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EFFECTIVENESS OF MODERN MEDICAL DEVICES IN DENTISTRY AND ORTHODONTICS: A SYSTEMATIC REVIEW OF CAD/CAM 3D TECHNOLOGY

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Abstract

Background: Computer-aided design/computer-aided manufacturing (CAD/CAM) and related 3D technologies are now integral to orthodontics and restorative dentistry. We systematically reviewed clinical evidence on their effectiveness across common orthodontic and prosthodontic indications. Methods: Following PRISMA guidance, we screened nine original clinical studies for qualitative synthesis. Outcomes included treatment efficiency, stability/relapse, failure or complication rates, fit/accuracy, patient-reported outcomes (PROMs), and costs. Results: In randomized and comparative trials, CAD/CAM fixed retainers showed similar 6–24-month stability and failure rates to multistranded wires, with one RCT showing less relapse vs. chairside or lab-bent retainers, and another noting slight cost savings. Digital indirect bonding offered comparable accuracy with markedly shorter chair time. For brackets/appliances, customized systems delivered similar overall outcomes and treatment time to noncustomized appliances in multicenter RCTs and prospective studies, with trade-offs. In prosthodontics, digital workflows reduced clinical adjustment time and improved interim-crown fit. Conclusion: CAD/CAM 3D technology generally matches conventional methods and can improve efficiency or specific process metrics (chair time, adjustments). Longer follow-up and standardized outcomes are needed to clarify durability and cost-effectiveness across indications.

Keywords: CAD/CAM; Orthodontics; Fixed retainers; Customized Brackets; Indirect Bonding; Digital Impressions; 3D Printing; Prosthodontics.

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INTRODUCTION

Digital orthodontics and dentistry leverage CAD/CAM and 3D printing to individualize appliances and streamline workflows from impression to delivery. Systematic reviews on customized versus noncustomized fixed appliances generally report similar clinical effectiveness for core outcomes (treatment duration, quality, appointments), while noting workflow differences such as longer planning but shorter finishing with customization (Yassir et al. 2024) and material- or method-dependent trade-offs in slot precision, torque expression, and bond strength (Elabed et al. 2024). For retention, a network meta-analysis suggests CAD/CAM retainers achieve short-term stability comparable to stainless-steel multistranded retainers, potentially with lower plaque indices, though evidence on failure rates is mixed and follow-up often ≤6 months (Bardideh et al. 2023). Accuracy studies of transfer trays indicate CAD/CAM jigs can achieve high precision but may differ from PVS trays depending on tray stiffness and vertical dimension (Palone et al. 2023). Beyond orthodontics, comprehensive reviews in restorative and prosthetic dentistry outline the broad application of CAD-CAM materials and digital workflows, emphasizing adequate marginal/internal fit, efficiency gains, and the influence of material selection on performance (Rexhepi et al. 2023). Against this background, we synthesize original clinical evidence from nine trials to examine how CAD/CAM technologies affect efficiency, stability, accuracy, and patient-centered outcomes across orthodontic fixed retention, bonding, customized brackets, and digital prosthodontics. (Yassir et al. 2024; Elabed et al. 2024; Bardideh et al. 2023; Palone et al. 2023; Rexhepi et al. 2023).

METHODS

We followed PRISMA recommendations for transparent reporting. The review question was: “In clinical orthodontic and dental settings, how do CAD/CAM and digital 3D workflows compare with conventional methods regarding efficiency, accuracy, stability/failure, PROMs, and costs?”

We included original clinical studies (randomized or prospective comparative trials) evaluating CAD/CAM or digital workflows in orthodontics or prosthodontics. Eligible outcomes were treatment time/appointments, relapse or stability indices, failure/complications, fit/adjustment time, PROMs, or costs. Narrative/systematic reviews and purely in-vitro studies were excluded from the primary synthesis but used for contextual discussion.

This review synthesized a predefined corpus of 17 full texts provided by the requester (nine original studies and eight reviews). Two reviewers (single author in this context, with a second pass for verification) screened titles/abstracts and full texts. PRISMA flow (description): Records identified from user-provided sources (n=17); screened (n=17); full texts assessed for eligibility (n=17); excluded (n=8) as reviews/discussion or non-original studies; included in qualitative synthesis (n=9). No additional database searching beyond the provided corpus was undertaken.

We extracted study design, setting, sample, interventions/comparators, follow-up, and outcomes. Given heterogeneity of populations and endpoints, we performed narrative

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synthesis; quantitative pooling was not attempted. We summarized study characteristics in Table 1 and key clinical outcomes in Table 2.

Because the corpus comprised published RCTs and prospective comparative studies with variable reporting, we qualitatively considered randomization/concealment, blinding, attrition, and outcome measurement consistency as described by each paper. We highlight were short follow-up, small samples, or protocol deviations limit certainty. No automation tools, imputation, or outcome transformations were used.

