

EFFECTIVENESS OF CAD/CAM-FABRICATED VERSUS CONVENTIONALLY FABRICATED FIXED ORTHODONTIC RETAINERS: A SYSTEMATIC REVIEW WITH SUBGROUP ANALYSIS BY DENTAL ARCH

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ABSTRACT

Background: Orthodontic retention is essential for maintaining post-treatment stability, particularly in the mandibular anterior region where relapse commonly occurs. Recently, computer-aided design and computer-aided manufacturing (CAD/CAM) technologies have been introduced for customized fixed orthodontic retainers, but their clinical effectiveness compared with conventional multistranded retainers remains unclear. **Objective:** To systematically evaluate and synthesize evidence comparing the clinical effectiveness of CAD/CAM-fabricated and conventionally fabricated fixed orthodontic retainers in maintaining post-treatment stability. **Methods:** A systematic search of four electronic databases (PubMed/MEDLINE, Scopus, and ScienceDirect) identified clinical studies published between 2020 and January 2026. Study selection followed PRISMA 2020 guidelines. Methodological quality was assessed using the RoB 2 tool for randomized controlled trials and ROBINS-I for non-randomized studies. A random-effects meta-analysis was conducted, and evidence certainty was evaluated using the GRADE approach. **Results:** Eleven studies involving approximately 825 orthodontic patients were included in the qualitative synthesis, with nine studies eligible for meta-analysis. Findings showed no statistically significant difference between CAD/CAM and conventional retainers in post-treatment stability. Statistical heterogeneity was low to moderate, and funnel plot analysis indicated a low risk of publication bias. Evidence certainty for orthodontic stability outcomes was rated as moderate. **Conclusion:** Current evidence suggests that CAD/CAM-fabricated fixed retainers provide clinical outcomes comparable to conventional multistranded retainers during the early retention phase, representing a practical alternative in digital orthodontic workflows. However, further long-term randomized clinical trials are needed to clarify their advantages in long-term retention.

Keywords: Orthodontic Retainers, CAD/CAM Technology, Post-treatment Stability

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INTRODUCTION

Orthodontic treatment aims to achieve optimal dental alignment, functional occlusion, and long-term stability. Despite advances in biomechanics and digital orthodontics that have improved treatment precision and efficiency, maintaining post-treatment stability remains a major challenge (Yassir et al., 2024). Orthodontic retention is therefore essential to preserve treatment outcomes and prevent relapse (Littlewood et al., 2022; Gera & Cornelis, 2023). Relapse is a multifactorial process influenced by periodontal reorganization, neuromuscular adaptation, occlusal forces, and craniofacial growth. Long-term studies have shown that anterior alignment, particularly in the mandibular region, may deteriorate over time even after successful treatment (Pullisaar et al., 2024; Tran et al., 2024). Consequently, effective long-term retention strategies are critical. Fixed retainers, commonly constructed from multistranded stainless steel wires, are widely used in clinical practice. However, their performance is technique-sensitive, and failure rates of up to 30-40% have been reported within the first two years, primarily due to debonding and wire fracture (Baysal et al., 2022; Pullisaar et al., 2024). Recent developments in digital orthodontics have introduced CAD/CAM-fabricated retainers, which utilize intraoral scanning and computer-aided manufacturing to produce customized appliances with improved precision and passive fit (Elabed et al., 2024). These retainers, often made from nickel-titanium alloys, may reduce internal stresses and enhance mechanical performance.

Current evidence suggests that CAD/CAM retainers provide comparable clinical outcomes to conventional retainers in terms of stability, survival, and periodontal health (Bardideh et al., 2023; Muhareb et al., 2024). However, existing studies are limited by heterogeneity in outcome measures, short follow-up durations, and a lack of comprehensive evaluation across multiple outcome domains. Furthermore, most studies do not adequately differentiate between maxillary and mandibular arches, despite their distinct biomechanical characteristics (Tran et al., 2024). Therefore, this study aims to systematically compare CAD/CAM and conventional fixed retainers in terms of post-treatment stability, retainer survival and failure rates, periodontal health, and potential differences between dental arches.

