	Preliminary IO scan with SBs. Second IO scan with 3D printed splint fixed to 2 SBs with autopolymerizing resin to provide references to IO scanner.	No	Yes (custom.)	Yes	3	Low-level skills demanding steps (scanning device positioning)	More than 1 additional step	Acceptable (case report; passive fit clinical and Rx examination)
Cappare et al, 2019[37]	IO scan with SBs splinted using orthodontic wire and light-polymerizing flowable composite resin. Second IO scan of only soft tissues. Digital alignment of both files.	No	No	No	3	High-level skills demanding steps (resin splinting by direct technique)	1 additional step	Acceptable (RCT; passive fit examination, clinical)
Ferreira de Almeida et al 2020[38]	IO scan using patient's interim removable prosthesis connected to some implants with drilled holes accommodating some of SBs. Second IO scan with all SBs. Digital alignment of both files.	No	Yes (custom.)	Yes	2	Low-level skills demanding steps (scanning device positioning)	1 additional step	Unfavorable (dental technique description)
Gómez-Polo et al, 2020[39]	IO scan with SBs. Perforate of PMMA splint (with references) and capture of interim abutments with autopolymerizing material. EO scan of splint to register implant locations. Digital alignment of both files using SBs locations registered in EO scan of splint.	No	Yes (prefab.)	No	2	Low-level skills demanding steps (scanning device positioning)	1 additional step	Unfavorable (dental technique description)
Mandelli et al, 2020[8]	Preliminary IO scan and manufacture of PMMA perforated bar. Capture of pick-up transfers with bar in Type IV stone, screw of implant analogs and definitive cast poured. Connection of SBs to this cast and EO scan. Digital alignment of both files taking as reference SBs locations registered in EO scan.	No	Yes (custom.)	Yes	2	High-level skills demanding steps (gypsum impression)	1 additional step	Acceptable (5 clinical cases; passive fit evaluation clinical)
Mizumoto et al, 2020 (a)[40]	IO scan with SBs and glass fiducial markers attached to interimplant mucosa	No	Yes (prefab.)	No	1	Low-level skills demanding steps (fiducial markers positioning)	Comparable with conventional IO scan	Favorable (in vitro study vs conventional IOs)

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Table 3. (*Continued*) Description and qualitative assessment of included studies

