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From analog to digital: evolving workflows in the fabrication of complete dentures

Abstract

This integrative review critically evaluates analog and digital workflows for complete denture fabrication, highlighting clinical performance, mechanical behavior, adaptation, patient satisfaction, and workflow efficiency. Searches were conducted in PubMed/MEDLINE, Scopus, Web of Science, SciELO, and Google Scholar (2015–2025). Findings indicate that CAD/CAM-milled dentures exhibit superior adaptation, mechanical strength, predictability, and reduced clinical chair time. Although 3D-printed dentures have evolved considerably, limitations remain regarding dimensional stability, long-term resistance, and soft tissue capture in edentulous arches. Patient reported outcomes are comparable to or better than those of conventional dentures, especially in comfort and retention. Challenges persist due to high equipment costs and difficulty acquiring accurate intraoral scans of movable tissues. Hybrid workflows that combine conventional impressions with digital design presently offer the most reliable and clinically feasible approach.

Keywords: prosthodontics, dental materials, complete denture, 3D-priinted dentures

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Introduction

Edentulism remains a significant global oral health burden, especially among older adults in developing regions. Complete dentures continue to be a primary rehabilitative option, directly influencing mastication, phonetics, facial support, and overall quality of life.[1,2] Conventional fabrication relies on impression techniques, gypsum models, occlusal wax rims, try in procedures, and heat polymerized acrylic resin bases. Although widely used, analog workflows depend heavily on operator skill and are susceptible to dimensional changes during impression making, model pouring, waxing, packing, and polymerization.[3-6]

Digital dentistry has introduced CAD/CAM workflows employing subtractive milling of pre-polymerized polymethyl methacrylate (PMMA) blocks and additive manufacturing through 3D printing technologies.[7,8] Clinical and laboratory studies have demonstrated superior accuracy, mechanical performance, and reproducibility for milled dentures compared with traditional methods.[9-12] 3D-printed dentures, although showing significant improvements, still exhibit limitations in long-term stability and mechanical reliability.[13,14]

Given the rapid evolution of digital prosthodontics, a comprehensive evaluation comparing analog and digital workflows is essential to guide clinical decision-making and future research.

Methodology

This study followed the integrative review methodology described by Whittemore and Knafl.[15] Searches were conducted between January and August 2025 in PubMed/MEDLINE, Scopus, Web of Science, SciELO, and Google Scholar using the terms: “complete denture,” “digital denture,” “CAD-CAM denture,” “analog denture,” and “prosthodontics.” Inclusion criteria consisted of: (1) randomized clinical trials, (2) non-randomized comparative studies, (3) in vitro analyses, and (4) systematic reviews published from 2015 to 2025 in English, Portuguese, or Spanish. Exclusion criteria comprised isolated case reports, editorials, letters, and studies evaluating only partial dentures. Two independent reviewers screened titles, abstracts, and full texts. Methodological quality was assessed using RoB 2.0 for randomized trials, ROBINS-I for non-randomized studies and AMSTAR-2 for systematic reviews. Disagreements were resolved by consensus. Ultimately, XX studies met the inclusion criteria.

Study outcome of literature

General overview and evolution of the digital workflow

Since the mid-2010s, digital denture workflows have progressed from hybrid methods to fully digital fabrication systems. CAD software enables virtual tooth arrangement, occlusal plane orientation, and base morphology. Subtractive milling of pre-polymerized PMMA blocks yields highly dense, homogeneous bases with minimal porosity.[16-18] 3D-printed resins have evolved significantly, though their performance is highly dependent on printer technology, resin formulation, layer orientation, and post-curing protocols.[19-22]

Clinical time, efficiency, and cost-effectiveness

Randomized and crossover trials indicate that digital dentures reduce the number of clinical visits, laboratory time, and post-delivery adjustments.[23-25] Patients often report preference for digital dentures due to improved retention, comfort, and esthetics.[26,27]

Adaptation, dimensional accuracy, and stability

Milled dentures consistently demonstrate superior trueness, precision, and long-term dimensional stability compared with both conventional and 3D-printed versions.[28] Although printed dentures may achieve clinically acceptable accuracy, their long-term behavior remains less predictable.

