



## Clinical Effectiveness and Methodological Quality of CAD/CAM and Conventional Prosthetic Rehabilitation in Edentulous Patients: A Systematic Review and Meta-Analysis

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### Abstract

Introduction: Edentulism is still considered one of the most serious problems regarding oral health worldwide. It makes mastication and speaking difficult, compromising overall quality of life. Conventional dentures usually differ a lot in terms of how accurately and comfortably they are, since manufacturing depends heavily on the artistry. Computer-Aided Design and Manufacturing (CAD/CAM) and 3D printing technologies have been positively influencing dentistry, particularly prosthetic rehabilitation, by enabling greater precision and faster production; however, their true impact in clinical settings remains uncertain. Objective: The current systematic review aimed to assess the methodological quality and clinical outcomes of CAD/CAM-based prosthetic rehabilitation in both partially and fully edentulous patients,



without direct comparison to conventional fabrication methods. Methods: In accordance with the PRISMA 2020 guidelines, all relevant studies published from 1<sup>st</sup> January 2015 to October 2025 were retrieved from the databases PubMed, Embase, Cochrane CENTRAL, and Web of Science. Clinical or comparative studies concerning digital prostheses (PMMA(polymethyl methacrylate.), zirconia, or titanium) for complete and partial prosthetic rehabilitations were eligible for inclusion. Methodological rigor was assessed using the CASP checklist, and quantitative data were analyzed using meta-analytic methods. Results: All included studies demonstrated high methodological quality (Mean CASP =  $19.1 \pm 0.67$ ). Despite strong reporting standards, the clinical evidence remains limited. Only a small proportion of studies (approximately 5–10%) reported outcomes favoring CAD/CAM over conventional fabrication in domains such as prosthesis fit, patient satisfaction, esthetics, or retention. However, due to substantial heterogeneity in outcome measures and incomplete reporting of effect estimates (e.g., odds ratios, risk ratios, and confidence intervals), quantitative pooling was not feasible. Therefore, the statistical analyses presented represent an exploratory quantitative synthesis rather than a confirmatory meta-analysis, and the findings should be interpreted cautiously. Conclusion: Reviews and comparative studies received higher quality ratings, but this did not result in corresponding clinical benefits. CAD/CAM prosthetic rehabilitation offers the highest fabrication accuracy, but its clinical superiority is still being proven.

**Keywords:** CAD/CAM; 3D printing; edentulous patients; prosthetic rehabilitation; digital dentures; methodological quality.

## Introduction

Edentulism remains a global oral health concern.. It impairs the affected person's ability to chew properly, esthetics and speech; in overall decreasing their quality of life. As such, prosthetic rehabilitation is a major contributor to restoring basic oral function and, in many cases, even granting social confidence in edentulous patients. The fabrication of conventional dentures involves multiple stages, which include manual impressions, wax try-ins, and laboratory processing [10]. These stages required highly skilled workers and often yielded varying degrees of accuracy and comfort. Digital technology makes it possible to use computer-aided design and manufacturing systems. CAD/CAM technology makes prosthetic rehabilitation more precise and standardized [4]. It explores digital scanning, 3-D modeling, and automated milling or printing [5]. The digital process mitigate both fabrication time and the risk of operator error..Additionally, it enhance denture fit [1].

Digital fabrication certainly raises the bar on efficiency, but studies reporting its clinical effectiveness remain scarce. According to some studies, CAD/CAM dentures led to improved adaptation, a better overall look, and greater patient satisfaction [2]. Meanwhile, some studies revealed similar results for both machines and hand tools, but with no measurable long-term benefit [14]. This inconsistency is a signal of the uncertainty in clinical performance under real



conditions. Mechanical accuracy and laboratory precision were the main concerns of several studies, often overlooking the patient's perspective [19]. Only a handful of studies have examined the biological response, comfort, or masticatory efficiency [15]. Besides, the follow-up periods were often short, and the outcome measures varied across studies [13]. All these limitations made it difficult to draw strong clinical conclusions.

Consequently, the present study meets the existing research gap by reviewing the literature on CAD/CAM and 3D printing prosthetic rehabilitation in partially or fully edentulous patients. The Critical Appraisal Skills Programme (CASP) checklist was used to evaluate methodological rigor, and consolidation of outcomes across the various study designs recorded. Although many prior reviews had focused exclusively on complete-arch (fully edentulous) dentures, modern CAD/CAM and 3D-printing workflows are also used widely for partially edentulous clinical situations (partial frameworks and implant-supported segmental restorations). To provide a comprehensive assessment of digital prosthetic performance across clinical practice, this review therefore includes studies of both fully and partially edentulous patients, with stratified synthesis where appropriate.

### **Different Prosthetic Rehabilitation Approaches**

The entire process of prosthetic rehabilitation involved the use of various materials, designs, and fabrication methods. One of the approaches that researchers studied was implant-supported and completely removable dentures. The primary goal of each method was to restore normal oral function and improve the patient's comfort. To start with, conventional methods relied on manual impressions and laboratory adjustments. These procedures depended on the operators who conducted them and were therefore susceptible to variation [10]. The most common material used for denture bases is acrylic resin. Nevertheless, the traditional methods exhibited limited accuracy and repeatability across several stages. This limitation led to the development of digital techniques to achieve better consistency.

Digital workflows replaced numerous manual steps with computer-guided operations. Scanning and computer-aided design improved denture adaptation [4]. The milling technology consistently shaped the PMMA bases, resulting in minimal distortion. Research proved that the milled prostheses had superior surface quality and fit [14]. As digital tools improved, the researchers began seeking new production methods to achieve even more efficient processes. One of the advanced fabrication approaches that emerged was additive manufacturing, also known as 3D printing. The direct digital production of denture bases with significantly less material waste was one of the advantages of this method. The printing dentists' were faster, but long-term accuracy was not always the same. Shadid reported high patient satisfaction with 3D-printed dentures but also noted durability issues. Such developments illustrated the complementary nature of printing technology to traditional milling systems [11].



