THE JOURNAL OF PROSTHETIC DENTISTRY

SYSTEMATIC REVIEW

# Time efficiency and cost of fabricating removable complete dentures using digital, hybrid, and conventional workflows: A systematic review

Nada El Osta, DDS, MSc, PhD, HDR,[a] Marion Bessadet, DDS, MSc, PhD,[b] Noémie Drancourt, DDS, MSc,[c] and Cindy Batisse, DDS, MSc, PhD[d]

## ABSTRACT

**Statement of problem.** Analysis of the cost and time efficiency of removable complete dentures (RCDs) fabricated using conventional and computer-aided design and computer-aided manufacturing (CAD-CAM) processes remains limited.

**Purpose.** The purpose of this systematic review was to evaluate the time efficiency and cost of conventional, hybrid, and completely digital workflows throughout the entire process of RCD fabrication.

**Material and methods.** Article selection followed the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) 2015 guidelines and was registered with the international prospective register of systematic reviews (PROSPERO). The bibliographic search covered the PubMed and Cochrane databases using keywords related to removable complete dentures, digital workflows, and economic factors and covered articles from January 2010 to June 2024. In total, 1188 articles were identified and assessed. A bottom-up search identified an additional 10 articles through cited works. Data on cost and time analyses were reported in a qualitative synthesis.

**Results.** The qualitative synthesis included 8 articles published between 2015 and 2024 showing that digital and hybrid workflows generally reduced both clinical and laboratory time and overall costs compared with conventional workflows. The hybrid protocol required significantly less clinical time, with reductions ranging from approximately 1 to 4 hours. Hybrid and completely digital workflows reduced laboratory manufacturing time by approximately 6 to 7 hours compared with conventional workflows. Cost analyses revealed that digital and hybrid workflows were more profitable and cost effective than conventional workflows.

**Conclusions.** The findings suggest that digital and hybrid workflows for RCD fabrication are more time efficient and cost effective than conventional methods. (J Prosthet Dent 2025;133:1194-1208)

Edentulism remains a persistent challenge for healthcare providers despite advancements in curative and preventive dental care.[1] Treatment options vary widely, ranging from removable complete dentures (RCDs) to implant-retained removable and implant-supported fixed prostheses.[2] The choice of treatment is influenced by financial constraints, treatment duration, fear of surgery, and systemic health.[3]

RCDs still remain an option for rehabilitating edentulous patients.[2,4,5] The conventional fabrication protocol requires several clinical visits, extensive chairside time, and complex laboratory procedures.[6] This process includes preliminary impressions, custom tray fabrication for border molding and definitive impressions, creation of occlusion rims to establish maxillo-mandibular records, tooth selection, trial denture, denture processing, denture insertion, and subsequent adjustments to address discomfort or other issues.[7] This multistep process increases the likelihood of errors, extending treatment duration and significantly

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

[a]Professor, Department of Prosthodontics, UFR d'Odontologie, Clinical Odontology Research Center (CROC), University of Clermont Auvergne, Clermont-Ferrand, France.
[b]Senior Lecturer, Department of Prosthodontics, UFR d'Odontologie, Clinical Odontology Research Center (CROC), University of Clermont Auvergne, Clermont-Ferrand, France; and Hospital Practitioner, CHU Clermont-Ferrand, Odontology Department, Clermont-Ferrand, France.
[c]Lecturer, Department of Prosthodontics, UFR d'Odontologie, Clinical Odontology Research Center (CROC), University of Clermont Auvergne, Clermont-Ferrand, France; and Hospital Practitioner, CHU Clermont-Ferrand, Odontology Department, Clermont-Ferrand, France.
[d]Senior Lecturer, Department of Prosthodontics, UFR d'Odontologie, Clinical Odontology Research Center (CROC), University of Clermont Auvergne, Clermont-Ferrand, France; and Hospital Practitioner, CHU Clermont-Ferrand, Odontology Department, Clermont-Ferrand, France.

## Clinical Implications

The integration of digital workflows into the manufacturing of removable complete dentures significantly reduces clinical time and costs compared with conventional fabrication methods. This approach offers a more affordable and cost effective option for the rehabilitation of completely edentulous patients, enhancing both the efficiency and accessibility of dental care.

raising costs associated with high labor and material demands.[8–11]

In recent years, computer-aided design and manufacturing (CAD-CAM) techniques have emerged as an alternative to conventional methods of constructing RCDs.[12–14] Digital systems typically involve intraoral optical scanning or scanning impressions or casts of the edentulous jaws. Although the accuracy and feasibility of using intraoral scanners for complete arches has been documented, they are not yet routinely used to fabricate CAD-CAM RCDs.[15] Consequently, the procedures for impression making and jaw relation recording remain similar to those used in conventional protocols.[16,17] However, the subsequent manufacturing processes use digital techniques, resulting in a hybrid workflow, also called mixed analog-digital workflow or partial digital protocol.[14] The conventional records are transferred to a dental laboratory to create a virtual design of the RCDs, which are then manufactured using either subtractive milling processes from a prepolymerized resin block or additive printing processes, which build RCDs layer by layer.[18,19]

Evidence indicates that CAD-CAM dentures have advantages over conventional RCDs, including greater accuracy,[20,21] better surface adaptation,[21–23] enhanced mechanical properties,[23–25] and improved biocompatibility.[26] They have also been reported to shorten treatment duration[27,28] and allow for digital archiving to fabricate additional dentures.[29]

Digital and hybrid workflows offer advantages for clinical and laboratory practices.[30–32] However, challenges like patient perception, integration issues, and financial constraints must be addressed.[31,33] Time and cost are key factors in patient decisions regarding prosthetic treatments, highlighting the need to assess the effectiveness and economic feasibility of new technology before adoption.[24,34,35] While there are reports on digitally fabricated RCDs, evidence-based research on their time efficiency and cost remains limited, even though this evaluation is essential for patients, healthcare providers, and third-party payers.

This systematic review aimed to compare the time efficiency and cost of RCDs fabricated with conventional, hybrid, and completely digital workflows throughout the entire prosthetic treatment process. The null hypothesis was that no differences in clinical and laboratory times or costs would be found among the conventional, hybrid, and digital workflow for RCD fabrication.

## MATERIAL AND METHODS

The article selection adhered to the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocol (PRISMA-P 2015).[36] The protocol, which detailed the analysis methods and inclusion criteria, was registered with the Prospective International Register of Systematic Reviews (PROSPERO) (CRD42023458734), and no similar protocol was identified. The population, intervention, comparison, outcome (PICO) format for the review is specified in Table 1. The bibliographic search included PubMed and Cochrane databases using the following keywords (Denture OR Prosthodontic OR restorative dentistry) AND (CAD CAM OR Digital workflow OR Computer Dentistry OR Digital Design) AND (Economic OR cost OR Financial OR time efficiency). Filters were applied to consider reports published between January 2010 and June 2024. A bottom-up search approach was also performed from citation works. Inclusion criteria were articles written in English, published between January 2010 and June 2024, and comparing the cost and time efficiency of conventional, digital, and hybrid workflows for RCD fabrication. Exclusion criteria were articles not written in English, in vitro studies, clinical reports, reviews, or opinion-based articles.

Two independent investigators (M.B., N.E.O.) conducted the initial search using the specified keywords and performed the article selection process. Data extraction was managed with spreadsheets (Excel; Microsoft Corp), and a

**Table 1.** Search strategy

| Focused Question | How Much Time and Cost are Involved in Making Removable Complete Dentures Using Either Completely Digital or Partially Digital Workflows Compared with Conventional Workflows for Fully Edentulous Patients? | |
|---|---|---|
| PICO | Population | Fully edentulous patient receiving maxillary and mandibular removable complete dentures. |
| | Intervention | Digital and/or hybrid protocol for the fabrication of RCDs. |
| | Comparison | Conventional protocol for the fabrication of RCDs. |
| | Outcome | Time and cost to fabricate RCDs. |
| Search Strategy | Keywords | (Denture OR Prosthodontic OR restorative dentistry) AND (CAD CAM OR Digital workflow OR Computer Dentistry OR Digital Design) AND (Economic OR cost OR Financial OR time efficiency). |
| Database search | PubMed, Cochrane, PROSPERO, bottom-up searches from citation works. | |

CAD-CAM, computer-aided design and computer-aided manufacture; RCDs, removable complete dentures.

pilot form was tested by the investigators. Collected data included the first author, publication year, study design, prosthetic discipline, type of prosthesis, groups compared, clinical and laboratory steps of digital, hybrid, and/or conventional workflows, evaluation criteria for cost and time efficiency, conclusions about comparisons, reasons for exclusion, and manuscript language.

Two investigators (N.E.O., N.D.) used the Consolidated Standards of Reporting Trials (CONSORT) GRADE approach to evaluate the quality of evidence in randomized controlled studies[37] and the STROBE GRADE[38] approach for observational studies. Each investigator independently assessed and scored the articles, resolving disagreements through discussion. The findings were synthesized in a systematic review comparing the time efficiency and cost of completely digital, hybrid, and/or conventional workflows for the fabrication of RCDs. Costs reported in Swiss Francs (CHF) or Japanese Yen (JPY) were converted to United States Dollars (USD) using 2017 and 2021 exchange rates.[39,40]

## RESULTS

The search performed in June 2024 identified 1372 records in PubMed and 57 records in Cochrane. After removing duplicates and articles published before January 2010, 1188 records remained. Title screening excluded 1073 records, and abstract review excluded another 84.

