

Digital Complete Removable Denture (CRD, PAT): State of the Art and Contribution of Digital Workflows

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ABSTRACT

Introduction: The complete removable denture (CRD, PAT) remains the standard treatment for completely edentulous patients. The conventional protocol is complex, time-consuming, and highly dependent on the expertise of the clinician and the dental technician. The integration of digital technologies (subtractive and additive CAD/CAM) has emerged as a promising alternative to improve accuracy, optimize material properties, and reduce the number of clinical appointments. This review evaluates the contribution of these digital workflows compared with conventional methods.

Materials and Methods: A literature search was conducted on PubMed, Scopus, and Google Scholar (2020–2025) using the PICO model. Of 381 articles initially identified, 38 were retained after rigorous screening based on clinical relevance and scientific quality.

Results and Discussion: Digital CRDs provide clinical performance equivalent to or superior to conventional techniques in terms of fit accuracy, retention, and occlusal accuracy. Digital workflows enable a significant reduction in the number of appointments (2 to 4 versus 5) and in laboratory fabrication time. Patient satisfaction is generally comparable between techniques.

Conclusion: Hybrid workflows currently represent the safest and most widely adopted compromise. Optimization of printable materials and the progressive integration of artificial intelligence offer prospects for complete digitalization of the prosthetic care chain.

Keywords: Complete removable denture (CRD, PAT); CAD/CAM; 3D printing; milling; completely edentulous patients

1. INTRODUCTION

The complete removable denture (CRD, PAT) is regarded as the cornerstone of prosthetic management

for the completely edentulous patient [1,2]. Despite advances in preventive dentistry and the rise of implantology, total edentulism remains a global public health issue, driven by population aging and inequalities in access to care [2,3]. In this context, the CRD remains the most widely used treatment to restore masticatory function, esthetics, and quality of life for affected patients.

The conventional protocol for fabrication of CRDs is based on five demanding clinical and laboratory steps: mucostatic impression, functional impression, recording of the maxillomandibular relationship, esthetic and functional try-in, and insertion [4,5]. Although well established, these techniques are time-consuming and highly dependent on the expertise of the clinician and the dental technician. Each step represents a potential source of cumulative error that may compromise the quality of the final result.

In recent years, dentistry has undergone a profound transformation driven by the integration of digital technologies, giving rise to the concept of the digital CRD [6]. This approach is based on workflows using computer-aided design (CAD) and computer-aided manufacturing (CAM), according to two main processes: subtractive manufacturing (milling of pre-polymerized PMMA blocks) and additive manufacturing (3D printing by photopolymerization) [7,8]. These digital approaches aim to improve fit accuracy, optimize the mechanical and biological properties of materials, reduce the number of clinical appointments, and simplify therapeutic management.

Given the proliferation of clinical, in vitro, and observational studies, this narrative review aims to critically evaluate the contribution of digital workflows to CRD fabrication in terms of clinical performance, material properties, patient satisfaction, and cost-effectiveness.

2. MATERIALS AND METHODS

2.1 Study type

This work is a systematic review. It aims to gather, organize, and critically analyze the available scientific data on the digital CRD. The objective is to provide a comprehensive and structured overview of current knowledge and to highlight future research perspectives in this field.

2.2 Research question (PICO model)

The primary research question is as follows: What is the contribution of digital workflows (subtractive and additive CAD/CAM) to the fabrication of CRDs in terms of clinical performance, mechanical and biological material properties, patient satisfaction, and cost-effectiveness?

Table 1: Description of PICO criteria.

