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SYSTEMATIC REVIEW

# Evaluation of the clinical performance of dentures manufactured by computer-aided technology and conventional techniques: A systematic review

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## ABSTRACT

**Statement of problem.** The introduction of computer-aided design and computer-aided manufacturing (CAD-CAM) technology for complete denture fabrication may have improved clinical outcomes compared with conventional techniques. However, systematic reviews comparing these techniques are lacking.

**Purpose.** The purpose of this systematic review was to identify, compare, and synthesize the outcomes of published clinical studies related to complete denture fabrication, with respect to the differences between CAD-CAM technology and conventional techniques.

**Material and methods.** A comprehensive search of studies published up to March 16, 2020, was conducted by using the PubMed/MEDLINE, Web of Science, Cochrane Library, SciELO, and Embase databases according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement criteria and was registered in the International Prospective Register of Systematic Reviews (PROSPERO ID 42020202614). The population, intervention, comparison, and outcome (PICO) question was: Do CAD-CAM complete dentures have a similar functional performance to those fabricated by conventional techniques? The quality of publications was appraised by using the Critical Appraisal Skills Program (CASP) checklists.

**Results.** Of the 1232 titles, 6 articles were selected. The studies reported better retention of digitally manufactured complete dentures without denture adhesives than that of conventional complete dentures with or without denture adhesives. Other studies reported that dentures manufactured with digital systems were better adapted to tissue surfaces, required less clinical time, were lower in cost, and provided better experience and satisfaction to patients.

**Conclusions.** The assessment of CAD-CAM planning and manufacturing through clinical studies is ongoing. However, preliminary results indicate better clinical performance and lower overall costs of digital complete dentures than conventional dentures. (J Prosthet Dent 2023;129:547-53)

Computer-aided design and computer-aided manufacturing (CAD-CAM) technology has revolutionized clinical and dental laboratory procedures, with improved clinical outcomes.[1] It has multiple applications, including in prosthetic dentistry, enabling the manufacturing of digital casts through scans, planning with specific software programs, building of prototypes, and manufacturing of parts from various materials in an automated and expedited way.[2]

CAD-CAM complete dentures (CDs) can significantly reduce clinical time and allow the storage of digital casts and designs in a digital library. The digital record can be stored in a database as a standard tessellation language (STL)

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## Clinical Implications

The clinical performance of CAD-CAM complete dentures is comparable with that of conventional complete dentures; moreover, there is evidence that CAD-CAM complete dentures present better surface adaptation, provided more retention, and demanded less clinical time and cost.

file. The fabrication of the designed CD can be additive (rapid prototyping) or subtractive (milling of prefabricated blocks).[3]

The subtractive method is currently more commonly used, milling the denture base from prefabricated blocks of polymethylmethacrylate (PMMA) resin that had been polymerized by injection under high temperature and pressure. The blocks exhibit improved mechanical and physical properties compared with conventionally processed PMMA materials.[4] Traditional materials experience greater dimensional changes, more internal bubbles, less resistance to fracture, fewer residual monomers, and greater surface roughness, all of which can compromise oral hygiene. A porous denture base may lead to the development of denture stomatitis, one of the most recurrent pathologies among CD users.[4,5]

Therefore, CDs designed and manufactured with CAD-CAM may be advantageous over conventional dentures. Clinical studies have been conducted to evaluate this hypothesis,[3,4] but systematic reviews are lacking. The purpose of this systematic review was to identify, compare, and summarize the outcomes of clinical studies related to CD manufacturing, with respect to the differences between CAD-CAM technology and conventional techniques. The null hypotheses were that no differences would be found in denture base retention in denture manufacturing by using CAD-CAM versus traditional techniques and that these techniques would be similar in terms of cost, clinical time, adaptation, patient satisfaction, and unscheduled postinsertion visits.