Study	Description	Need for Extra X-ray Exposure	Need for Extra Device	Requirement of Previous Impression for Manufacturing of Extra Device	Number of IO Scans	Difficulty and Time Demand for Clinical Steps	Difficulty and Time Demand of Software Steps	Scientific Evidence of Accuracy
Mizumoto et al, 2020 (b)[40]	IO scan with SBs and pressure indicating paste attached to interimplant and palatal mucosa	No	No	No	1	Low-level skills demanding steps (pressure indicating paste positioning)	Comparable with conventional IO scan	Favorable (in vitro study vs conventional IO scan)
Mizumoto et al, 2020 (c)[40]	IO scan with SBs splinted together by using dental floss	No	No	No	1	Low-level skills demanding steps (dental floss positioning)	Comparable with conventional IO scan	Favorable (in vitro study vs conventional IO scan)
Tallarico et al, 2020[41]	Preliminary implant dental plan (CBCT and guided surgery software programs) used to design perforated 3D printed resin splint. IO scan of splint with SBs in place. No information on soft tissues provided.	Yes	Yes (custom.)	Yes	1	Low-level skills demanding steps (scanning device positioning)	1 additional step	Favorable (in vitro study assessing scan accuracy)
Venezia et al, 2019[5]	Preliminary IO scan with SBs in place. Second IO scan of 3D printed resin splint with holes accommodating SBs, stabilized by bone anchored metal pins. Digital alignment of both files taken as reference SBs locations registered in IO scan of device.	No	Yes (custom.)	Yes	3	Low-level skills demanding steps (scanning device positioning)	More than 1 additional step	Acceptable (case report; passive fit evaluation clinical)
Ahmed et al, 2021[42]	EO scan of complete denture and manufacture of custom scanning device with windows (resin-based material). First IO scan registering information of scanning device and soft tissues (partially, through windows). Second IO scan to complete soft tissues information and implant platforms. Digital trim of implant platforms and rescan with SBs (third scan).	No	Yes (custom.)	Yes	3	Low-level skills demanding steps (scanning device positioning)	1 additional step	Unfavorable (dental technique description)
Chochlidakis et al, 2020[27]	IO scan using SBs and resin fiducial markers attached to palatal mucosa	No	Yes (prefab.)	No	1	Low-level skills demanding steps (fiducial markers positioning)	Comparable with conventional IO scan	Acceptable (clinical study 16 patients; passive fit, clinical evaluation)
Gómez-Polo et al, 2020[43]	IO scan and CBCT with SBs in same position. Digital merge of both files.	Yes (CBCT)	No	No	1	Comparable to conventional IO scan technique	1 additional step	Unfavorable (dental technique description)
Huang et al, 2020[44]	IO scan using titanium custom SBs with extensional structure	No	Yes (custom. or prefab.)	No	1	Comparable to conventional intraoral scan technique	Comparable with conventional IO scan	Favorable (in vitro study assessing scan accuracy)
Imburgia et al, 2020[45]	IO scan with SBs. Second IO scan with SBs splinted with thermoplastic resin and light-polymerizing flowable composite resin. Digital alignment taking as reference SBs	No	No	No	2	High-level skills demanding steps (resin splinting by direct technique)	1 additional step	Acceptable (clinical study 35 patients; passive fit, clinical and Rx evaluation)

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Table 3. (*Continued*) Description and qualitative assessment of included studies

Study	Description	Need for Extra X-ray Exposure	Need for Extra Device	Requirement of Previous Impression for Manufacturing of Extra Device	Number of IO Scans	Difficulty and Time Demand for Clinical Steps	Difficulty and Time Demand of Software Steps	Scientific Evidence of Accuracy
	locations registered in IO scan with splint.							
Papaspyridakos et al, 2020[46]	IO scan using SBs and resin fiducial markers attached to palatal mucosa	No	Yes (prefab.)	No	3	Low-level skills demanding steps (fiducial markers positioning)	More than 1 additional step	Acceptable (case reports; passive fit clinical and Rx examination)

3D, three-dimensional; CBCT, cone bean computed tomography; Custom, customized; EO, extraoral; IO, Intraoral; PMMA, poly methyl methacrylate; Prefab, prefabricated; RCT, randomized clinical trial; SBs, scan bodies.

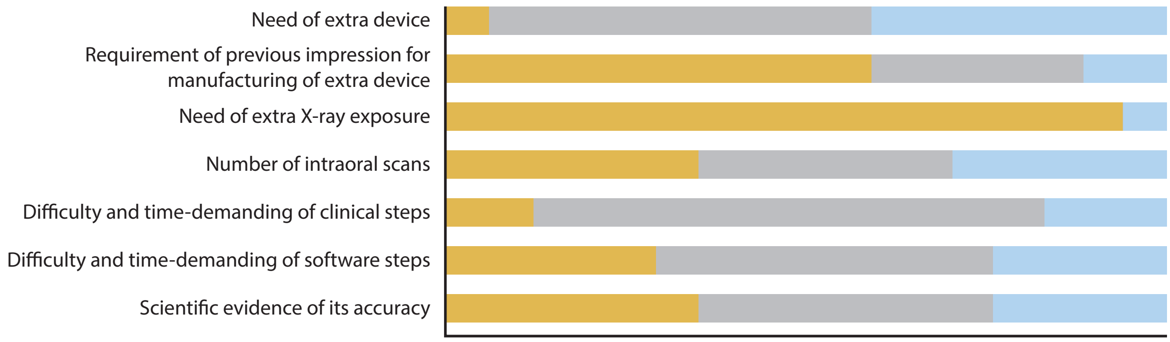

Figure 2. Percentages of techniques classified according to each variable in comparison with conventional technique (*orange*: favorable; *grey*: acceptable; *blue*: unfavorable).

