Received: 15 May 2023 | Accepted: 20 October 2023

DOI: 10.1111/jopr.13786

AMERICAN COLLEGE OF PROSTHODONTISTS
Your smile. Our specialty.®

REVIEW

Patient-reported outcomes and framework fit accuracy of removable partial dentures fabricated using digital techniques: A systematic review and meta-analysis

Balqees Almufleh BDS, PhD[1] | **Alexia Arellanob DDS**[2] | **Faleh Tamimi BDS PhD**[2]

[1]Department of Prosthetic Dental Sciences, College of Dentistry, King Saud University, Riyadh, Saudi Arabia

[2]College of Dental Medicine, QU Health, Qatar University, Doha, Qatar

Correspondence
Dr Faleh Tamimi, Professor, College of Dental Medicine, QU Health, Qatar University, Doha, Qatar, Arab League St, Doha, Annex A105, Qatar.
Email: fmarino@qu.edu.qa

This article is part of the Special Issue: Digital Scans in Prosthodontics. Guest Editor: Dr Marta Revilla-León

Abstract

Purpose: This review aimed to summarize the evidence on patient-reported outcomes and clinical performance of digitally fabricated removable partial dentures (RPDs) compared to traditionally fabricated dentures.

Methods: Three databases were systematically searched (PubMed, CENTRAL, and Wiley online library) for clinical studies comparing digitally and conventionally fabricated RPDs regardless of data acquisition methods used for fabrication. The Cochrane Collaboration risk of bias assessment tool 2 and the Oxford Center for Evidence-based Medicine tool were used to assess risk of bias, and level of evidence, respectively. Descriptive narrative analysis was used to summarize data on patient-reported outcomes, as there were inadequate studies to pool data in a meta-analysis. A random-effects model was used to analyze the data of framework fit accuracy.

Results: Ten randomized controlled trials were included in the systematic review, and 4 were included in the meta-analysis. Two studies showed that digitally fabricated RPDs are associated with higher patient satisfaction than conventionally fabricated RPDs (with a mean difference of 12.5 mm on a 100-satisfaction scale, $p = .008$). The pooled standardized mean difference for framework fit accuracy was 0.49 ($p = 0.02$) in favor of conventionally fabricated RPDs, which showed that conventionally fabricated RPDs have a quantitatively better fit compared to digitally fabricated RPDs. However, clinical evaluation studies showed that both frameworks have clinically acceptable fit.

Conclusions: Current evidence shows that digitally fabricated RPDs are associated with higher patient satisfaction compared to conventionally fabricated RPDs. However, the scarcity of literature here warrants the generalization of this conclusion. Both digitally and conventionally fabricated metal RPD frameworks showed acceptable fit clinically.

KEYWORDS
CAD-CAM, clinical performance, digital scanning, removable partial dentures, systematic review

The prevalence of partial edentulism ranges from 30% to 60% among Europeans over the age of 65.[1] In the UK, it is expected that approximately 96% of adults will be at least partially dentate by 2028, with similar trends reported in other parts of the world (Germany and Japan).[2,3] Tooth loss has been associated with several negative biological and psychological sequelae.[4,5] Several treatment options are available nowadays to restore partial edentulism, including implant-supported restorations, tooth-supported fixed partial dentures, and removable partial dentures (RPDs).[6] Despite the high success rates reported for implant treatments,[6] RPDs are still the treatment of choice for many patients for a variety of

reasons such as patient health, patient preferences, socioeconomic status, and accessibility to care.[3,7–9] Indeed, as much as 13% to 29% of adult European populations wear RPDs.[9]

RPDs are traditionally fabricated using the lost wax technique, which is a demanding technique that is prone to a wide range of technical errors.[3,10,11] Recently, digital technologies were introduced to fabricate RPDs to save time, minimize human errors, and reduce material waste.[12,13] Additionally, digital technologies have expanded the range of materials available for RPD framework fabrication to include flexible polymers, high-performance polymers (polyetheretherketone, PEEK), and titanium.[12,14] PEEK seems a promising alternative due to its superior esthetics, high mechanical properties, excellent biocompatibility, and stability.[3,15,16] However, concerns remain over the difficulty of polishing the frameworks, and adjustment of clasp retention.[17]

Several in vitro studies and case reports showed that digital technologies were able to produce accurate frameworks.[18–24] In clinical settings, a framework fit is considered accurate when upon clinical examinations and pressing test the framework remains stable, and all rests are fully seated in their prepared tooth surfaces, with minimal gaps if any could be identified between rests and prepared tooth surfaces. Also, all clasp parts and lingual plating parts that should contact tooth surfaces are contacting with no space in between upon tactile examination with an explorer.[25,26] Previous systematic reviews concluded that both digitally and conventionally fabricated RPDs showed acceptable fit in the patient's mouth.[15,27–30] They also pointed out the scarcity of published clinical studies on this topic and had therefore pooled data from in vitro studies, yielding weak evidence to support clinical decisions.[15,27–29] More clinical studies have been published since then,[25,31,32] which could answer pending questions on the effectiveness of these new technologies with higher levels of evidence. Additionally, none of these reviews summarized the evidence of the clinical performance of these dentures in terms of patient-reported outcomes, which is paramount to evaluating the effectiveness of any restorative treatment.[33,34] Patient satisfaction is the ultimate objective of therapeutic interventions for chronic conditions like partial edentulism, and therefore this and other patient-reported outcomes are used to assess treatment effectiveness.[33,34]

The aim of this systematic review and meta-analysis was to summarize the evidence on the patient-reported outcomes and framework fit accuracy of digitally fabricated RPDs in comparison to traditionally fabricated dentures. The primary outcomes were patient-reported outcomes including patient satisfaction and oral-health-related quality of life (OHRQoL). A secondary outcome was framework fit accuracy.

METHODS

This systematic review was conducted to answer the following clinical question, highlighting the four essential elements (P: Population, I: intervention, C: comparison, O: outcome): in partially edentulous patients (population) is there a difference in patient-reported outcomes and framework fit accuracy (outcome) between digitally (intervention) and traditionally (comparison) fabricated removable partial dentures?

The intervention considered in this review was RPDs fabricated by digital manufacturing methods, regardless of data acquisition methods (digital or conventional). Further sub-analysis was done to assess the effect of different data acquisition methods of digitally fabricated RPDs on the targeted outcomes.

The systematic review was conducted following Cochrane guidelines for conducting systematic reviews of interventions,[35] and was reported following the updated Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA 2020) guidelines.[36] A protocol for this review was written and followed during the review. This review protocol was not registered or published.