Full-text reading led to the exclusion of 25 more records. A bottom-up search identified 10 articles from citations, with 2 meeting inclusion criteria. Figure 1 shows the selection process per PRISMA 2020 guidelines.[41] The qualitative synthesis included 8 articles published between 2010 and 2024, comparing time and cost for RCD workflows.[16,17,39,40,42–45] These studies involved sample sizes ranging from 6 to 44 participants, totaling 170 across studies (Table 2). All studies were conducted in universities except one.[17] The mean CONSORT score was 24.5 for randomized trials, and STROBE scores ranged from 12 to 22 for observational studies. Conventional, digital (intraoral scan and CAD-CAM), and hybrid workflows (including conventional intraoral impressions digitized in the laboratory) are detailed in Table 3, with cost and time efficiency outcomes in Table 4.

The time needed for fabricating RCDs was reported in 6 articles, highlighting clinical and laboratory time efficiencies (Table 5).[16,17,39,42,44,45] Four studies focused on clinical chairside time.[39,42,44,45] Three of these reported that the hybrid protocol required significantly

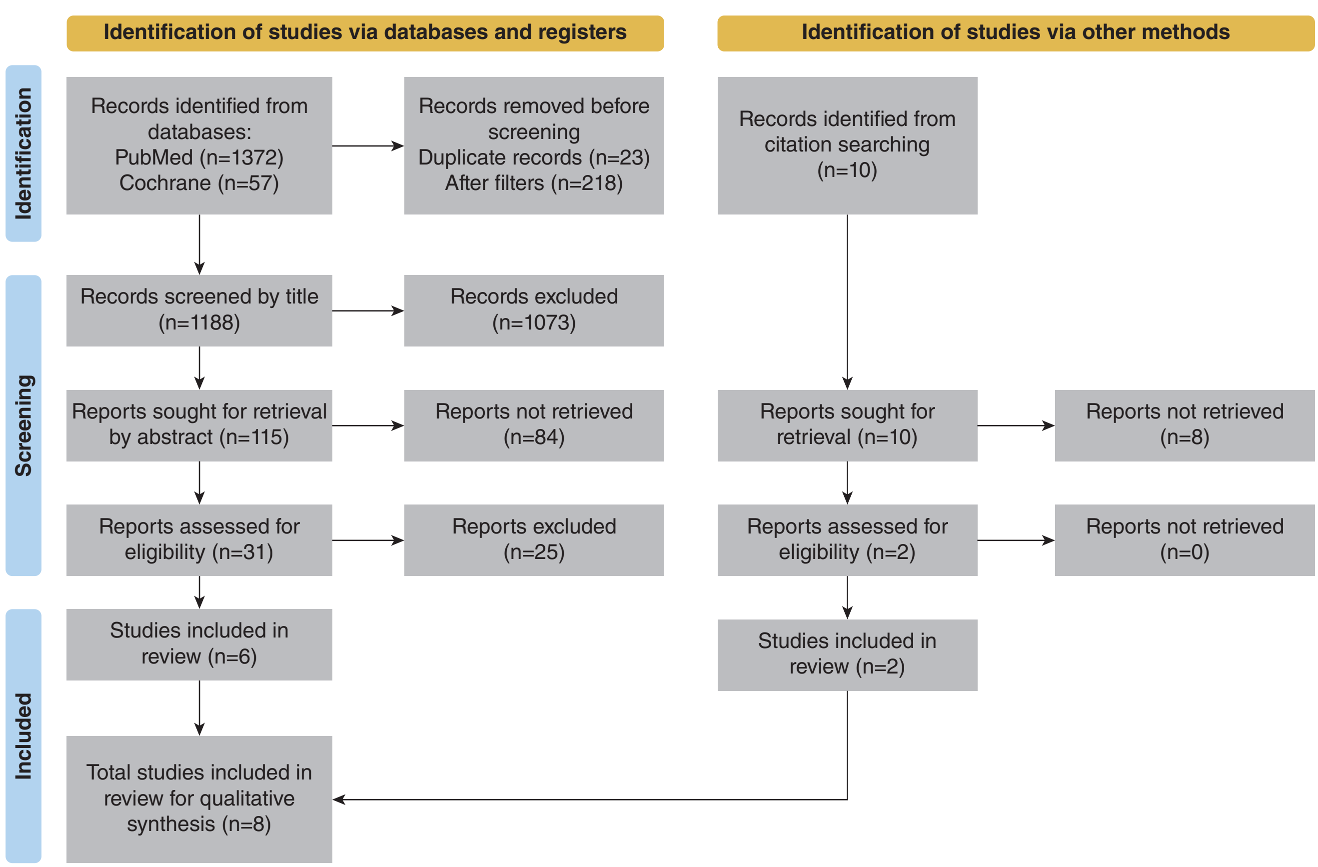


**Figure 1.** PRISMA flowchart for study selection. PRISMA, Preferred Reporting Items for Systematic Review and Meta-Analysis.

**Table 2.** References included in qualitative synthesis

| References | Titles | Sample Size | Settings | Manufacturing Process of Dentures | Design |
|---|---|---|---|---|---|
| Kattadiyil et al, 2015[42] | Comparison of treatment outcomes in digital and conventional complete removable dental prosthesis fabrications in a predoctoral setting. | 15 edentulous patients receiving maxillary and mandibular removable complete dentures. | University | Milled dentures. | Prospective clinical crossover study. |
| Srinivasan et al, 2019[39] | CAD/CAM milled removable complete dentures: time and cost estimation study. | 6 edentulous patients receiving maxillary removable complete denture.12 edentulous patients receiving mandibular removable complete dentures. | University | Milled dentures. | Prospective clinical crossover study. |
| Smith et al, 2021[43] | Economic and clinical impact of digitally produced dentures. | 30 edentulous patients receiving maxillary and mandibular removable complete dentures. | University | All milled dentures. Printed trial denture and milled definitive denture. | Retrospective study. |
| Arakawa et al, 2022[16] | Clinical outcomes and costs of conventional and digital complete dentures in a university clinic: a retrospective study. | 16×2 edentulous patients receiving maxillary and mandibular removable complete dentures. | University | Milled dentures. | Retrospective clinical parallel study. |
| Ohara et al, 2022[44] | Patient satisfaction with conventional dentures vs. digital dentures fabricated using 3d-printing: a randomized crossover trial. | 15 edentulous patients receiving maxillary and mandibular removable complete dentures. | University | 3D printed dentures: denture base and artificial teeth printed separately. | Randomized controlled crossover clinical trial. |
| Peroz et al, 2022[45] | Digital versus conventional complete dentures: A randomized, controlled, blinded study. | 16 edentulous patients receiving maxillary and mandibular removable complete dentures. | University | Milled dentures. | Randomized controlled crossover blinded clinical trial. |
| Lo Russo et al, 2024[17] | Comparative cost-analysis for removable complete dentures fabricated with conventional, partial, and complete digital workflows. | 10 small private dental laboratory and clinics. | Dental clinics and laboratories. | Seven manufacturing options. milled base / stock teeth; milled base / milled teeth; milled base / 3D printing teeth; 3D printing base / stock teeth; 3D printing base / milled teeth; 3D printing base / 3D printing teeth; milled in monobloc. | Retrospective study. |
| Otake et al, 2024[40] | Patient-reported outcome and cost-effectiveness analysis of milled and conventionally fabricated complete dentures in a university clinic: a retrospective study. | 22×2 edentulous patients receiving maxillary and mandibular removable complete dentures. | University | Milled dentures with custom disk method. | Retrospective clinical parallel study. |

less clinical time than the conventional protocol, with reductions of about 1 to 4 hours.[39,42,45] Ohara et al[44] also reported fewer visits for the hybrid protocol (3.8 ±1.3 visits) compared with the conventional protocol (5.6 ±1.2 visits) (Table 5).

Laboratory manufacturing time was evaluated in 2 studies.[17,45] Peroz et al[45] reported that the hybrid workflow reduced laboratory time by about 5 hours compared with the conventional protocol. Lo Russo et al[17] reported that the hybrid and digital workflows reduced manufacturing time by 5.90 to 7.35 hours, respectively, compared with the conventional workflow. They also noted shorter working times for milled monobloc dentures, while entirely 3-dimensionally (3D) printed bases and teeth required the longest time (Table 5).

Overall the clinical and laboratory time for denture fabrication was reported in 2 studies.[16,45] Peroz et al[45] reported that the hybrid workflow required only a third of the time compared with the conventional approach. In contrast, Arakawa et al[16] reported no significant difference in treatment duration between digitally and conventionally fabricated RCDs.