PICO criterion	Description
P – Population	Completely edentulous patients (maxillary and mandibular) requiring rehabilitation with a complete removable denture (CRD, PAT)
I – Intervention	Computer-aided design and manufacturing (CAD/CAM): subtractive workflows (milling) and additive workflows (3D printing)
C – Comparator	Conventional fabrication methods for complete removable dentures
O – Outcomes	Clinical performance (fit, retention, occlusion), mechanical and biological properties, patient satisfaction, cost-effectiveness, and time savings

2.3 Search strategy

A computerized search was performed in PubMed/MEDLINE, Scopus, and Google Scholar. The keywords (MeSH terms) included: "Computer-Aided Design", "Computer-Aided Manufacturing", "Workflow", "printing, three dimensional", "denture, complete", "Dental Prosthesis Design", and "Jaw, Edentulous". Boolean operators combined these terms using AND/OR/NOT. Filters applied covered the period 2020–2025, with full-text access, in English or French.

2.4 Eligibility criteria

Inclusion criteria

Included were randomized clinical trials (RCTs), non-randomized clinical studies, and in vitro studies directly related to the digital CRD. The target population included fully edentulous (bimaxillary) patients. Studies had to address at least one of the following outcome measures: fit, retention, patient satisfaction, mechanical properties, esthetics, occlusion, or cost.

Exclusion criteria

Excluded were implant-supported or hybrid prostheses; studies on animal models or partially edentulous patients; isolated clinical case reports, letters to the editor, and editorials; articles published before 2020 or without accessible full text; as well as duplicates and systematic reviews (meta-analyses).

2.5 Article selection

Of the 381 articles initially identified (PubMed: 130; Scopus: 208; Google Scholar: 43), 183 duplicates were removed using Zotero. After screening titles (198 → 76), abstracts (76 → 54), and full texts, 38 articles were retained for final analysis: 11 randomized clinical trials, 14 comparative observational clinical studies, and 13 in vitro studies.

2.6 Assessment of methodological quality of randomized clinical trials

The 11 included randomized clinical trials underwent additional assessment of risk of bias using the Cochrane RoB 2 tool (overall risk: low, moderate, or high) and of methodological quality according to the Jadad scale (score out of 5). This assessment, presented in the methodological summary table (Table 3, section 3), informed the weighting of each trial's contribution to the interpretation of this review's results.

3. RESULTS

The final corpus comprises 38 articles that met the inclusion criteria. The main results are presented in the tables below.

Table 2: Summary of included randomized clinical trials (n=11).

Author(s), [ref.]	year	Study design	Objective	Main results
Abozaed et al., 2025 [9]		Crossover RCT (n=10)	Satisfaction: prefabricated teeth vs. milled teeth	Milled teeth were acceptable; they showed superior masticatory efficiency but inferior esthetic results compared with prefabricated teeth

Hebeshi et al., 2025 [10]	RCT (n=20)	Effect of adaptation time of 3D-printed PATs on retention.	Greater increase in retention observed for 3D-printed PATs.
Iwaki et al., 2024 [11]	Double-blind RCT (n=20)	Satisfaction and OHRQoL of 3D-printed PATs vs. conventional	No significant difference in OHRQoL; 3D-printed PATs are clinically applicable
Kang et al., 2024 [12]	Single-blind crossover RCT (n=9)	3D-printed PATs vs. conventional	3D-printed PATs performed less well in masticatory efficiency and speech; overall fit was comparable
Peroz et al., 2024 [13]	Double-blind crossover RCT (n=16)	Digital PAT 2-visit (Baltic Denture) vs. conventional (5 visits)	Correctable overextensions; no significant clinical differences at 2 weeks and 3 months
Maniewicz et al., 2024 [14]	Crossover RCT (n=19)	Fit and retention of digital PATs.	Similar fit and retention; digital PATs were clinically acceptable
Zupancic Cepic et al., 2023 [15]	Crossover RCT (n=10)	Clinical performance and OHIP of digital PATs.	Performance and satisfaction were similar to conventional PATs
Peroz et al., 2022 [16]	Single-blind RCT (n=16)	Satisfaction (OHIP) with 2-visit digital PATs.	No significant difference in OHIP; saved 3 visits and approximately 1 hour of chairside time
Ohara et al., 2022 [17]	Crossover RCT (n=20)	Satisfaction with 3D-printed PATs.	Satisfaction was slightly higher for conventional PATs; 3D-printed PATs were clinically comparable
AboHeikal et al., 2022 [18]	RCT (n=48)	Satisfaction and retention: 3D-printed and milled vs. conventional PATs	No significant difference among the three methods
Srinivasan et al., 2021 [19]	Crossover RCT (n=15)	Milled vs. 3D-printed CRDs	Comparable performance; higher cost and time required for 3D-printed CRDs

