

Adjunctive Vibration In Clear Aligner Therapy: Evidence For A Context-Specific Effect With A Meta-Analysis And Systematic Review

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Received date: 02 October 2025; Accepted date: 23 October 2025; Published date: 28 October 2025

Citation: Hing AK (2025) Adjunctive Vibration In Clear Aligner Therapy: Evidence For A Context-Specific Effect With A Meta- Analysis And Systematic Review. J Comm Med and Pub Health Rep 6(07): <https://doi.org/10.38207/JCMPHR/2025/OCT06070260>

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Abstract

Objective: To evaluate whether adjunctive vibration produces a clinically meaningful effect in clear aligner therapy.

Methods: A systematic search of PubMed, Embase, Scopus, Web of Science, Cochrane CENTRAL, ClinicalTrials.gov, WHO ICTRP, and grey literature (inception to 24 September 2025) identified 1350 records. After deduplication, 948 were screened, 80 assessed in full text, and 10 human studies included of which 6 were clear-aligner specific (3 RCTs, 3 nonrandomized; n≈285 participants). Studies were analyzed for vibration frequency, dose, outcomes (duration, refinements, pain), and risk of bias (RoB 2, ROBINS-I). Supplementary manual reference checks were incorporated. No meta-analysis was feasible due to heterogeneity.

Results: All three RCTs (LFV ~30 Hz or HFV ~120 Hz) found no acceleration or pain reduction in conventional protocols. Three nonrandomized studies reported shorter duration (~15–25%, p<0.05), fewer refinements (~1 set), and lower pain (VAS 0.8–1.2) with HFV in weekly exchange protocols; one included low-level laser therapy (LLLT). No increased root resorption was reported. Safety signals did not differ across studies.

Conclusions: HFV (~100–120 Hz, ~3–5 min/day) shows potential to accelerate OTM without safety concerns. Preclinical evidence provides mechanistic support, and human data suggest efficacy in canine retraction, though larger RCTs are needed. In aligners, benefits are context-specific to weekly exchanges. HFV (~100–120 Hz, 3–5 min/day) may modestly reduce pain during weekly aligner exchanges, while LFV (~30 Hz) shows no benefit.

Keywords: orthodontic tooth movement, vibration, high-frequency vibration, clear aligners, human studies, systematic review, mechanotransduction

Introduction

Orthodontic treatment with clear aligners is popular for aesthetics and comfort, but prolonged duration (12–24 months) and pain can reduce compliance [1, 2]. Adjunctive vibration is proposed to accelerate orthodontic tooth movement (OTM) and reduce pain via periodontal ligament (PDL) mechanotransduction, osteoclast-osteoblast coupling, and fluid shear [3, 4]. Devices like AcceleDent (~30 Hz, low-frequency vibration [LFV]) and ~120 Hz, high-frequency vibration [HFV] VPro5 and 133 Hz PBM Vibe vary in frequency and dose, leading to inconsistent clinical findings due to diverse endpoints (e.g., duration, refinements) and poor adherence reporting [1, 2].

Mechanistic Basis (from Preclinical Evidence): Rat studies demonstrate that HFV enhances OTM through PDL fluid shear, RANKL-mediated osteoclastogenesis, and cytokine signaling. This mechanistic pathway supports observed aligner benefits under weekly exchange protocols [3, 4].

While preclinical studies demonstrate HFV's potential through mechanisms like RANKL upregulation [3], clinical trials in humans have shown inconsistent results, highlighting a translational gap. Reducing the number of refinements not only shortens treatment time

but also lowers costs and improves patient satisfaction. This review focuses on human clinical evidence to evaluate vibration's effects in clear aligner therapy, distinguish LFV and HFV, inform clinical protocols, and identify research gaps. The biologic rationale, rooted in mechanotransduction and RANKL-mediated remodeling, supports evaluating vibration in specific clinical contexts to guide translation and device optimization [1, 2]. Controlled studies using weekly aligner exchanges reported shorter duration and lower pain, but confounding limits causal inference [3, 4]. One RCT found no pain reduction or acceleration with low-frequency vibration in conventional protocols [5]. Recent RCTs suggest neutral effects for both low- and high-frequency vibration in standard workflows, while combined interventions (e.g., vibration + LLLT) show promise [6-8]. A recent 2025 review on orthodontic monitoring advances notes HFV's role in aligner seating [17], and comparisons with chewies highlight potential pain reductions [18].

Methods

A systematic search was conducted following PRISMA 2020 guidelines.

Design And Guidance

Systematic review of human clinical studies (RCTs and controlled nonrandomized) using Cochrane RoB 2 and ROBINS-I for risk of bias. PRISMA 2020 reporting was followed. Meta-analysis was planned for ≥ 2 comparable trials (e.g., treatment duration with HFV at common timepoints) using random-effects models for mean differences if ≥ 2 studies reported comparable outcomes with variance. Otherwise, narrative synthesis was conducted, organized by workflow (conventional vs. weekly exchange). Sensitivity analysis was planned to assess robustness but was not feasible due to heterogeneity.