## MATERIAL AND METHODS

This systematic review was conducted according to the criteria established by the Cochrane Collaboration (Cochrane Handbook for Systematic Reviews of Interventions, Handbook 6.2)[6] and followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations to develop and elaborate on a systematic review.[7-9] This systematic review, which was limited to clinical studies, was registered in the International Prospective Register of Systematic Reviews (PROSPERO) database (CRD42020202614) to evaluate the proposed methodological design.

Analyses were based on the population, intervention, comparison, and outcome (PICO) index: those undergoing prosthetic treatment involving CDs (population), those receiving digitally manufactured CDs (intervention), those receiving CDs by using digital and conventional methods (comparison), and studies evaluating retention, tissue surface adaptation, time and costs, and unscheduled visits (outcome). Studies were selected according to the search strategy with respect to 4 inclusion criteria: English language; studies involving scanning (intraoral or laboratory), planning, and printing or milling of CDs with the CAD-CAM technology; clinical studies; and studies that used conventional dentures as a comparison. Clinical reports, proofs of concept, and systematic reviews were excluded.

The databases used included Medline/PubMed, Cochrane Library, SciELO, Web of Science, and Embase. Searches were conducted for articles published from 1991 to March 16, 2020. The following MeSH/PubMed-based Boolean operators were used: "Removable complete Denture", "Complete denture", "Removable denture", "CAD-CAM", "Digital", "OR", and "AND". A related search of PubMed is presented in Supplementary Table 1 (available online). A manual search of specific journals and related studies on dental dentures and digital technology was also conducted.

Two previously calibrated reviewers (H.S.V., A.P.C.C.) conducted the article selection and data collection; articles related to the theme were sought, submitted, and approved by using the kappa test ($\kappa$=1.0). The study included 3 other researchers (M.D.P., R.M.B.C., J.F.S.Jr), who evaluated the selected articles, data collection analysis, and risk of bias. Further clarifications on doubts and technical support were provided by an additional reviewer (V.C.P.). The clinical studies included were evaluated for their methodology and classified according to the type of research (randomized controlled trials, cohort studies, cross-sectional studies, or case control studies).[10] All data in the tables (qualitative data and risk of bias) were extracted by 2 investigators (H.S.V., A.P.C.C.) and checked by another investigator (J.F.S.Jr). For bias risk analysis, comparisons were evaluated by using methodology structure and classified according to the type of study conducted and the clinical outcomes.[11] The quality of publications was appraised by using the Critical Appraisal Skills Program (CASP) checklists for randomized controlled trials; results were analyzed and discussed by using a narrative synthesis approach (Table 1).

## RESULTS

The initial search resulted in 1232 titles, of which 12 were selected based on the title and abstract. On reading, 6 studies were excluded as they did not meet the inclusion

**Table 1.** Quality appraisal by using CASP checklist for randomized controlled trials

| CASP Randomized Control Study Checklist | Drago and Borget, 2019 | AlRumaih et al, 2017[12] | AlHelal et al, 2016[13] | Kattadiyil et al, 2015[14] | Yoon et al, 2020[16] | Srinivasan et al, 2018[15] |
|---|---|---|---|---|---|---|
| Did the trial address a clearly focused issue? | Yes | Yes | Yes | Yes | Yes | Yes |
| Was the assignment of patients to treatments randomized? | Yes | Yes | Yes | Yes | Yes | Yes |
| Were all patients who entered the trial properly accounted for at its conclusion? | Yes | Yes | Yes | Yes | Yes | Yes |
| Were patients, health workers, and study personnel blind to treatment? | No | Yes | Yes | Inconclusive | Yes | No |
| Were groups similar at the start of the trial? | Yes | Yes | Yes | Yes | Yes | Yes |
| Aside from experimental intervention, were groups treated equally? | Yes | Yes | Yes | Yes | Yes | Yes |
| How large was the treatment effect? | Not significant ($P$=.55) | Not significant ($P$>.05) | Significant ($P$<.001) | Significant ($P$=.0007), ($P$=.001), ($P$<.01), ($P$<.05) | Not significant ($P$<.05) | Significant ($P$<.02) |
| How precise was the estimate of the effects of treatment? | Cannot tell (no CI limits) | Cannot tell (no CI limits) | Cannot tell (no CI limits) | Cannot tell (no CI limits) | Cannot tell (no CI limits) | Cannot tell (no CI limits) |
| Are the results applicable in your context? (Or to the local population) | Yes | Yes | Yes | Yes | Yes | Yes |
| Were all clinically important outcomes considered? | Yes | Yes | Yes | Yes | Yes | Yes |
| Are the benefits worth the harms and costs? | No | Yes | Yes | Yes | No | Yes |

