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Accuracy and Clinical Performance of 3D-Printed Versus CAD/CAM-Milled Dental Restorations: A Systematic Review

Ahmed Suwaydir Aljohani

Dental Technician, Islamic University of Madinah, Madinah, Saudi Arabia, 11RT0012993

ABSTRACT: Background: Assessment of In Vitro Fit and Clinical Performance of Additively Manufactured Dental Restorations Additive manufacturing, also referred to as 3D printing, has been suggested as a viable alternative to subtractive CAD/CAM milling in dental restorations. Nonetheless, it is not yet clear whether 3D-printed restorations perform clinically and accurately when compared to their milled counterparts. The aim of this review is to compare accuracy (marginal and internal fit), trueness, precision, mechanical behavior and clinical performance of 3D-printed and CAD/CAM-milled restorations.

Methods: The Pub Med database was searched for comparative studies published between 2020 and 2025. Comparative studies involving a 3D-printed restoration or prosthesis versus a milled device were considered for analysis. Data were collected using a standardized form and in vitro risk of bias was evaluated with the QUIN tool, and the randomized trial was assessed with Cochrane RoB 2 at the abstract level. When means, standard deviations, and sample sizes were reported, a random-effects meta-analysis was performed using Der Simonian-Laird, with Hedges g.

Results: A total of 230 titles and abstracts were identified, of which 40 were screened, and 19 (18 in vitro and 1 randomized clinical trial) were included. Two meta-analyses for the pooled analysis of marginal/internal gap showed no significant difference between 3D printing and milling (SMD -0.20, 95% CI -1.08 to 0.68; k = 4; I2 = 78%). Printed restorations were more precise (SMD -2.61, 95% CI -3.45 to -1.76; k = 2; I2 = 0%) than milled zirconia crowns. Trueness was higher for milled zirconia crowns in the only included study with pooled-ready data. Eight studies rated as medium risk of bias using QUIN were identified. One randomized clinical trial of 48 zirconia crowns evaluated the clinical performance over 12 months and reported no difference.

Conclusion: The two fabrication techniques can produce restorations that generally are within the clinically acceptable range. However, the direction of the difference depends on the material, printing technology, and outcome. Because much of the evidence is based on small in vitro studies, one must await the results of long-term randomized clinical trials before drawing more definitive conclusions

1. INTRODUCTION

Digital workflows have revolutionized the manufacturing of indirect restorations. Intraoral scanners and CAD enable two main manufacturing routes; subtractive manufacturing, where the restoration is machined from a pre-made block, and additive manufacturing, where the restoration is built up in layers (Sulaiman, 2020; Watanabe et al., 2022). While milling has been the traditional route for chair side and laboratory manufacturing, it is a subtractive method that generates wastage of material and the geometry of the tools used may limit the fabrication of complex internal features (Watanabe et al., 2022). Additive manufacturing requires less material and enables complex geometries. It has progressed from creating models and provisionals

to the manufacture of definitive materials such as ceramic-filled resins and zirconia (Duarte & Phark, 2024; Zhu et al., 2024). The manufacturing route used in digital workflows can also be applied to the creation of implant-supported restorations (Pyo et al., 2020), removable frameworks (Suzuki et al., 2020) and models, with the outcomes being the reproducibility of the results (Appiani et al., 2024).

Whether the fit and performance of the printed restorations are comparable to those of the milled restorations is also a relevant clinical question. The marginal and internal fit of restorations affects cement thickness, micro leakage, and retention. In addition, trueness and precision are important considerations in determining how well a digital process repeats to produce a given result. Narrative reviews suggest that the evidence of the chemical and mechanical properties of printed materials to date is limited, and the clinical performance has yet to be demonstrated (Sulaiman, 2020; Duarte & Phark, 2024). Systematic reviews conducted to date have mostly addressed restorative types or outcomes and included studies on zirconia (Alghauli et al., 2024), intracranial restorations and veneers (Alghauli & Alqutaibi, 2024), interim fixed dental prostheses (Al-Humood et al., 2023), complete dentures (Srinivasan et al., 2021), implant-supported prostheses (Ioannidis et al., 2023), and mechanical characteristics (Valenti et al., 2022). The results of these reviews often differ on the basis of the restoration material and type.

In recent years, there has been a growth in the quantity of comparative studies, ranging from the first randomized trial of a printed zirconia crown (Cai et al., 2025) to the current array of studies. As a result, this review aims to combine the body of comparative evidence from 2020-2025 of different restorations and tackle one primary question: how do 3D-printed and CAD/CAM-milled restorations compare?