Systematic search

Three databases were searched for relevant studies: PubMed, Cochrane Library, and Cochrane Central Register of Controlled Trials (CENTRAL), and Wiley Online Library. A systematic search strategy was developed for the PubMed database using a combination of Medical subject headings and keywords for the terms of the population and the intervention combined with Boolean operator "AND". The strategy was further modified and used for the other two databases Wiley Online Library and CENTRAL databases (Table 1). A search was run in the three databases on December 21, 2022, with limits set on publication dates from 1980 to date. No language restrictions were set. Additionally, the references of the relevant reviews retrieved, and included primary studies were manually searched for eligible studies. For Grey literature, the first 100 hits on Google Scholar search were screened for eligibility. All resulting publications were saved in one Endnote library, and duplicates were removed.

Eligibility criteria

Clinical studies including randomized clinical trials, prospective, retrospective, and cross-sectional studies were included. Case reports, case series, in vitro studies, reviews, editorials, and conference abstracts were excluded.

Only studies directly comparing between an intervention (digitally fabricated RPD) and a comparison (conventionally fabricated RPD) within the same study, and reporting results for each group separately were included. Only studies on conventional clasp-retained RPDs (both metal and nonmetal) were included, while studies on implant-supported, telescopic crown-retained, double crown-retained, attachment-retained RPD or removable partial overdentures were excluded. Only English studies were included. Studies that assessed or reported results for one type of fabrication technique only and studies with inadequate information on the fabrication process were excluded.

TABLE 1 Systematic review search strategy in all databases.

Database	Search strategy
PubMed accessed December 21, 2022	#1: (Jaw, Edentulous, Partially [MeSH]) OR (partial* adj5 (dentition* or dentate* or edentul*)) OR (Dental Clasps [MeSH]) OR (Denture, Partial, Removable [MeSH]) OR (removabl* adj3 partial* adj5 (denture* or dent* or prosth*)) OR (RPD) OR ((Kennedy or aramany) adj1 class*) OR (Denture Bases [MeSH]) OR (Denture Design [MeSH])
	#2: (Computer-Aided Design [MeSH]) OR (printing, three-Dimensional [MeSH]) OR (stereolithography [MeSH]) OR (CAD CAM) OR (Computer Aided Design denture) OR (Computer Aided Manufacturing denture) OR (digital denture*) OR (digital* fabricat* partial* denture*) OR (Milling CAD CAM) OR (3D print*) OR (Milled denture) OR (subtractive fabrication) OR (three dimensional print*) OR (Stereolithography) OR (SLA denture) OR (additive fabrication) OR (rapid prototyping) OR (DMLS) OR (Direct metal laser sintering) OR (SLS) OR (selective laser sintering) OR (resin printing) OR (selective laser melting)
	#3: #1 AND #2
Wiley Online Library accessed December 21, 2022	("removable partial denture" OR "partial edentulous" OR "partial removable dental prosthesis" OR "RPD") AND ("CAD CAM" OR "digital" OR " milled" OR "printed" OR "computer aided design" OR "computer aided manufacture" OR "laser sintered")
CENTRAL accessed December 21, 2022	((mh (denture partial removable)) OR (mh (jaw edentulous partially)) OR (RPD) OR (removable partial denture) OR (removable partial prosthesis)) in All Text AND ((CAD CAM) OR (milled) OR (printed) OR (digital) OR (computer aided) OR (rapid prototyping) OR (additive technology) OR (laser sintered))

For this review, patient-reported outcomes including patient satisfaction, and oral health-related quality of life assessed using validated surveys, were considered for primary outcome. Framework fit accuracy was considered for the secondary outcome.

Screening

Initial screening of studies was made by two authors independently by title and abstract. Potentially eligible articles were then screened for full text to determine eligibility. Any conflict between the two reviewers was resolved by agreement.

Data collection, risk of bias assessment, and level of evidence

Data collection, risk of bias assessment, and level of evidence were assessed by two reviewers independently. Any conflict was resolved by agreement. The following data were collected from each included study: author names, year of publication, study design, study setting, number of recruited participants, female percentage, mean age or age range, follow-up time, number of drop outs, outcomes assessed, and measurement methods. Also, the following framework fabrication details: data acquisition technique, RPD design software, fabrication technique, and framework material with brand names, were recorded. Results data of framework fit accuracy presented in mean gaps and standard deviation was collected and used in the analysis.

The Cochrane Collaboration risk of bias assessment tool RoB 2 (version August 22, 2019) was used for parallel-groups randomized controlled trials.[37] Domains of this tool were adapted and used to assess risk of bias in randomized controlled trials with within-person study design. RoB 2 tool for crossover studies (version March 18, 2021) was used for crossover randomized clinical trials. Level of evidence was assessed using the Oxford center for evidence-based medicine level of evidence tool.[38]

Data synthesis

Standardized mean difference (SMD) was used to compare digitally and conventionally fabricated RPDs on framework fit accuracy. Inverse-variance statistical method in a random effects model was used to account for interstudy variations.[35] Heterogeneity among the pooled studies was tested using Cochran Q test and $I2$ statistic. $I2$ statistic of more than 50% was considered an indicator of heterogeneity of outcomes. A $p < 0.05$ was considered significant. A forest plot was used to present the results of the meta-analysis.

Funnel plots of studies included in the meta-analysis were used to assess potential publication bias. Tests of funnel plot asymmetry were not performed as less than ten studies were included in the meta-analysis. All analyses were conducted by a specific software program (Review Manager 5.3 software: Cochrane Collaboration, Copenhagen, Denmark).

Descriptive narrative analysis was used to summarize data on patient satisfaction, and OHRQoL as there were inadequate studies to pool data in a meta-analysis. A narrative sub-analysis of data was used to assess the effectiveness of intraoral digital scans compared to extraoral scans and traditional impressions on framework fit accuracy in the included studies.