CASP, Critical Appraisal Skills Program; CI, confidence interval. Significance, $P<.05$.

criteria; the remaining 6, all clinical studies,[12-17] were selected (Fig. 1). Two assessed retention,[12,13] 2 evaluated the time and cost,[14,15] 1 reported the tissue surface adaptation,[16] 1 presented the experience and satisfaction of patients,[14] and the other counted the unscheduled and postinsertion adjustment visits of digital and conventional CDs.[17] Several CD-manufacturing techniques were reported, including pack and press and injection molding as traditional processes and milling and digital light processing as digital processes (Table 2). The main results were divided based on the objectives, summarizing each selected study.

Two articles[12,13] evaluated the retention between conventional and digital dentures. Both studies included the same participants (n=20) who received conventional and digital CDs in the maxilla. In the initial study, AlHelal et al[13] reported that complete digital dentures made by using the milling technique provided greater retention (74.14 N) than conventional CDs (54.23 N) ($P$<.001). Subsequently, the research group also evaluated the effect of using adhesives (Fixodent; Procter & Gamble Co). Similarly, AlRumaih et al[12] reported that digital CDs (74.14 N) had a greater retention than conventional CDs (54.23 N) ($P$<.001). When adhesives were used, no significant differences were found in the retention means with digital CDs (58.79 N) compared with the conventional CDs (52.81 N) ($P$=.088). Additionally, there was no significant increase in the retention of conventional CDs with the use of the adhesive ($P$=.570).

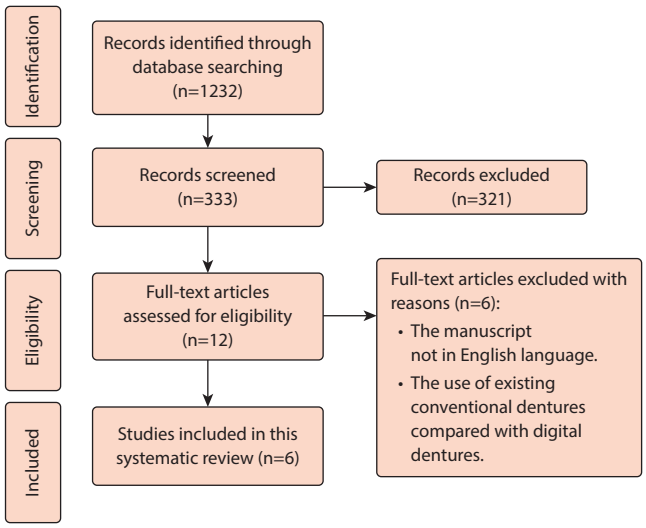


**Figure 1.** Data on article selection according to PRISMA diagram. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

Two articles[14,15] assessed the time required to manufacture digital and conventional dentures; both studies used the Avadent block to manufacture digital CDs. Kattadiyil et al[14] reported that the conventional manufacturing of CDs required significantly ($P$=.003) more clinical time than digital manufacturing of CDs, with the time difference between the techniques averaging 205 minutes. Similarly, Srinivasan et al[15] reported statistically significant differences between the