2. METHODS

2.1 Protocol and reporting

The review followed the PRISMA 2020 statement (Page et al., 2021). Methods for effect-size calculation and heterogeneity followed the Cochrane Handbook (Higgins et al., 2023).

2.2 Eligibility criteria

Table 1. PICOS eligibility criteria

Domain	Inclusion	Exclusion
Population	Dental restorations and prostheses: crowns, inlays/onlays, veneers, fixed dental prostheses, implant abutments, denture bases	Orthodontic or other appliances (e.g., occlusal splints); models only
Intervention	Additive manufacturing (SLA, DLP, inkjet/nanoparticle jetting, lithography-based or gel-deposition processes)	Studies with no additive arm
Comparator	CAD/CAM subtractive milling of the same restoration type	No milled comparator
Outcomes	Marginal/internal fit, trueness, precision; fracture/fatigue, bond strength, surface properties; clinical success; cost and time	—
Study design	Comparative in vitro studies; clinical studies (RCT, cohort)	Narrative, scoping and systematic reviews; case reports; position papers
Limits	Published 2020–2025; English	Published before 2020

2.3 Information sources and search

A systematic search of the Pub Med database (MEDLINE) was performed using the search string: (3D-printed OR additive manufacturing) AND (milled OR CAD/CAM subtractive) AND (crown OR restoration OR denture OR fixed dental prosthesis) AND (accuracy OR trueness OR fit OR marginal), with a date limit set from the year 2020-2025. This returned 230 records, which were ordered by relevance and the first 40 records were screen for inclusion. No other databases, grey literature sources or citation searches were performed.

2.4 selection and data extraction

One reviewer conducted the screening of titles and abstracts and the assessment of eligibility. Data were extracted into a standardized sheet (see table 3) which included: design, restoration type, additive technology and material, subtractive system and material, number of samples in each group, outcomes, and main results. For studies available through Pub Med Central the

number data were extracted from the full text, while for studies without full texts, values that were available in the abstract were extracted. If the data was not reported in the abstract these values were assigned NR (not reported). No value imputation was carried out.

2.5 Risk of bias

The QUIN tool was used to assess in vitro studies consisting of 12 criteria, 2 (adequately specified), 1 (inadequately specified) or 0 (not specified); criteria were excluded from assessment if specified to not apply (Sheth et al., 2024). The total score was calculated as the percentage of criteria scored as applicable out of total applicable criteria and given as low (>70%), medium (50-70%) or high (<50%) risk (Sheth et al., 2024). The QUIN tool was only used on the in vitro studies as the full text article was accessible through Pub Med Central. The randomized trial was assessed on all five domains of Risk of Bias 2 (RoB 2) based on information from the abstract and not the full text. Studies were not appraised if the full text was inaccessible.

2.6 Synthesis

When possible, means, SDs and sample sizes were used to calculate Hedges g (additive minus subtractive); positive values indicates greater gap or deviation and therefore poorer printing performance. Two comparator groups from the same study were combined using the Cochrane formula for combining groups. Outcomes were pooled (using a Der Simonian-Laird random-effects model), with heterogeneity measured using Q and τ2 and I2 values, and a sensitivity analysis undertaken for the gap outcome using a Knapp-Hartung confidence interval and leave-one-out analysis. Due to the number of different methods and units of measurement, a standardized mean difference was used. A funnel plot was produced at the comparison level for exploration only. Using the percentages reported, risk ratio and risk difference were calculated from the data from the one randomized trial (it consisted of 24 teeth per group). The rest of the studies were summarized narratively by outcome domain.

3. RESULTS

3.1 Study selection

The search on Pub Med provided a total of 230 records. Out of the 40 records that were screened, 21 was excluded, as 18 was narrative, scoping or systematic reviews or position papers, 1 was a case report (Zhang et al., 2023), 1 did not include an additive arm (Toma et al., 2023), 1 investigated an occlusal splint and not a restoration (Wu et al., 2025), leaving 19 primary studies to be included (Figure 1). The 190 records that were below the screening criteria were not further screened.