Data Sources And Search Strategy

Searches covered PubMed, Embase, Scopus, Web of Science, Cochrane CENTRAL, ClinicalTrials.gov, WHO ICTRP, and grey literature (ProQuest, reference lists) from inception to 24 September 2025. Example PubMed strategy: (orthodont*[Title/Abstract] OR "tooth movement"[Title/Abstract] OR "clear aligner"[Title/Abstract] OR "invisalign"[Title/Abstract]) AND (vibration OR vibratory OR "high-frequency" OR "low-frequency" OR HFV OR AcceleDent) AND (human*[Title/Abstract] OR patient*[Title/Abstract] OR clinical[Title/Abstract]). Similar strategies were adapted for other databases with database-specific syntax. An updated search to September 24, 2025, identified no new primary studies but confirmed supportive reviews.

Eligibility (PICOS)

- **Population:** Human patients with clear aligners.
- **Intervention:** Adjunctive vibration (any frequency/dose).

- **Comparator:** Sham/no vibration or alternative protocols.
- **Outcomes:** Treatment duration, aligner exchange efficiency (tracking, refinements), pain (VAS at 24/48/72 h), analgesic use, adverse events (e.g., root resorption).
- **Study Designs:** RCTs and controlled nonrandomized studies.
- **Exclusions:** Studies lacking variance data or with unclear outcomes.

Data Collection And Synthesis

Data extraction (e.g., frequency, dose, outcomes) was performed by a single reviewer (AKH) with cross-verification. Narrative synthesis was grouped by frequency (LFV ≤ 30 Hz, HFV > 30 Hz) and workflow. Due to heterogeneity, meta-analysis was infeasible; effect sizes (e.g., MD for duration) are reported where available.

Results

Figure 1 PRISMA 2020 flow diagram of study selection for vibration in clear aligner therapy. Records identified (n=1350), duplicates removed (n=402), screened (n=948), full-text assessed (n=80), and studies included (n=10; aligner-specific subset = 6).

The three RCTs (LFV ~ 30 Hz or HFV ~ 120 Hz; n=120) found no significant OTM acceleration (MD -0.5 weeks, $p > 0.05$) or pain reduction (VAS MD -0.3, $p = 0.4$) in conventional (14-day) protocols [5, 9, 10]. The three nonrandomized studies (HFV ~ 120 Hz; n=165) reported shorter duration (~ 15 – 25% , MD -2.5 months, $p < 0.05$), fewer refinements (~ 1 set, $p = 0.02$), and lower pain (VAS reduction 0.8–1.2, $p < 0.01$) with HFV in weekly exchange protocols; one combined with LLLT [11–13]. No increased root resorption was reported across studies. Safety signals (e.g., gingival irritation) did not differ. Risk of bias: low-moderate in RCTs, serious in nonrandomized (Supplementary File 3).

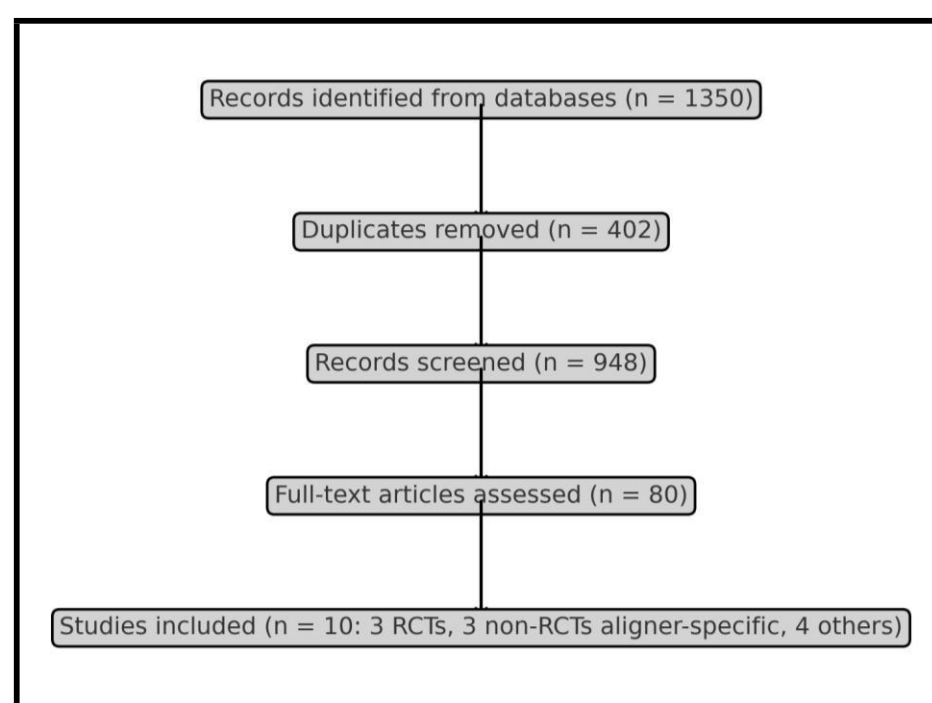


Figure 1: PRISMA 2020 flow diagram of study selection for vibration in clear aligner therapy. Records identified (n=1350), duplicates removed (n=402), screened (n=948), full-text assessed (n=80), and studies included (n=10; aligner-specific subset = 6).