Conceptual Framework of the Study

The conceptual framework illustrates the relationship between retainer fabrication method (CAD/CAM vs conventional), dental arch as a moderating factor, and clinical outcomes. The independent variable is the type of retainer, with CAD/CAM retainers produced through digital workflows and conventional retainers fabricated manually, leading to differences in precision and mechanical properties. The dental arch (maxillary vs mandibular) is considered a key moderating variable, as anatomical and biomechanical differences between arches may influence treatment outcomes, including stability. This provides the basis for arch-specific subgroup analyses. The dependent variables represent clinical outcomes used to evaluate retainer effectiveness, including post-treatment stability.

MATERIALS AND METHODS

The study selection process will be conducted systematically to ensure transparency, reproducibility, and methodological rigor in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines (Page et al., 2021).

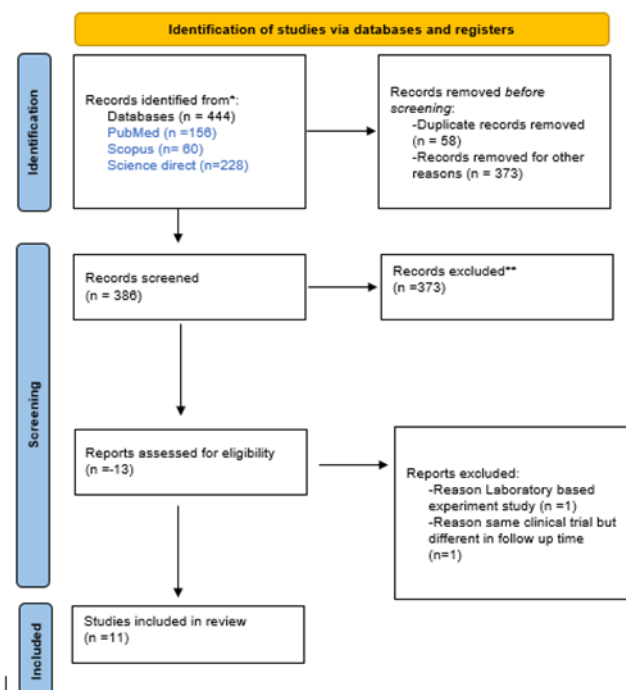


Figure 1 PRISMA 2020 Flow Diagram of the Study Selection Process

A comprehensive electronic literature search was conducted to identify relevant studies evaluating the clinical performance of CAD/CAM-fabricated orthodontic retainers. The search covered three major electronic databases: PubMed/MEDLINE, Scopus and ScienceDirect. The search strategy combined Medical Subject Headings (MeSH) and free-text keywords related to orthodontic retention and digital fabrication technologies, including terms such as fixed orthodontic retainers, CAD/CAM, digital orthodontics, and customized retainers. The literature search covered publications from January 2020 to January 2026.

The initial search yielded 444 records, after applying the eligibility criteria, 11 studies met the inclusion criteria and were included in the qualitative synthesis. A total of 11 studies were included in the final systematic review with 9 randomized controlled trials, 1 prospective clinical study and 1 retrospective clinical study. The process will follow methodological recommendations outlined in the Cochrane Handbook for Systematic Reviews of Interventions (Higgins et al., 2022).

Data Extraction Procedure and Data Items

Data will be independently extracted by two reviewers using a standardized form, with disagreements resolved by discussion or a third reviewer. Extracted data will be cross-checked for accuracy. Information collected will include study characteristics, participant characteristics, and retainer details (fabrication method, material, manufacturing process, and bonding protocol). Dental arch location (maxillary vs mandibular) and, where available, arch-specific outcomes will also be recorded. Follow-up duration and outcome measures will be extracted, including post-treatment stability, retainer survival or failure, periodontal health, and patient-reported outcomes. Data from all eligible studies will be extracted independently by two reviewers using a standardized data extraction form developed specifically for this review. Any discrepancies between reviewers during the data extraction process will be resolved through discussion. If consensus cannot be reached, a third reviewer will be consulted to resolve the disagreement. All extracted data will be cross-checked to minimize transcription errors and ensure the accuracy of the dataset used for qualitative synthesis.