To weight the contribution of these 11 trials in the interpretation of the results, we performed additional assessments of risk of bias (Cochrane RoB 2) and methodological quality (Jadad scale) (Table 3). Srinivasan et al., 2021 serves as the methodological benchmark of the corpus (low risk of bias, Jadad 5/5),

whereas Kang et al., 2024 and Zupancic Cepic et al., 2023 show the highest risk of bias (Jadad 1/5) and should be interpreted with caution.

Table 3: Methodological assessment of included randomized clinical trials (RoB 2 risk of bias and Jadad scale).

No.	Author(s), Year	Design / Sample (N)	Overall risk of bias (RoB 2)	Jadad score	Level of evidence	Inclusion decision
1	Abozaed H.W. et al., 2025	Crossover, N=10	Moderate	5/5	Moderate	Inclusion recommended (small sample should be noted)
2	Ahmed Teama E.M. et al., 2025	Parallel (3 arms), N=24	High	1/5	Low	Inclusion possible for microbiological data; exercise caution for satisfaction outcomes
3	Hebeshi et al., 2025	Parallel (2-arm), N=20	Moderate	2/5	Moderate	Inclusion recommended (objective retention criterion).
4	AboHeikal M.M. et al., 2022	Parallel (3-arm), N=48	Moderate	2/5	Moderate to good	Inclusion recommended.
5	Iwaki M. et al., 2024	Crossover, N=20 (18 analyzed)	Moderate	3/5	Good	Inclusion recommended.
6	Kang Y.J. et al., 2024	Crossover, N=9 (8 analyzed)	High	1/5	Low	Inclusion with reservation (very small sample size).
7	Ohara Y. et al., 2022	Crossover, N=20 (15 analyzed)	High	2/5	Moderate	Inclusion possible with caution.
8	Peroz I. et al., 2022	Crossover, N=54 (16 analyzed)	Moderate	5/5	Good	Inclusion recommended.
9	Srinivasan M. et al., 2021	Crossover, N=15	Low	5/5	High	Strongly recommended for inclusion (methodological reference).

No.	Author(s), Year	Design / Sample (N)	Overall risk of bias (RoB 2)	Jadad score	Level of evidence	Inclusion decision
10	Zupancic Cepic L. et al., 2023	Crossover, N=10	High	1/5	Low to moderate	Inclusion with major reservation (detection bias).
11	Maniewicz S. et al., 2024	Intra-subject crossover (3 conditions), N=20 (19 analyzed)	Moderate	3/5	Good (objective) / Moderate (subjective).	Recommended for inclusion.

Table 4: Summary of comparative observational studies and representative in vitro studies.

Author(s), year [ref.]	Study type	Objective	Main results
Kahya Karaca & Akca, 2024 [20]	Comparative clinical study (n=15)	Conventional vs. digital impressions of edentulous ridges	No significant difference; digital impressions are a reliable clinical alternative
Faur et al., 2024 [21]	Observational clinical study (n=15)	Accuracy of CRDs printed using a fully digital workflow	Superior intaglio surface accuracy for 3D printing versus conventional methods
Lo Russo et al., 2024 [22]	Cost comparison	Costs of digital versus conventional workflows	Reduced costs with digital workflows, with further reductions when using 3D printing and milled/printed teeth
Otake et al., 2024 [23]	Retrospective (n=24)	Patient satisfaction and cost-effectiveness of milled CRDs	Higher satisfaction and greater cost-effectiveness for milled CRDs
Lo Russo et al., 2023 [24]	Observational clinical study (n=14)	Intaglio accuracy: milled versus 3D-printed CRDs	Milled CRDs demonstrated slightly superior intaglio accuracy; the difference was not clinically significant.
Deng et al., 2023 [25]	Pilot comparative study (n=10)	Clinical outcomes and digital fabrication times	Similar clinical effectiveness, with time savings both at