RESULTS

Fixed retainers and post-treatment stability

A two-centre RCT randomized 181 patients to CAD/CAM nitinol versus conventional multistranded fixed retainers in both arches with 24-month follow-up. Among 153 attendees at 24 months, Little's Irregularity Index (LII), arch widths/lengths, first-time failure rates, and patient satisfaction did not differ significantly; a cost-minimization analysis showed CAD/CAM retainers were slightly cheaper (Pullisaar et al. 2024).

In the same programme's 6-month report (n=178 evaluable), stability and survival were likewise comparable between groups, with a minimal LII change in the CAD/CAM group (mean difference =0.2 mm) judged clinically trivial (Gera et al. 2023). A single-centre three-arm RCT followed 43 patients at 2 years after allocation to CAD/CAM stainless-steel retainers, lab-fabricated stainless-steel, or chairside Ortho-FlexTech. CAD/CAM showed significantly less relapse (ICW and LII) than lab and chairside at multiple timepoints; failures were numerically lowest with CAD/CAM (21.4%) but differences were not statistically significant (Tran et al. 2024).

Bonding method and chair time

A three-arm RCT (n=45) compared direct bonding, traditional indirect bonding (IB), and CAD/CAM digital IB using printed trays. Radiographic and model-based accuracy after leveling/alignment was similar across groups, but chair time was markedly shorter with CAD/CAM IB (=1.1±11.8 min documented for tray procedures vs =53–57 min for conventional bonding sessions), with no serious harms (Ueno et al. 2025).

Customized vs noncustomized fixed appliances

In a large RCT (n=180), customized Insignia vs noncustomized Damon Q showed no significant differences in treatment duration (=1.3 vs =1.24 years) or posttreatment PAR scores; customized treatment required longer planning, had more loose brackets and more complaints (Penning et al. 2017).

A prospective quasi-randomized study (n=38) found similar overall treatment time, number of appointments, and ABO scores between indirect-bonded customized Insignia and directly bonded self-ligating Damon; bonding failures were more frequent in the customized arm; indirectly bonded brackets required fewer repositionings (Hegele et al. 2021).

In a comparative trial (n=24), CAD/CAM customized self-ligating systems reduced overall orthodontic treatment time by about 26% vs indirect-bonded standard self-ligating, with

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similar final ABO scores and PROMs (Jackers et al. 2021). In an implant crown RCT (32 patients; 45 restorations), crowns fabricated from intraoral scans required significantly less adjustment time at placement than those from conventional impressions (=3.35 vs 6.09 minutes; p=0.039), with high short-term survival and minimal complications (Derksen et al. 2021). In tooth-supported interim single crowns (40 participants), a randomized trial found the digital workflow yielded shorter total fabrication time and better fit/occlusion than conventional methods; less-experienced clinicians especially benefited, achieving quality comparable to experienced operators when using digital processes (Cheng et al. 2020).

Table 1: Characteristics of included original clinical studies.

Study (year)	Design/setting	Sample (n) & follow-up	Interventions / Comparators	Primary outcomes	Key notes
Pullisaar et al. 2024	Two-centre RCT	181 randomized; 24 mo (153 analyzed)	CAD/CAM Ni-Ti vs multistranded retainers (both arches)	LII; arch widths/lengths; first failure; PROMs; costs	No significant differences; CAD/CAM slightly cheaper
Gera et al. 2023	Two-centre RCT (preliminary)	=178 at 6 mo	CAD/CAM vs multistranded retainers	Stability (LII, arch dims); failures; PROMs	No differences; trivial LII change in CAD/CAM
Tran et al. 2024	Single-centre 3-arm RCT	43 at 24 mo (75 allocated)	CAD/CAM SS vs lab SS vs chairside Ortho-FlexTech	Relapse (ICW, LII); failures	Less relapse with CAD/CAM; failures NS
Ueno et al. 2025	3-arm RCT	45 randomized; post-alignment assessment	Direct bonding vs traditional IB vs CAD/CAM IB	Bracket positioning accuracy; chair time	Similar accuracy; chair time much shorter with CAD/CAM IB
Penning et al. 2017	Multicentre RCT	180 randomized; =1.2–1.3 y	Customized Insignia vs Damon Q	Treatment duration; PAR; visits; loose brackets; complaints	No duration/quality difference; more planning time & failures with customized
Hegele et al. 2021	Prospective quasi-randomized	38; treatment completed	Indirect customized Insignia vs direct Damon	Treatment time; appointments; ABO; failures	Similar efficiency; more bonding failures with customized
Jackers et al. 2021	Comparative trial	24; treatment completed	CAD/CAM customized self-ligating vs indirect standard self-ligating	Overall treatment time; ABO; PROMs	26% shorter time with CAD/CAM; similar quality
Derksen et al. 2021	RCT (implants)	32 pts; 45 crowns; 1 y	IOS vs conventional impression → monolithic zirconia crown on ti-base	Adjustment time; survival; complications	Shorter adjustments with IOS; low complications
Cheng et al. 2020	RCT (tooth-supported)	40 participants	Digital vs conventional interim crowns	Total fabrication time; fit; occlusion; operator experience	Digital: faster and better fit; narrows experience gap

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Table 2: Main clinical findings across studies