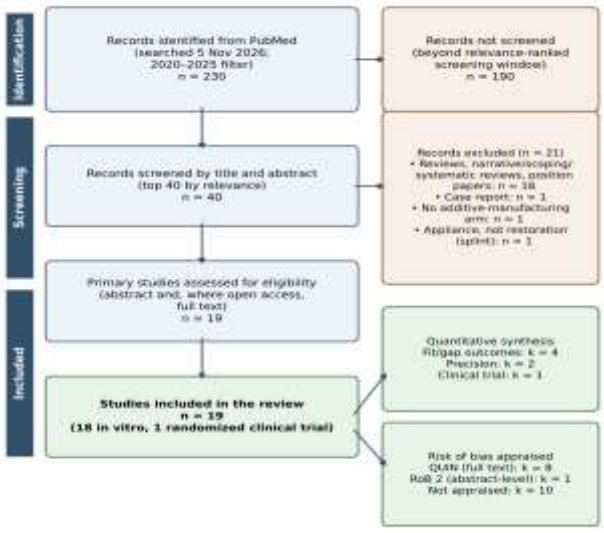

Figure 1. PRISMA 2020 flow diagram of study selection.

3.2 Characteristics of included studies

The studies analyzed in this review were published between 2021 and 2025, with a higher number of articles published in 2024 (7 articles) (Figure 6). Nineteen studies were in vitro studies and only one was a randomized clinical study. The most common type of restoration studied was zirconia crowns (eight studies) followed by dentures (three studies), veneers and on lays (three

studies), hybrid-ceramic crowns (two studies), lithium disilicate crowns, (one study), interim fixed prostheses (one study), and abutments (one study). The average sample size was 10 specimens per group for the in vitro studies. Study characteristics are reported in detail in the data extraction sheet (Table 3), and the numerical data used for pooling in Table 4.

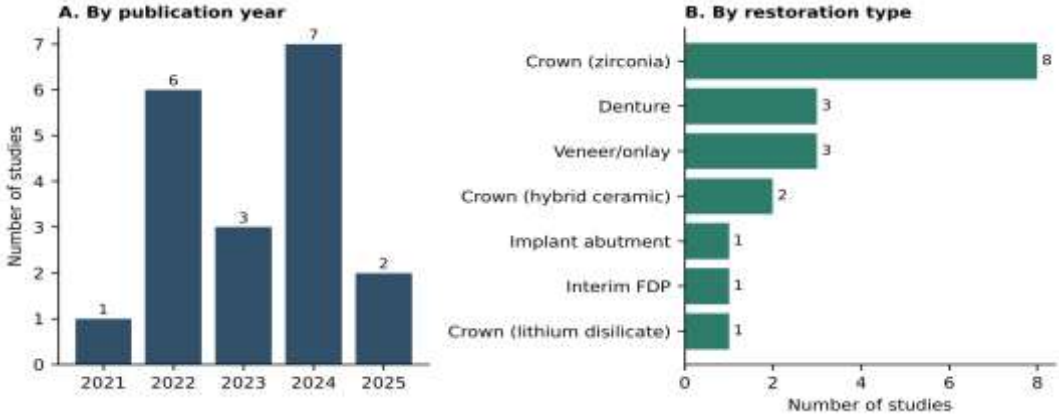

Figure2: Distribution of the 19 studies

3.4 Bias Risk

Eight in vitro studies were scored using the full text of the QUIN assessment tool (Figure 4). All papers had a medium risk of bias and scored between 50.0% and 66.7% (Table 5). The objectives, comparisons, methods of approaches, and measurement of the outcomes and statistical evaluation were on the whole reported appropriately. Descriptions of assessors and blinding were absent from most articles, while only three of the eight studies included details of operators and randomization. Sample-size calculations were reported in only three papers. Criterion 12 (presentation of results) was based on the texts obtained, and the absence of tables in a number of articles may have led to an overly cautious score. The randomized trial by Cai et al. (2025) had an adequate account of sequence generation and allocation concealment, although the validity of blinding and attrition check from the abstract, in an overall assessment , had some reservations. Of the 18 papers, 10 studies could not be evaluated because their full articles were not available.