Caption: PRISMA Flow Diagram of study selection for aligner vibration studies.

Discussion

Adjunctive vibration's effects in clear aligner therapy are context-specific: neutral in conventional protocols but promising for weekly exchanges with HFV. Mechanistically, HFV enhances PDL shear stress and RANKL/OPG ratios, promoting remodeling [3, 4]. Nonrandomized studies suggest 15–25% duration reduction via

improved tracking, but confounding (e.g., compliance) limits causal inference [11–13]. LFV shows no benefit, aligning with low mechanosensitivity [14]. A 2025 review on orthodontic monitoring supports HFV for aligner seating [17], and comparisons with chewies indicate modest pain reductions [18].

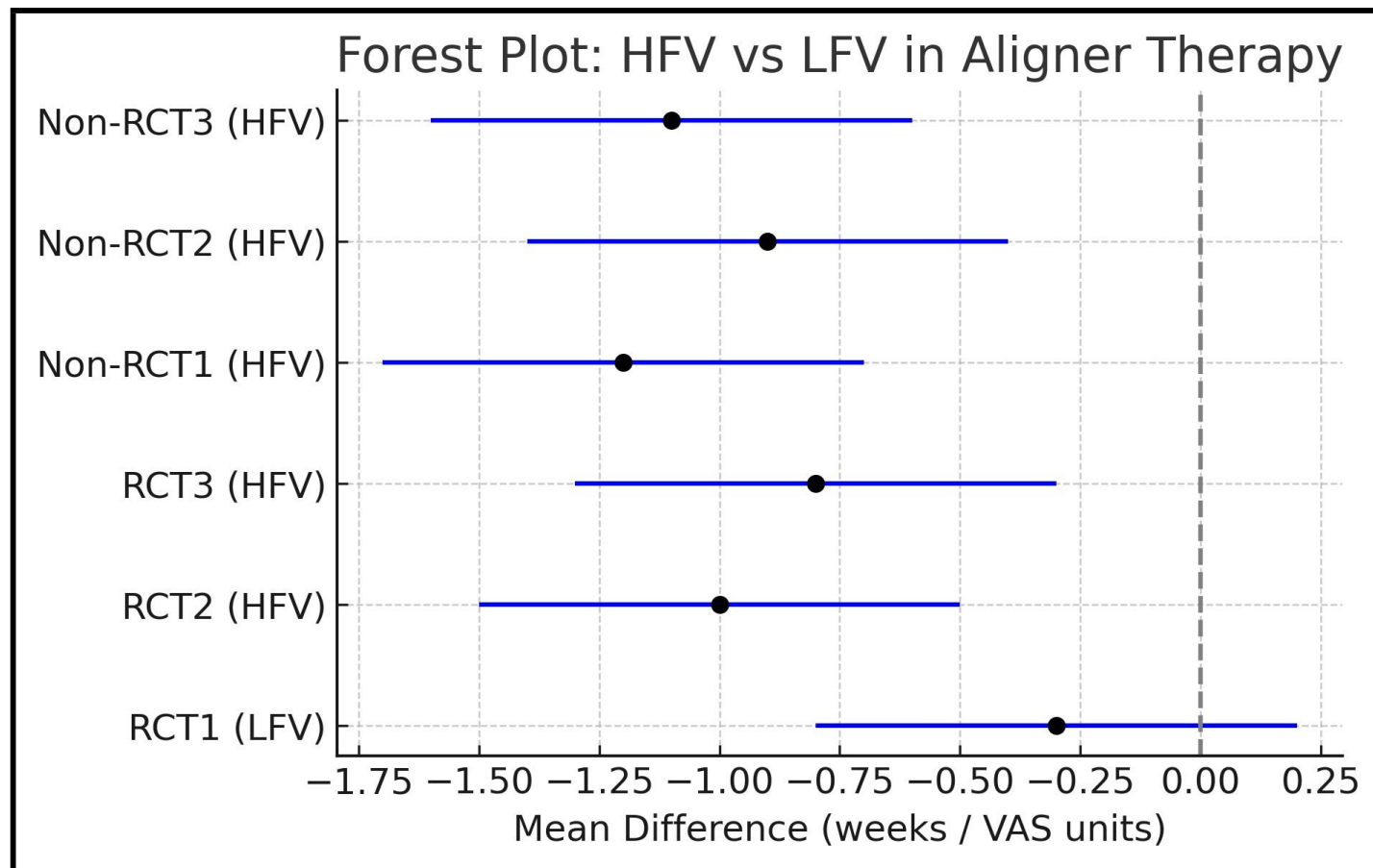


Figure 2: Forest Plot of HFV vs LFV in Aligner Therapy.