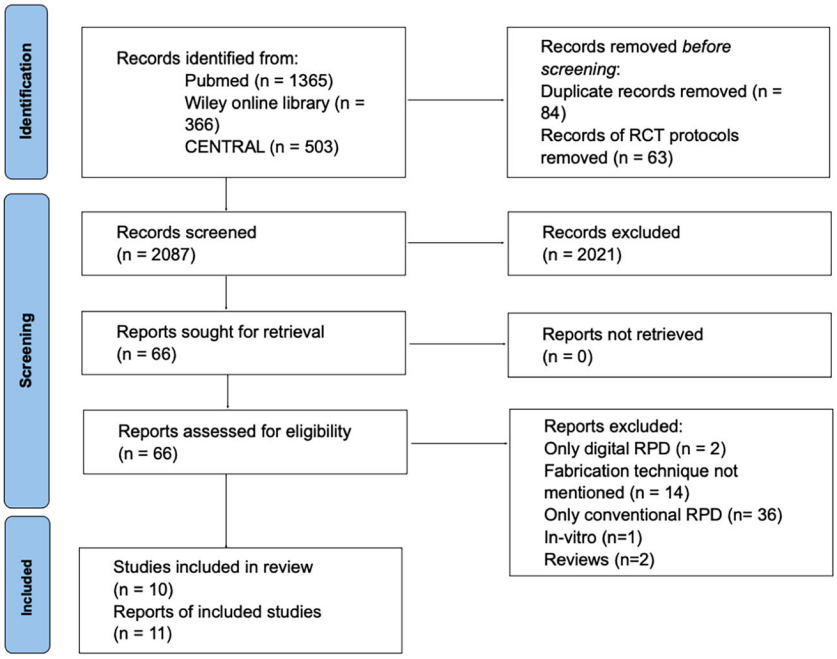

FIGURE 1 Search results illustrated in PRISMA flowchart.

RESULTS

Out of the 2234 studies retrieved from the combined databases, 2087 were screened for title and abstract. A total of 2021 reports were excluded, and 66 reports were screened for full text. Out of these, 10 studies were included in this review. Search results are illustrated in the PRISMA flowchart (Figure 1).

All of the included studies were clinical randomized studies; four were crossover studies,[39–42] one was a randomized parallel groups clinical trial,[31] and five studies used within subject study design.[25,32,43–45] The earliest study was published in 2017,[45] and the latest in 2022.[25,31] Populations of all studies were patients attending prosthodontic clinics of dental schools. Half of the studies used a single time measurement, with no follow-up,[25,32,43–45] and the other half followed up the patients for 4 weeks,[42] 3 months,[39,40] and 1 year.[31,41] Sample size ranged from 7,[43] to 32 patients.[25] Studies were conducted in different geographic locations; three in Egypt,[39,40,43] two in Canada,[31,42] one in China,[45] one in Singapore,[25] one in the USA,[44] one in Portugal,[32] and one in the UK[41] (Table 2).

Six studies assessed the accuracy of framework fit before tooth set-up and denture processing,[25,31,32,43–45] one study assessed processed denture retention,[39] two studies assessed patient satisfaction,[40,42] and 1 study evaluated oral health-related quality of life (OHRQoL)[41] (Table 2).

Risk of bias assessment

Risk of bias assessment showed that half of these studies have a high overall risk of bias.[32,39–41,43] Poor reporting and execution of randomization and blinding, and inadequate standardization of outcome assessment (training and calibration of assessors were not reported, also reliability of assessors data was not calculated) accounted for the high risk of bias in 3 studies.[39,40,43] The other two studies lacked sufficient statistical power to test the difference between digitally and conventionally fabricated RPD as it was a secondary outcome in one of them,[41] while the other did not report a priori sample size calculation, which raised doubts about the power of the study especially given that the results turned out negative[32] (Figure 2, Figure S1).[46]

Other issues noticed in general in these studies were related to the lack of standardization of framework fabrication in the different workflows (conventional and digital). Most of the studies used two different impressions and casts for each workflow.[25,31,41,44,45] Among the 10 included studies, only three studies used the same impression and cast for both workflows,[32,42,43] and only three studies reported that one technician fabricated both frameworks which standardized the lab procedures too.[32,42,44] Only two studies[41,42] reported a registered protocol for the clinical trial, which led to some concerns regarding selective reporting risk of bias assessment. Also, most of the studies used within subject comparisons, but statistical tests selected in some studies ignored the correlated nature of data[39,40,43,44] (Figure 2, Figure S1).[46]

A major issue was identified in the studies of framework accuracy which is related to the lack of standardization of finishing and polishing procedures performed on frameworks of both workflows,[25,31,43,45] which can affect the framework fit accuracy, especially for the studies that assessed fit accuracy before any clinical adjustments.[31,43,44] Only one study reported finishing and polishing procedures in detail,[32] and two studies reported that these procedures were performed by one technician for both workflows.[32,44]

TABLE 2 Characteristics of included studies in the systematic review.

First author, location, date of study	Study design	Sample size** Pt/dentures	Age Mean±SD (range) years	Female %	Outcome measured	Follow-up time	Drop-out (n)
Tregerman, USA, 2019	Within subject RCT	9/27 (3 dentures/Pt)	NR	NR	Framework fit accuracy	No follow-up	-
Ye, China, 2017	''	15/30 (2 dentures/Pt)	(41-79)	60	"	"	-
Conceição, Portugal, 2021	"	15/40 (2 dentures/Pt)	NR	NR	'	"	-
Chia, Singapore, 2022	"	29/58 (2 dentures/Pt)	NR	NR	"	"	-
Saad, Egypt, 2019	"	7/14 (2 dentures/Pt)	NR	NR	"	"	-
Pelletier, Canada, 2022	Parallel-group RCT	18/24 (C* = 9/13; D* = 9/11)	NR	50%	"	1 year	11
Maryood, Egypt, 2019	Crossover RCT	20/40 (2 dentures/Pt)	58.4 ± 8.3	55	Denture retention	3 months each denture	0
Almufleh, Canada, 2018	"	12/24 (2 dentures/Pt)	65.6 ±11.3	33.3	Pt satisfaction	4 weeks each denture	3
Mohamed, Egypt, 2019	"	10/20 (2 dentures/Pt)	(30-50)		"	3 months each denture	NR
Ali, UK, 2020	"	25/50 (2 dentures/Pt)	(39- 85)64.8 ± 12.4	42.3	OHRQoL, Pt satisfaction, denture preference, periodontal indices	1 year	6

NR: Not reported, C: Conventional RPD, D: Digital RPD, Pt: Patients, RCT: randomized controlled trials.

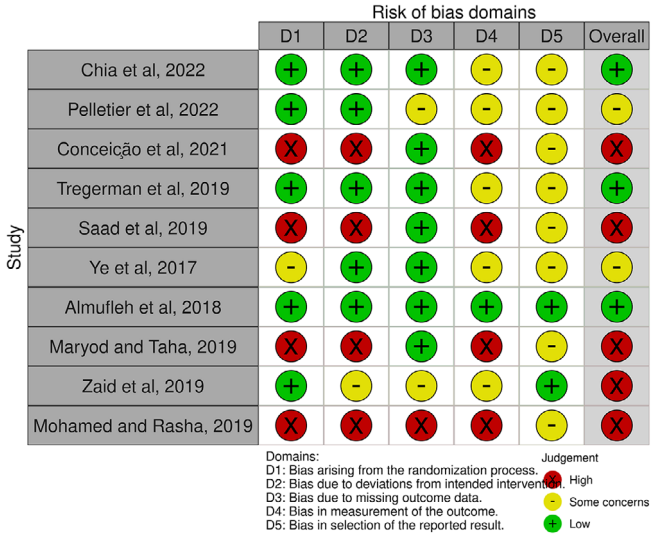

FIGURE 2 Risk of bias assessment of individual included studies.