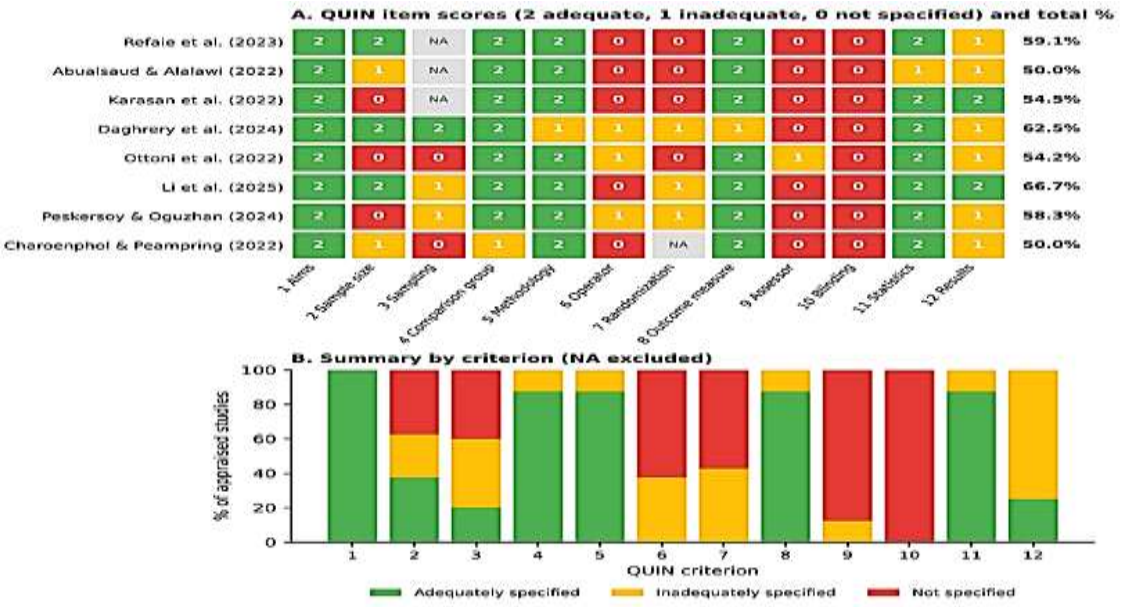

Figure3: Risk of bias

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Table 3. *Data extraction sheet of the 19 included studies*

ID	Study; country	Design	Restoration; n per group	Additive route	Subtractive route	Outcomes	Main finding
1	Refaie et al. (2023); Germany/Egypt	In vitro	Zirconia crown; 10 vs 10	Lithography-based ceramic (Lithoz 210 3Y, CeraFab 7500)	DWX-520 milling (ZirCAD LT)	Marginal gap (VMGT, replica), internal fit	Printed gap larger (80±30 vs 60±20 μm), both acceptable
2	Abualsaud & Alalawi (2022); Saudi Arabia	In vitro	Zirconia crown; 10 vs 10	Ceramic paste printing (3DMix ZrO, CERAMAKER C900 Flex)	PrograMill PM7 (CopranZri)	Internal fit, marginal adaptation, trueness, precision	Fit similar; printed trueness better occlusal/axial, worse intaglio; printed more precise (9.59±0.75 vs 17.31±3.39 μm)
3	Refaie et al. (2024); Germany/Egypt	In vitro	Zirconia crown; 10 vs 10	DLP printing	Milling	Trueness, precision (RMS)	Milled trueness better (96±27 vs 140±14 μm); printed precision better (31±5 vs 61±17 μm)
4	Lee et al. (2024); Korea	In vitro	Zirconia crown; 10 per group, 3 groups	SLA (CERAMAKER 900); DLP (ZIPRO)	Datron D5 milling	Trueness, precision (RMS)	Milled lowest RMS in all areas; DLP second; all acceptable
5	Cho et al. (2024); Korea	In vitro	Zirconia crown; n NR	4 DLP and 1 SLA techniques	Subtractive milling	Trueness, voids, roughness	Trueness within acceptable limits; voids and greater roughness in all printed groups

ID	Study; country	Design	Restoration; n per group	Additive route	Subtractive route	Outcomes	Main finding
6	Oh et al. (2024); Korea	In vitro	Zirconia crowns, disks, bars; n NR	Additive zirconia	CNC milling	Flexural strength, marginal/internal gap	Printed gaps larger; mechanical properties comparable
7	Camargo et al. (2022); Belgium	In vitro	Zirconia crown; 10 per group, 3 groups	Inkjet (XJet Carmel 1400)	Chairside Cerec MCXL; laboratory LX-O 5-axis	Trueness, cement space (micro-CT)	Lab milling best marginal accuracy; printed intermediate; external trueness similar
8	Suksuphan et al. (2023); Thailand	In vitro	Hybrid-ceramic crown; 10 per group, 9 groups	DLP (Freeform Pro 2; VarseoSmile)	CEREC MCX (Cerasmart; Vita Enamic)	Marginal adaptation, fracture load	Printed smallest gaps; lowest fracture load (1480–1747 N)
9	Abdulkareem & Al-Shamma (2024); NR	In vitro	Resin-matrix ceramic crown; 10 per group, 3 groups	VarseoSmile Crown plus	Cerasmart 270; Vita Enamic	Marginal gap, fracture load	Printed smallest gap (15.07 vs 20.01/21.08 µm after cementation); fracture load similar to Cerasmart
10	Ottoni et al. (2022); Brazil/USA	In vitro	Lithium disilicate crown; 15 vs 15	3D-printed pattern + heat-press	Milled e.max CAD	Gap (micro-CT), fatigue	Occlusal gap smaller, axial gaps larger for printed/press; fatigue similar
11	Karasan et al. (2022); Switzerland	In vitro	3-unit interim FDP; 10 per group, 6 groups	DLP (RapidShape); SLA (Formlabs 2)	Telio CAD milled	Marginal/axial/occlusal space	Printed valid alternative; resin and mode influenced marginal space