**Table 2.** Clinical studies of dentures processed by CAD-CAM systems and conventional techniques

| Author | Year | Number of Patients | Level of Evidence | Fabrication Technique/ Patients | Framework Material | Arch | Methodology | Results |
|---|---|---|---|---|---|---|---|---|
| AlRumaih et al[12] | 2017 | 20 | III-2 | Milled/20 Conventional (pack and press)/20 | Avadent PMMA block Lucitone 199 | Maxilla | Motorized test stand (ESM301L, Mark-10 Corp)+advanced digital force gauge (Series 5; Mark-10 Corp). | Milled denture presented significantly higher retention than heat-activated resin bases without use of denture adhesives. Denture adhesives significantly affected retention of milled dentures. |
| AlHelal et al[13] | 2016 | 20 | III-2 | Milled/20 Conventional (pack-press)/20 | Avadent PMMA block Lucitone 199 | Maxilla | Motorized test stand (ESM301L, Mark-10 Corp)+advanced digital force gauge (Series 5; Mark-10 Corp). | Milled complete dentures presented higher retention than conventional heat-polymerized dentures. |
| Drago and Borgert[17] | 2019 | 106 | III-2 | Milled/73 Conventional (Injection molding)/33 | Avadent PMMA block SR Ivocap Injection System (Ivoclar AG) | Maxilla and mandible | Computerized search of the electronic medical records by using the American Dental Association codes (5110, maxillary complete denture; 5120, mandibular complete denture). | No significant differences in number of unscheduled postinsertion visits in patients that received conventional or milled dentures. |
| Srinivasan et al[15] | 2018 | 12 | III-2 | Milled/12 Conventional/12 | Avadent PMMA block Candulor Aesthetic red | Maxilla (6) Both arches (12) | Cost minimization analysis: Estimated hourly labor cost=(clinical cost-mean clinical materials cost)/mean chairside time (in h) | Clinical chairside time and laboratory and overall cost of CAD-CAM denture protocol significantly lower than conventional protocol, despite material costs for this protocol being higher. |
| Yoon et al[16] | 2020 | 9 | III-2 | Milled/9 DLP/9 Conventional (pack and press)/9 | Vipi block gum Next Dent base SR Triplex Hot, Ivoclar AG | Maxilla (7) Mandible (5) | Evaluation of adaptation indicator (Fit checker II)+Stereomicroscope (SZX16) at ×50 magnification+image analysis software program (ToupView, Touptek) | DLP denture bases demonstrated superior adaptation to tissue surfaces than MIL or PAP denture bases. The MIL denture bases showed acceptable level of adaptation to tissue surfaces and, when compared with PAP bases, had better adaptation on lingual slope. |
| Kattadiyil et al[14] | 2015 | 15 | III-2 | Milled/15 Conventional (lost wax technique)/15 | Avadent PMMA block Lucitone 199 | Maxilla and mandible | 5-point Likert rating scale (0-4) | Milled technique more efficient than conventional technique in predoctoral program. |

CAD-CAM, computer-aided design and computer-aided manufacture; DLP, digital light processing; MIL, milling technique; PAP, pack and press (conventional technique).

techniques ($P$=.02, $P$=.002), with mean differences of 108 minutes for a single-arch CD and 233 minutes for opposing CDs, with less time for digitally made CDs. In addition, Srinivasan et al[15] evaluated differences in material costs, concluding that there were significant differences ($P$<.001) between techniques. Conventional CDs had the lowest average values (18.46 ±1.91 CHF), and the laboratory costs were statistically significant ($P$=.008) between the techniques, with digital CDs having the lower average cost (1022.70 ±74.09 CHF).[15]