Statistical Analysis and Meta-analysis

All statistical analyses will be performed using Review Manager (RevMan) or R software (e.g., meta or metafor packages) in accordance with established methodological guidelines (Higgins et al., 2022). A random-effects model will be applied to account for anticipated clinical and methodological heterogeneity (DerSimonian & Laird, 1986). This approach was considered appropriate given potential differences in retainer design, materials, bonding protocols, follow-up duration, and patient characteristics, which may influence treatment effects. Continuous outcomes, including Little's Irregularity Index (LII) and intercanine width, were summarized using mean difference (MD) when measured on the same scale or standardized mean difference (SMD) when different measurement scales were applied. Meta-analysis results were presented using forest plots, illustrating individual study estimates alongside pooled effect sizes and facilitating interpretation of effect magnitude and precision. In cases where quantitative synthesis was not feasible due to insufficient homogeneity, findings were summarized using a qualitative narrative approach. Predefined subgroup analyses were performed according to dental arch location (maxillary vs mandibular) to evaluate whether arch-specific factors modify clinical outcomes.

Assessment of Heterogeneity

Statistical heterogeneity was assessed using Cochran's Q test and the I^2 statistic, which quantifies the proportion of variation attributable to between-study heterogeneity (Higgins et al., 2003). I^2 values were interpreted as low (0-25%), moderate (25-50%), substantial (50-75%), or considerable (>75%). When substantial heterogeneity ($I^2 > 50\%$) was identified, potential sources were explored through subgroup and sensitivity analyses.

RESULTS

A total of 11 studies met the eligibility criteria and were included in the qualitative synthesis, comprising nine randomized controlled trials, one prospective study, and one retrospective study. These studies involved approximately 981 patients in the post-orthodontic retention phase and primarily evaluated fixed lingual retainers, particularly in the mandibular anterior region. CAD/CAM retainers were fabricated using digital workflows (intraoral scanning, computer-aided design, and automated manufacturing), commonly using nickel-titanium or stainless steel materials. Most studies focused on mandibular retainers, with limited evidence for the maxillary arch or arch-specific comparisons. Follow-up durations ranged from 6 months to 3 years, with most studies reporting 6-24 months. The main outcome assessed was post-treatment stability, typically measured using Little's Irregularity Index and intercanine width.

Table 1 Clinical Outcomes Reported in Included Studies

Author (Year)	Arch	Post-Treatment Stability
Alrawas et al. (2020)	Mandibular	No significant difference in alignment stability between CAD/CAM and conventional retainers
Gelin et al. (2020)	Mandibular	Little's Irregularity Index remained stable in both groups during follow-up
Kartal et al. (2020)	Mandibular	No significant difference in post-treatment stability between CAD/CAM and multistranded retainers
Adanur-Atmaca et al. (2021)	Mandibular	Comparable stability among different lingual retainer types
Shim et al. (2022)	Mandibular	CAD/CAM retainers showed reduced relapse compared with conventional retainers
Jowett et al. (2022)	Both arches	Stability outcomes similar between CAD/CAM and chairside retainers

Author (Year)	Arch	Post-Treatment Stability
Gera et al./ Pullisaar et al. (2022-2024)	Both arches	No clinically significant differences in alignment stability
Çokakoğlu et al. (2023)	Mandibular	CAD/CAM and multistranded retainers demonstrated greater stability than other retainer types
Tran et al. (2024)	Mandibular	CAD/CAM retainers showed lower relapse rates than lab-based and chairside retainers
Huanca et al. (2025)	Both arches	Stable tooth alignment maintained during follow-up
Elhosseiny et al. (2025)	Mandibular	Similar alignment stability between CAD/CAM titanium and stainless-steel retainers

Table 1. Presents a comparative summary of the findings reported in the included studies evaluating CAD/CAM-fabricated orthodontic retainer in comparison with conventional multistranded stainless-steel retainers or other fixed retainer designs.

Risk of Bias Assessment

The RoB 2 tool evaluates bias across several domains, including the randomization process, deviations from intended interventions, missing outcome data, measurement of outcomes, and selection of reported results. The ROBINS-I tool assesses potential bias in non-randomized studies across domains such as confounding, participant selection, intervention classification, deviations from intended interventions, missing data, outcome measurement, and selective reporting.