ID	Study; country	Design	Restoration; n per group	Additive route	Subtractive route	Outcomes	Main finding
12	Daghrery et al. (2024); Saudi Arabia	In vitro	Laminate veneer; 10 per group, 3 groups	DLP (Asiga; VarseoSmile TriniQ, Crown Plus)	inLab MCX5 (Brilliant Crios)	Marginal, internal, overall discrepancy (CBCT)	Printed internal gap smaller (0.25–0.29 vs 0.40 mm); marginal difference not significant
13	Peskersoy & Oguzhan (2024); Turkey	In vitro	Onlay; 20 per group	DLP (Varseo XS; VarseoSmile Crown Plus)	CAMcube (Cerasmart)	Marginal gap, voids, bond strength	Gap similar (81 vs 61 μm, ns); bond strength lower for printed
14	Daher et al. (2022); Switzerland	In vitro	Onlay; n NR	VarseoSmile Crown Plus	Tetric CAD, Telio CAD, IPS e.max CAD	Marginal integrity after fatigue, cost, time	Printed similar to e.max and better than PMMA; 5.5–10.2 times cheaper
15	Li et al. (2025); China	In vitro	Zirconia abutment; 10 per group, 4 groups	3D gel deposition (self-glazed zirconia)	inLab MC X5 (Lava)	Abutment gaps (micro-CT)	Printed two-piece external gap smaller (31±20 vs 79±48 μm)
16	Yoshidome et al. (2021); Japan	In vitro	Maxillary denture base; n NR	SLA ×2, DLP ×1	Milled PMMA	Trueness, fitting accuracy	Milled best; SLA at 45° comparable to conventional
17	Charoenphol & Peampring (2022); Thailand	In vitro	Denture base; 10 vs 10	DLP (Asiga Max)	5-axis milled PMMA	Fit (RMSE)	Milled better overall and in bearing area; printed better in peripheral seal

ID	Study; country	Design	Restoration; n per group	Additive route	Subtractive route	Outcomes	Main finding
18	Saaedi et al. (2023); NR	In vitro	Complete dentures; 10 vs 10	3D-printed bases and teeth	Milled PMMA	Base and tooth accuracy, tooth position	Milled bases more accurate; printed teeth more accurate
19	Cai et al. (2025); China	RCT	Posterior zirconia crown; 24 vs 24 teeth, 12 months	Nanoparticle jetting	CAD/CAM milled	FDI criteria, PES/WES, periodontal, satisfaction	No FDI difference; success 95.8% vs 91.6%; one fracture each

NR = not reported in the available record. AM = additive manufacturing; SM = subtractive manufacturing; VMGT = vertical marginal gap technique; ns = not significant. Values come from full text (studies 1, 2, 11, 12, 10, 13, 15, 17) or from the published abstracts (others).

3.3 Numerical data extracted for quantitative synthesis

Table 4. Extracted means and effect sizes (additive minus subtractive)

Study	Outcome	Unit	AM: n / mean / SD	SM: n / mean / SD	Hedges g [95% CI]	Pooled in
Refaie et al. (2023)	Marginal gap (VMGT)	µm	10 / 80 / 30	10 / 60 / 20	0.75 [-0.16, 1.66]	Gap
Karasan et al. (2022)	Molar marginal space (4 AM groups combined)	µm	40 / 99.2 / 29.9	10 / 83.3 / 68.7	0.39 [-0.31, 1.09]	Gap
Daghrery et al. (2024)	Internal gap (2 AM groups combined)	µm*	20 / 266 / 202	10 / 397 / 50	-0.75 [-1.54, 0.03]	Gap
Li et al. (2025)	Abutment–Ti-base external gap	µm	10 / 31 / 20	10 / 79 / 48	-1.25 [-2.21, -0.29]	Gap
Refaie et al. (2024)	Precision (RMS)	µm	10 / 31 / 5	10 / 61 / 17	-2.29 [-3.42, -1.16]	Precision
Abualsaud & Alalawi (2022)	Precision, overall (RMS)	µm	10 / 9.59 / 0.75	10 / 17.31 / 3.39	-3.01 [-4.29, -1.73]	Precision
Refaie et al. (2024)	Trueness (RMS)	µm	10 / 140 / 14	10 / 96 / 27	1.96 [0.89, 3.03]	Single study