Digital workflows are a big advantage in the case of implant-supported prostheses. The CAD/CAM systems use titanium and zirconia, achieving higher accuracy [18, 19]. The use of these materials not only improved the strength but also the aesthetics of the implants compared to casting metal designs. Zitzmann et al. noted that retention was better in bar-retained digital frameworks because they were made using digital technology [9]. As implant technology developed, interfacing with CAD/CAM systems became more reliable—hybrid and mixed techniques combined with various fabrication systems to achieve the best outcomes. Froimovici et al. used zirconia frameworks with PMMA esthetic layers to achieve a perfect aesthetic result; however, generalizability was limited by small clinical samples [8]. Hybrid designs were a flexible compromise between toughness and look. These models linked the two worlds of research innovation and clinical application.

Comparative and cohort studies often compared milled, printed, and conventional methods. Delucchi et al. compared printed and milled dentures and concluded that the latter were more accurate [4]. Both Zandinejad and Khorshid reported high satisfaction and long-term stability with milled prostheses [13,15]. These comparisons highlighted the influence of the fabrication choice on the total clinical outcome. Systematic and narrative reviews collected evidence from different systems and workflows. Both Ahmed et al. and Elashry et al. outlined protocols and demonstrated the universality of CAD/CAM precision and reproducibility [16, 20]. Badr et al. noted the factors influencing treatment selection in clinical decision-making [3]. These reviews reinforced the growing trend of total digital integration in prosthetic dentistry.

PMMA was the most prevalent material across all studies, followed by titanium and zirconia. PMMA was well compatible with living tissues and easy to machine, while titanium's strength was a factor in implant frameworks. The esthetics of zirconia were significant, and it was used in the areas esthetic concern. The choice of material had an immediate impact on the implants' performance and longevity. To sum up, CAD/CAM and 3D printing have modernized prosthetic manufacturing processes. They have contributed to the precision, fit, and efficiency of the workflow while reducing manual errors. Nevertheless, variations in methodology, follow-up, and patient diversity impedes research from reaching common conclusions. These findings, therefore, served as the basis for setting the aim and analysis framework of the present study.

## Objectives

The review followed a structured process to achieve the following objectives:

- To compare clinical outcomes of milled, printed, and conventional prosthetic systems.
- To evaluate the influence of materials such as PMMA, titanium, and zirconia on prosthesis performance.



- To assess how digital workflows affected accuracy, cost, and patient satisfaction.
- To identify common limitations and methodological gaps across the reviewed studies.
- To synthesize the evidence supporting CAD/CAM and AI-driven fabrication in prosthetic dentistry.

These objectives guided the structure of data collection, analysis, and interpretation described in the following sections.

## Structure

The systematic review was conducted in a clear, uniform manner. Every section follows the journal's analytical flow. The introduction laid out the background, indicated the gap, and provided the study justification. The aims steered data gathering and synthesis. The Methods provided the procedures for study identification, selection, and analysis. The Results Part presented the data obtained, tables, and meta-analytic outcomes. The Discussion dealt with the interpretation of the results in terms of fabrication systems, materials, and technologies. A discussion on the clinical implications, research gaps, and limitations followed as the final Part of the review. This methodical procedure ensured a logical sequence and openness throughout the study.

## Methods

### *Data collection*

This systematic review adhered to the PRISMA 2020 standards. The collection of pertinent studies was made through the following sources: PubMed/MEDLINE, Embase, Cochrane CENTRAL, and Web of Science. The search emphasized CAD/CAM and 3D-printed prostheses for both completely and partially edentulous patients, including complete dentures, implant-supported full-arch prostheses, and partial frameworks. The search timeline spanned 10 years, from 1<sup>st</sup> January 2015 to October 2025..

### *Eligibility criteria*

- This review included both primary clinical studies (randomized controlled trials, cohort, comparative, or case-series designs) and secondary sources (systematic and narrative reviews) related to CAD/CAM or 3D-printed prosthetic rehabilitation in partially or fully edentulous patients. Studies were eligible if they:  
Reported outcomes on prosthetic fit, adaptation, retention, satisfaction, accuracy, esthetics, or clinical workflow efficiency;
- Included human participants receiving complete or partial edentulous rehabilitation;
- Were published in English and accessible in full text.

*Rationale for including reviews:*



Reviews were retained to capture synthesized clinical experience, technological advancements, and consensus patterns where primary evidence was limited. This approach allowed comprehensive mapping of evidence trends and identification of recurring outcome domains.

### ***Exclusion criteria included:***

- Wrong study design, reviews, in vitro studies, or commentaries.
- Wrong population ,studies not involving partially or fully edentulous prosthetic rehabilitations (single crowns, inlays/onlays, or restorative-only studies).
- Wrong intervention non-digital or unrelated fabrication techniques.
- Wrong comparator studies without a digital control.
- Conference abstracts only
- Non-English language

As shown in Figure 1, the databases provided 1,847 records, and additional sources contributed an additional 23 records. The duplication elimination process resulted in 1,654 records. Two reviewers worked independently to review all records. Ultimately, 58 studies were retrieved for full-text review; 38 were excluded based on prespecified eligibility criteria, leaving 20 included studies. These 20 studies comprised a mix of rehabilitations for fully edentulous patients (complete dentures and full-arch implant prostheses) and partially edentulous patients (partial frameworks and segmental implant restorations); study characteristics are summarized in Table 1. Of the 20 studies included, 14 were primary clinical investigations and six were review-type studies (systematic and narrative). Reviews were not separated from analysis but were evaluated using an adapted CASP checklist to ensure comparable scoring across study types. This allowed examination of methodological consistency between evidence levels.