PMMA-milled prototype framework and evaluating the fit between the bar and the implants.[46]

DISCUSSION

The use of IOSs in dental practice is becoming more predictable, but complete-arch edentulous intraoral digital scanning continues to be challenging.[18,71] The present systematic review evaluated modified protocols for intraoral scanning for complete-arch implant-supported fixed prostheses and compared them with the conventional digital technique. Limitations of this review included that the identification of the techniques may have been affected by the lack of a common terminology describing these novel protocols, forcing the authors to set a broader online database search string and leading to the loss of relevant information. In addition, the heterogeneity of the study designs was a limitation, as common outcome variables across all the studies were lacking. Therefore, the suggested evaluation tool for these techniques was based mainly on procedural parameters rather than on a quantitative evaluation of scanning accuracy. Although these observations may suggest that a systematic review study design could be premature, the procedural parameters discussed in this review allowed a relevant assessment of the techniques and should help clinicians throughout the digital workflow of complete-arch implant-supported FDPs.

The splinting of the SBs, either directly or indirectly, was a distinctive characteristic of most of these techniques.[5,8,35-42,45] Some of them used supplementary devices to provide additional reference points for the IOSs in the acquisition of long-span edentulous areas. Several designs were observed, but only 1 study provided comparative data of the accuracy between different splint devices.[40] Nonetheless, previous research suggests that devices must include smooth and regular shapes, as these references have been reported to impact the scanning procedure positively.[72]

The complexity and time consumption of clinical steps for each technique were closely related to most of the parameters considered, especially for those techniques where chairside procedures were adopted for splinting the SBs, because their preparation relied entirely on the clinician.[37,45] A lesser impact should be expected in those situations where an indirect splinting device was used and the chairside procedure consisted only of securing the device to the SBs or the mucosa.[5,8,27,35,36,38-42,44,46] Although a previous scan was necessary to fabricate an indirect splinting device, the clinical workflow was not identical for all methods, and an additional appointment for the acquisition of an STL scan of the implants was only necessary in 2 of them.[8,36] When no additional appointment was required, the STL file was acquired by either scanning the patient's existing complete denture or by using the surgical template designed for guided