Mechanical properties and material performance

Industrial PMMA blocks exhibit high strength, low porosity, and excellent fatigue resistance due to controlled polymerization under high pressure and temperature. Printed resins, although improving, still present inferior mechanical performance compared with milled materials.

Patient satisfaction, OHRQoL, and adjustment needs

Prospective studies demonstrate comparable outcomes between digital and conventional dentures, with digital workflows often showing advantages in retention, esthetics, and comfort. Patient-reported oral health-related quality of life (OHRQoL) has also been shown to improve with digital dentures.

Intraoral scanning of edentulous arches and functional impressioning

Current evidence indicates that milled dentures consistently demonstrate superior adaptation, dimensional stability, and mechanical performance, supporting their growing incorporation into academic clinics and private practices. However, high initial costs and the need for robust digital infrastructure continue to limit widespread adoption.[16-19]

In contrast, 3D-printed dentures represent a viable option in cases of lower functional demands or when used as interim prostheses, largely due to their rapid and cost-effective fabrication. Still, long-term prospective studies are required to assess their clinical performance beyond two years.[13] Future developments include the integration of artificial intelligence and machine learning into prosthetic design and planning software, with the potential to enhance personalization, streamline clinical workflows, and reduce operator-dependent variability.[10]

Although intraoral scanning is well consolidated in fixed prosthodontics, current consensus statements highlight persistent limitations when applied to fully edentulous arches particularly in regions of mobile mucosa (soft palate, vestibular and sublingual sulci). As a result, traditional peripheral impression techniques continue to play a central role, even within predominantly digital protocols.[6-8]

3D printing vs. milling: a critical synthesis

Double-blind crossover trials comparing milled and 3D-printed dentures generally report subtle or non-significant differences in patient satisfaction and functional performance.[2,3] Nonetheless, milled prostheses consistently maintain an advantage in precision, dimensional stability, and mechanical strength.[18] Thus, the selection between milling and 3D printing should be based on patient-specific factors, material properties, clinical availability, and the experience of the dental team.[22-25]

Gaps and future directions

Key gaps persist in the literature, including the need for long-term follow-ups (≥3–5 years) for 3D-printed dentures; standardization of metrics for evaluating adaptation, stability, and post-processing procedures; economic analyses addressing learning curves and equipment maintenance; and validated strategies for accurate intraoral capture of fully edentulous arches. Multicenter trials with larger samples and patient-centered outcome measures remain a priority.[9,11,14,16]

Discussion

The findings of this review corroborate the expanding body of evidence supporting digital denture workflows as a reliable alternative to conventional fabrication methods. CAD/CAM-milled dentures consistently demonstrate superior accuracy, mechanical performance, and production standardization, which collectively result in reduced chair time, fewer post-insertion adjustments, and enhanced patient satisfaction. Despite these advantages, digital workflows still present practical limitations, particularly regarding intraoral scanning of fully edentulous arches, where mobile mucosa and functional border capture remain challenging.

Hybrid workflows combining conventional impression techniques with digital design have emerged as pragmatic solutions that harness the strengths of both approaches.[9,11,14,16] These protocols help mitigate the variability inherent to analog fabrication while overcoming the current limitations associated with intraoral capture in edentulous patients. Despite continuous technological advancements, more robust clinical trials with long-term follow-up periods (>5 years) and standardized assessment protocols are essential to further substantiate the clinical predictability of digital dentures. Future developments involving artificial intelligence, machine learning, and advanced biomaterials are expected to strengthen customization potential and improve rehabilitation outcomes.[6-8]