One article[16] was selected to compare the surface adaptation between different digital techniques (digital light processing and milling) and the conventional technique (pack and press) in 9 edentulous participants with 12 completely edentulous arches (7 maxillary and 5 mandibular). This study did not report statistical differences in the absolute tissue surface adaptation among the 3 denture base fabrication techniques ($P$>.05). However, in terms of relative tissue surface adaptation, the maxillary dentures manufactured with the DLP technique had better adaptation to tissues in the maxillary arch areas of tension (residual ridge and midpalatal suture) than the conventional method ($P$=.001, $P$=.005). The maxillary denture manufactured with the milling technique had small gaps between the supporting tissue and denture base. In terms of the mandibular denture, both digital techniques demonstrated a more intimate adaptation in the lingual inclination area than the conventional denture.[16]

One article[14] assessed the experience and satisfaction of 16 participants rehabilitated with CDs manufactured with conventional and digital techniques; this assessment was conducted by using a questionnaire and a 5-point Likert rating scale (0 to 4). The study found a statistically significant difference ($P$=.001) between the scores of conventional CDs and digital CDs, with the participants preferring the digital CDs.

One of the digital CDs had an open anterior occlusal relationship, and it was necessary to remake the mandibular CD. In terms of the CDs manufactured with the conventional technique, 1 required relining as the retention, stability, and occlusion were compromised.[14]

One article[17] was selected to evaluate the number of unscheduled postinsertion adjustment visits of patients with CDs. This study involved 106 nonsmoking participants, predominately women. The first 33 received CDs manufactured with the conventional technique (injection molding), and 73 received digital dentures (milling). No statistically significant differences ($P>.05$) were found between the number of unscheduled postinsertion adjustments for participants provided with digital CDs and that for those provided with conventional CDs.[17]

## DISCUSSION

The first null hypothesis of this systematic review was rejected. The qualitative synthesis results demonstrate that CDs manufactured with CAD-CAM technology provide better retention than the conventionally manufactured CDs. The second null hypothesis was partially rejected, as no significant differences were found between CAD-CAM and conventional techniques in terms of unscheduled postinsertion adjustment visits. However, significant differences were found for other variables, including experience, satisfaction, time, and cost.

In terms of retention, both studies reported better retention in CAD-CAM CDs than in conventional CDs, possibly related to a better fit obtained with the prepolymerized CAD-CAM CDs.[12,13,18-21] Contrary to the findings in previous studies,[22-25] AlRumaih et al[12] reported that denture adhesives significantly reduced the retention of CAD-CAM CD. This reduction may be attributed to the better adaptation and intimate contact of the milled CDs on the maxillary tissues, which does not allow an adequate settlement of the adhesive. However, these studies did not assess the adaptation of the CDs; the performance of denture adhesives on CAD-CAM dentures should be further investigated.

An intimate adaptation of the intaglio surfaces of dentures is important for successful treatments, directly influencing the retention and stability of CDs.[20,26] Yoon et al[16] reported a significant difference between CDs manufactured by milling and DLP techniques, which provided better adaptation to tissues of the maxillary ridge and hard palate. Additionally, DLP-manufactured dentures may contribute to better adaptation in stress-bearing areas than conventional and CAD-CAM milled dentures.[16] Also, CDs manufactured with the conventional technique tended to press the center of the palate in contrast with the CDs manufactured by using the DLP and milling techniques.[16] This finding was consistent with the finding of Hwang et al,[27] who reported trueness and surface adaptation improvement in CDs manufactured with the DLP, displaying a misfit within 100 μm. Previous studies have also indicated the better adaptation of CAD-CAM-milled CDs.[20,28] These may be related to the more precise standardization of procedures with CAD-CAM techniques and reduced polymerization shrinkage, a significant factor with the conventional technique.[20]

The reduction of chairside time is considered one of the significant advantages of the CAD-CAM technique, whereby treatment was concluded in 2 to 3 visits depending on the system and protocol used.[19-21] Kattadiyil et al[14] indicated that CAD-CAM CDs required a mean of 205 minutes less chairside time than conventional dentures. Srinivisan et al[15] also reported that providing milled CDs required significantly less chairside time, with differences of 108.3 minutes for maxillary CDs and 233 minutes for maxillary and mandibular CDs. Other studies also reported the practicality of the CAD-CAM workflow for CDs.[18-20,29,30] Thus, the versatility of this technique, with the potential to obtain definitive impressions, interocclusal relationship records, and tooth selection at the first appointment, is the primary factor in these results. By contrast, the conventional technique requires 5 to 6 visits, which may introduce difficulties, particularly for less experienced clinicians.[14,15]