The cost analyses documented in 5 articles indicated that the fabrication cost of RCDs was significantly higher for conventional workflows than digital[17] or hybrid workflows (Table 6).[16,17,39,40,43] Srinivasan et al[39] reported that both laboratory and overall costs were significantly higher for the conventional protocol than for the hybrid protocol. The estimated hourly labor cost was 173.4 USD for the hybrid workflow and 128.2 USD for the conventional workflow, indicating greater profitability for the hybrid approach. Applying these findings to predoctoral students producing dentures could save 147 900 USD over 10 years (Tables 6 and 7). Smith et al[43] reported that an in-house laboratory with an all-milled

**Table 3.** Summary of conventional, digital, and hybrid workflows reported in 8 studies included in systematic review

| References | Complete Digital Workflows: IOS Scanning and CAD-CAM | Hybrid Workflows: At Least Conventional Intraoral Impression Digitized in Laboratory | Conventional Workflows |
|---|---|---|---|
| Kattadiyil et al, 2015[42] | | 2-visit protocol with AvaDent<br>First visit. definitive impressions, interocclusal records, and tooth selection.<br>Records sent to digital system to be scanned.<br>Submission of virtual tooth arrangement for preview and approval before fabricating dentures.<br>Second visit. delivery of denture. | 5-visit protocol<br>First visit. preliminary impressions.<br>Second visit. definitive impressions.<br>Third visit. interocclusal records and tooth selection.<br>Fourth visit. wax trial placement.<br>Fifth visit. Denture adjustment and insertion.<br>Students made custom trays occlusion rims, denture tooth arrangement, and festooning.<br>Dental laboratory processed acrylic resin by using conventional lost wax technique and heat-polymerizing acrylic resin with long polymerization cycle (9 h in water bath at 73 ±1 °C followed by 1/2 h in boiling water), finishing, and polishing. |
| Srinivasan et al, 2019[39] | | 2-visit protocol<br>First visit. definitive impressions of edentulous arches with prefabricated stock impression trays and polyvinyl siloxane (PVS) impression material.<br>Inter-occlusal jaw relationship recorded with anatomical device and confirmed with gothic arch tracing.<br>Jaw record registered PVS occlusal registration material.<br>Anterior plane of occlusion aligned parallel to inter-pupillary line using special occlusal plane indicator. Esthetic parameters (labial fullness, labial support, lip and smile lines) verified.<br>Tooth selection (size, form, and shade) and clinical records sent to digital denture laboratory.<br>Clinical records scanned and imported to design software (AVADENT; Global Dental Science Europe BV).<br>Anatomical landmarks identified and peripheral limits set on virtual casts and virtual tooth arrangement.<br>Virtual set-up sent to clinician for approval. Subsequent preview generated after incorporation of changes suggested by clinician.<br>Dentures milled, finished, and shipped to clinic.<br>Second visit. denture insertion. | 5–6 visits protocol<br>First visit. preliminary impression with irreversible hydrocolloid impression material using stock Schreinemakers trays. Impression used to pour preliminary stone cast for fabrication of auto-polymerizing polymethylmethacrylate (PMMA) resin custom impression tray in a conventional dental laboratory.<br>Second visit. custom tray checked for fit and extension followed by border molding using low fusing impression compound (Kerr Dental Europe).<br>Definitive impressions with zinc oxide eugenol impression paste (SS White) and sent to laboratory for fabrication of definitive casts.<br>Definitive base plates constructed on definitive casts and occlusal rims added.<br>Third visit. facebow transfer, recording of vertical and horizontal jaw relations, esthetic parameters, and tooth selection.<br>Centric jaw relation record verified with gothic arch tracing using intraoral tracers. Models mounted in laboratory and anterior tooth arrangement completed.<br>Fourth visit. anterior tooth arrangement verified intraorally.<br>Once complete, articulator returned to dental laboratory technician for posterior tooth arrangement.<br>Fifth visit. Trial denture visit.<br>Dentures fabricated using heat polymerizing PMMA resin, trimmed and polished by dental laboratory technician.<br>Sixth visit. denture insertion. |
| Smith et al, 2021[43] | | 4-visit protocol and in-house fabrication laboratory<br>First visit. preliminary impressions with AccuGel in stock AccuGel trays, papilla meter reading, centric bite relationship with putty and light body PVS wash afterwards, and UTS CAD readings (all products of Ivoclar AG, Schaan, Liechtenstein).<br>Second visit. PVS border molded definitive impressions with closed mouth impression technique with 3D occlusal plates, gothic arch tracings with gnathometer CAD mounted on 3D bite plates after definitive impressions, and maxillo-mandibular records.<br>Third visit. Trial denture visit with all milled process or printed trial denture and milled definitive denture.<br>Fourth visit. denture insertion.<br>Post-insertion denture adjustment visits.<br>Additional visits required at trial denture visit to reset teeth or remount bite. | 5-visit protocol and commercial laboratory denture fabrication<br>First visit. preliminary impressions with alginate.<br>Second visit. definitive impressions with PVS in border molded custom trays.<br>Third visit. maxillo-mandibular records visit with baseplates/occlusal rims made from final casts.<br>Fourth visit. trial denture visit.<br>Fifth visit. definitive denture insertion visit<br>Post-insertion denture adjustment visits.<br>Additional visits required at trial denture visit to reset teeth or remount bite. |

**Table 3** (*Continued*)

| References | Complete Digital Workflows: IOS Scanning and CAD-CAM | Hybrid Workflows: At Least Conventional Intraoral Impression Digitized in Laboratory | Conventional Workflows |
|---|---|---|---|
| Arakawa et al, 2022[16] | | Processes of impression making and jaw relation recording are similar to those performed in conventional RCD fabrication, while technical manufacturing procedure in dental laboratory performed by using digital techniques:<br>AvaDent Digital Dental Solutions (DDS-AV). subtractive milling process during 2-appointment protocol. Maxillomandibular relation recorded with anatomic measuring device.<br>Wieland Digital Denture system (DD-IV) with 4 clinical steps, including 1 optional clinical denture evaluation session. Maxillomandibular relations recorded with intraoral gothic arch tracing. | 5–6 visits protocol for impression making, maxillomandibular relation recording, and clinical evaluation. |
| Ohara et al, 2022[44] | | 3-visit protocol<br>First visit. definitive impressions recorded using DENTCA trays. After try-in of trays in mouth, border molding performed using heavy-bodied PVS impression material (Flexitime Heavy Trays; Kulzer Japan Co, Ltd), followed by definitive impressions using light-bodied vinyl polysiloxane impression material (Flexitime Collect Flow, Ltd).<br>After vertical jaw relationship recorded, posterior border of definitive impression cut according to posterior extent of denture, gothic arch tracers attached, and centric position determined on same day.<br>Intermaxillary relationship record with PVS bite material (Flexitime Bite; Kulzer Japan Co, Ltd).<br>Trial denture fabricated using 3D printer (ZE-NiTH U; Yoshida Co, Ltd) according to definitive impressions. Denture base (dima print denture base; Kulzer Japan Co) and artificial teeth (dima print denture teeth; Kulzer Japan Co) separately fabricated using 3D printer.<br>Second visit. try-in of trial denture.<br>Intermaxillary records, and occlusion, vertical intermaxillary relationship, midline, occlusal plane, horizontal and vertical overlap evaluated.<br>Third visit. delivery of denture and adjusted until as comfortable as CDs. | Primary impressions with irreversible hydrocolloid impression material.<br>Laboratory process employed plaster cast made from primary impression, and individual trays fabricated from polymethylmethacrylate (PMMA) resin.<br>Border molding performed using individual trays and specific impression compounds (Iso Compound and Peri Compound, GC Corp),<br>Definitive impressions with PVS impression material (Exafine regular type and injection type, GC Corp).<br>Laboratory process include definitive cast poured from definitive impression and record base waxed to obtain occlusal rims.<br>Determination of denture occlusion, vertical and centric jaw relationships recorded using record bases with occlusal rims.<br>Artificial teeth (Verasia SA, SHOFU INC) set in occlusal rims by dental laboratory technician.<br>Trial denture visit for occlusal relationship and esthetics.<br>Denture processing using heat-processed PMMA and denture delivery.<br>Denture adjustment for tissue impingement and/or occlusal interferences. |
| Peroz et al, 2022[45] | | 2-visit protocol with Baltic Denture (BD) System<br>First visit. individualization of maxillary BD key and adjustment with BD plane. vertical dimension of occlusion determined.<br>BD Keys (Merz Dental GmbH) and border molding achieved with thermoplastic impression material (BD Impress; Merz Dental GmbH) as per bipupillary line, Camper plane, and facial midline.<br>Definitive maxillary impression with silicone.<br>Individualization of mandibular BD Key: mandibular BD Key guided by investigator to establish optimal sagittal and transverse relationship.<br>Definitive mandibular impression made with light-body PVS (Provil Novo medium; Kulzer GmbH).<br>Second visit. delivery of definitive denture.<br>Two dental laboratory technicians fabricated prostheses. | 5-visit protocol<br>First visit. anatomical impression with edentulous impression tray and alginate.<br>Second visit. definitive impression with individual impression tray and polyether.<br>Centric record and facebow registration<br>Third visit. Jaw relation record and adjustment of occlusal rims: length of anterior parts, orientation on Camper plane, dental median line, position of canines, smile line and lip support.<br>Fourth visit. wax evaluation.<br>Fifth visit. delivery of definitive denture.<br>Two dental laboratory technicians t fabricated custom tray (Centric Tray; Ivoclar AG) and facebow transfer combined with maxillary impression tray. Prostheses designed with canine guidance and 3 posterior teeth in each quadrant. |