			chairside and in the laboratory.
Kim et al., 2021 [26]	Retrospective study (n=637 CRDs)	Complaints with 3D-printed versus conventional CRDs (1 year)	Less pain and fewer ulcerations with 3D-printed CRDs; better aesthetics reported for conventional CRDs.
Clark et al., 2021 [27]	Retrospective study (n=281 CRDs)	Number of appointments and remakes for digital CRDs (2-year follow-up)	Significant reduction in post-insertion appointments for digital CRDs.
Özcan et al., 2025 [28]	In vitro	Physicochemical properties and bacterial adhesion: 3D-printed PMMA versus conventional PMMA	3D-printed specimens showed lower surface roughness and higher hydrophilicity, with increased bacterial adhesion but evidence of biofilm inhibition.
Jamjoom et al., 2024 [29]	In vitro	Impact of intraoral scanner (IOS) type and scanning strategy on the accuracy of edentulous ridges	The P-O-B scanning strategy was most accurate; TRIOS 4 yielded greater accuracy; maxillary arches were more accurate than mandibular.
Al-Dwairi et al., 2023 [30]	In vitro	Mechanical and surface properties: 3D-printed PMMA versus conventional PMMA	Overall comparable performance; 3D-printed PMMA appears clinically promising.
Al-Dwairi et al., 2020 [31]	In vitro	Flexural strength, impact resistance, and flexural modulus: milled resin versus conventional	PMMA CAD/CAM was superior in flexural strength, flexural modulus, and impact resistance.

4. DISCUSSION

4.1 Design and manufacturing workflows

Three major categories of digital workflows have been identified [7]. The fully digital workflow relies on direct data acquisition with an intra-oral scanner (IOS), followed by computer-aided design and manufacturing. This workflow is sparsely represented in the literature because of inherent difficulties in scanning edentulous arches (extensive featureless surfaces, mobile mucosa, saliva control, and delicate delineation of the posterior border) [32,33]. The semi-digital (hybrid) workflow combines conventional steps with digital design and manufacturing and is the most frequently reported in the literature [7,32].

The indirect workflow is based on digitization of conventional impressions or plaster models using a desktop scanner [7].

Recent studies show that intra-oral scanners now achieve clinically acceptable accuracy for completely edentulous arches [20]. A scanning strategy that begins in the posterior region, progresses along the palatal or lingual aspect of the ridge, and finishes with the buccal aspect has been associated with the best accuracy outcomes [29]. Performance remains dependent on the scanner used, the scanning strategy, and the arch involved (the maxilla offering better conditions than the mandible) [29,33].

Recording the intermaxillary relation (IMR) remains the most sensitive step of the digital workflow. Although digital alternatives have been described (silicone keys, gothic arch, printed diagnostic dentures) [34], the majority of studies still report the use of conventional techniques for this step [1]. A tendency toward mandibular protrusion has been reported with fully digital methods, and IMR errors remain more frequent in protocols lacking a clinical try-in [34].

4.2 Materials and manufacturing techniques

PMMA remains the reference material for fabrication of complete removable dentures (CRDs) [35]. Milling from pre-polymerized PMMA blocks eliminates polymerization shrinkage and significantly reduces the presence of residual monomer, conferring milled dentures with excellent mechanical properties (flexural strength, elastic modulus, impact resistance) [31,36] and biological properties (smooth surface, low bacterial adhesion) [37]. However, this technique entails a high initial cost and material waste associated with machining.

3D printing is primarily based on vat photopolymerization technologies (SLA, DLP, MSLA) [8]. These processes offer great geometric freedom, reduced waste, and lower fabrication costs. However, printed resins generally exhibit inferior mechanical properties compared with milled resins [36,38,39] and a tendency to discoloration. Biocompatibility is the most concerning limitation of printed CRDs: several in vitro studies report significantly higher microbial adhesion and metabolic activity, attributed to the surface roughness inherent to the layer-by-layer process, the presence of residual monomer [40], and the material's surface free energy [41].