Positive g = larger gap or deviation (worse) with printing. *Reported in mm and converted (×1000); the unit is inferred from the source text. Sources with internal inconsistencies (Daghrery et al., 2024) were used as stated in the Results text. Replica-technique gaps (Refaie et al., 2023) and internal gaps (Li et al., 2025) were not pooled to avoid counting the same specimens twice.

Table 5. QUIN total scores

Study	Score (applicable max)	Percentage	Risk of bias
Refaie et al. (2023)	13/22	59.1%	Medium
Abualsaud & Alalawi (2022)	11/22	50.0%	Medium
Karasan et al. (2022)	12/22	54.5%	Medium
Daghrery et al. (2024)	15/24	62.5%	Medium
Ottoni et al. (2022)	13/24	54.2%	Medium
Li et al. (2025)	16/24	66.7%	Medium
Peskersoy & Oguzhan (2024)	14/24	58.3%	Medium
Charoenphol & Peampring (2022)	11/22	50.0%	Medium

Abualsaud & Alalawi (2022) and Charoenphol & Peampring (2022) sit exactly at the 50% boundary between medium and high risk.

3.5 Quantitative review

Margin and Internal Gap. Four studies were included in this comparison (Figure 2A). No significant differences was seen with the pooled effect size (-0.20, 95% CI -1.08 to 0.68, p = 0.65) and very high heterogeneity (Q = 13.4, p = 0.004; $\tau 2$ = 0.62; I2 = 78%). The Knapp-Hartung interval spanned from -1.68 to 1.28. The two studies which examined zirconia crowns and interim prostheses implied larger gaps with printing while those studying veneers and abutments implied smaller gaps with printing. Leave-one-out estimates ranged from -0.50 to 0.12, none of which were significant (see Table 6).

Accuracy. Two studies on zirconia crowns exhibited statistically significant less root mean square (RMS) deviation for printed crowns (SMD -2.61, 95% CI -3.45 to -1.76; I^2 = 0%; Figure 2B). For accuracy, pooled data from a single study (Refaie et al., 2024) favored milling in only a single study (g = 1.96, 95% CI 0.89 to 3.03); a second study (Lee et al., 2024) also found the lowest accuracy error for milled zirconia crowns, although no numerical data extractable from the abstract was reported.

Table 6. Sensitivity (leave-one-out) analysis for marginal/internal gap

Analysis	SMD [95% CI]	I^2	p
All four studies	-0.20 [-1.08, 0.68]	78%	0.65
Omitting Refaie et al. (2023)	-0.50 [-1.47, 0.47]	77%	0.31
Omitting Karasan et al. (2022)	-0.42 [-1.55, 0.72]	80%	0.47
Omitting Daghrery et al. (2024)	-0.01 [-1.12, 1.10]	81%	0.98
Omitting Li et al. (2025)	0.12 [-0.75, 0.98]	72%	0.79

Omitting Li et al. (2025), whose additive route also involves milling of the intaglio surface, changed the estimate from −0.20 to a slightly positive value, which shows how unstable the pooled estimate is with four studies.

3.6 Publication Bias

Due to the limited number of less than ten independent studies, a formal test for small-study effects is invalid. A funnel plot showing all 13 comparison-level effects from six studies is included for illustrative purposes only (see Fig. 3). The effects are relatively evenly spread on either side of the pooled estimate which means the funnel plot is not meaningful evidence either for or against publication bias. The only noticeable feature of the funnel plot is a large positive outlier stemming from a small-variance comparison in a single study (Refaie et al., 2023, replica technique).