**Table 3** (*Continued*)

| References | Complete Digital Workflows: IOS Scanning and CAD-CAM | Hybrid Workflows: At Least Conventional Intraoral Impression Digitized in Laboratory | Conventional Workflows |
|---|---|---|---|
| Lo Russo et al, 2024[17] | Fully digital workflow with intraoral scan<br>Clinical procedures<br>Step 1. intraoral scans<br>Step 2. jaw relation record<br>Step 3. trial placement<br>Step 4. denture delivery.<br>Laboratory procedures<br>Step 1. occlusion rims.<br>Step 2. scans alignment, denture CAD, trial denture 3D print.<br>Step 3. denture base CAM, finishing, polishing. | Mixed analog-digital workflow: conventional intraoral impression digitized in laboratory<br>Clinical procedures<br>Step 1. primary impressions.<br>Step 2. impression for definitive casts.<br>Step 3. jaw relation record.<br>Step 4. trial placement.<br>Step 5. denture delivery.<br>Laboratory procedures<br>Step 1. scan impression, custom tray.<br>Step 2. scan impression, occlusion rims.<br>Step 3. digital casts align, denture CAD, trial denture 3D print.<br>Step 4. denture base CAM, finishing, polishing. | 5-visit protocol<br>Clinical procedures<br>Step 1. primary impressions.<br>Step 2. impression for working casts.<br>Step 3. jaw relation record.<br>Step 4. trial placement.<br>Step 5. denture delivery.<br>Laboratory procedures<br>Step 1. primary casts, custom tray.<br>Step 2. definitive casts, occlusion rims.<br>Step 3. articulator mounting, tooth arrangement.<br>Step 4. flasking, injection / packing, finishing, polishing. |
| | 7 manufacturing options. milled base / stock teeth; milled base / milled teeth; milled base / 3D printing teeth; 3D printing base / stock teeth; 3D printing base / milled teeth; 3D printing base / 3D printing teeth; milled in monobloc. | | |
| Otake et al, 2024[40] | | 3-visit protocol using custom disk method (CDM)<br>First visit. intraoral scanner (TRIOS 3; 3Shape A/S) to scan maxillary and mandibular edentulous jaws.<br>Preliminary maxillomandibular relation record with putty-type silicone impression material (Fusion II Putty Type; GC Corp) between arches.<br>Trial denture designed from maxillary and mandibular data using CAD software (3Shape Dental System; 3Shape A/S and Freeform; 3D Systems) and 3D printed (Form3; Formlabs Inc) in resin marketed for surgical guides (Dental SG; Formlabs Inc).<br>Second visit. anterior tooth arrangement evaluated with trial denture.<br>Definitive impressions (Exadenture; GC Corp) and maxillomandibular relation record (Correct Quick Bite; PENTRON).<br>Impressions scanned (E–3; 3Shape A/S) and definitive denture fabricated with custom disk.<br>Third visit. denture delivery.<br>Adjustments visits | 5-visit protocol<br>First visit. preliminary impression for fabricating diagnostic cast and individual<br>tray.Second visit. definitive impression for fabricating master cast and occlusal<br>rim.Third visit. maxillomandibular relation record, mounting cast and fabricating wax<br>denture.Fourth visit. wax denture evaluation and fabricating definitive<br>denture.Fifth visit. delivery of denture.Adjustment visit. |

CAD-CAM, computer-aided design and computer-aided manufacture; IOS, intraoral optical scan; PMMA, polymethylmethacrylate; PVS, polyvinyl siloxane.

**Table 4.** Summary of outcome variables reported in 8 studies included in review

| References | Time Efficiency | Cost Analyses |
|---|---|---|
| Kattadiyil et al, 2015[42] | Total clinical treatment time (hours) for each fabrication technique, including any additional clinical time required for remakes or repetitions of procedures. | NR |
| Srinivasan et al, 2019[39] | Clinical chairside time spent by student for each patient visit during entire course of denture construction. Timed with stopwatch and recorded for each protocol. Single investigator clocked students discretely.<br>Total time (hours) spent combining all visits together for each protocol. | – Clinical fees (CHF). costs of patient charge by dental school for clinical steps, and billed at 40% discounted rate. Included clinical materials and excluded dental laboratory fees. Fixed cost by institution and uniformly generated for all patients irrespective of denture protocol.<br>– Clinical materials costs (CHF) for all materials used in clinic for each denture protocol. Comprised expenditure incurred during each clinical protocol (including impression materials, trays and instruments used). Infrastructure costs excluded.<br>– Laboratory costs (CHF). final laboratory invoice billed for completed denture.<br>– Overall costs (CHF) for clinical materials and laboratory fees.<br>– Cost minimization analysis. estimated hourly labor cost calculated based on clinical costs charged by institution.<br>– Estimated hourly labor cost = (clinical cost - mean clinical materials cost) / mean chairside time in hours. |
| Smith et al, 2021[43] | NR | – Lab cost per unit (lower and upper denture) in USD.<br>– Cost saving comparing to conventional commercial lab denture per denture / per 400 dentures (upper and lower) in USD.<br>– Profitability per chair hour in USD = (Patient fee - material or lab cost) / hours of chair time. At university, patient fee for maxillary and mandibular dentures equivalent to 1230 USD. |
| Arakawa et al, 2022[16] | Treatment duration (in days) recorded at T0 (preliminary alginate impression), T1 (denture delivery), and T2 (last scheduled postdelivery adjustment).<br>Overall treatment duration in days divided into:<br>– Production. preliminary irreversible hydrocolloid impression to denture delivery (T0-T1).<br>– Postdelivery. denture delivery to last intentionally scheduled post-delivery adjustment (T1-T2).<br>– Recall. last intentionally scheduled postdelivery adjustment to last patient follow-up (T2-T3). | – Dental treatment costs (USD) included dentist's fees and materials used during T0-T1 and T1-T2.<br>– Dental laboratory costs (USD) based on final dental laboratory invoice.<br>– Total costs (USD) included sum of treatment and laboratory costs. |
| Ohara et al, 2022[44] | – Number of patients visits required for denture fabrication using 3D printing, including number of remakes.<br>– Treatment time required for denture fabrication (hours). starting from when patients sat down on dental chair to when patients discharged after treatment.<br>– Number of adjustment visits.<br>– Time required for denture stabilization (hours). After denture delivery until patients were able to eat without pain after denture delivery. | NR |
| Peroz et al, 2022[45] | – Sum of working time for dentist in minutes estimated for clinical procedures (impressions, maxillomandibular relation, clinical evaluation, delivery).<br>– Sum of working time for dental technician (minutes) estimated for technical procedures and included milling or hardening of gypsum or resin.<br>– Total working time (minutes). | NR |
| Lo Russo et al, 2024[17] | Laboratory manufacturing time needed to complete each workflow (hours) and each manufacturing option. | – Costs (USD) related to fabrication of single-arch complete denture<br>– Costs for materials, labor, packaging, packaging and shipping; capital investment and fixed costs for software program and hardware technology, and maintenance fees.<br>– Effect of manufacturing workflows and their options on outcomes of interest investigated using generalized estimated equations models.<br>– Cost minimization, sensitivity analysis, and break-even points calculated for equipment capital costs related to implementation of workflows. |
| Otake et al, 2024[40] | NR | – Labor cost calculated from recorded hours and average hourly earnings of dentists and dental laboratory technicians (Basic Survey on Wage Structure, Ministry of Health, Labor and Welfare, Japan in 2020).<br>– Material cost based on quantity of materials used by dentist and dental laboratory technician from first visit to completion of denture adjustment, and purchase price of materials by university.<br>– Total equipment cost calculated based on service life and equipment purchase price.<br>– Total cost in Japanese Yen (labor, material, and equipment).<br>– Cost-effectiveness analysis (CEA) using incremental cost-effectiveness ratio (ICER) as incremental cost per change in general patient satisfaction for denture fabricated with hybrid workflow with respect to that of conventional workflow. |

CEA, cost-effectiveness analysis; CHF, Swiss francs; ICER, incremental cost-effectiveness ratio; NR, not reported; USD, United States dollars.