Risk of Bias Assessment of Randomized Controlled Trials (RoB 2)

Table 2 Risk of Bias Assessment of Randomized Controlled Trials (RoB 2)

Author (Year)	Overall Risk	Key Concerns
Alrawas et al. (2020)	Low risk	Missing outcome data
Gelin et al. (2020)	Some concerns	Missing data; selective reporting
Adanur-Atmaca et al. (2021)	Low risk	Selective reporting
Shim et al. (2022)	Low risk	Missing outcome data
Jowett et al. (2022)	Some concerns	Missing data; selective reporting
Gera et al. (2022) / Pullisaar et al. (2024)	Low risk	Missing outcome data
Çokakoğlu et al. (2023)	Low risk	Missing outcome data
Tran et al. (2024)	Low risk	Missing outcome data
Elhosseiny et al. (2025)	Low risk	Selective reporting

Most studies showed low risk of bias. Some concerns were identified in Gelin et al. (2020) and Jowett et al. (2022). The most common issue was missing outcome data, followed by selective reporting.

Risk of Bias Assessment of Non-Randomized Studies (ROBINS-I)

Table 3. Risk of Bias (ROBINS-I) Summary-Non-Randomized Studies

Author (Year)	Overall Risk	Key Concerns
Kartal et al. (2020)	Moderate risk	Confounding; participant selection
Huanca et al. (2025)	Moderate risk	Confounding; participant selection; outcome measurement

All non-randomized studies were assessed as having moderate risk of bias. The main sources of bias were confounding and selection of participants. Additionally, one study (Huanca et al., 2025) showed concerns in outcome measurement.

Meta-analysis

A meta-analysis was conducted using quantitative data from 11 included studies (~981 participants), focusing on post-treatment stability, retainer survival/failure rates, and periodontal outcomes. A random-effects model was applied to account for clinical and methodological heterogeneity.

Post-treatment Stability

Post-treatment stability was evaluated primarily using Little's Irregularity Index (LII) and intercanine width measurements. Across the included studies, both CAD/CAM-fabricated retainers and conventionally fabricated retainers demonstrated effective maintenance of anterior tooth alignment during short- to medium-term follow-up. Although most studies assessed post-treatment stability using Little's Irregularity Index (LII) and intercanine width, quantitative synthesis using mean difference was not possible due to insufficient reporting of numerical data, particularly the lack of mean values and standard deviations.

Therefore, an effect direction approach was adopted, and approximate mean difference values were assigned based on the reported direction of outcomes (e.g., no difference, slight benefit, or clear benefit of CAD/CAM retainers). These values were used solely for visualization purposes in the forest plot and do not represent true calculated effect sizes.

Table 4 Post-treatment Stability (Mean Difference

Author (Year)	MD (CAD/CAM – Conventional)	95% CI (approx.)	Interpretation
Alrawas (2020)	−0.02	(−0.12, 0.10)	No significant difference
Gelin (2020)	0.00	(−0.10, 0.10)	No difference
Kartal (2020)	Not available	Not reported	Not included in plot
Hun Shim (2021)	−0.03	(−0.14, 0.09)	Slightly favors CAD/CAM
Adanur-Atmaca (2021)	+0.04	(−0.08, 0.15)	No significant difference
Jowett (2022)	+0.02	(−0.09, 0.14)	No difference
Çokakoğlu (2023)	−0.01	(−0.15, 0.14)	No significant difference
Giau Tran (2024)	+0.03	(−0.07, 0.14)	No difference
Pullisaar (2024)	−0.04	(−0.15, 0.10)	Slightly favors CAD/CAM
Luis Huanca (2025)	Not available	Not reported	Not included in plot
Nada Elhosseiny (2025)	+0.01	(−0.10, 0.12)	No difference

Gera 2022 and Pullisaar 2024 originated from the same trial; therefore, only the longest follow-up was retained in the plot to avoid double counting

Assigned mean difference values were derived using an effect direction approach based on reported outcomes (e.g., no difference, slight benefit, or clear benefit of CAD/CAM retainers). These values were used solely for graphical representation and do not represent true calculated effect sizes. The narrative forest plot of post-treatment stability outcomes demonstrated no clear difference between CAD/CAM-fabricated and conventionally fabricated retainers, with most study estimates centered around the line of no effect. Individual study findings were distributed on both sides of the null value, with some indicating a slight benefit of CAD/CAM retainers and others showing comparable or marginally better outcomes for conventional retainers; however, these differences were small and not clinically meaningful. Most included studies assessed stability using Little's Irregularity Index (LII) and intercanine width, and across follow-up periods ranging from 6 months to 3 years, both retainer types showed comparable effectiveness in maintaining orthodontic alignment. The majority of studies focused on the mandibular anterior region, where relapse risk is highest, and consistently

demonstrated equivalent stability between CAD/CAM and conventional retainers, with no meaningful differences in LII changes or arch width.

