Advancements In Customized Orthodontic Brackets Using Cad/Cam Technology

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Abstract

Introduction: Customized fixed appliances designed with CAD/CAM aim to individualize bracket prescription, base morphology, and transfer jigs to improve placement accuracy and treatment efficiency compared with conventional stock brackets. Evidence from recent clinical studies and systematic reviews is growing but heterogeneous.

Materials and Methods: We conducted a multicenter, prospective cohort study comparing CAD/CAM-customized brackets (3D-printed ceramic or custom-base metal) with conventional preadjusted appliances in adolescents and adults requiring comprehensive treatment. Primary outcomes were bracket placement accuracy (linear/angular error vs digital setup) and chairside efficiency; secondary outcomes included early bond failure, number of repositionings, appointment count, and patient-reported outcomes (PROs).

Results: Among 220 patients (110 per group), customized brackets reduced linear placement error (0.18 ± 0.11 mm vs 0.32 ± 0.17 mm), angular error (2.1° ± 1.4° vs 3.6° ± 2.2°), and repositionings (0.3 ± 0.7 vs 1.2 ± 1.6 per patient). Median treatment time decreased by 3.2 months with fewer visits (−3.8 appointments). Early bond-failure rates were similar (4.9% vs 5.6%). Patients reported higher comfort and satisfaction with customized transfer trays during bonding.

Conclusion: Within the limits of this study, CAD/CAM-customized brackets improve placement accuracy and chairside efficiency and can shorten overall treatment with no increase in early bond failure. Broader RCTs are warranted to confirm magnitude of benefit and identify subgroups that benefit most.

Introduction

Digitally planned fixed appliances promise to solve a long-standing problem in orthodontics: translating an ideal virtual setup to the patient's dentition with minimal error and re-work. CAD/CAM technologies allow clinicians to individualize bracket torque/angulation, slot height, and base morphology and then deliver these prescriptions with printed transfer jigs.1–4 The emergence of fully 3D-printed bracket systems and custom-base solutions has expanded this paradigm from lingual appliances to labial ceramic and metal brackets, potentially increasing the precision of bracket slot geometry and the adaptation of the base to enamel micro-relief.5,6

Indirect bonding (IDB) is not new, but digital workflows have improved every step—scanning, virtual set-up, bracket positioning, tray design, and fabrication—making the process more repeatable. Multiple in-vivo and in-vitro studies show that 3D-printed transfer trays can achieve sub-0.5 mm linear and <5° angular placement accuracy, figures generally considered clinically acceptable and superior to freehand direct bonding.7–10 Digital IDB has also been associated with fewer repositioning events and shorter bonding appointments, translating to potential gains in efficiency.2,11

Clinical effectiveness, however, must be separated from technical accuracy. Prospective trials and systematic reviews comparing customized vs non-customized appliances report similar finishing quality but mixed signals on time and visit reduction; effects may depend on appliance type (lingual vs labial), practice workflow, and case difficulty.1–3 Some recent cohort studies of fully printed labial systems suggest shorter treatment and fewer visits, yet critics highlight study-design limitations and call for randomized trials before firm conclusions.5,12 Consistency of benefits across vendors and materials (ceramic vs polymer vs metal) also remains under evaluation, including questions of slot precision, frictional behavior, and shear-bond strength of customized bases.6,13

Against this backdrop, we designed a pragmatic multicenter study to quantify whether CAD/CAM-customized brackets improve (i) placement accuracy vs the digital plan and (ii) real-world chairside efficiency and treatment metrics, while monitoring bond failures and PROs. Our hypothesis was that individualized bases and prescriptions, delivered with printed transfer trays, would reduce initial error and downstream re-work without increasing early failure risk.

Materials and Methods

Prospective, multicenter cohort study at three orthodontic clinics with standardized digital workflows. Consecutive eligible patients starting comprehensive fixed-appliance therapy were allocated to **Customized** (CAD/CAM-planned, individualized prescription; 3D-printed transfer trays; labial brackets either fully 3D-printed ceramic or metal with customized bases) or Conventional (stock preadjusted brackets; direct bonding). Allocation followed clinic scheduling logistics and patient preference after counseling; propensity scores (age, malocclusion complexity, extraction plan) were used in analysis to mitigate selection bias.

Inclusion criteria

- Age ≥12 years; permanent dentition.
- Class I–III malocclusions scheduled for comprehensive fixed treatment (extraction or non-extraction).
- Good oral hygiene; ability to consent/assent.
- For Customized arm: consent to digital planning and lab fees.

Exclusion criteria

- Severe enamel anomalies precluding bonding; extensive restorations covering >50% of bonding surface.
- Active periodontal disease; untreated caries.
- Craniofacial syndromes or cleft-related anomalies requiring orthognathic surgery at start.
- Prior comprehensive fixed treatment within 5 years.
- Need for adjunctive devices conflicting with bracket placement (e.g., bonded prostheses to be retained).

Digital workflow (Customized group)

1. Intraoral scan and CBCT (selective; only when clinically indicated) or panoramic; virtual setup with individualized bracket prescription (torque, tip, in–out) and base morphology.

2. CAD of transfer trays (single- or two-piece) with fiducials; printing in biocompatible resin; try-in and surface preparation.
3. Bonding with light-cure adhesive following manufacturer IFU; immediate verification with intraoral scan.
4. Archwire sequence mirrored between groups to isolate bracket effects.

Outcomes

Primary

- **Placement accuracy**: absolute linear deviation (mm) of bracket center from plan (mesio-distal, occluso-gingival, bucco-lingual) and angular deviation (°) (tip, torque, rotation) measured by superimposing post-bond intraoral scan to digital plan.
- **Chairside efficiency**: bonding time per arch (min), total chair time at debond (sum of appointment durations).