**Table 5.** Time analyses for digital, hybrid, and conventional protocol for removable complete denture fabrication

| References | Time Efficiency Outcomes | Complete Digital Workflows: IOS Scanning and CAD-CAM | Hybrid Workflows: at least a Conventional Intraoral Impression Making Digitized in Laboratory | Conventional Workflows | P |
|---|---|---|---|---|---|
| Kattadiyil et al, 2015[42] | Total clinical treatment time including additional clinical time required for remakes (mean ±SD) (hours: minutes: seconds) | | Mean time difference (conventional workflow - hybrid workflow) 03:25:00 ±01:28:00 | | .003 |
| Srinivasan et al, 2019[39] | Clinical chairside time for entire course of denture fabrication (mean ±SD) (hours: minutes: seconds) | | 06:54:00 ±00:36:00 | 10:42:00 ±00:54:00 | .002 |
| Arakawa et al, 2022[16] | Production (median; IQR days) | | 10; 32 days | 49; 31.25 days | .889 |
| | Post-delivery (median; IQR days) | | 11.5; 18 days | 50; 27.5 days | .675 |
| | Recall (median; IQR days) | | 69; 42.25 days | 70; 39.75 days | .978 |
| | Overall duration (median; IQR days) | | 99; 283.5 days | 207; 169.5 days | .757 |
| Ohara et al, 2022[44] | Time required for denture fabrication (mean ±SD) (hours: minutes: seconds) | | 02:12:51 ±00:52:51 | 02:08:34 ±00:53:34 | >.05 |
| | Time required for denture stabilization (mean ±SD) (hours: minutes: seconds) | | 01:05:42 ±00:50:00 | 00:57:08 ±00:52:08 | >.05 |
| | Number of patients visits (mean ±SD) | | 3.8 ±1.3 visits | 5.6 ±1.2 visits | <.05 |
| | Number of adjustments visits (mean ±SD) | | 3.7 ±2.2 visits | 3.5 ±2.2 visits | >.05 |
| Peroz et al, 2022[45] | Sum of working time for dentist (hours: minutes: seconds) | | Preliminary impression and delivery 01:52:00 | Preliminary impression, definitive impression, maxillo-mandibular relation, trial denture, and delivery 02:50:00 | |
| | Sum of working time for dental technician (hours: minutes: seconds) | | 02:20:00 | 07:40:00 | NR |
| | Total working time (hours: minutes: seconds) | | 04:12:00 | 10:30:00 | NR |
| Lo Russo et al, 2024[17] | Laboratory manufacturing time to complete workflow (mean ±SD) (hours: minutes: seconds) | Range for 7 manufacturing options: 01:09:00 ±00:06:00 and 02:12:00 ±00:10:12 | Range for 7 manufacturing options 01:33:00 ±00:06:00 and 02:36:00 ±00:12:00 | For injection/packing denture base / stock teeth 08:30:00 ±00:42:00 | <.001 |
| | Option 6- 3D printed base / 3D printed teeth | 02:12:00 ±00:10:12 | 02:36:00 ±00:12:00 | | >.05 |
| | Option 5- 3D printed base / milled teeth | 01:48:00 ±00:08:21 | 02:12:00 ±00:10:12 | | >.05 |
| | Option 3- milled base / 3D printed teeth | 01:48:00 ±00:08:21 | 02:12:00 ±00:10:12 | | >.05 |
| | Option 4- 3D printed base / stock teeth | 01:42:00 ±00:07:48 | 02:06:00 ±00:09:36 | | >.05 |
| | Option 1- milled base / stock teeth | 01:36:00 ±00:07:48 | 02:00:00 ±00:09:36 | | >.05 |
| | Option 2- milled base / milled teeth | 01:24:00 ±00:06:36 | 01:48:00 ±00:08:21 | | >.05 |
| | Option 7- milled in monobloc | 01:09:00 ±00:06:00 | 01:33:00 ±00:06:00 | | >.05 |

CAD-CAM, computer-aided design and computer-aided manufacture; IOS, intraoral optical scan; IQR, interquartile range; NR, not reported; SD, standard deviation.

process yielded a profit of 121.48 USD per chair hour, while a strategy combining the printing of interim appliances and the milling of the definitive denture generated a higher profit of 143 USD per chair hour. In contrast, the conventional 5-visit process results in a profit of only 69 USD per chair hour. These findings show that in-house strategies, particularly the combination of printing and milling, are significantly more profitable than the conventional protocol (Tables 6, 7). Arakawa et al[16] reported that laboratory costs were significantly lower in hybrid workflows than in conventional workflows, with similar clinical fees between the groups, leading to reduced overall costs for the hybrid workflow.

Otake et al[40] reported that the total labor, material, and equipment costs of fabricating RCDs using the custom disk method (CDM) were 362 USD, significantly less than the 398 USD for the conventional fabrication protocol. They also calculated an incremental cost-effectiveness ratio (ICER) of −251.4, indicating that each unit of patient satisfaction improvement cost 251.4 USD less with the CDM compared with the conventional method (Tables 6, 7).

Lo Russo et al[17] reported that the hybrid workflow reduced total costs for materials, labor, packaging, and shipping by 81 to 169 USD, with an additional 34 USD saving for a complete digital workflow compared with the conventional method. The conventional workflow, being significantly more labor intensive (requiring 5.90 to 7.35 more hours than hybrid or digital workflows), incurred higher opportunity costs, making it the least cost effective and least profitable. Transitioning from conventional to hybrid workflows required an average long-term capital investment of 28 750 to 81 075 USD, reduced by 13 800 USD with a complete digital workflow because of the elimination of equipment for impression making. Digital and hybrid workflows also incurred fixed yearly costs of 1150 to 2300 USD for equipment operation, support, and maintenance. The sensitivity analysis indicated break-even points ranging from 170 RCDs (3D printed base and 3D printed teeth) to 933 RCDs (milled base and stock teeth) for hybrid workflows and from 73 RCDs (3D printed base and 3D printed teeth) to 534 RCDs (milled base and stock teeth) for completely digital options to cover the investment (Tables 6, 7).

**Table 6.** Cost analyses for digital, hybrid, and conventional protocols for removable complete denture fabrication

| References | | Complete Digital Workflows: IOS Scanning and CAD-CAM | Hybrid Workflows: at least a Conventional Intraoral Impression Making Digitized in Laboratory | Conventional Workflows | *P* |
|---|---|---|---|---|---|
| Srinivasan et al, 2019[39] | Clinical fees charged to patient | | 1367.1 CHF ≈ 1394.4 USD | 1367.1 CHF ≈ 1394.4 USD | |
| | Clinical materials costs, mean ±SD | | 202.8 ±29.6 CHF ≈ 206.9 ±30.2 USD | 18.5 ±1.9 CHF ≈ 18.9 ±1.9 USD | <.001 |
| | Laboratory costs, mean ±SD | | 819.9 ±61.8 CHF ≈ 836.3 ±63.0 USD | 1980.8 ±504.9 CHF ≈ 2020.4 ±515.0 USD | <.001 |
| | Overall costs of set of dentures, mean ±SD | | 1022.7 ±74.1 CHF ≈ 1043.2 ±75.6 USD | 1990.3 ±505.4 CHF ≈ 2030.1 ±515.5 USD | .008 |
| | Estimated hourly labor costs: (Clinical cost - mean clinical materials cost) / mean chairside time in hours. | | 169.97 CHF profit / hour ≈ 173.37 USD profit / hour | 125.69 CHF profit / hour ≈ 128.2 USD profit / hour | |
| Smith et al, 2021[43] | Laboratory cost per unit (upper and lower denture) | | – All milled: 379.7 USD<br>– Printing interim appliances, milled denture: 229.0 USD | Conventional commercial laboratory denture: 678.0 USD | NR |
| | Cost saving per unit compared to conventional commercial laboratory denture | | – All milled: 298.3 USD saving/unit<br>– Printing interim appliances, milled definitive denture: 448.9 USD saving/unit | | NR |
| | Profitability per chair hour | | – All milled: (1230 USD - 379 USD) / 7 h = 121.48 USD profit/chair hour<br>– Printing interim appliances, milled definitive denture: (1230 USD- 229 USD) / 7 h = 143 USD profit / hour | Conventional commercial laboratory denture:<br>(1230 USD - 678 USD) / 8 h =<br>69 USD profit /chair hour | NR |
| Arakawa et al, 2022[16] | Dental treatment costs included dentist's fees and materials used | | 1111 USD - 2515 USD | 1409 USD - 2633 USD | .060 |
| | Dental laboratory costs based on final dental laboratory invoice | | 926 USD - 1591 USD | 1821 USD - 2190 USD | .001 |
| | Total costs | | 2791 USD - 4102 USD | 3864 USD - 4824 USD | .011 |
| Otake et al, 2024[40] | Labor cost of dentist, median (IQR) | | 17 302 (4183) JPY ≈ 152 (37) USD | 13 711 (8795) JPY ≈ 121 (77) USD | .087 |
| | Labor cost for dental laboratory, median (IQR) | | 6868 (669) JPY ≈ 61 (6) USD | 22 810 (87) JPY ≈ 201 (0.8) USD | <.001 |
| | Total labor cost, median (IQR) | | 24 516 (5044) JPY ≈ 216 (44) USD | 36 583 (8771) JPY ≈ 322 (77) USD | <.001 |
| | Material cost in clinic, median (IQR) | | scan, preliminary maxilla mandibular relation record, definitive impression, maxilla mandibular relation record, delivery, adjustments<br>1984 (529) JPY ≈ 17.5 (4.7) USD | Preliminary and definitive impressions, maxillomandibular relation record, denture evaluation, delivery, adjustments<br>3847 (292) JPY ≈ 34 (2.6) USD | <.001 |
| | Material cost of laboratory, median (IQR) | | Fabricating trial and definitive denture<br>12 297 (709) JPY ≈ 108 (6.2) USD | Fabricating cast-occlusal rim, mounting cast and fabricating definitive denture<br>4764 (361) JPY ≈ 42 (3.2) USD | <.001 |
| | Total material cost, median (IQR) | | 14 206 (655) JPY ≈ 125 (5.8) USD | 8641 (412) JPY ≈ 76 (3.6) USD | <.001 |
| | Total equipment cost, median (IQR) | | 2278 (258) JPY ≈ 20 (2.3) USD | 323 (0) JPY ≈ 2.8 (0) USD | <.001 |
| | Labor, material, equipment cost, median (IQR) | | 41 104 (6112) JPY ≈ 362 (54) USD | 45 276 (8619) JPY ≈ 398 (76) USD | .004 |
| | Incremental cost-effectiveness ratio | | −251.4 USD | | |
| Lo Russo et al, 2024[17] | Costs to fabricate single-arch RCD | | | | |
| | 1- Materials and consumables | | | 98.09 ±7.7 USD | NR |
| | Option 7- milled in monobloc | 116.72 ±8.6 USD | 117.99 ±9.3 USD | | |
| | Option 1- milled base / stock teeth | 112.7 ±8.9 USD | 113.96 ±8.9 USD | | |
| | Option 2- milled base / milled teeth | 77.05 ±5.9 USD | 78.31 ±6.2 USD | | |
| | Option 4- 3D printed base / stock teeth | 73.6 ±5.7 USD | 74.86 ±5.8 USD | | |
| | Option 3- milled base / 3D printed teeth | 54.05 ±3.4 USD | 55.3 ±4.4 USD | | |
| | Option 5- 3D printed base / milled teeth | 39.1 ±3.1 USD | 40.36 ±3.2 USD | | |
| | Option 6- 3D printed base / 3D printed teeth | 16.1 ±1.1 USD | 17.36 ±1.4 USD | | |
| | 2- Packing and shipping | 20.7 ±1.8 USD | 48.3 ±3.8 USD | 55.2 ±4.4 USD | <.001 |
| | 3- Labor | | | 117.3 ±9.2 USD | <.001 |
| | Option 6- 3D printed base / 3D printed teeth | 30.36 ±2.3 USD | 35.88 ±2.9 USD | | |
| | Option 3- milled base / 3D printed teeth | 24.84 ±1.9 USD | 30.36 ±2.3 USD | | |