3.7 Clinical Performance

Only one trial met the inclusion criteria. In a 12-month trial with random allocation of 43 participants (48 posterior teeth, 24 in each group) measuring clinical success and failure according to FDI criteria there was no statistically significant difference between nanoparticle-jetting zirconia crowns and milled crowns with percentages of clinical success being 95.8% and 91.6%, respectively, and 1 fracture in each group (Cai et al., 2025). Based on the percentages reported the risk ratio was calculated to be 1.05 (95% CI 0.90 to 1.21) and the risk difference was 4.2 percentage points (-9.5 to 17.8). The trial was not sufficiently powered for these outcomes. The printed crowns showed a better Pink Esthetic Score at baseline and 12 months ($p = 0.02$), the plaque index increased at 6 months in the milled group ($p = 0.04$). Both groups improved oral health related quality of life.

3.8 Narrative Synthesis by Outcome Domain

With regard to marginal and internal fit, of the 16 studies which reported on fit, six studies favoured milling, four studies favoured printing, four studies demonstrated no difference while two studies showed inconsistent results (Figure 8). Milling was mostly favored for zirconia crowns (Refaie et al., 2023; Oh et al., 2024; Camargo et al., 2022) and denture bases (Yoshidome et al., 2021; Charoenphol & Peampring, 2022; Saaedi et al., 2023). Printing was mostly favored for resin-based and hybrid-ceramic crowns (Suksuphan et al., 2023; Abdulkareem & Al-Shamma, 2024), laminate veneers (Daghrery et al., 2024) and self-glazed zirconia abutments (Li et al., 2025). However, when gaps were reported in micrometers, the mean values for both methods remained below or close to the 120 µm margin for both methods proposed by Camargo et al. (2022) and Peskersoy & Oguzhan (2024) in each of the studies.

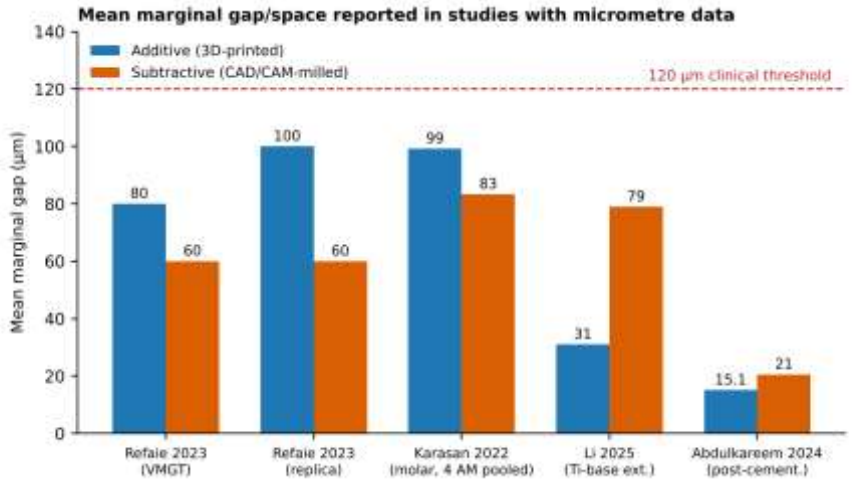

Figure 4: Mean marginal gap by manufacturing method Trueness and Precision

The findings of the study show that printing reproduces the occlusal and axial surfaces effectively, but milling is more accurate in reproducing the fitting surface (Abualsaud & Alalawi, 2022; Refaie et al., 2024). Milled showed the lowest trueness error in all areas (Lee et al., 2024). It was also found that the accuracy of printed denture teeth was greater than that of the milled teeth, but that the milled bases were more accurate (Saaedi et al., 2023).

Mechanical and Other Properties

Printed resin crowns had fracture loads between 1,480 and 1,750 N, less than milled hybrid materials (Suksuphan et al., 2023). Printed onlays had a weakened bond strength to tooth structures (Peskersoy & Oguzhan, 2024) and printed zirconia had more voids and a rougher surface (Cho et al., 2024). The fatigue performance of printed-and-pressed lithium disilicate crowns was similar to that of milled crowns (Ottoni et al., 2022).

Efficiency

In addition, printed composites onlays are shown to be 5.5-10.2 times more economical than milled ones and also more time efficient when producing greater than eight restorations (Daher et al., 2022).

4. DISCUSSION

From this review, although printed and milled restorations showed similar accuracy, there were no pooled differences in the marginal or internal gaps, but a trend of better accuracy of printing was observed. Nevertheless, this cannot be generalized, and differences in outcome could be material-, technology- and restoration-geometry dependent. For zirconia crowns, although milled crown margins were smaller and trueness better, printed crowns showed better repeatability and clinical adequacy, but were comparable in marginal gap size; whereas for the other indicated crowns, the fit of printed restorations was at least comparable or better, but when compared with milleds, they showed lower bond strength and fracture strength. The sole available randomized trial showed no clinical differences at 12 months.