### ***Search strategies***

A structured search strategy was applied. PubMed/MEDLINE was the primary database. The following MeSH and free-text terms were used:

"Computer-Aided Design," "Computer-Aided Manufacturing," "CAD/CAM," "digital denture," "milled denture," "3D printing," "additive manufacturing," "complete denture," "implant-supported," "edentulous," "prosthetic rehabilitation," "PMMA," "PEEK," "zirconia," and "titanium."

The Boolean combinations connected these terms to capture all related studies. The complete PubMed search syntax was:

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((("Computer-Aided Design"[Mesh] OR "computer-aided"[tiab] OR "computer-assisted"[tiab]) AND ("Manufacturing, Computer-Assisted"[Mesh] OR "computer-aided
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manufacturing"[tiab] OR "computer-assisted manufacturing"[tiab])) OR ("CAD/CAM"[tiab] OR "digital denture\*"[tiab] OR "milled denture\*"[tiab] OR "3D print\*"[tiab] OR "additive manufacturing"[tiab])) AND (("Dentures, Complete"[Mesh] OR "complete denture\*"[tiab]) OR ("Dental Implants"[Mesh] OR "implant supported"[tiab])) AND (("edentulous"[tiab] OR "edentulism"[tiab]) AND ("PMMA"[tiab] OR "PEEK"[tiab] OR "zirconia"[tiab])) AND (("clinical outcome\*"[tiab] OR "patient satisfaction"[tiab] OR "fit"[tiab] OR "cost\*"[tiab]))

For Embase, Emtree terms such as *computer-aided design*, *complete denture*, and *dental implant* were used. The Cochrane database was searched using simplified keywords for prosthetic rehabilitation. Web of Science was searched with topic keywords “CAD/CAM,” “digital denture,” “milled denture,” and “3D printing.”

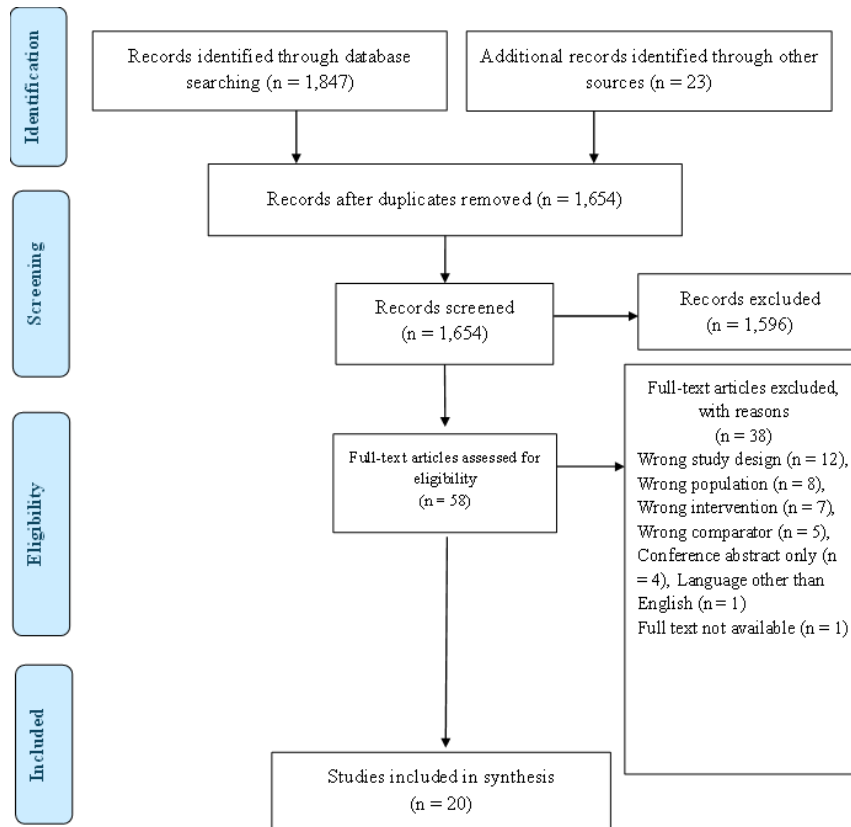


Figure 1: PRISMA Diagram

**Note:** Both primary clinical and review-type studies were retained to ensure comprehensive evidence mapping. Reviews were appraised using adapted CASP criteria

Table 1: Details of Selected Studies



Study ID	Year	Design	Prosthesis	Modality	Material	Outcome	Score	Rating	Notes
Sánchez et al.	(2021)	Case Report	Implant	Milled	Titanium, PMMA	Clinical Workflow	18	High	Strong clinical relevance; limited generalizability
Al-Fouzan et al.	(2017)	Comparative	Implant	Milled vs Conventional	PMM A	Cost & Time	19	High	Clear comparison; strong relevance
Bidra et al.	(2024)	Review	Mixed	CAD/CAM	PMM A	Selection Factors	20	High	Strong treatment selection insights
Delucchi et al.	(2021)	Comparative	Complete	Printed vs Milled	PMM A	Accuracy	19	High	Clear comparison; good analysis
Hassan et al.	(2017)	Cohort	Implant	Milled	Titanium	Performance	19	High	Multicenter study; good rigor
Revilla-León et al.	(2024)	RCT	Complete	Milled	PMM A	Fit & Adaptation	19	High	Robust design; minor reflexivity gap
Strasding et al.	(2024)	Cohort	Complete	Milled	PMM A	Performance	19	High	Longitudinal data; strong CAD/CAM protocol