Study	Outcome domain	CAD/CAM result	Conventional result	Interpretation
Pullisaar 2024	Stability/failures/PROMs/costs	Comparable; slight cost advantage	Comparable	Non-inferior; minor economic benefit
Gera 2023	Short-term stability/failures	Comparable; tiny LII change	Comparable	No clinically meaningful differences at 6 mo
Tran 2024	Relapse & failures	Less relapse; failures lowest (NS)	More relapse; failures higher (NS)	Suggests relapse benefit for CAD/CAM
Ueno 2025	Bonding accuracy & chair time	Similar accuracy; markedly shorter time	Similar accuracy; longer time	Efficiency gain without accuracy loss
Penning 2017	Treatment duration & quality	Similar duration/quality; more failures/complaints	Similar duration/quality; fewer failures	Trade-offs: planning ↑, failures ↑
Hegele 2021	Efficiency & failures	Similar efficiency; failures ↑	Similar efficiency; failures ↓	Comparable outcomes; monitor bonding
Jackers 2021	Treatment time & quality	Time ↓ =26%; quality similar	Longer time; quality similar	Potential time saving
Derksen 2021	Adjustment time & survival	Adjustment time ↓; survival high	Adjustment time ↑; survival high	Clinical efficiency at insertion
Cheng 2020	Time, fit, occlusion, operator effect	Faster; better fit/occlusion; helps novices	Slower; variable fit; experience-dependent	Digital improves consistency

In orthodontic retention, two large two-centre RCTs demonstrated non-inferiority of CAD/CAM fixed retainers to multistranded wires over 6–24 months, with one single-centre trial suggesting reduced relapse vs. lab-fabricated or chairside retainers. In appliance therapy, the largest RCT of customized vs noncustomized systems showed equivalent treatment duration and outcomes, echoing prospective findings, though failure rates and planning demands can be higher with customization.

Digital IB markedly reduces chair time without compromising early accuracy. In prosthodontic workflows, digital impressions and design consistently shorten clinical or overall time and improve initial fit/occlusion, demonstrating cross-disciplinary efficiency gains attributable to CAD/CAM. (Pullisaar et al. 2024; Gera et al. 2023; Tran et al. 2024; Ueno et al. 2025; Penning et al. 2017; Hegele et al. 2021; Jackers et al. 2021; Derksen et al. 2021; Cheng et al. 2020).

DISCUSSION

This synthesis aligns with contemporary reviews indicating that customized systems and CAD/CAM workflows deliver similar endpoint quality to conventional approaches, while redistributing effort, more planning up front, less chairside detailing, and sometimes reducing chair or overall treatment time (Yassir et al. 2024; Jackers et al. 2021; Penning et al. 2017).

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Improved slot precision or passive fit support stability or efficiency, yet bond strength, tray accuracy, and material properties can offset these gains and influence failures (Elabed et al. 2024; Palone et al. 2023). For fixed retention, a network meta-analysis synthesized seven RCTs and found similar short-term stability of CAD/CAM vs multistranded retainers and possible plaque-index advantages; long-term durability remains uncertain and at least one trial reported high CAD/CAM failures, prompting early termination (Bardideh et al. 2023).

Our included two-centre RCTs corroborate non-inferiority up to two years, and a smaller single-centre RCT suggests less relapse with CAD/CAM vs lab or chairside fabrication, differences that may reflect wire type, design, and bonding protocols. Broader digital dentistry evidence reinforces efficiency and accuracy themes: printed models, splints, and guides generally achieve clinically acceptable accuracy, though printing method and geometry matter (Rajagopalan et al. 2024).

Systematic reviews of CAD-CAM restorative materials confirm adequate marginal/internal fit and highlight material-specific performance and learning curves (Rexhepi et al. 2023; Svanborg 2020).

A recent orthodontic meta-analysis reported shorter treatment time with digital workflows and better adaptation of CAD/CAM-manufactured aligners, while urging optimization of long-term performance (Ingle et al. 2025).

Taken together, CAD/CAM appears to be a safe and efficient alternative across indications, with implementation details—appliance design, bonding method, tray material, operator training—being critical moderators. Strengths of this review include restriction to original clinical trials with prespecified outcomes and transparent PRISMA reporting.

Limitations include reliance on a predefined corpus (no external database search), heterogeneity of populations and endpoints precluding meta-analysis, short follow-up in several studies, and small samples in some trials. Future research should prioritize multicentre RCTs with standardized outcome sets, longer follow-up (≥36 months for retention), and economic evaluations to clarify total cost of ownership.

CONCLUSION

Across nine clinical studies, CAD/CAM 3D technologies in orthodontics and dentistry achieved clinical outcomes comparable to conventional methods and often improved efficiency—reducing chair time, adjustment time, or total fabrication time—without compromising stability or treatment quality.

Evidence also suggests potential advantages for relapse control in specific retainer designs and workflow consistency for less-experienced operators. Given heterogeneity and limited long-term data, clinicians should individualize use of CAD/CAM based on case complexity, materials, and bonding/tray protocols, while forthcoming high-quality trials clarify durability and cost-effectiveness.

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