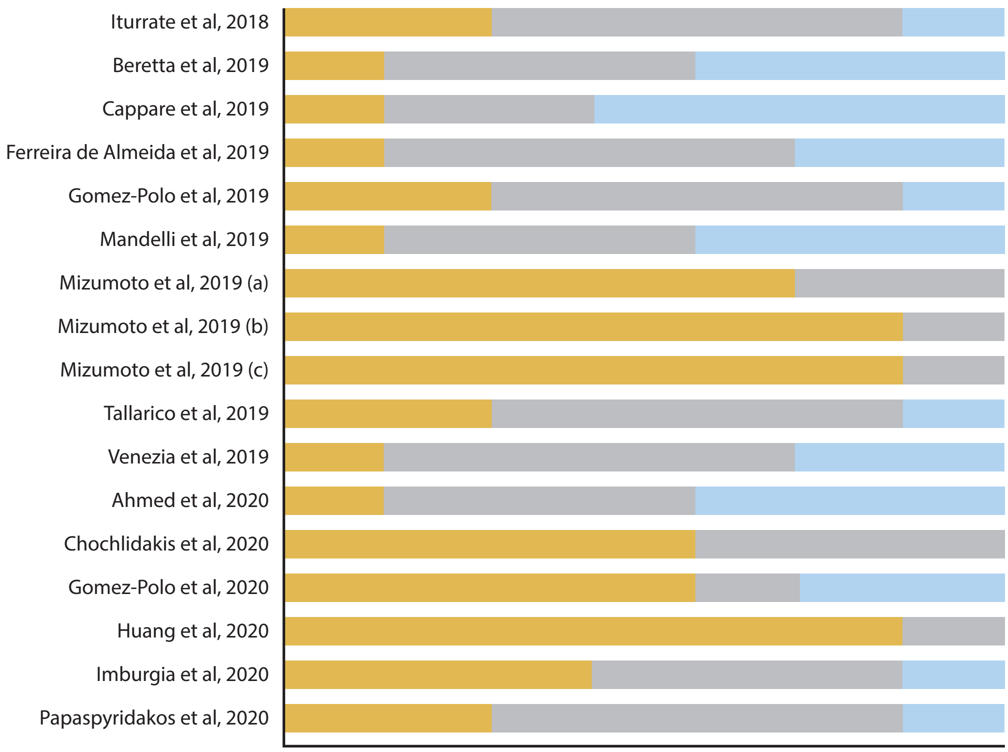

Figure 3. Percentages of favorable (*orange*), acceptable (*grey*), and unfavorable (*blue*) qualifications for each technique.

implant placement.[5,38,41,42] The total number of complete-arch intraoral digital scans carried out during each procedure was also considered as an influencing procedural aspect. However, because of substantial heterogeneity among those protocols, fewer assumptions can be made. Still, it seems reasonable to assume that, when a scanning template is integrated into the prosthetic workflow, multiple scans may be necessary to record information concerning the soft tissues to ensure an accurate mucosal architecture in the definitive digital cast.[5,8,35-39,42,45] The duration of the scanning process also impacted the overall duration of the clinical procedure. Using a splinting device during the scan took 50% longer than for the conventional complete-arch intraoral digital scan technique.[41] However, the number of scans required to achieve an accurate representation was significantly lower for splinted SBs than that for unsplinted SBs.[41] This finding indicates that, even though clinical steps may require more time, the overall duration of the procedure could be shorter when using splinting devices.

Regarding the difficulty and time consumption of the software program steps, those techniques using a single intraoral digital scan were the most straightforward to perform, as all the necessary information was provided by the original STL file.[27,40,44] However, when the superimposition of multiple STL files was necessary, the steps in the software program increased.[5,8,35-42,45,46] Even though the technique required merging more than 2 STL files, the complexity should not vary significantly. The time consumption, however, may change, especially for operators less familiar with the procedure and where additional software programs are required. Both the complexity and time consumption increased in those situations where guided surgical approaches were adopted because additional time and skills are needed to design the surgical template.[5,36] The choice of the technique should be also driven by a thorough consideration of the digital capabilities of both the clinician and dental laboratory technician.[1-3,6]

The need for additional X-ray exposure, observed in 2 of the techniques,[41,43] was considered as a procedural parameter and consisted of integrating data from CBCT scans in the prosthetic workflow. Three-dimensional imaging techniques have been shown to provide clinically acceptable results for the manufacturing of interim tooth supported fixed prostheses and definitive prosthetic frameworks.[73-75] However, the high difference in contrast between the implant material and the surrounding tissues led to the conclusion that a prosthesis designed directly from a CBCT file, although possible,[75] could have undesirable distortions. When considering implant-supported fixed prostheses, CBCT scanning could be effective in improving the accuracy of long-span interimplant distances in comparison with IOSs, while the latter seem more suitable for short-span prostheses.[43]