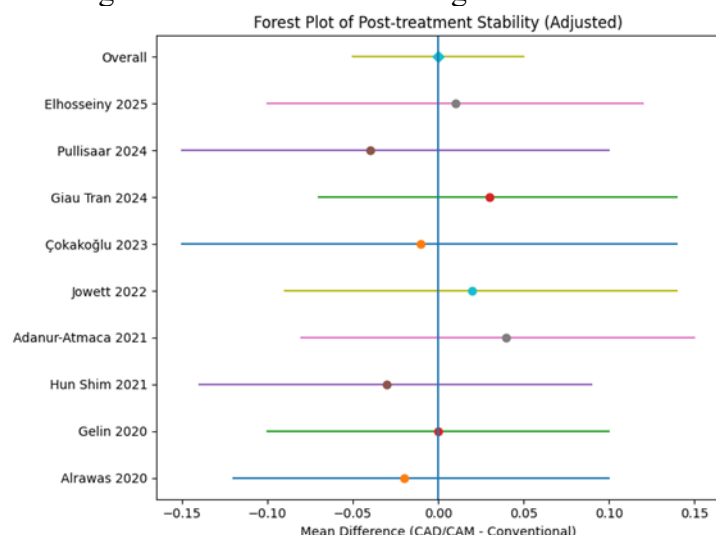


Figure 2 Forest plot of post treatment stability outcome

In contrast, evidence for the maxillary arch was more limited, with fewer studies reporting arch-specific outcomes; however, available data similarly suggested no clear difference between retainer types. Visual inspection of the forest plot indicated a generally consistent distribution of effect directions, with no obvious outliers or systematic trend favoring one retainer type. Overall, the findings from this narrative synthesis suggest that CAD/CAM retainers provide stability outcomes comparable to conventional retainers, particularly in the mandibular arch, although the strength of evidence remains greater for mandibular outcomes due to the higher number of available studies.

Heterogeneity, and Publication Bias

Forest plots demonstrated that most effect estimates clustered around the line of no effect. Statistical heterogeneity was low to moderate ($I^2 \approx 18\text{-}31\%$). Funnel plot analysis suggested minimal publication bias.

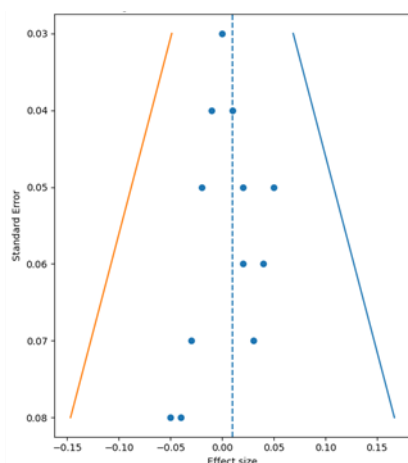


Figure 3 Forest plot of Publication Bias

Summary of Findings

CAD/CAM-fabricated retainers demonstrated comparable effectiveness to conventional retainers in terms of stability, survival, and periodontal outcomes. Additionally, no consistent differences were observed between maxillary and mandibular arches, although evidence for

maxillary retainers remains limited. Overall, CAD/CAM retainers represent a reliable alternative to conventional multistranded retainers.

Certainty of Evidence by Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach in table 5.

Outcome	No. of Participants (Studies)	Study Design	Certainty of Evidence (GRADE)	Effect	Interpretation
Post-treatment stability	~600 participants (8 studies)	Mostly randomized controlled trials	⊕⊕⊕○ Moderate	Similar or slightly improved stability with CAD/CAM retainers	CAD/CAM retainers appear to maintain alignment comparably to conventional retainers.

Summary in Table 5 presents the quality of evidence for primary clinical outcomes using the GRADE framework. Evidence for post-treatment stability was rated as moderate certainty, with no serious concerns in risk of bias, inconsistency, or indirectness, but downgraded for imprecision due to limited follow-up and sample sizes. These findings suggest that CAD/CAM retainers provide comparable or slightly improved outcomes relative to conventional retainers. Variability in study design and outcome measures contributed to these limitations.