**Table 6** (*Continued*)

| References | | Complete Digital Workflows: IOS Scanning and CAD-CAM | Hybrid Workflows: at least a Conventional Intraoral Impression Making Digitized in Laboratory | Conventional Workflows | *P* |
|---|---|---|---|---|---|
| | Option 5- 3D printed base / milled teeth | 24.84 ±1.9 USD | 30.36 ±2.3 USD | | |
| | Option 4- 3D printed base / stock teeth | 23.46 ±1.8 USD | 28.98 ±2.3 USD | | |
| | Option 1- milled base / stock teeth | 22.08 ±1.7 USD | 27.6 ±2.2 USD | | |
| | Option 2- milled base / milled teeth | 19.32 ±1.5 USD | 24.8 ±1.7 USD | | |
| | Option 7- milled in monobloc | 15.87 ±1.15 USD | 21.39 ±1.7 USD | | |
| | 4- Total material, packing, and labor costs | | | 270.6 USD | <.001 |
| | Option 1- milled base / stock teeth | 155.48 USD | 189.86 USD | | |
| | Option 7- milled in monobloc | 153.29 USD | 187.68 USD | | |
| | Option 4- 3D printed base / stock teeth | 117.9 USD | 152.14 USD | | |
| | Option 2- milled base / milled teeth | 117.07 USD | 151.41 USD | | |
| | Option 3- milled base / 3D printed teeth | 99.59 USD | 133.96 USD | | |
| | Option 5- 3D printed base / milled teeth | 84.64 USD | 119.02 USD | | |
| | Option 6- 3D printed base / 3D printed teeth | 67.16 USD | 101.54 USD | | |
| | 5- Capital investment in software program | | | 0 USD | <.001 |
| | Option 1- milled base / stock teeth | 13 800 ±1092.5 USD | 13 800 ±1092.5 USD | | |
| | Option 2- milled base / milled teeth | 13 800 ±1092.5 USD | 13 800 ±1092.5 USD | | |
| | Option 3- milled base / 3D printed teeth | 13 800 ±1092.5 USD | 13 800 ±1092.5 USD | | |
| | Option 5- 3D printed base / milled teeth | 13 800 ±1092.5 USD | 13 800 ±1092.5 USD | | |
| | Option 7- milled in monobloc | 13 800 ±1092.5 USD | 13 800 ±1092.5 USD | | |
| | Option 4- 3D printed base / stock teeth | 4025 ±437 USD | 4025 ±437 USD | | |
| | Option 6- 3D printed base / 3D printed teeth | 4025 ±437 USD | 4025 ±437 USD | | |
| | 6- Capital investment in hardware technology | | | 0 USD | <.001 |
| | Option 3- milled base / 3D printed teeth | 53 475 ±4220.5 USD | 67 275 ±5318.7 USD | | |
| | Option 5- 3D printed base / milled teeth | 53 475 ±4220.5 USD | 67 275 ±5318.7 USD | | |
| | Option 1- milled base / stock teeth | 47 725 ±3772 USD | 61 525 ±4864.5 USD | | |
| | Option 2- milled base / milled teeth | 47 725 ±3772 USD | 61 525 ±4864.5 USD | | |
| | Option 7- milled in monobloc | 47 725 ±3772 USD | 61 525 ±4864.5 USD | | |
| | Option 4- 3D printed base / stock teeth | 10 925 ±862.5 USD | 24 725 ±1955 USD | | |
| | Option 6- 3D printed base / 3D printed teeth | 10 925 ±862.5 USD | 24 725 ±1955 USD | | |
| | 7- Annual fees | | | 0 USD | <.001 |
| | Option 1- milled base / stock teeth | 2300 ±184 USD | 2300 ±184 USD | | |
| | Option 2- milled base / milled teeth | 2300 ±184 USD | 2300 ±184 USD | | |
| | Option 3- milled base / 3D printed teeth | 2300 ±184 USD | 2300 ±184 USD | | |
| | Option 5- 3D printed base / milled teeth | 2300 ±184 USD | 2300 ±184 USD | | |
| | Option 7- milled in monobloc | 2300 ±184 USD | 2300 ±184 USD | | |
| | Option 4- 3D printed base / stock teeth | 1150 ±97.7 USD | 1150 ±97.7 USD | | |
| | Option 6- 3D printed base / 3D printed teeth | 1150 ±97.7 USD | 1150 ±97.7 USD | | |
| | Sensitivity analysis and break-even points | 73 (3D printed base / 3D printed teeth) to 534 (milled base / stock teeth) dentures needed to cover investment and reach break-even point. | 170 (3D printed base / 3D printed teeth) to 933 (milled base / stock teeth) dentures needed to cover investment and reach break-even point. | | |

CAD-CAM, computer-aided design and computer-aided manufacture; CHF, Swiss francs; IOS, intraoral optical scan; IQR, interquartile range; JPY, Japanese yen; NR, not reported; RCD, removable complete denture; SD, standard deviation; USD, United States dollars.

**Table 7.** Comparative summary of time and cost analyses among workflows in included articles

| References | Countries | Workflows | Time Required to Complete Stages of Denture Fabrication | | | Cost Analysis | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Clinical Chairside Time | Laboratory Time | Overall Time | Clinical Cost | Laboratory Cost | Clinical and Laboratory Costs | Cost Effectiveness |
| Kattadiyil et al, 2015[42] | USA | Hybrid versus Conventional | Significantly 3 h less time with hybrid. | - | - | - | - | - | - |
| Srinivasan et al, 2019[39] | Switzerland | Hybrid versus Conventional | Significantly 4 h less time with hybrid. | - | - | Significantly lower for conven-tional. | Significantly lower for hybrid. | Significantly lower for hybrid. | Hourly labor cost:<br>173.4 USD for hybrid<br>128.2 USD for conventional<br>Saving of over 147 900 USD over 10 years in educational setting |
| Smith et al, 2021[43] | USA | Hybrid versus Conventional | - | - | - | - | Significantly lower for hybrid. | - | –In-house laboratory strategy profit:<br>All-milled process: 121.48 USD / chair hour<br>Printing interim appliances and milling definitive denture: 143 USD /chair hour<br>–Conventional profit: 69 USD / chair hour |
| Arakawa et al, 2022[16] | Switzerland | Hybrid versus Conventional | - | - | No significant difference | No significant difference | Significantly lower for hybrid. | Significantly lower for hybrid. | - |
| Ohara et al, 2022[44] | Japan | Hybrid versus Conventional | Fewer visits with hybrid (3.8 ±1.3) versus conventional (5.6 ±1.2) workflows. | - | - | - | - | - | - |
| Peroz et al, 2022[45] | Germany | Hybrid versus Conventional | Significantly 1 h less time with hybrid. | Significantly 5 h less time with hybrid. | Significantly 6 h less time with hybrid. | - | - | - | - |
| Lo Russo et al, 2024[17] | Italy | Digital, Hybrid, versus Conventional | - | Significantly 5.9 to 7.35 h less time with digital and hybrid. | - | - | Material, packing, and labor costs reduced by 81 to 169 USD for hybrid workflow. Additional saving of 34 USD for digital workflow. | - | Long-term capital investment of 28 750 to 81 075 USD for hybrid reduced by 13 800 USD for digital workflow.<br>Fixed yearly costs of 1150 to 2300 USD for digital and hybrid workflows.<br>170 to 933 dentures for hybrid versus 73 to 534 dentures for digital to cover investment. |
| Otake et al, 2024[40] | Japan | Hybrid versus Conventional | - | - | - | Significantly lower for conven-tional. | Significantly lower for hybrid. | Significantly lower for hybrid. | ICER of −251.4: each unit of patient satisfaction costs 251.4 USD less with hybrid workflow. |

ICER, incremental cost-effectiveness ratio; USA, United States of America; USD, United States dollars.