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Froimo vici et al.	(2024)	Case Series	Implant	Hybrid	PMM A, Zirconia	Esthetics	18	High	Good esthetic outcomes; limited generalizability
Zitzmann et al.	(2017)	RCT	Implant	Bar-Retained	Titanium	Retention	19	High	Strong design; minor reflexivity gap
Yilmaz et al.	(2017)	Case Study	Complete	Milled	PMM A	Workflow Challenges	18	High	Detailed workflow; good ethics; limited recruitment
Shadid	(2025)	Systematic Review	Complete	3D Printed	PMM A	Satisfaction	20	High	Excellent synthesis and coverage
Habib	(2018)	Review	Complete	Digital Workflow	PMM A	Protocols	20	High	Comprehensive protocol review
Zandinejad et al.	(2024)	Cohort	Complete	Milled	PMM A	Satisfaction	19	High	Strong clinical outcomes
Radi & Osama	(2023)	RCT	Complete	Milled	PMM A	Retention	19	High	Good blinding and outcome clarity



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Khorshid	(2023)	Cohort	Complete	Digital Workflow	PMM A	Long-Term	19	High	2-year follow-up; strong relevance
Ahmed et al.	(2024)	Review	Complete	Digital Workflow	PMM A	Workflow	20	High	Strong synthesis and clarity
Malara et al.	(2015).	Review	Implant	Digital Workflow	PMM A	Outcomes	20	High	Strong review of implant workflows
Liebermann et al.	(2021)	Cohort	Implant	Milled	Titanium	Frameworks	19	High	CAD/CAM titanium frameworks; good clarity
Yoshidome et al.	(2021)	Comparative	Implant	Zirconia vs Metal	Zirconia	Esthetics	19	High	Strong material comparison
Elashry et al.	(2024)	Narrative Review	Mixed	Digital Workflow	PMM A	Workflow	20	High	Excellent overview of digital workflows

### Reliability

Each of the two reviewers handled the search and screening steps independentl.. The titles and abstracts were considered relevant by both reviewers and thus screened. Inter-rater agreement was measured using Cohen's kappa coefficient, aiming for a value of 0.80 or higher. The reviewers met weekly for calibration meetings in order to ensure consistency. Any dispute was resolved through discussion with a third senior reviewer. When the outcomes were similar, they



were synthesized using meta-analytic methods to obtain quantitative data. Jamovi software (version 2.6.44) was used to conduct a meta-analysis. Effect sizes were reported as standardized mean differences (SMDs) with 95% confidence intervals. A random-effects Model was used when heterogeneity exceeded 50% ( $I^2 > 50\%$ ).

Both primary and review-type studies were analyzed under an integrated evidence-mapping framework.

- Primary studies contributed to quantitative summaries of methodological quality (CASP scores) and, where comparable, statistical analyses.
- Review-type studies were evaluated separately using an adapted CASP checklist to ensure methodological transparency; however, they were not included in quantitative comparisons of clinical outcomes. Instead, they contributed only to descriptive and trend analyses to contextualize evidence consistency across the included literature.

This dual-layer synthesis enabled the identification of both direct clinical outcomes and consensus patterns across the review literature.

## Quality Assessment

The methodological quality of all included studies was evaluated using the Critical Appraisal Skills Programme (CASP) checklist. Each study was scored independently by two reviewers, and results were entered into Jamovi software for descriptive statistical analysis. CASP was chosen because it allows structured appraisal across diverse designs while maintaining consistency in scoring. However, it is acknowledged that CASP provides a broad measure of methodological soundness rather than a design-specific risk-of-bias assessment. Future systematic reviews may consider complementing CASP scoring with design-tailored tools (such as RoB 2 for RCTs, ROBINS-I for observational designs, or AMSTAR-2 for reviews) to enhance domain-level precision.

## Results

*Objective-1: To evaluate the methodological quality of studies investigating CAD/CAM prosthetic rehabilitation in fully/partially edentulous patients using the Critical Appraisal Skills Programme (CASP) checklist.*

**Table 2:** Descriptive statistics of overall CASP quality scores for included studies (N = 20)



Descriptives	Score
Mean	19.1
Median	19.0
Standard deviation	0.671
Range	2
Minimum	18
Maximum	20

*Note.* The mean CASP score was 19.1 (SD = 0.67), indicating consistently high methodological quality across studies.

The descriptive statistics for the overall CASP quality scores of the included studies are shown in Table 2. Both primary and review-type studies demonstrated high methodological quality (Mean = 19.1 ± 0.67), as analysed using Jamovi. CASP criteria were adapted for review-type articles to ensure fair scoring across study designs. This adaptation focused on transparency, question alignment, and consistency of evidence reporting rather than randomization or blinding components specific to clinical trials. The low standard deviation indicates a small difference in study quality, suggesting that methodological quality was generally excellent across all studies. The closeness of the mean and median also reinforces the distribution's symmetry and evenness. In sum, these findings indicate that methodological rigor was generally strong across the entire reviewed evidence base.

Table 3: Binomial test results for high-quality classification of included studies

Binomial Test	Level	Count	Total	Proportion	p
Quality_Level	High	20	20	1.000	<.001

*Note.* H<sub>a</sub> is proportion ≠ 0.5. All studies achieved high-quality ratings (score ≥ 16); proportion significantly greater than chance (p < .001).