Treatment cost is another critical parameter to be assessed, as it influences treatment applicability and acceptability by clinicians and patients alike. Srinivisan et al[15] evaluated the costs associated with treatments for conventional and CAD-CAM-milled CDs by dividing them into clinical fees, clinical materials, and laboratory costs and by stipulating an hourly labor cost. They reported that, except for clinical materials, treatment with CAD-CAM CDs was markedly cheaper than other parameters and that a lower price in general was a treatment option. This study was conducted in Switzerland, and the authors stated that it was difficult to extrapolate these results to other countries because of the particularities of and variations in costs, which was a study limitation.

In terms of the patient experience and level of satisfaction with conventional and CAD-CAM CDs, Kattadiyil et al[14] indicated significantly higher preferences for CAD-CAM CDs in terms of comfort, mastication, prosthesis selection, and technique efficiency. However, some problems have been reported; one of the CAD-CAM CDs presented with an open anterior occlusal relation requiring replacement. For CDs manufactured by the conventional technique, one required relining as the retention, stability, and occlusion were compromised.[14] These findings may be related to complications encountered during the treatments in both techniques, which may have influenced patient perceptions. Moreover, the lower number of clinical visits and steps required by the CAD-CAM workflow may also have influenced patient perceptions on treatment.[14]

In terms of unscheduled postinsertion adjustment visits required for conventional and milled CAD-CAM CDs, the number of unscheduled visits was found not

to be related to the technique, rather to patients with single CDs and to those who attended scheduled visits after CD insertion.[17] The study suggests that this may be related to the adequate standardization of treatment protocols or the location of the clinical practice, which may be distant and difficult for patients to access. Only 20% of patients attended scheduled visits, thus corroborating this hypothesis. The average number of unscheduled visits recorded was 1.7 for CAD-CAM and 1.8 for conventional CDs. Conversely, Bidra et al [31] reported an average of 3.3 adjustments after insertion. However, this study applied a 2-visit protocol, which included conventional CDs and implant-supported overdentures, and had a small sample size; these factors may have produced different outcomes. Standardized protocols to assess postinsertion visits should be applied in further studies.

Limitations of this systematic review included the small number of clinical studies published on this subject that fit the inclusion criteria and the potential for non-English language articles. Randomization of participants and sample size calculations were lacking, as was difficulty in establishing a blinding method to evaluate patients and research personnel.[14,17] However, there was concern for eliminating certain clinical conditions that may affect treatment outcomes, such as palatal tori, alveolar ridges presenting severe undercuts, and reduced salivary flow.[18,19,21] Some studies used the classification of maxillary arches and/or palatal throats as a inclusion criteria for participants.[12-16] Additionally, the small sample sizes and differences among methodologies prevented meta-analysis. Thus, future studies should standardize treatment protocols to obtain comparable clinical outcomes.

The association between the adaptation and retention of dentures and the role of denture adhesives in CAD-CAM CDs should be assessed in further studies. Clinical studies addressing longer follow-up periods are necessary to compare differences among techniques. However, cost and clinical time outcomes that demand CD manufacturing with both techniques are already achievable.

## CONCLUSIONS

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

1. Rehabilitation with digitally manufactured dentures offers higher retention than CDs manufactured by conventional techniques.
2. The clinical time and overall cost of digital dentures were lower than those for conventional CDs.
3. The CAD-CAM CDs demonstrated better adaptation than conventional CDs, improving patient experience and satisfaction.
4. No differences were found between digital and conventional CDs in terms of the number of unscheduled postinsertion visits.

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