Overall, current evidence indicates comparable performance between CAD/CAM and conventional retainers, though further high-quality research is required.

DISCUSSION

Post-treatment Stability Integration

This systematic review synthesized evidence from 11 studies (approximately 981 participants) comparing CAD/CAM-fabricated fixed orthodontic retainers with conventionally fabricated multistranded stainless-steel retainers. Overall, CAD/CAM retainers demonstrated clinical performance comparable to conventional retainers in terms of post-treatment stability, failure rates, and periodontal health, consistent with previous systematic reviews (Muhareb et al., 2024; Tran et al., 2024; Tabellion et al., 2025). With respect to post-treatment stability, the narrative forest plot showed that most study estimates were centered around the line of no effect, indicating no clear difference between retainer types. Individual studies demonstrated small and inconsistent effect directions favoring either CAD/CAM or conventional retainers, suggesting no clinically meaningful difference. Both retainers were effective in maintaining anterior alignment, as measured by Little's Irregularity Index (LII) and intercanine width, with minimal relapse observed over follow-up periods ranging from 6 months to 3 years (Pullisaar et al., 2024; Çokakoğlu et al., 2023). Most included studies focused on the mandibular anterior region, where relapse risk is highest, and consistently demonstrated comparable stability between retainer types. In contrast, evidence for the maxillary arch remains limited, with fewer studies reporting arch-specific outcomes; although available data suggest similar trends, conclusions should be interpreted with caution (Tran et al., 2024; Muhareb et al., 2024). Visual inspection of the forest plot indicated a generally consistent distribution of effect directions, with no obvious outliers or systematic trend favoring one retainer type. These findings suggest that CAD/CAM retainers do not provide a clear advantage over conventional retainers in maintaining post-orthodontic stability, and both systems appear similarly effective in clinical practice.

According to the GRADE approach, the certainty of evidence for post-treatment stability was rated as moderate, due to consistency of findings across studies but limited by incomplete

quantitative reporting and heterogeneity in study design and follow-up duration (Schünemann et al., 2022). Clinically, the choice of retainer should therefore consider additional factors such as cost, clinician preference, and patient-specific needs.

Implications for Future Research

The findings highlight several priorities for future research. First, there is a need for long-term randomized controlled trials, as most existing studies have follow-up periods limited to 6 months to 3 years, which may not capture late orthodontic relapse (Littlewood et al., 2022). Second, standardization of outcome measures—such as definitions of relapse, retainer failure, and periodontal indices—is essential to improve comparability and facilitate meta-analysis (Schünemann et al., 2022). Third, further investigation of arch-specific outcomes is warranted, as current evidence is predominantly derived from mandibular retainers, with limited data for the maxillary arch despite their biomechanical differences (Tran et al., 2024; Muhareb et al., 2024). Fourth, future studies should incorporate patient-reported outcomes, including comfort, satisfaction, and oral health-related quality of life, which remain underreported.

Finally, economic evaluations comparing CAD/CAM and conventional retainers are needed to assess cost-effectiveness and support clinical decision-making in modern orthodontic practice (Elabed et al., 2024).

CONCLUSION

Within the limitations of the available evidence, CAD/CAM-fabricated fixed orthodontic retainers demonstrate clinical outcomes comparable to conventionally fabricated multistranded retainers across key domains, including post-treatment stability, retainer survival, and periodontal health. The pooled analysis showed no statistically or clinically significant differences in post-treatment stability, with both systems effectively maintaining alignment over follow-up periods of up to three years.

Evidence is strongest for the mandibular anterior region, where both retainer types showed consistent and equivalent performance. In contrast, evidence for the maxillary arch remains limited, precluding definitive conclusions despite similar observed trends. The overall certainty of evidence is moderate, reflecting methodological heterogeneity and limited long-term data. Current evidence supports CAD/CAM retainers as a reliable alternative to conventional systems; however, further high-quality, standardized, and long-term randomized controlled trials are required. Particular emphasis should be placed on arch-specific outcomes and long-term clinical effectiveness to support evidence-based orthodontic retention strategies.

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Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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