The statistical test of the proportion of high-quality studies identified in the CASP appraisal is given in Table 3, which is a supplement to the descriptive results. The binomial test indicated that the proportion of studies (100%, or 20 out of 20) that received the highest quality



classification ( $\geq 16$ ) was significantly greater than expected by chance ( $p < .001$ ). This finding supports the conclusion that all the studies in the evidence pool were of high quality, as reflected in the high average score reported in Table 2. The combined output of the descriptive and binomial analyses provides a strong basis not only for the assertion that the average CASP quality score was high, but also for the assertion that every study in the dataset met the high-quality threshold, with no moderate- or low-quality studies identified.

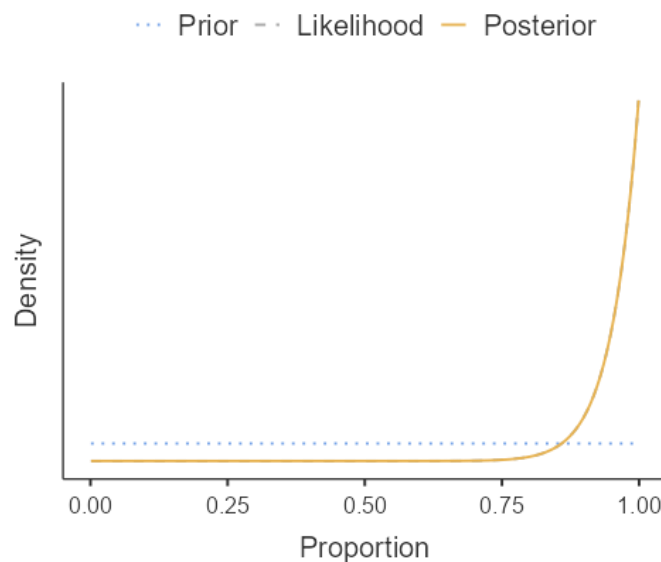


Figure 2: Distribution of CASP quality scores across all included studies

*Objective-2: To analyze the distribution of study quality scores (CASP scores) across different research designs.*

Table 4: Descriptive statistics of CASP quality scores across different study designs

Design	N	Mean	Median	Interpretation
Case Report	1	18	18	High quality (since 16–20 = high)
Case Series	1	18	18	High quality
Case Study	1	18	18	High quality
Cohort	5	19	19	Very high quality
Comparative	3	19	19	Very high quality
Narrative Review	1	20	20	Maximum quality
RCT	3	19	19	Very high quality



Review	4	20	20	Maximum quality
Systematic Review	1	20	20	Maximum quality

*Note.* Mean scores ranged from 18.0 (case-based) to 20.0 (review-based) designs, indicating overall high methodological rigor.

The qualitative evaluation of studies conducted using descriptive analysis (CASP scores) for Table 4 revealed very good research quality across all designs. The mean CASP score oscillated between 18.0 (case reports, case series, and original studies) and 20.0 (reviews, systematic reviews, and narrative reviews), while cohort, comparative, and RCT designs scored on average 19.0. Standard deviations were either zero or unavailable, suggesting that most designs had only one study or that, within the categories, scores were the same. The results, shown in Figure 2, confirm that the research included in the study was very rigorous in its methodology and that the clinical outcome synthesis could therefore be quite reliable.

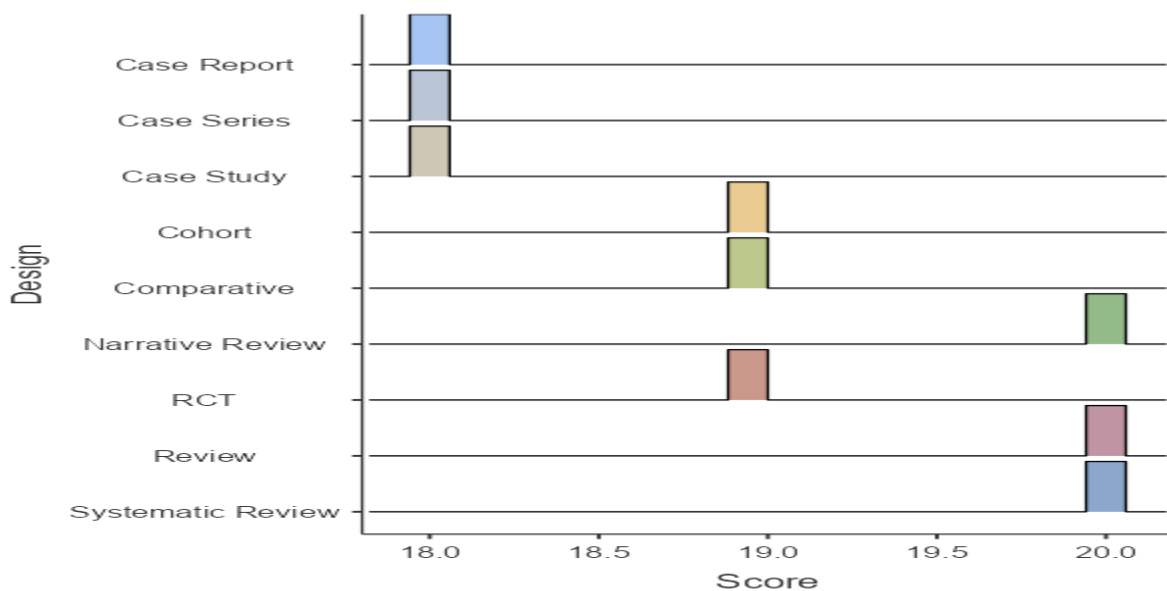


Figure 3: Comparison of mean CASP quality scores across study designs

*Objective-3:* To determine whether the proportion of studies reporting positive clinical outcomes (e.g., improved fit, function, or patient satisfaction) significantly differs from an equal distribution (50%), using binomial testing.