These results concur with those of previous overviews. Specifically, Alghauli et al. (2024) observed smaller marginal gaps for milled when compared to printed crowns, except for nanoparticle jetting, with the two techniques having satisfactory fit within the clinical threshold and higher trueness on printed axial surfaces; Alghauli & Alqutaibi (2024) reported increased trueness and fit for printed intracranial restorations and veneers; Valenti et al. (2022) did not report differences in marginal discrepancy, trueness or internal fit between the two techniques, but reported lower flexural strength and fracture load for printed polymers; a scoping review did not find difference between the two techniques in the marginal gap of optimal (best-fit) printed and milled zirconia interim crowns. In studies on dentures, printed bases had worse trueness and occlusal accuracy than milled ones, but both were clinically acceptable; printed bases had the same phase accuracy, but worse trueness than milled ones (Srinivasan et al., 2021; Wang et al., 2025). Similar narrative reviews observed inferior denture base adaptation and flexural strength for printed dentures (Goodacre & Goodacre, 2022) and worse surface roughness for additively manufactured removable denture frameworks (Suzuki et al., 2020). The estimate of the effect size in this overview suggests that the effect size, by direction, was inconsistent for crowns, veneers, abutments and interim prostheses, which accounts for the high heterogeneity.

The underlying causes behind this difference could be explained by several mechanisms. Printed zirconia, made from a ceramic slurry with the final sintering process, contain influences of shrinkage, support structures and layer orientation on the fitting surface (Cho et al., 2024). It was found that printed zirconia crowns contained voids and rougher surfaces (Cho et al., 2024), and printed ceramic crowns are still deemed to be in a nascent stage of development (Pinelli et al., 2025). By comparison, milling of relatively thin resin or ceramic restorations was limited by bur diameter to define narrow internal angles and very thin margins, but printing could potentially be able to achieve this (Alghauli & Alqutaibi, 2024). Build orientation and post-processing have also been proved to have an effect on accuracy (Yoshidome et al., 2021; Wang et al., 2025).

The clinical significance then highlights a tentative stance. Since most of the inaccuracy was within acceptable ranges, the inaccuracy can still be reconciled with the use of printing, such as temporary restorations, veneers and onlays, where printing can be time and cost saving (Daher et al., 2022). However, in terms of finalized crowns and fixed-coverage restorations in areas of high stress, the evidence for strength and longevity is perhaps lacking (Duarte & Phark, 2024). Furthermore, no clinical investigation of printed implant-retained fixed restorations could be found within other reviews (Ioannidis et al., 2023; Dewan, 2023). Cai et al.'s (2025) promising trial of 48 teeth for 12 months does not alone account for anticipated long-term differential failure from fracture, wear or secondary caries.

4.1 Limitations

This review has several important limitations. First, the search was confined to Pub Med, and although only the 40 highest-ranked results were screened out of 230, several relevant studies were inevitably not captured. Second, screening, extraction and appraisal were conducted by a single author with the support of automation tools and no duplicate verification, and values extracted from PDFs were not verified in the respective sources. Third, no review registration was completed. Fourth, quantification involved four and two studies in the fit and precision analysis, respectively, with different measurement approaches and materials, hence the combined estimation is not only unstable but also largely demonstrative. Fifth, all but one study involved ten specimens per group with a medium risk of bias; ten studies could not be rated because their complete articles could not be obtained, and several points included only the information available from abstracts. Sixth, some sources had internal inconsistencies or were inconsistent with each other (e.g. Units or p-values), the unit used by Daghrery et al. (2024) was inferred. Finally, the eligibility span restricted to English articles published between 2020 and 2025. These considerations imply that the conclusions should be regarded as a systematic overview rather than a systematic review. A multi-database search, duplicate screening and registration will be recommended before the time of submitting to a journal.

5. CONCLUSIONS

From the gathered evidence, both 3D-printed and CAD/CAM-milled restorations, in general, appeared to perform within a clinically acceptable range of accuracy. Printing was not inferior to milled restorations in terms of marginal and internal fit, but scored higher precision and was promising for resin restorations and veneers. In contrast, milling was not inferior to printing in terms of trueness, but for the fit of zirconia crowns and denture bases, it has the added benefit of the better physical properties of specific materials. From a clinical perspective, only one RCT exists for 12 months. Future RCTs should be of a high quality and power, long term with the use of computer aided accuracy evaluation methods and consistent reporting of operator experience, randomization and blinding.

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