## DISCUSSION

This systematic review evaluated the time efficiency and cost effectiveness of RCDs fabricated using conventional, hybrid, and completely digital workflows. The null hypotheses that no differences in time or cost would be found among these workflows were rejected. The results determined that digital and hybrid workflows were more time efficient and cost effective than conventional methods.

The hybrid protocol reduced clinical chairside time by 1 to 4 hours[39,42,45] and decreased the number of dental visits,[44] highlighting the benefits of digital technologies in streamlining procedures and reducing patient appointments.[31] Even a reduction of 1 or 2 visits can greatly improve patient satisfaction and practice efficiency. However, the AVADent process, which involved a 2-appointment protocol, was used in 3 studies.[16,39,42] This protocol includes making definitive impressions, recording interocclusal records, and selecting teeth during the first visit, with records sent to a digital system for scanning and virtual arrangement approval. The second visit is for denture delivery. This process does not account for the initial consultation, clinical evaluation, or follow-up adjustments, potentially underestimating the actual time required for RCD fabrication with a digital or hybrid workflow.

Both hybrid and completely digital workflows reduce manufacturing laboratory time by about 6 to 7 hours compared with conventional workflows.[17,45] Digital processes such as milled monobloc dentures contribute to these time savings.[17] This reduction in clinical and laboratory time can enhance productivity and patient satisfaction,[28] allowing dentists to focus more on patient care and improving clinic efficiency by reducing the number and length of patient visits.

Cost analyses show that digital and hybrid workflows are more economically efficient than conventional methods for fabricating RCDs. Srinivasan et al[39] reported that hybrid workflows significantly reduced both laboratory and overall costs for milled RCDs compared with conventional workflows. Smith et al[43] reported increased profitability with in-house laboratory strategies with milled RCDs fabricated using hybrid workflow. Otake et al[40] reported that milled RCDs with the custom disk method were more cost effective and enhanced patient satisfaction compared with conventional approaches. The subtractive method, which involves milling denture bases from prepolymerized polymethyl methacrylate (PMMA) resin blocks,[46,47] has also been reported to improve the physical and mechanical properties of PMMA materials compared with conventional processing methods.[23,25,48]

Traditional materials have been associated with issues that include dimensional changes, internal bubbles, reduced resistance to fracture, residual monomer,[26] and increased surface roughness, which can compromise oral hygiene and lead to conditions such as denture stomatitis.[49] Adopting milled base dentures addresses these problems, potentially improving patient comfort and oral health outcomes.[23,50]

Lo Russo et al[17] reported that the digital workflow offered long-term cost savings and increased profitability despite the initial investment. Their findings suggested that complete digital or hybrid workflows improved time efficiency and reduced costs for RCDs fabrication. However, scanning edentulous arches presents challenges, including the absence of anatomic landmarks, the need to capture functional borders, and determining the posterior palatal seal.[23] Intraoral scans (IOSs) provide a preliminary digital method for capturing ridges,[23,50,51] but conventional impression techniques, with clinical steps such as border molding and posterior palatal seal compression, offer better retention.[15] The mucodynamic technique used in conventional methods captures peripheral tissues in a functional state, creating a peripheral seal that remains intact during muscle movement.[51,52] Future advancements may integrate mucodynamic techniques into IOS, improving the accuracy and effectiveness of digital scans for RCD fabrication.

Conversely, Lo Russo et al[17] reported that 3D printed base dentures were more cost effective and profitable than milled base dentures. However, 3D printed dentures have been limited to trial dentures because of the inadequate mechanical properties, poor adaptation, and lower accuracy compared with subtractive techniques.[19,53–55]

Investing in digital technologies can provide long-term financial benefits, despite the initial cost.[17] Ongoing investment is necessary to keep technology updated and effective. Institutions may benefit from investing in digital technologies to streamline denture fabrication, enhancing patient satisfaction and reducing chairside time. However, conventional workflows remain crucial in teaching curricula to ensure students understand the fundamental concepts that are the basis of both traditional and digital methods.[39]

This systematic review outlined the advantages of digital and hybrid workflows over conventional methods in fabricating RCDs, highlighting their time efficiency and cost effectiveness. These advancements significantly reduce overall costs, thereby enhancing affordability and patient access to advanced dental treatments. However, the review identified several limitations. Firstly, most studies were conducted in educational institutions, and 1 study involved a small number of private dental laboratories and clinics, which may not fully represent private practice settings. Future research should include studies in dental practice settings to improve the generalizability of the findings. Secondly, variability in fabrication processes, equipment, and materials among digital and hybrid workflows suggests a need for standardized protocols to increase consistency and comparability. Thirdly, the review notes that studies are predominantly from only a few countries (Switzerland, Italy, Germany, USA, Japan), indicating a need for research in other regions with different healthcare systems and cost structures.

The review consolidates evidence on CAD-CAM versus conventional RCD fabrication and provides a basis for future research. Further studies, especially larger randomized controlled trials in diverse clinical settings, are needed to validate these findings and explore long-term outcomes and patient satisfaction with different digital manufacturing processes.

## CONCLUSIONS

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

1. Digital and hybrid workflows for RCD fabrication are more time efficient than conventional methods.
2. Digital and hybrid workflows for RCD fabrication are more cost effective than conventional methods.