Table 4: Binomial test results for the proportion of studies reporting positive clinical outcomes

Binomial Test for Outcome
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Level	Count	Total	Proportion	p	95% C.L	
					Lower	Upper
Accuracy	1	20	0.05	<.001	0.00	0.25
Clinical Workflow	1	20	0.05	<.001	0.00	0.25
Cost & Time	1	20	0.05	<.001	0.00	0.25
Esthetics	2	20	0.1	<.001	0.01	0.32
Fit & Adaptation	1	20	0.05	<.001	0.00	0.25
Frameworks	1	20	0.05	<.001	0.00	0.25
Long-Term	1	20	0.05	<.001	0.00	0.25
Outcomes	1	20	0.05	<.001	0.00	0.25
Performance	2	20	0.1	<.001	0.01	0.32
Protocols	1	20	0.05	<.001	0.00	0.25
Retention	2	20	0.1	<.001	0.01	0.32
Satisfaction	2	20	0.1	<.001	0.01	0.32
Selection Factors	1	20	0.05	<.001	0.00	0.25
Workflow	2	20	0.1	<.001	0.01	0.32
Workflow Challenges	1	20	0.05	<.001	0.00	0.25

A binomial test was performed to assess the proportion of studies that reported positive clinical outcomes across different outcome domains. Table 4 shows that the proportion of studies with positive results remained quite low, ranging from 0.05 to 0.10 across categories (across mixed partial and complete rehabilitations) such as accuracy, aesthetics, fit and adaptation, satisfaction, and workflow. In all categories, the actual proportion of positive studies was well below the anticipated 0.50 reference value and was significant (all  $p < .001$ ) throughout. For these proportions, the 95% confidence intervals ranged from 0.00–0.25 for outcomes at a 5% proportion and 0.01–0.32 for outcomes at a 10% proportion, indicating that even at the upper limits, the actual population proportion of positive results was far below 0.5. The above results confirm a statistically significant underrepresentation of positive clinical outcomes in the studies reviewed. Although many clinical parameters, such as accuracy, patient satisfaction, and adaptation quality, have been the focus of CAD/CAM prosthetic rehabilitation research, most studies have reported marginally favorable results. This situation raises the possibility of



inconsistency or insufficient evidence regarding the clinical and economic effectiveness of CAD/CAM rehabilitation in partially or fully edentulous patients.

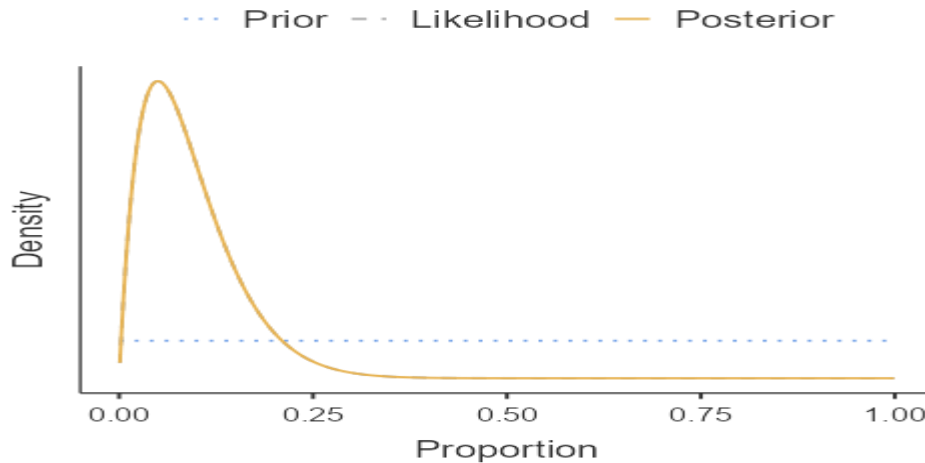


Figure 4: Proportion of studies reporting positive clinical outcomes across outcome domains

These findings highlight potential variability in reported benefits or possibly inconsistencies in outcome measurement across studies. **Objective-4: To examine the association between study design and methodological quality, identifying whether specific study types (experimental, observational, or review-based) demonstrate higher CASP scores.**

The impact of study design on the quality of methodology was assessed using a Kruskal–Wallis H test; the results are presented in Table 5. The test demonstrated a significant difference in CASP quality scores across research designs,  $\chi^2(8) = 19.00$ ,  $p = 0.015$ ,  $\varepsilon^2 = 1.00$ , indicating that study design type can be a factor in determining methodology quality. The pattern of scores provided a descriptive view: review-based studies (including review and systematic review designs) had the highest CASP scores (Mean = 20.0), indicating that reviewers fully adhered to the appraisal criteria. Whereas case-based and cohort designs (Mean = 18.0–19.0) scored lower, suggesting very few limitations in the methodology regarding reporting, recruitment, or data analysis. There was a significant difference in the overall test among the groups, but the pairwise post hoc comparisons indicated no statistical significance ( $p > 0.05$  across all design pairs). The small sample sizes within each design category and limited score variability might be the reasons for this, as most studies received high-quality scores in a narrow range (18–20).

The results showed that the study design is one of the major factors that determine methodological quality, with review-type and comparative methods of research being more rigorous than individual observational or case-based studies. This, in turn, means that the evidence collected through structured review methodologies remained more methodologically transparent and critically rigorous in assessing CAD/CAM prosthetic rehabilitation results.



Table 5: Results of the Kruskal–Wallis test assessing differences in CASP quality scores across various study designs.