Table 4. Risk-of-bias (RoB) assessment of included articles

Authors	Year	Study Design	RoB (Randomization Process)	RoB (Effect of Assignment to Intervention)	RoB (Effect of Adhering to Intervention)	Missing Outcome Data	Risk of Bias in Measurement of the Outcome	Risk of Bias in Selection of the Reported Result	Overall Risk of Bias
Iturrate et al[35]	2018	In vitro	NA	NA	NA	Low	Low	Low	High
Beretta et al[36]	2019	NRSI	NA	NA	NA	Low	Medium	Low	High
Cappare et al[37]	2019	RCT	Low	Low	Low	Low	Low	Medium	Low
Ferreira de Almeida et al[38]	2019	Dental technique	NA	NA	NA	NA	NA	NA	High
Gómez Polo et al[39]	2019	Dental technique	NA	NA	NA	NA	NA	NA	High
Mandelli et al[8]	2019	NRSI	NA	NA	NA	Low	Medium	Low	High
Mizumoto et al[40]	2019	In vitro	NA	NA	NA	Low	Low	Low	High
Tallarico et al[41]	2019	In vitro	NA	NA	NA	Low	Low	Low	High
Venezia et al[5]	2019	NRSI	NA	NA	NA	Low	Medium	Low	High
Ahmed et al[42]	2020	Dental technique	NA	NA	NA	NA	NA	NA	High
Chochlidakis et al[27]	2020	NRSI	NA	NA	NA	Low	Medium	Low	High
Gómez-Polo et al[43]	2020	Dental technique	NA	NA	NA	NA	NA	NA	High
Huang et al[44]	2020	In vitro	NA	NA	NA	Low	Low	Low	High
Imburgia et al[45]	2020	NRSI	NA	NA	NA	Low	Medium	Low	High
Papaspyridakos et al[46]	2020	Dental technique	NA	NA	NA	NA	NA	NA	High

NA, not applicable; NRSI, nonrandomized study of intervention; RoB, risk of bias.

Gómez-Polo et al[43] suggested merging a CBCT image converted to an STL file with the digital cast obtained from an IOS to take advantage of both techniques. Factors such as the positioning of the patient during the radiographic examination, as well as the setting of the machine, may also impact the outcome of the treatment.[76] Even though the use of CBCT scans as an auxiliary technique in implant-supported fixed prosthesis scans could improve the prosthetic outcome, evidence for recommending its use is currently lacking, and additional research is needed to provide quantitative information.

The overall quality of the scientific evidence supporting the techniques was identified as low. Also, as a strong heterogeneity was observed among the outcome variables in the studies identified in this review, the information gathered about the potential risk of bias is of limited relevance. Although in vivo evidence reported high survival and success rates for the prostheses fabricated though these procedures, it provided only qualitative information with short-term follow-up.[5,8,27,36,37,45,46] In vitro evidence also provided quantitative information.[35,40,41,44] Deviations between 59 and 200 μm for digital scans have been reported to be clinically acceptable for complete arches.[77-80] Even though all the techniques considered in this review reported acceptable impression accuracy,[27,35,40,44] except the technique where the SBs were splinted by using dental floss that scored values higher than 200 μm,[40] not all had equivalent performance. The use of fiducial markers or pressure-indicating paste on the interimplant mucosa did not improve the quality of the scan with respect to conventional complete-arch intraoral digital scanning.[40] However, when a resin splinting device was connected to the SBs, the scanning accuracy was improved over the conventional technique.[35] Similarly, splinting titanium-milled SBs with an extensional structure resulted in higher trueness and precision, which has also been described as comparable with the conventional analog technique.[44] As the shape and material of the SBs have been reported as an influencing factor for impression accuracy,[16,40] further research is needed to understand how these factors influence complete-arch intraoral digital scanning protocols when a splinting device is used.

CONCLUSIONS

Based on the findings of this systematic review, the following conclusions were drawn:

1. Different techniques for intraoral scans of complete-arch implant-supported fixed dental prostheses could lead to improved accuracy with respect to conventional digital scanning techniques.
2. Time consumption, additional scans, the need for supplementary material and prefabricated or custom devices, and the complexity of the clinical and software program steps should be considered as differences from the conventional technique.

3. Overall, scientific evidence for the efficacy of complete-arch implant digital scans is still scarce.

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https://doi.org/10.1016/j.prosdent.2021.08.018