Level of evidence

Using the Oxford Center for Evidence-based Medicine level of evidence tool, half of the studies were considered level 2,[25,31,42,44,45] and the other half level 3.[32,39–41,43]

Patient-reported outcomes

Two studies assessed patient satisfaction as the primary outcome,[40,42] and one assessed it as a secondary outcome.[41] One compared digitally fabricated metal RPD against conventionally cast metal,[42] and the other two compared digitally fabricated PEEK RPD versus conventionally cast metal.[40,41] Two studies used the McGill denture satisfaction questionnaire,[41,42] and one used the Arabic version of the OHIP-EDENT instrument.[40] Two studies found that patients were more satisfied with digitally fabricated RPDs compared with conventionally fabricated ($p<0.05$),[40,42] and the third study found no difference between both treatments ($p>0.05$).[41] Meta-analysis of the results of these studies was not possible as the material used for digital fabrication of RPDs and the instrument used for outcome measurement were different across studies (Table S1).

Only one study assessed OHRQoL and denture preference, which was a crossover study. It compared PEEK RPD with conventionally fabricated metal RPD at several follow-up points after 4 weeks, 6 months, and 1 year.[41] It showed that patients had significant improvement in OHRQoL after using both frameworks, however, there was no significant difference between both frameworks in OHRQoL. There was also no difference in denture preference between PEEK and conventionally fabricated RPD[41] (Table S1).

Framework fit accuracy

Seven studies assessed framework fit. Six assessed framework fit accuracy at the framework try-in session only,[25,31,32,43–45] and one study assessed the final processed

denture.[39] Digitally fabricated RPD frameworks in the seven studies were produced using additive prototyping techniques. In five studies direct additive techniques were used, which were selective laser melting,[25,44,45] and selective laser sintering.[31,32] In the last two studies, an indirect additive technique was used, where the framework resin pattern was 3D printed followed by conventional casting[39,43] (Table 3).

Three studies assessed initial framework fit accuracy before any clinical adjustment,[31,43,44] and the other three assessed final framework fit after clinical adjustments.[25,32,45] All studies assessed framework fit under occlusal rests, but three also assessed framework fit under the major connectors and proximal plates.[25,43,44]

Methods of measurement of framework fit varied across studies; one used a clinical evaluation to fill a yes/no survey of seven framework-related parameters,[44] another study used visual examination of the framework sprayed with disclosing agent to identify the points of interference,[43] and four studies used a silicone replica technique of the gap between occlusal rests and rest seats, which were assessed by different microscopies.[25,31,32,45]

Results of the four studies that used silicone replica measurement technique found numerically smaller gaps for the conventionally fabricated framework which means better fit accuracy compared with digitally fabricated RPD, and that difference was statistically significant in two studies,[31,45] but not statistically significant in the other two studies.[25,32] The pooled SMD was 0.49 (z = 2.35, 95% CI: 0.08, 0.91, p = 0.02) in favor of conventionally fabricated RPD, which showed that conventionally fabricated RPDs have significantly smaller gaps, and hence better fit compared to digitally fabricated RPDs. No statistical heterogeneity was found ($I2$ = 34%, x2 = 4.55, df = 3, p = 0.210) (Figure 3). It should be noted that 3 of the included studies in this meta-analysis used within subject analysis,[25,32,45] while 1 used between subject analysis,[31] and upon pooling, all data were treated as between subject analysis, which usually provides a more conservative result.

The other two studies which used clinical evaluation and visual examination found that a digitally fabricated RPD framework has significantly better fit accuracy.[43,44] However, all six studies found that framework accuracy of both digitally and conventionally fabricated frameworks at the framework try-in stage was within clinically acceptable values (Table S1).[25,31,32,43–45]

One crossover study on 20 patients, with a 3-month follow-up, assessed the final processed denture fit and retention intraorally using a digital force gauge device.[39] It compared conventionally cast RPDs with digitally fabricated RPDs fabricated using 3D-printed resin patterns that were then cast conventionally.[39] Results showed that digitally fabricated RPDs had significantly higher retention at insertion, 1 month, and 3 months follow-up compared to conventionally cast RPD.[39] However, this study had a very high risk of bias.

Digital scanning intraoral or lab scanning

For data acquisition to fabricate digitally fabricated RPDs, seven studies used lab scanning of the master cast poured from conventional final impressions,[25,31,32,40,42,43,45] one used intraoral scanners with no physical impression,[39] 1 did not report the mechanism of data acquisition[41] and one compared lab scanners and intraoral scanners for data acquisition.[44] This last study assessed nine participants, four were Kennedy class I, three were Kennedy class II, and two were Kennedy class III. Framework fit accuracy was assessed through a clinical evaluation to fill a yes/no survey of seven framework-related parameters.[44] It found that fully digital workflow using intraoral scanners resulted in the best framework fit accuracy, and digital fabrication using the lab scanner of the stone master model resulted in the worst fit accuracy, even significantly worse than the conventional cast group [44] (Table 3).

Publication bias

To assess publication bias in framework fit accuracy outcomes, a funnel plot was constructed. The funnel plot was visually asymmetrical, indicating the possibility of publication bias or a systematic difference between smaller and larger studies "small study effect" (Figure 4).

DISCUSSION

The results of this review showed that digital fabrication has heterogeneous effects on patient-reported outcomes. It was associated with higher patient satisfaction in two studies, no difference in OHRQoL, and no difference in denture preference. While conflicting results were observed regarding framework fit accuracy, with some studies favoring conventionally fabricated and others favoring digitally fabricated RPDs, all reported results were within the clinically acceptable range. However, the included studies varied in risk of bias and evidence quality level, and this should be taken into consideration when considering their conclusions.

Nowadays, the importance of considering patient-reported outcomes to assess treatment effectiveness of therapeutic interventions has been understood in the research community.[33,47] However, in this review only 3 out of the 10 included studies assessed patient-reported outcomes for digitally fabricated RPDs,[40–42] and two of them were pilot studies and not full-scale clinical trials.[41,42] These studies showed that patients had significantly higher satisfaction wearing digitally fabricated metal RPDs and more patients preferred the digitally fabricated RPDs over the conventionally fabricated metal RPDs at the end of the 4-week cross over study.[42] Their reasons for preference related to better fit and retention, and that the framework feels lighter than the conventionally fabricated RPD.[42] These observations could be related to the

TABLE 3 Framework fabrication techniques in the included studies.