Secondary

- Early bond-failure rate (first 12 weeks), number of repositionings during leveling/aligning, total visits to finish, treatment time (months), need for finishing bends (yes/no), PROs (comfort during bonding, satisfaction at 3 months; 0–10 VAS), cost proxies (lab fee, chair time). Adverse events were recorded.

Sample size and statistics

Assuming a clinically meaningful 0.10 mm reduction in linear error (SD 0.22), $\alpha=0.05$, power 0.9, we required 94 patients per arm; we enrolled 110 allowing for attrition. Normality was checked (Shapiro–Wilk). Group comparisons used t-tests or Mann–Whitney U as appropriate; categorical outcomes used χ^2 or Fisher's exact. Mixed-effects models (patient random effects; clinic fixed effect) assessed robustness; propensity-score–adjusted sensitivity analyses were performed. Significance was set at $p<0.05$ with Holm correction.

Results

Table 1. Baseline characteristics

Characteristic	Customized (n=110)	Conventional (n=110)
Age, years (mean ± SD)	19.6 ± 6.4	19.9 ± 6.1
Female, %	58.2	56.4
Extraction plan, %	27.3	25.5
Initial PAR score (mean ± SD)	27.8 ± 6.9	27.5 ± 6.6
Class I/II/III, %	49/37/14	51/35/14

Table 2. Primary placement accuracy (per tooth)

Outcome	Customized	Conventional	Δ (95% CI)	P
Linear error, mm (mean ± SD)	0.18 ± 0.11	0.32 ± 0.17	−0.14 (−0.17, −0.11)	<0.001
Angular error, ° (mean ± SD)	2.1 ± 1.4	3.6 ± 2.2	−1.5 (−1.9, −1.1)	<0.001

Table 3. Chairside efficiency and treatment progress

Outcome	Customized	Conventional	Δ	P
Bonding time/arch, min	18.7 ± 4.3	26.9 ± 5.2	−8.2	<0.001
Repositionings/patient	0.3 ± 0.7	1.2 ± 1.6	−0.9	<0.001
Visits to finish (median [IQR])	10 [9–12]	14 [12–16]	−4	<0.001
Treatment time, months (median)	18.1	21.3	−3.2	0.002

Table 4. Bond failures and adverse events (first 12 weeks)

Outcome	Customized	Conventional	RR (95% CI)	P
Any early bond failure, % of teeth	4.9	5.6	0.88 (0.63–1.22)	0.44
Soft-tissue irritation (self-reported), %	7.3	9.1	0.80 (0.45–1.40)	0.43

Table 5. Patient-reported outcomes (0–10 VAS)

Domain	Customized	Conventional	Δ	P
Comfort during bonding	8.3 ± 1.2	7.4 ± 1.5	+0.9	<0.001
Satisfaction at 3 months	8.6 ± 1.0	8.0 ± 1.2	+0.6	0.001

Table 6. Cost proxies

Domain	Customized	Conventional	Δ
Lab fee/patient (USD)	+280	—	+280
Chair time saved (min/patient)	−96	—	−96
Net clinic time per finished case	Lower	—	—

Discussion

This multicenter cohort suggests that CAD/CAM-customized brackets deliver **meaningful reductions in placement error, chair time, and visits** without increasing early bond failures. Our accuracy findings align with reports that digital IDB using 3D-printed trays achieves sub-0.5 mm / <5° transfer errors and often outperforms direct bonding.7–10,14 For example, in vivo assessments of printed trays and CAD/CAM jigs demonstrated high fidelity in linear and angular positioning, corroborating our reduced need for repositioning.

Regarding efficiency, our results echo prospective and practice-based studies showing fewer appointments and shorter treatment with fully customized systems, including 3D-printed labial brackets.5 Some systematic reviews/meta-analyses conclude that finishing quality is similar between customized and conventional appliances, while time savings are possible but not guaranteed—depending on appliance type, workflow integration, and operator learning curve.1–4 Our multicenter design, standardized archwire protocols, and propensity adjustments aimed to minimize these confounders, yet we agree that randomized controlled trials remain the gold standard.12

Early bond-failure rates were comparable, contrasting with at least one controlled study that observed more early failures with a CAD/CAM system but fewer repositionings overall—suggesting that materials, tray stiffness, and bonding protocols may modulate outcomes.2 Differences in tray design (hard vs soft; shell vs bar; multi-piece) can affect transfer accuracy and early loss, an area where recent clinical trials provide granular guidance that clinics can use to tailor their workflow.

Beyond placement and time metrics, customization may influence mechanical aspects—slot precision, torque expression, and friction—which in turn affect finishing. Recent reviews and bench studies report that customized/printed brackets can provide high slot fidelity and acceptable sliding resistance, though long-term durability and wear of printed polymers/ceramics warrant further study.6,13,15,21 Our study did not directly test torque transmission or long-term bracket integrity; future work should include mechanical endpoints alongside clinical outcomes.

Finally, although practice-based evidence is encouraging, critical appraisals have pointed out design limitations in some custom-bracket studies (e.g., nonrandom allocation, center effects). Our findings should therefore be interpreted as effectiveness data under real-world conditions rather than definitive efficacy estimates. Pragmatic RCTs stratified by case difficulty, plus cost-effectiveness analyses incorporating lab fees and scheduling gains, would clarify where customized brackets offer the highest value.

Conclusion

CAD/CAM-customized brackets, delivered with printed transfer trays, enhanced placement accuracy and chairside efficiency in comprehensive orthodontic treatment and were associated with fewer visits and shorter treatment time without increasing early bond failures. These advantages, together with improving digital toolchains and materials, support broader adoption—ideally accompanied by ongoing audit, standardized bonding protocols, and high-quality randomized trials to refine indications and quantify value.

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