## REFERENCES


1. Al-Rafee MA. The epidemiology of edentulism and the associated factors: A literature review. *J Family Med Prim Care*. 2020;9:1841–1843.
2. El Osta N, El Osta L, Moukaddem F, et al. Impact of implant- supported prostheses on nutritional status and oral health perception in edentulous patients. *Clin Nutr ESPEN*. 2017;18:49–54.
3. Srinivasan M, Schimmel M, Leles C, McKenna G. Managing edentate older adults. *Prim Dent J*. 2020;9:29–33.
4. Douglass CW, Shih A, Ostry L. Will there be a need for complete dentures in the United States in 2020? *J Prosthet Dent*. 2002;87:5–8.
5. El Osta N, Haddad E, Fakhouri J, Saad R, El Osta L. Comparison of psychometric properties of GOHAI, OHIP-14, and OHIP-EDENT as measures of oral health in complete edentulous patients aged 60 years and more. *Qual Life Res*. 2021;30:1199–1213.
6. Paulino MR, Alves LR, Gurgel BCV, Calderon PS. Simplified versus traditional techniques for complete denture fabrication: A systematic review. *J Prosthet Dent*. 2015;113:12–16.
7. Jacob RF. The traditional therapeutic paradigm: complete denture therapy. *J Prosthet Dent*. 1998;79:6–13.
8. Rudd RW, Rudd KD. A review of 243 errors possible during the fabrication of a removable partial denture: Part III. *J Prosthet Dent*. 2001;86:277–288.
9. Rudd RW, Rudd KD. A review of 243 errors possible during the fabrication of a removable partial denture: Part II. *J Prosthet Dent*. 2001;86:262–276.
10. Zupancic Cepic L, Gruber R, Eder J, Vaskovich T, Schmid-Schwap M, Kundi M. Digital versus conventional dentures: A prospective, randomized cross-over study on clinical efficiency and patient satisfaction. *J Clin Med*. 2023;12:434.
11. Omar H, Atta O, El-Mowafy O. Difference between selected and obtained shade for metal-ceramic crown systems. *Oper Dent*. 2008;33:502–507.
12. Baba NZ, AlRumaih HS, Goodacre BJ, Goodacre CJ. Current techniques in CAD/CAM denture fabrication. *Gen Dent*. 2016;64:23–28.
13. Bonnet G, Batisse C, Travers C, Bessadet M. Integration of CAD/CAM technology in global dental prosthetic treatment: A case report. *Int Multispecial J Health*. 2016;2:9–12.
14. Bonnet G, Batisse C, Bessadet M, Nicolas E, Veyrune JL. A new digital denture procedure: A first practitioners appraisal. *BMC Oral Health*. 2017;17:155.
15. Chebib N, Kalberer N, Srinivasan M, Maniewicz S, Perneger T, Müller F. Edentulous jaw impression techniques: An in vivo comparison of trueness. *J Prosthet Dent*. 2019;121:623–630.
16. Arakawa I, Al-Haj Husain N, Srinivasan M, Maniewicz S, Abou-Ayash S, Schimmel M. Clinical outcomes and costs of conventional and digital complete dentures in a university clinic: A retrospective study. *J Prosthet Dent*. 2022;128:390–395.
17. Lo Russo L, Zhurakivska K, Guida L, Chochlidakis K, Troiano G, Ercoli C. Comparative cost-analysis for removable complete dentures fabricated with conventional, partial, and complete digital workflows. *J Prosthet Dent*. 2024;131:689–696.
18. Kattadiyil MT, Goodacre CJ, Baba NZ. CAD/CAM complete dentures: A review of two commercial fabrication systems. *J Calif Dent Assoc*. 2013;41:407–416.
19. Kalberer N, Mehl A, Schimmel M, Müller F, Srinivasan M. CAD-CAM milled versus rapidly prototyped (3D-printed) complete dentures: An in vitro evaluation of trueness. *J Prosthet Dent*. 2019;121:637–643.
20. Srinivasan M, Cantin Y, Mehl A, Gjengedal H, Müller F, Schimmel M. CAD/CAM milled removable complete dentures: An in vitro evaluation of trueness. *Clin Oral Investig*. 2017;21:2007–2019.
21. Wang C, Shi YF, Xie PJ, Wu JH. Accuracy of digital complete dentures: A systematic review of in vitro studies. *J Prosthet Dent*. 2021;125:249–256.
22. Chen H, Wang H, Lv P, Wang Y, Sun Y. Quantitative evaluation of tissue surface adaption of CAD-designed and 3D printed wax pattern of maxillary complete denture. *Biomed Res Int*. 2015;2015:453968.
23. Batisse C, Nicolas E. Comparison of CAD/CAM and conventional denture base resins: A systematic review. *Appl Sci*. 2021;11:5990.
24. Srinivasan M, Gjengedal H, Cattani-Lorente M, et al. CAD/CAM milled complete removable dental prostheses: An in vitro evaluation of biocompatibility, mechanical properties, and surface roughness. *Dent Mater J*. 2018;37:526–533.
25. Baba NZ, Goodacre BJ, Goodacre CJ, Müller F, Wagner S. CAD/CAM complete denture systems and physical properties: A review of the literature. *J Prosthodont*. 2021;30:113–124.
26. Steinmassl PA, Wiedemair V, Huck C, et al. Do CAD/CAM dentures really release less monomer than conventional dentures? *Clin Oral Investig*. 2017;21:1697–1705.
27. Janeva NM, Kovacevska G, Elencevski S, Panchevska S, Mijoska A, Lazarevska B. Advantages of CAD/CAM versus conventional complete dentures - A review. *Open Access Maced J Med Sci*. 2018;6:1498–1502.
28. Avelino MEL, Costa RTF, Vila-Nova TEL, Vasconcelos BC do E, Pellizzer EP, Moraes SLD. Clinical performance and patient-related outcome measures of digitally fabricated complete dentures: A systematic review and meta-analysis. *J Prosthet Dent*. 2024;132:748.e1–748.e10.
29. Le Texier L, Nicolas E, Batisse C. Evaluation and comparison of the accuracy of three intraoral scanners for replicating a complete denture. *J Prosthet Dent*. 2024;131:706.e1–706.e8.
30. Drancourt N, Auduc C, Mouget A, et al. Accuracy of conventional and digital impressions for full-arch implant-supported prostheses: An in vitro study. *J Pers Med*. 2023;13:832.
31. Bessadet M, Drancourt N, El Osta N. Time efficiency and cost analysis between digital and conventional workflows for the fabrication of fixed dental prostheses: A systematic review. *J Prosthet Dent*. 2025;133:71–84.
32. El Osta N, Drancourt N, Auduc C, Veyrune JL, Nicolas E. Accuracy of conventional impressions and digital scans for implant-supported fixed prostheses in maxillary free-ended partial edentulism: An in vitro study. *J Dent*. 2024;143:104892.
33. Bessadet M, Auduc C, Drancourt N, Nicolas E, El Osta N. Comparative analyses of time efficiency and cost in fabricating fixed implant-supported prostheses in digital, hybrid, and conventional workflows: A systematic review and meta-analysis. *J Prosthet Dent*. 2025;133:689–712.
34. Shrirao ND, Deshmukh SP, Pande NA, Radke UM. An evaluation of patient's decisions regarding dental prosthetic treatment. *J Indian Prosthodont Soc*. 2016;16:366–371.
35. Beauchemin M, Cohn E, Shelton RC. Implementation of clinical practice guidelines in the healthcare setting: A concept analysis. *ANS Adv Nurs Sci*. 2019;42:307.
36. Moher D, Shamseer L, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst Rev*. 2015;4(1).
37. Cuschieri S. The CONSORT statement. *Saudi J Anaesth*. 2019;13:S27–S30.
38. Cuschieri S. The STROBE guidelines. *Saudi J Anaesth*. 2019;13:S31–S34.
39. Srinivasan M, Schimmel M, Naharro M, McKenna O' Neill C, Müller G. F. CAD/CAM milled removable complete dentures: Time and cost estimation study. *J Dent*. 2019;80:75–79.
40. Otake R, Kanazawa M, Iwaki M, Soeda Y, Hada T, Katheng A, et al. Patient-reported outcome and cost-effectiveness analysis of milled and conventionally fabricated complete dentures in a university clinic: A retrospective study. *J Prosthet Dent*. 2024;131:227–232.
41. 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:n71.
42. Kattadiyil MT, Jekki R, Goodacre CJ, Baba NZ. Comparison of treatment outcomes in digital and conventional complete removable dental prosthesis fabrications in a predoctoral setting. *J Prosthet Dent*. 2015;114:818–825.
43. Smith PB, Perry J, Elza W. Economic and Clinical Impact of Digitally Produced Dentures. *J Prosthodont*. 2021;30:108–112.

44. Ohara K, Isshiki Y, Hoshi N, Ohno A, Kawanishi N, Nagashima S, et al. Patient satisfaction with conventional dentures vs. digital dentures fabricated using 3D-printing: A randomized crossover trial. *J Prosthodont Res*. 2022;66:623–629.
45. Peroz S, Peroz I, Beuer F, Sterzenbach G, von Stein-Lausnitz M. Digital versus conventional complete dentures: A randomized, controlled, blinded study. *J Prosthet Dent*. 2022;128:956–963.
46. Alqutaibi AY, Baik A, Almuzaini SA, Farghal AE, Alnazzawi AA, Borzangy S, et al. Polymeric Denture Base Materials: A Review. *Polymers ((Basel))*. 2023;15:3258.
47. de Oliveira Limírio JPJ, Gomes JM, de L, Alves Rezende MCR, Lemos CAA. Rosa CDDRD, Pellizzer EP. Mechanical properties of polymethyl methacrylate as a denture base: Conventional versus CAD-CAM resin - A systematic review and meta-analysis of in vitro studies. *J Prosthet Dent*. 2022;128:1221–1229.
48. Al-Dwairi ZN, Tahboub KY, Baba NZ, Goodacre CJ, Özcan M. A Comparison of the Surface Properties of CAD/CAM and Conventional Polymethylmethacrylate (PMMA). *J Prosthodont*. 2019;28:452–457.
49. Chappuis Chocano AP, Venante HS, Bringel da Costa RM, Pordeus MD, Santiago Junior JF, Porto VC. Evaluation of the clinical performance of dentures manufactured by computer-aided technology and conventional techniques: A systematic review. *J Prosthet Dent*. 2023;129:547–553.
50. Maniewicz S, Imamura Y, El Osta N, Srinivasan M, Müller F, Chebib N. Fit and retention of complete denture bases: Part I - Conventional versus CAD-CAM methods: A clinical controlled crossover study. *J Prosthet Dent*. 2024;131:611–617.
51. Chebib N, Imamura Y, El Osta N, Srinivasan M, Müller F, Maniewicz S. Fit and retention of complete denture bases: Part II - conventional impressions versus digital scans: A clinical controlled crossover study. *J Prosthet Dent*. 2024;131:618–625.
52. Srivastava G, Padhiary SK, Mohanty N, Molinero-Mourelle P, Chebib N. Accuracy of Intraoral Scanner for Recording Completely Edentulous Arches-A Systematic Review. *Dent J ((Basel))*. 2023;11:241.
53. Prpić V, Schauperl Z, Ćatić A, Dulčić N, Čimić S. Comparison of Mechanical Properties of 3D-Printed, CAD/CAM, and Conventional Denture Base Materials. *J Prosthodont*. 2020;29:524–528.
54. Srinivasan M, Kamnoedboon P, McKenna G, Angst L, Schimmel M, Özcan M, et al. CAD-CAM removable complete dentures: A systematic review and meta-analysis of trueness of fit, biocompatibility, mechanical properties, surface characteristics, color stability, time-cost analysis, clinical and patient-reported outcomes. *J Dent*. 2021;113:103777.
55. Bento VAA, Gomes JML, Oliveira-Limirio JPJ, Rosa CDDRD, Lemos CAA, Dos Santos DM, et al. Effect of Aging on the Mechanical Properties of CAD/CAM-Milled and 3D-Printed Acrylic Resins for Denture Bases. *Int J Prosthodont*. 2024;37:5–11.



**Corresponding author:**

Prof Nada El Osta
University of Clermont Auvergne
Clinical Odontology Research Center (CROC)
Clermont-Ferrand F-63000
FRANCE
Email: nada.el_osta@uca.fr


**CRediT authorship contribution statement**

**Nada El Osta**: Conceptualization, Methodology, Validation, Resources, Writing-original draft, Writing - review and editing, Visualization, Supervision. **Marion Bessadet**: Conceptualization, Methodology, Resources, Visualization. **Noémie Drancourt**: Validation, Methodology. **Cindy Batisse**: Visualization, Writing - review and editing, Supervision.


https://doi.org/10.1016/j.prosdent.2024.10.008