	Intervention group (digital)				Control group (conventional)		
Author, date	**Data acquisition**	**Designing software**	**Framework Fabrication technique**	**Framework material**	**Data acquisition**	**Fabrication method**	**Framework material**
Tregerman et al., 2019	PVS, stone cast. EOS (D800; 3Shape)	(Dental System 2016 Premium; 3Shape)	Selective laser melting	Co-Cr (EOS Cobalt Chrome SP2; EOS GmbH)	PVS impression	Casting	Co-Cr (Vitallium 2000; Dentsply Sirona)
	IOS (3Shape TRIOS III; 3Shape)	(Dental System 2016 Premium; 3Shape)	Selective laser melting	"			
Ye et al, 2017	PVS, stone cast. EOS (D800, 3Shape)	(Dental System, 3Shape)	Selective laser melting (M270, EOS)	Co-Cr (Wirebond C+, Bego)	PVS impression	Casting	Co-Cr
Conceição et al, 2021	Alginate, stone cast, EOS (S600 Arti, Zirkonzahn GmbH)	(Partial Planner, Zirkonzahn GmbH)	Direct metal laser sintering (EOSINT M270)	Co-Cr (SP2 alloy, EOS GmbH)	Same impression and cast used here	Casting (Ducatron Quattro, Ugin Dentaire)	Co-Cr (Remanium G 380+, Dentaurum GmbH & Co)
Chia et al, 2022	Alginate, stone cast, EOS (D800; 3Shape A/S)	(Dental system 2018; 3Shape)	Selective laser melting (M270;EOS)	Co-Cr (Cobalt Chrome SP2; EOS GmbH)	Alginate, and stone cast.	Casting	Co-Cr (Remanium G800+; Dentaurum)
Pelletier et al, 2022	PVS, EOS (NR)	NR	Selective laser sintering	Co-Cr (NR)	PVS, and stone cast.	Casting	Co-Cr (NR)
Maryood, Taha, 2019	IOS (Trios 3rd edition, 3 Shape)	(3Shape Dental System)	Digital light processing (Rapid shape D30), casting	Co-Cr (NR)	Conventionally	Casting	Co-Cr (NR)
Saad et al, 2019	PVS, stone cast, EOS (D900 digital scanner, 3shape)	(3Shape)	3D printing of wax pattern, casting	Co-Cr (NR)	Same cast used	Casting	Co-Cr (NR)
Mohamed, 2019	Duplicate of stone cast, EOS (Zirkonzahn S600 ARTI Scanner)	(3Shape Dental System)	Milling (Roland DWX-50, 5-Axis milling)	PEEK (Juvora Ltd.)	Conventionally	Casting	Co-Cr (NR)
Zaid et al, 2020	NR	NR	Milling	PEEK (Juvora Dental Discs)	NR	Conventional	Co-Cr (NR)
Almufleh et al, 2018	PVS, stone cast. EOS (3Series; Dental Wings)	(3Shape CAD Points; 3Shape)	Selective laser sintering (PM100 Dental; Phenix Systems)	Co-Cr (Sintech Metal)	Same cast	Casting	Co-Cr (NR)

Abbreviations: NR, not reported; PVS, polyvinyl siloxane impressions; Co-Cr, cobalt chromium alloys; IOS, intraoral scanners; EOS, extraoral scanners.

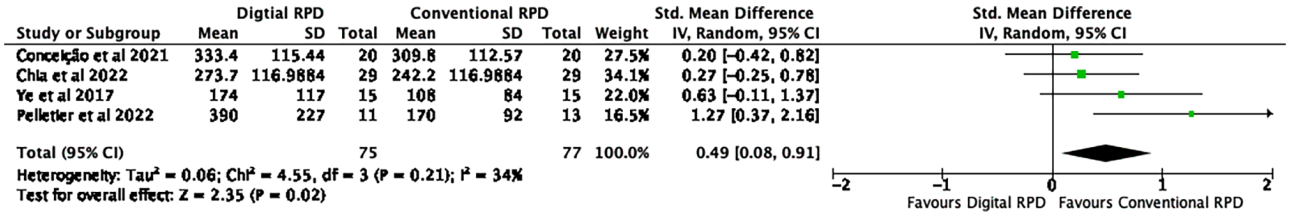

FIGURE 3 Forest plot results of framework fit accuracy.

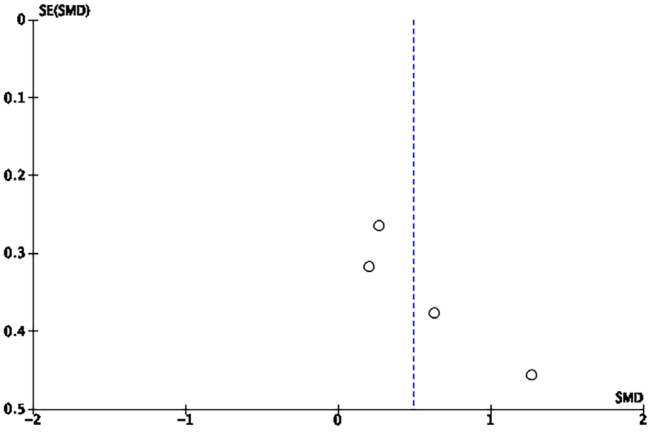

FIGURE 4 Publication funnel plot of included studies in the meta-analysis.

improved mechanical properties of digitally fabricated alloys compared to conventional alloys.[12,30,48,49]

Regarding PEEK RPDs, patients were significantly more satisfied with PEEK RPDs compared to conventionally fabricated metal RPDs, and this was related to esthetics, retention, and stability as reported in one study.[40] In the other study, there was no significant difference in patient satisfaction, oral health-related quality of life, and denture preference between PEEK and conventional metal RPD.[41] However, this study showed that both RPDs resulted in positive improvement in OHRQoL over the follow-up period, which came in agreement with previous systematic reviews.[6,50]

There are several methods available to evaluate framework fit accuracy in a research setting, one of them is clinical physical examination in the patient's mouth which is the standard clinical procedure to evaluate framework fit in everyday clinical practice. This could be considered a subjective qualitative method of outcome assessment and could be less accurate in identifying small misfits.[29] However, the results of this method, if performed by calibrated experienced blinded operators with a high level of inter and intra-examiner reliability, can be easily translated to clinical practice as it shows whether a framework is clinically acceptable or not, and it represents the overall framework fit. Four of the included studies used this method for assessment,[25,43–45] examination was performed by blinded assessors in three studies,[25,44,45] with high inter-examiner reliability reported in two studies.[25,44]