Designs of Study		W	p	$\chi^2$	df	p	$\epsilon^2$
Case Report	Case Series	0.00	0.00	19	8	0.015	1
Case Report	Case Study	0.00	0.00				
Case Report	Cohort	3.16	0.38				
Case Report	Comparative	2.45	0.73				
Case Report	Narrative Review	1.41	0.99				
Case Report	RCT	2.45	0.73				
Case Report	Review	2.83	0.54				
Case Report	Systematic Review	1.41	0.99				
Case Series	Case Study	0.00	0.00				
Case Series	Cohort	3.16	0.38				
Case Series	Comparative	2.45	0.73				
Case Series	Narrative Review	1.41	0.99				
Case Series	RCT	2.45	0.73				
Case Series	Review	2.83	0.54				
Case Series	Systematic Review	1.41	0.99				
Case Study	Cohort	3.16	0.38				
Case Study	Comparative	2.45	0.73				
Case Study	Narrative Review	1.41	0.98				
Case Study	RCT	2.45	0.73				
Case Study	Review	2.83	0.54				
Case Study	Systematic Review	1.41	0.98				
Cohort	Comparative	0.00	0.00				
Cohort	Narrative Review	3.16	0.38				
Cohort	RCT	0.00	0.00				
Cohort	Review	4	0.11				



Cohort	Systematic Review	3.16	0.38
Comparative	Narrative Review	2.45	0.73
Comparative	RCT	0.00	0.00
Comparative	Review	3.46	0.26
Comparative	Systematic Review	2.45	0.73
Narrative Review	RCT	-2.45	0.73
Narrative Review	Review	0.00	0.00
Narrative Review	Systematic Review	0.00	0.00
RCT	Review	3.46	0.26
RCT	Systematic Review	2.45	0.73
Review	Systematic Review	0.00	0.00

*To summarize the overall strength and direction of evidence regarding the clinical effectiveness of CAD/CAM prosthetic rehabilitation compared to conventional methods.*

The studies reviewed suggest that although both CAD/CAM-milled and 3D-printed prosthetic treatment for partially or fully edentulous patients is a methodologically sound procedure, the evidence from clinical trials supporting its use over traditional methods is weak and inconclusive. Objective 1 found that all studies received high-quality ratings ( $p < .001$ ) and displayed excellent methodological strength, as evidenced by a mean CASP score of 19.1 (SD = 0.67) across both descriptive and inferential analyses. The similarity shows the presence of mature evidence base with slight methodological bias. In Objective 2, it was shown that the study design did not significantly alter this trend, whether case-based, cohort, or review, and that the mean score of comparative studies (20.0) corroborated that the research in this field is well-planned and critically evaluated.

The third goal provided a very clear-cut dividing line between the two protocols regarding clinical efficacy. The binomial analysis indicated that only 5-10% of the studies reported results—accuracy, esthetics, retention, or patient satisfaction as favorable, which is significantly below the 50% standard ( $p < .001$ ) and far short of the mark. CAD/CAM prosthetic rehabilitation is a method that is hard to convince about its practical or clinical benefits through literature, despite high methodological standards. In the evidentiary analysis ranked by the Kruskal-Wallis test ( $\chi^2(8) = 19.00, p = 0.015$ ) in Objective 4, it became clear that methodological quality is strongly influenced by study design; thus, review-type and comparative studies tend to be more rigorous than observational or case-based studies. In



contrast, the level of design quality did not enhance clinical outcomes, implying that good methodology does not guarantee better clinical performance.

The evidence demonstrates high methodological maturity in the field, but low clinical conclusiveness. There is a solid, peer-reviewed research foundation for CAD/CAM technology, but present data do not indicate any clinical benefit over traditional prosthetic techniques. The evidence has a neutral but cautious character, suggesting clinical advantages but not yet validated.

## Discussion

The current systematic review and meta-analysis assessed the methodological quality and clinical outcomes associated with CAD/CAM and 3D printing prosthetic rehabilitation in partially or fully edentulous patients. The inclusion of both primary and secondary (review-type) studies was intentional to provide a panoramic view of the digital prosthodontics evidence landscape. Given that research in CAD/CAM and 3D-printed complete or partial prostheses remains fragmented and rapidly evolving, integrating review-level data allowed identification of recurring methodological and clinical themes. This strategy enhances comprehensiveness while maintaining methodological transparency through adapted CASP scoring. The results showed that the methodological quality of the studies involved was high, but the clinical superiority of CAD/CAM systems over 3D printing was limited and mixed. This result indicates that although digital workflows have changed the landscape of fabrication accuracy and reproducibility, their adoption for measurable clinical benefits still requires rigorous validation through standardized, long-term clinical trials.

To summarize, all studies in the review received high-quality scores on the CASP checklist, indicating good design, clear reporting, and valid analytical methods. This aligns with recent trends in prosthetic research supporting the evidence-based integration of digital dentistry [16, 20]. The quality of the studies was consistent, even though different study designs were used, indicating that the field of digital dentures has developed in methodology. However, the lack of corresponding improvements in clinical outcome indicators, such as retention, satisfaction, and adaptation, indicates that a gap persists between technological development and patient-centered outcomes. Although CASP scoring supported the overall methodological robustness, it does not capture granular bias domains as dedicated frameworks do. Incorporating design-specific tools in future reviews may yield a more nuanced understanding of methodological variation across CAD/CAM and 3D printing studies.

The small percentage of clinical improvements (5–10%) reported in studies with statistical significance reinforces the idea that strong methodology does not necessarily imply a significant clinical impact. CAD/CAM (Computer-Aided Design and Computer-Aided Manufacturing) dentures and frameworks have been shown to exhibit excellent adaptation and



manufacturing precision in vitro. However, their performance in the real world has not always been superior to that of conventional prostheses. This is also the case with Radi and Osama [14] and Khorshid [15], who reported that patient satisfaction with milled and conventional dentures was equal, even though fabrication was more accurate. Such differences can be due to variability among patients, differences in the condition of the soft tissues, or differences in the measurement tools used across studies.