Recent advances involve the incorporation of nanofillers (ZnO, TiO₂, CeZr) into printed resins to improve certain mechanical and colorimetric properties [42]. These innovations still require long-term clinical validation.

4.3 Clinical performance

Overall, the studies report superior fit accuracy of digital CRDs compared with conventional techniques [21,43]. No statistically significant difference is demonstrated between CRDs manufactured by milling and those produced by 3D printing, although milled dentures show a slightly higher accuracy at the level of the residual ridges in some studies [24,44]. Regarding retention, digital CRDs exhibit equal or superior retention compared with conventional dentures, with a more marked advantage for milled CRDs [14,45,46]. Occlusal fidelity is improved with both digital techniques, resulting in better stability and functional efficiency [25,43].

4.4 Clinical time and manufacturing cost

The majority of studies confirm that digital workflows reduce the number of clinical visits (2 to 4 appointments versus 5 for the conventional technique) and chairside time (estimated savings between 1 and 4 hours depending on the authors and the protocol) [16,32,47]. This benefit is particularly pronounced for elderly patients or those with reduced mobility. Laboratory fabrication time is also significantly

reduced (savings of 5 to 7 hours) [22,32]. Digitization is particularly efficient in situations of renewal or duplication of existing dentures.

Despite the high initial investment required to acquire digital equipment, studies generally report lower or comparable total costs for digital CRDs [22,23], mainly due to reduced chairside time, automation, and lower laboratory costs [32,48]. However, few studies include initial capital expenditures in their economic analyses, and most were conducted in academic settings in a limited number of countries.

4.5 Complications and patient satisfaction

The most frequent post-insertion complications include mucosal pain and ulceration, occlusal errors, insufficient retention, unsatisfactory aesthetic outcomes, and prosthetic base fractures [47]. Milled CRDs require significantly fewer adjustment visits than conventional CRDs, whereas 3D-printed CRDs require a comparable number of visits [8,26]. A lower success rate has been reported for some 3D-printed CRDs at five years, mainly related to base fractures or tooth detachment [49].

Overall patient satisfaction is high after delivery of CRDs, with no statistically significant difference between manufacturing techniques in terms of oral health-related quality of life (OHIP), comfort, speech, or masticatory function [12,15,46,48]. Some studies report slightly lower aesthetic satisfaction for 3D-printed CRDs, probably related to the use of monoblock teeth and increased susceptibility to discoloration [1,26]. Clinician satisfaction is significantly higher for milled CRDs compared with conventional CRDs [48].

4.6 Comparison of milled and 3D-printed digital CRDs

Table 5: Comparison of milled and 3D-printed digital complete removable dentures.

Parameter [ref.]	Digitally milled CRD (milling)	Digitally 3D-printed CRD (3D printing)
Mechanical properties [31,36,42]	Superior (flexural strength, elastic modulus, impact resistance)	Good but heterogeneous, depending on technology and brand
Biocompatibility [28,37,41]	Better: nonporous structure, smooth surface, and near absence of residual monomer	Higher microbial adhesion and metabolic activity, even after post-processing and polishing.
Fit [21,24,44,50]	Superior to conventional CRDs; equivalent to 3D-printed CRDs.	Superior to conventional CRDs; equivalent to milled CRDs.
Retention [10,14,45,46]	Superior to conventional CRDs.	Equivalent to conventional CRDs.
Aesthetics [26,51]	Comparable to or superior to conventional CRDs.	Variable results; aesthetic satisfaction is sometimes inferior (discoloration, monoblock teeth).
Durability [47,49]	Improved medium-term durability.	Lower 5-year success rate (base fractures, tooth detachment).
Number of appointments [1,16,19,32]	2 to 4 appointments (vs. 5 for the conventional technique)	2 to 4 appointments (vs. 5 for the conventional technique)

Manufacturing cost [22,23,47,48]	Higher material costs; total cost lower than for conventional CRDs.	Lowest material cost among the three methods.
Clinical follow-up [7,35]	More extensive clinical follow-up; reference option for definitive CRDs.	Recent, rapidly evolving technology with limited clinical follow-up.