Other more objective and quantitative methods of measurement are assessment of gaps between the framework and corresponding tooth surfaces using silicone replica registration of the gap, and measuring the thickness of this replica under different microscopes with the aid of special measuring software.[25] This method has several drawbacks, as it is technique sensitive to handle the thin silicone material, which can be easily torn or distorted upon removal from the tooth surface or upon fixation for assessment under the microscope.[25] Additionally, thickness measurements are made on different spots but none of these spots represent the overall framework fit. This technique was used in four of the included studies in this review, and the gap assessed was the gap between occlusal rest and rest seats.[25,31,32,45]

All included studies in this review compared framework fit accuracy between digitally and conventionally fabricated cobalt chromium frameworks. Results of the two studies that used clinical evaluation and visual inspection of the framework as the assessment method, found that digitally fabricated RPD frameworks had significantly better fit accuracy compared to conventional frameworks.[41,42] It should be noted that these two studies assessed framework fit accuracy before any clinical adjustments, which might not be critical for clinical success as most frameworks need clinical adjustment to exhibit acceptable fit.[26]

The other four studies that assessed framework fit accuracy using the silicone replica technique showed that digitally fabricated RPDs present larger gaps than conventionally fabricated RPDs, and the pooled standardized mean difference showed that conventionally fabricated RPDs had significantly smaller gaps and hence fewer misfits compared to digitally fabricated RPDs.[25,31,32,45] It should be noted that these studies were limited to the assessment of gaps between rests and rest seats. These findings cannot be extrapolated into the overall framework fit accuracy without considering other areas of the framework, framework stability, and rotation.

The results of this review are in agreement with previous systematic reviews.[27–30] However, these reviews included only one or two clinical comparative studies, most of the included studies were in vitro studies and case reports.[27–29] The results of this review confirmed previous results with six included comparative clinical studies of a higher level of evidence.

While Saad et al, and Tregerman et al concluded that digitally fabricated RPD frameworks showed significantly better fit accuracy than conventionally fabricated using visual examination assessment methods,[43,44] these results are in

contradiction to the quantitative results of silicone replica gap measurements studies. A possible explanation could be related to the differences in the measurement methods, or to the lack of standardization of finishing and polishing procedures which could bias the results. Different finishing and polishing procedures of frameworks could result in different amounts of metal material loss, which could affect framework fit accuracy differently.[25] More standardized procedures are recommended in upcoming clinical trials to provide clearer evidence in this regard.

However, regardless of whichever assessment method was used, results of all included studies showed that both digitally and conventionally fabricated RPD frameworks were considered acceptable on clinical examination, and the small recorded misfits remained within the clinically acceptable limits reported in the literature.[28,29,51,52] The average gap thickness reported in these studies varied greatly. After clinical adjustments of RPD frameworks, the gaps for digitally fabricated RPDs ranged from 174 ± 117 μm,[45] to 333.4 ± 115.44 μm,[32] while for conventionally fabricated frameworks ranged from 108 ± 84 μm,[45] to 309.8 ± 112.57 μm[32] (Figure 3). Previous clinical studies identified frameworks with misfits ranging from 69 to 828 μm, that were in service, without any patient complaints or clinical complications, which could be referred to as a clinically acceptable range of misfits.[51,52]

For digital fabrication of the RPD framework, two data acquisition techniques are possible; intraoral scanning and extraoral scanning. Intraoral scanning is associated with higher patient comfort, and satisfaction, less material waste, and elimination of possible errors introduced during the traditional pouring of conventional impressions.[53–55] Intraoral scanning is especially beneficial in difficult clinical cases of severe gag reflex, or limited mouth opening.[53] Currently, there is promising evidence supporting the use of intraoral scanners to produce various removable prostheses with good clinical outcomes.[53–55] Among all included studies, only two studies used intraoral scanners for data acquisition, one tested the retention of RPD frameworks, and the other tested framework fit accuracy.[39,44] Both studies showed that digitally fabricated RPDs, that were fabricated using IOS data, were significantly better than conventionally fabricated RPDs produced by conventional impressions.[39,44]

One of these studies compared the accuracy of frameworks produced using different data acquisition methods for digital workflows including conventional impressions and lab scanners, and intraoral scanners, with conventionally fabricated frameworks.[44] This study found that complete digital fabrication using an intraoral scanner resulted in the best framework fit accuracy, and digital fabrication using a lab scanner of the stone master model resulted in the worst fit accuracy, even worse than the conventional cast group.[44] This was explained by the additional step of physical impression and casting that may have introduced some errors. Data from case reports showed that IOS can result in prostheses with acceptable fitting and retention.[53–55] In vitro studies showed that trueness was better than conventional impressions and lab scanners, but precision was less.[56] Studies showed that scanning procedures, head size, and distance between arch and camera could play a role in the scanning accuracy.[56] More efforts to develop evidence-based standardized scanning protocols could help. Further clinical studies are needed to evaluate the effectiveness of intraoral scanning on patient satisfaction with prostheses, and other clinical outcomes.

One of the strengths of this review is the high quality of evidence in the included studies. All included studies were clinical randomized trials; four of them had a crossover study design, and the other five utilized a within-subject design in which treatment effect was estimated as the average of within-subject differences.[57] These designs have many advantages including that they require a smaller sample size due to the smaller variance in within-subject readings. On the other hand, several considerations should be accounted for when planning these studies, like the period, the sequence, and carryover effects, which require more complex statistics.[57] Additionally, this review, unlike previous reviews, summarized the evidence on patient-reported outcomes of digitally fabricated RPDs, and evaluated the risk of bias in detail using the updated Cochrane risk of bias tools, pointing out major issues in the studies which could help researchers conduct future studies of higher quality.

This review has a few limitations; it included English-only studies and could not reach conclusions in all outcomes assessed due to the scarcity of published literature so far. Although assessment of framework fit accuracy yielded mixed results between studies using different measurement methods, all the reported results were considered within the clinically acceptable range. Also, the risk of publication bias is a limitation that is known for any well-conducted systematic review.

CONCLUSIONS

Based on the findings of this systematic review, current evidence showed that digitally fabricated RPDs are associated with higher patient satisfaction compared to conventionally fabricated RPDs, but there was no difference in OHRQoL. However, the scarcity of literature on this topic warrants the generalization of this conclusion. Although conventionally fabricated RPD frameworks showed significantly smaller misfits compared to digitally fabricated RPDs, both metal frameworks showed clinically acceptable fit. Evidence of these conclusions was taken from randomized controlled trials with high level of evidence; however, half of these studies have a high risk of bias and therefore, these conclusions should be taken with care.