The results of this integrative review reinforce the growing literature supporting the benefits of digital workflows, particularly in terms of precision, standardization, and reduced clinical time. However, transitioning from analog to digital fabrication should be interpreted not as an abrupt replacement but as a gradual, adaptive process for clinicians and educational institutions.[5]

Additionally, recent narrative reviews emphasize the increasing relevance of 3D printing in complete denture rehabilitation, highlighting material advancements and expanding clinical applicability.[24] An important consideration is the learning curve associated with mastering CAD design software, intraoral scanners, and 3D printers. Evidence indicates that clinicians' familiarity with digital tools directly influences prosthesis quality and minimizes errors throughout the workflow.[22]

Consequently, professional training and the incorporation of digital prosthodontics in undergraduate and graduate curricula are critical for the consolidation of these techniques in clinical practice. In the laboratory domain, 3D-printed resins have undergone substantial evolution, with newer materials exhibiting improved flexural strength and reduced water sorption.[28] Nonetheless, the literature consistently identifies industrially milled PMMA blocks as the gold standard for resistance and dimensional stability, particularly in definitive prostheses.[9]

Clinically, although patient satisfaction tends to be comparable between analog and digital workflows, digital protocols may provide additional advantages in comfort and esthetics factors that play a crucial role in treatment acceptance.[12,15,17,18] Still, the scarcity of longitudinal studies extending beyond five years limits comprehensive understanding of the long-term survival and performance of digital dentures. Cost-benefit considerations are also significant: although digital equipment requires substantial initial investment, several studies suggest that medium- to long-term gains including reduced clinical time, fewer adjustment visits, and greater laboratory predictability may offset these costs.[23,24,27]

This aspect is particularly relevant in academic settings, where workflow standardization and reduced treatment time directly influence student training and patient satisfaction. Persisting technical challenges such as the accurate capture of soft tissues and peripheral extensions via intraoral scanning reinforce the continued importance of hybrid protocols. In these workflows, conventional impressions are incorporated into digital pipelines to ensure more reliable reproduction of anatomical details.[12,16,19] This analog–digital integration reflects current trends favoring complementarily between methods rather than radical substitution. Future directions in digital denture fabrication include the integration of artificial intelligence and machine learning into prosthetic planning, enabling workflow automation and predictive adjustment modeling based on large clinical datasets.[2,4,5]

Enhancements in 3D-printing technology and the development of next-generation biomaterials may further expand clinical applicability, improving reliability and accessibility. Despite considerable progress, the current literature exhibits notable methodological gaps, including heterogeneous criteria for evaluating adaptation, satisfaction, and clinical performance. Multicenter randomized clinical trials, with sufficiently powered samples and follow-ups exceeding five years, are necessary to consolidate evidence and guide clinically grounded protocols.[17]

Overall, the reviewed literature demonstrates that digital workflows offer significant clinical and laboratory advantages particularly regarding time efficiency, procedural standardization, and the superior mechanical properties of milled prostheses.[8] Nevertheless, analog methods remain relevant due to their accessibility, lower initial costs, and long-established clinical familiarity. The limitations identified such as scanning constraints, high upfront investment, and variability in clinical outcomes indicate that a complete shift to fully digital workflows is not yet universally achievable. In this context, hybrid approaches that integrate analog and digital steps currently represent a viable and promising alternative.[28]

Conclusion

Digital workflows, particularly CAD/CAM milling, provide superior adaptation, mechanical performance, reproducibility, and time efficiency compared with conventional complete dentures. However, analog techniques remain valuable for achieving accurate soft tissue capture. Currently, hybrid workflows offer the most reliable clinical approach by combining the precision of digital design with the anatomical fidelity of conventional impressions. Continued research, technological refinement, and material innovation are essential to support the full clinical transition to digital denture fabrication.

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Data availability

All data analyzed during this study are available from the corresponding author upon reasonable request.

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Conflicts of interest

The authors report no conflicts of interest regarding any of the products or companies discussed in this article.

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