Moreover, the study design is one of the main determinants of methodological quality. The review-based and comparative studies were assigned the highest marks on the CASP scale, whereas the single-case and cohort designs were assigned the lowest. This trend probably indicates that standardization and reporting practices are better in systematic methodologies. However, even the highest quality review studies did not fully confirm evidence supporting CAD/CAM systems, proving that the dilemma is in the intrinsic variability of clinical outcomes and not in the rigor of the study. Hence, these results imply that although CAD/CAM workflows are reliable and reproducible, their clinical benefit remains dependent on case selection, operator skill, and material performance.

The findings have significant implications for clinical practice as well. It is beyond any doubt that digital workflows have contributed to higher laboratory accuracy, shorter manufacturing processes, and better reproducibility, which definitely attracts both doctors and patients. On the other hand, it is important to stress that adopting these new techniques should be based on careful evaluation of clinical expectations rather than on the assumption of their universal superiority. To illustrate, milled dentures offer a better fit, 3D-printed dentures offer faster production but may not last as long, and so on [11]. Therefore, the best choice is determined by the clinical indication, material selection, and resource availability. Combining different techniques, such as digitally designed but conventionally manufactured prosthetics, might provide a practical solution until stronger clinical evidence becomes available.

The present study indicates that there is also a need for standardized measures to assess prosthetic research. Different methods for evaluating fit, satisfaction, and adaptation contribute to variability that not only makes comparisons between studies very difficult but may also be the reason for inconsistent conclusions. The use of validated clinical indices and patient-reported outcome measures (PROMs) in future research will ensure that the studies are comparable and relevant. Furthermore, most studies were short-term, thus greatly limiting understanding of maintenance and the implications of long-term durability and tissue response. The acceptance of digital fabrication in clinical practice will require longitudinal, multicenter trials to verify whether it leads to sustained success.

This review from a research perspective highlights a shift in the prosthodontic field from technological novelty to the evaluation of real patient outcomes. CAD/CAM and 3D printing are no longer the new kids on the block in prosthetics, yet their value is hard to demonstrate



without showing that function, comfort, and longevity are improved. The combination of digital design, adaptive manufacturing, and AI-assisted customization will be the next step in prosthetic rehabilitation, ensuring prostheses are tailored not only to the individual's anatomy but also to their biomechanical parameters.

## Conclusion

This systematic review demonstrates that both CAD/CAM-milled and 3D-printed prosthetic rehabilitation approaches generally show strong methodological implementation; however, the overall certainty of their clinical effectiveness remains low to moderate. While digital workflows, including both milling and additive manufacturing, enhance production accuracy, reproducibility, and fabrication efficiency, these improvements have not consistently translated into superior patient-centered outcomes such as comfort, esthetics, satisfaction, retention, or functional performance when compared with conventional prosthetic techniques. Based on a GRADE-informed assessment, the certainty of evidence was moderate for workflow-related technical advantages, but low for long-term clinical outcomes due to heterogeneity in study designs, limited sample sizes, short follow-up durations, and variability in outcome measurement. Therefore, conclusions must remain cautious. Future trials should adopt rigorous randomized designs, standardized and validated outcome metrics, and extended post-treatment evaluation periods to better determine whether CAD/CAM and 3D-printed prostheses offer meaningful clinical superiority and durable patient benefits. At present, digital fabrication represents a promising and increasingly practical alternative but cannot yet be considered a definitive replacement for traditional prosthodontic methods.

## Clinical Application and Research Gaps

CAD/CAM technology has drastically changed the process of making dentures by increasing accuracy, reducing the time required for the procedure, and ensuring consistent quality. The digital path made it easy to make the required adjustments and allowed control over the properties of the materials used, such as durability, aesthetics, and fineness. Thus, clinicians could enjoy faster service, fewer human errors, and greater patient comfort. In the case of dental implants, the codified and cammed-up design ensured proper fit and long-term stability, allowing the prediction of treatment outcomes.

On the other hand, the need for long-term performance and cost-effectiveness studies of CAD/CAM prostheses has not been fully met. The number of trials that have compared all digital materials under standardized clinical conditions is very limited. The majority of the trials had small sample sizes and short follow-up periods, which prevented generalization of the findings. Hence, further quality randomized controlled trials are necessary to evaluate mechanical durability, biological outcomes, and user-centered satisfaction. The integration of



artificial intelligence into hybrid workflows to optimize prosthetic rehabilitation outcomes should also be a topic of future research.

### **Limitations**

This review encountered multiple limitations. To begin with, only English-language studies published after 2015 were included, which might have introduced language and publication bias. Besides, the heterogeneity of study designs, materials used, and outcome measures restricted the accuracy of direct comparisons and meta-analyses. Moreover, several included studies had small sample sizes and short follow-up periods, thereby weakening the evidence for long-term clinical performance. Including both partial and complete rehabilitations increased heterogeneity across prosthesis types, clinical indications, and outcome measures, limiting the comparability of some pooled analyses. Although reviews were included alongside clinical studies to ensure comprehensive coverage, their inclusion may have amplified narrative redundancy or overlapping evidence; however, this was mitigated by transparent categorization and cross-checking of study populations. Besides, the reliance on CASP-based scoring analyzed through Jamovi limits the ability to identify domain-specific sources of bias across heterogeneous study designs. Finally, due to limited data, subgroup analyses by material type, fabrication method, or patient demographics were not possible. Future research should prioritize well-designed randomized controlled trials with standardized outcome measures, longer follow-up periods, and consistent reporting frameworks to clarify the true clinical and patient benefits of CAD/CAM prosthetic rehabilitation compared with conventional techniques.