Insufficient evidence exists regarding the superiority of IOS, however available evidence shows that the use of IOS is associated with better framework accuracy and better denture retention compared to conventional workflows, and digital workflows with conventional impressions.

CONFLICT OF INTEREST STATEMENT

None of the authors have a conflict of interest.

ORCID

Balqees Almufleh BDS, PhD https://orcid.org/0000-0002-9083-5671
Alexia Arellanob DDS https://orcid.org/0000-0002-2208-5039
Faleh Tamimi BDS PhD https://orcid.org/0000-0002-4618-8374

REFERENCES

1. Müller F, Naharro M, Carlsson GE. What are the prevalence and incidence of tooth loss in the adult and elderly population in Europe? Clin Oral Implants Res. 2007;18:2–14.
2. Carlsson GE, Omar R. Trends in prosthodontics. Med Princ Pract. 2006;15:167–79.
3. Kim JJ. Revisiting the Removable Partial Denture. Dent Clin North Am. 2019;63:263–78.
4. Zarb GA, Mackay HF. The partially edentulous patient. II. A rationale for treatment. Aust Dent J. 1980;25:152–62.
5. Gerritsen AE, Allen PF, Witter DJ, Bronkhorst EM, Creugers NH. Tooth loss and oral health-related quality of life: a systematic review and meta-analysis. Health Qual Life Outcomes. 2010;8:126.
6. Ali Z, Baker SR, Shahrbaf S, Martin N, Vettore MV. Oral health-related quality of life after prosthodontic treatment for patients with partial edentulism: a systematic review and meta-analysis. J Prosthet Dent. 2019;121:59–68.
7. Ikebe K, Hazeyama T, Ogawa T, Kagawa R, Matsuda K, Wada M, et al. Subjective values of different age groups in Japan regarding treatment for missing molars. Gerodontology. 2011;28:192–96.
8. Donovan TE, Derbabian K, Kaneko L, Wright R. Esthetic considerations in removable prosthodontics. J Esthet Restor Dent. 2001;13:241–53.
9. Zitzmann NU, Hagmann E, Weiger R. What is the prevalence of various types of prosthetic dental restorations in Europe? Clin Oral Implants Res. 2007;18:20–33.
10. Barraclough O, Gray D, Ali Z, Nattress B. Modern partial dentures—part 1: novel manufacturing techniques. Br Dent J. 2021;230:651–57.
11. Campbell SD, Cooper L, Craddock H, Hyde TP, Nattress B, Pavitt SH, et al. Removable partial dentures: the clinical need for innovation. J Prosthet Dent. 2017;118:273–80.
12. Alifui-Segbaya F, Williams RJ, George R. Additive manufacturing: a novel method for fabricating cobalt-chromium removable partial denture frameworks. Eur J Prosthodont Restor Dent. 2017;25:73–78.
13. Lang LA, Tulunoglu I. A critically appraised topic review of computer-aided design/computer-aided machining of removable partial denture frameworks. Dent Clin North Am. 2014;58:247–55.
14. Almufleh B, Tamimi F, Caron E, Alageel O. 3D-printed removable partial dentures. In: Tamimi F, Hirayama H, editors. Digital restorative dentistry: a guide to materials, equipment, and clinical procedures. Switzerland: Springer International Publishing; 2019. p. 95–113.
15. Takaichi A, Fueki K, Murakami N, Ueno T, Inamochi Y, Wada J, et al. A systematic review of digital removable partial dentures. Part II: CAD/CAM framework, artificial teeth, and denture base. J Prosthodont Res. 2022;66:53–67.
16. Harb IE, Abdel-Khalek EA, Hegazy SA. CAD/CAM Constructed Poly(etheretherketone) (PEEK) framework of Kennedy Class I removable partial denture: a clinical report. J Prosthodont. 2019;28:e595–98.
17. Ichikawa T, Kurahashi K, Liu L, Matsuda T, Ishida Y. Use of a polyetheretherketone clasp retainer for removable partial denture: a case report. Dent J (Basel). 2019;7:4.
18. Arnold C, Hey J, Schweyen R, Setz JM. Accuracy of CAD-CAM-fabricated removable partial dentures. J Prosthet Dent. 2018;119:586–92.
19. Lee JW, Park JM, Park EJ, Heo SJ, Koak JY, Kim SK. Accuracy of a digital removable partial denture fabricated by casting a rapid prototyped pattern: a clinical study. J Prosthet Dent. 2017;118:468–74.
20. Oh KC, Jeon J, Kim JH. Fabrication of a removable partial denture combining conventional and digital techniques. J Prosthet Dent. 2021;125:588–91.
21. Piao XY, Jeon J, Shim JS, Park JM. A digital workflow for the fabrication of a milled removable partial denture. Int J Environ Res Public Health. 2022;19:8540.
22. Seitz S, Cox N, Jones JD, Zimmermann R. A combination of various technologies in the fabrication of a removable partial denture: a case study. Tex Dent J. 2016;133:24–27.
23. Soltanzadeh P, Suprono MS, Kattadiyil MT, Goodacre C, Gregorius W. An in vitro investigation of accuracy and fit of conventional and CAD/CAM removable partial denture frameworks. J Prosthodont. 2019;28:547–55.
24. Rokhshad R, Tehrani AM, Nahidi R, Zarbakhsh A. Fit of removable partial denture frameworks fabricated from 3D-printed patterns versus the conventional method: an in vitro comparison. J Prosthet Dent. 2022;S0022-3913:00210-4.
25. Chia VAP, See Toh YL, Quek HC, Pokharkar Y, Yap AU, Yu N. Comparative clinical evaluation of removable partial denture frameworks fabricated traditionally or with selective laser melting: a randomized controlled trial. J Prosthet Dent. 2022;S0022-3913:00011-7
26. Phoenix RD, Cagna DR, DeFreest CF. Stewart's clinical removable partial prosthodontics. 3rd ed. Chicago: Quintessence Publishing; 2003.
27. Mai HY, Mai HN, Kim HJ, Lee J, Lee DH. Accuracy of removable partial denture metal frameworks fabricated by computer-aided design/computer-aided manufacturing method: a systematic review and meta-analysis. J Evid Based Dent Pract. 2022;22:101681.
28. Pordeus MD, Santiago Junior JF, Venante HS, Bringel da Costa RM, Chappuis Chocano AP, Porto VC. Computer-aided technology for fabricating removable partial denture frameworks: a systematic review and meta-analysis. J Prosthet Dent. 2022;128:331–40.
29. Carneiro Pereira AL, Bezerra de Medeiros AK, de Sousa Santos K, Oliveira de Almeida É, Seabra Barbosa GA, da Fonte Porto Carreiro A. Accuracy of CAD-CAM systems for removable partial denture framework fabrication: a systematic review. J Prosthet Dent. 2021;125:241–48.
30. Souza Curinga MR, Claudino Ribeiro AK, de Moraes SLD, do Egito Vasconcelos BC, da Fonte Porto Carreiro A, Pellizzer EP. Mechanical properties and accuracy of removable partial denture frameworks fabricated by digital and conventional techniques: a systematic review. J Prosthet Dent. 2023. doi:10.1016/j.prosdent.2023.01.032
31. Pelletier S, Pelletier A, Al Dika G. Adaptation of removable partial denture rest seats in prostheses made with selective laser sintering or casting techniques: a randomized clinical trial. J Prosthet Dent. 2022;S0022-3913:00327-4.
32. Conceição P, Franco M, Alves N, Portugal J, Neves CB. Fit accuracy of removable partial denture metal frameworks produced by CAD-CAM–a clinical study. Rev Port Estomatol Med Dent Cir Maxilofac. 2021;62:194–200.
33. de Souza RF, Ahmadi M, Ribeiro AB, Emami E. Focusing on outcomes and methods in removable prosthodontics trials: a systematic review. Clin Oral Implants Res. 2014;25:1137–41.
34. Awad MA, Feine JS. Measuring patient satisfaction with mandibular prostheses. Community Dent Oral Epidemiol. 1998;26:400–405.
35. Higgins JP, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, et al. Cochrane handbook for systematic reviews of interventions. New Jersey, UK: John Wiley & Sons; 2019.
36. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:1–9.
37. Sterne JA, Savović J, Page MJ, Elbers RG, Blencowe NS, Boutron I, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. BMJ. 2019;366:4898.