Several reviews conclude that 3D printing remains more reliable for trial CRDs, while milling remains more robust for definitive CRDs [47]. The clinical performance of printed resins is nonetheless continuously improving through optimization of printing parameters, post-processing, and the emergence of new resin formulations [42].

4.7 Methodological quality of the included randomized clinical trials

Assessment of risk of bias (RoB 2) and methodological quality (Jadad scale) of the 11 randomized clinical trials included (Table 3) revealed an overall moderate profile: eight trials had a moderate risk of bias and an intermediate Jadad score (2 to 3/5); one trial, Srinivasan et al., 2021, had a low risk of bias and the maximal Jadad score (5/5); and three trials (Ahmed Teama et al., 2025; Kang et al., 2024; Zupancic Cepic et al., 2023) had a high risk of bias and the lowest Jadad score (1/5).

Regarding bias domains, the most frequent limitations concern blinding of patients and assessors, which is difficult to achieve in trials comparing digital and conventional CRDs because of perceptible differences in clinical protocols, as well as often incomplete descriptions of random sequence generation and allocation concealment. The crossover design, which predominates in this body of literature, also exposes trials to carryover bias when the washout period between the two tested CRDs is insufficient or poorly documented; this concern notably applies to the trials judged at high risk of bias.

Juxtaposing these quality scores with the clinical results reported in 4.3 and 4.5 nuances their interpretation. The most methodologically robust trial (Srinivasan et al., 2021; low RoB; Jadad 5/5) concludes comparable clinical performance between milled and 3D-printed CRDs, while noting higher cost and manufacturing time for the latter. This conclusion can therefore be retained with a high level of confidence. Conversely, the trials at high risk of bias (Kang et al., 2024; Zupancic Cepic et al., 2023) report trends broadly concordant with those of higher-quality trials (comparable or slightly inferior clinical performance for 3D-printed CRDs), which reinforces the directional plausibility of these results despite greater uncertainty regarding the true magnitude of observed differences.

This methodological heterogeneity calls for weighting the contribution of each trial in the synthesis of clinical results in this review and highlights the need for future randomized trials with double-blind design (when feasible), explicit description of random sequence generation, allocation concealment, and washout duration, and larger sample sizes to strengthen the overall level of evidence in favor of digital workflows.

4.8 Limitations of this review

This review has limitations inherent to this methodology. The absence of a quantitative analysis prevents statistical synthesis. The included primary studies remain limited in terms of well-controlled RCTs, often characterized by small sample sizes and short follow-up durations. Heterogeneity of protocols, CAD/CAM systems, and evaluation criteria limits comparability of results and generalizability of conclusions.

5. CONCLUSION

Long considered one of the areas most resistant to digital dentistry, the complete removable denture (CRD,

PAT) is now experiencing a notable expansion driven by the evolution of digital tools, materials, and clinical protocols. Digital CRDs (PAT), whether produced by subtractive or additive processes, provide overall superior clinical outcomes compared with conventional techniques in fit accuracy, retention, and occlusal fidelity [51,52,53], with a significant reduction in the number of appointments and manufacturing time [32,47].

Milled CRDs (PAT) appear to be the most reliable option for definitive prostheses because of their superior mechanical and biological properties [31,36,37,42]. 3D-printed CRDs (PAT) constitute a clinically valid alternative, particularly relevant for trial CRDs and situations requiring flexibility and material economy [8,47].

Current evidence suggests that hybrid workflows represent the safest and most widely adopted compromise [1,7]. The progressive integration of artificial intelligence, optimization of printable resins, and development of fully digital protocols point toward the potential for complete dematerialization of the prosthetic care pathway, with the aim of improving access to care and the quality of life of completely edentulous patients.

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