38. Howick J, Chalmers I, Glasziou P, Greenhalgh T, Heneghan T, Liberati A, et al. The 2011 Oxford CEBM levels of evidence. Oxford centre for evidence-based medicine. 2011. https://www/cebm/net/index/aspx?/o/=/5653
39. Maryod WH, Taha ER. Comparison of the retention of conventional versus digitally fabricated remov-able partial dentures: a cross over study. Int J Dent & Oral Heal. 2019;5:13–19.
40. Mohamed SE, Rasha HG. Digital PEEK framework and patient satisfaction compared to conventional metal framework in removable partial dentures: a clinical trial. Egypt Dent J. 2019;65:3787–94.
41. Ali Z, Baker S, Sereno N, Martin N. A pilot randomized controlled crossover trial comparing early OHRQoL outcomes of cobalt-chromium versus PEEK removable partial denture frameworks. Int J Prosthodont. 2020;33:386–92.
42. Almufleh B, Emami E, Alageel O, de Melo F, Seng F, Caron E, et al. Patient satisfaction with laser-sintered removable partial dentures: a crossover pilot clinical trial. J Prosthet Dent. 2018;119:560–67.
43. Saad AS, Abbas FS, Elgharabawy SH. Clinical evaluation of removable partial denture constructed from 3d printed resin pattern designed using CAD CAM technology. Alex Dent J. 2019;44:15–21.
44. Tregerman I, Renne W, Kelly A, Wilson D. Evaluation of removable partial denture frameworks fabricated using 3 different techniques. J Prosthet Dent. 2019;122:390–95.
45. Ye H, Ning J, Li M, Niu L, Yang J, Sun Y, et al. Preliminary clinical application of removable partial denture frameworks fabricated using computer-aided design and rapid prototyping techniques. Int J prosthodont. 2017;30:348–53.
46. McGuinness LA, Higgins JPT. Risk-of-bias VISualization (robvis): an R package and Shiny web app for visualizing risk-of-bias assessments. Res Synth Methods. 2021;12:55–61.
47. Tang L, Lund JP, Taché R, Clokie CM, Feine JS. A within-subject comparison of mandibular long-bar and hybrid implant-supported prostheses: psychometric evaluation and patient preference. J Dent Res. 1997;76:1675–83.
48. Koutsoukis T, Zinelis S, Eliades G, Al-Wazzan K, Rifaiy MA, Al Jabbari YS. Selective laser melting technique of Co-Cr dental alloys: a review of structure and properties and comparative analysis with other available techniques. J Prosthodont. 2015;24:303–12.
49. Alageel O, Abdallah MN, Alsheghri A, Song J, Caron E, Tamimi F. Removable partial denture alloys processed by laser-sintering technique. J Biomed Mater Res B Appl Biomater. 2018;106:1174–85.
50. Choong EKM, Shu X, Leung KCM, Lo ECM. Oral health-related quality of life (OHRQoL) after rehabilitation with removable partial dentures (RPDs): a systematic review and meta-analysis. J Dent. 2022;127:104351.
51. Stern MA, Brudvik JS, Frank RP. Clinical evaluation of removable partial denture rest seat adaptation. J Prosthet Dent. 1985;53:658–62.
52. Dunham D, Brudvik JS, Morris WJ, Plummer KD, Cameron SM. A clinical investigation of the fit of removable partial dental prosthesis clasp assemblies. J Prosthet Dent. 2006;95:323–26.
53. AlRumaih HS. Clinical applications of intraoral scanning in removable prosthodontics: a literature review. J Prosthodont. 2021;30:747–62.
54. Mansour M, Sanchez E, Machado C. The use of digital impressions to fabricate tooth-supported partial removable dental prostheses: a Clinical Report. J Prosthodont. 2016;25:495–97.
55. Mourouzis P, Pandoleon P, Tortopidis D, Tolidis K. Clinical evaluation of removable partial dentures with digitally fabricated metal framework after 4 years of clinical service. J Prosthodont. 2023. doi:10.1111/jopr.13698
56. Hayama H, Fueki K, Wadachi J, Wakabayashi N. Trueness and precision of digital impressions obtained using an intraoral scanner with different head size in the partially edentulous mandible. J Prosthodont Res. 2018;62:347–52.
57. Li T, Yu T, Hawkins BS, Dickersin K. Design, analysis, and reporting of crossover trials for inclusion in a meta-analysis. PLoS One. 2015;10:e0133023.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Almufleh B, Arellanob A, Tamimi F. Patient-reported outcomes and framework fit accuracy of removable partial dentures fabricated using digital techniques: A systematic review and meta-analysis. J Prosthodont. 2023;1–11. https://doi.org/10.1111/jopr.13786