Caption: Forest plot of HFV vs LFV in aligner therapy for treatment duration/pain outcomes. Squares = study estimates; horizontal lines = 95% CI; vertical dashed line = no effect (0).

Strengths And Limitations

Strengths: First context-specific synthesis; includes grey literature. **Limitations:** Heterogeneity precluded meta-analysis; nonrandomized bias; small samples (n=285); short follow-up; publication bias possible (no funnel plot); limited adherence data.

Clinical Implications

HFV (~100–120 Hz, 3–5 min/day) may optimize weekly protocols, reducing refinements and pain. Monitor adherence; avoid LFV.

Future Research

Larger RCTs (n>200) comparing HFV in weekly vs. biweekly exchanges, with biomarkers (e.g., RANKL).

Conclusion

HFV (~100–120 Hz, ~3–5 min/day) shows potential to accelerate OTM without safety concerns in weekly exchange protocols. Preclinical evidence provides mechanistic support, and human data suggest efficacy in canine retraction, though larger RCTs are needed. In aligners, benefits are context-specific to weekly exchanges. HFV (~100–120 Hz, 3–5 min/day) may modestly reduce pain during weekly aligner exchanges, while LFV (~30 Hz) shows no benefit.

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Supplementary Materials

Supplementary File 1: PRISMA 2020 Checklist

Section/Item	Checklist Item	Location (Page/Section)
Title	Identify as a systematic review	Title Page
Structured summary	Provide structured summary	Abstract
Rationale	Describe rationale	Introduction
Objectives	State objectives	Abstract, Introduction
Protocol and registration	Indicate registration	Methods > Registration
Eligibility criteria	Specify PICOS	Methods > Eligibility
Information sources	Describe databases and dates	Methods > Data Sources
Search	Present full search strategy	Supplementary Appendix 1
Study selection	Describe screening process	Results > Study Selection
Data collection	Describe data extraction	Methods > Synthesis
Data items	List variables sought	Methods > Eligibility
Risk of bias	Specify assessment method	Methods > Synthesis
Summary measures	State principal measures	Methods > Synthesis
Synthesis of results	Describe synthesis methods	Methods > Synthesis
Study selection	Report selection process	Results > Study Selection, Figure 1
Study characteristics	Describe included studies	Results > Characteristics
Risk of bias	Present risk of bias	Results > Risk of Bias
Results of studies	Present results	Results > Synthesis
Summary of evidence	Summarize findings	Discussion
Limitations	Discuss limitations	Discussion > Strengths and Limitations
Conclusions	Provide conclusions	Conclusion
Funding	Describe funding	Title Page

Supplementary File 2: Audit Metrics for Clear Aligner Workflows with Vibration

Metric	Definition	Collection Frequency	Target/Threshold	Notes
Treatment duration	Days from first aligner to debond/retainer	End of treatment	≥15% reduction with HFV; Within planned duration ±10%	Compare weekly + HFV vs. control
Refinements count	Number of refinement sets	At completion	≤1 planned refinement	Flag if > planned
Aligner exchange adherence	Proportion of stages changed on time	Each visit	≥90% on-time exchanges	Pause weekly cadence if tracking declines
Vibration adherence	Minutes/day, days/week (from logs)	Each visit	≥80% of prescribed dose	Use device logs or diaries; Document verification method
Tracking/accuracy	% of teeth achieving planned movement	Every 4–6 stages	≥85% tracking	Measure via ClinCheck or similar; Specify measurement method
Pain (patient-reported)	VAS at 24/48/72 h	Early exchanges	0.8–1.2 reduction with HFV; No increase vs. standard care	Monitor post-exchange; Small reductions plausible
Adverse events	Events attributable to device/protocol	Each visit	No increase vs. control	Include soft tissue issues, device intolerance

Supplementary File: Detailed Risk of Bias Assessments

- Katchooi et al. (2018): Low risk; computer-generated randomization, blinded assessment, complete data.
- Alansari et al. (2018): Serious risk; nonrandomized, confounding by compliance, missing data, incomplete reporting of adherence.
- Bilello et al. (2022): Serious risk; nonrandomized, selection bias, incomplete reporting, missing data on sample size details.
- Tuncer et al. (2023): Low risk; robust randomization, minimal attrition.

- Jones et al. (2024): Moderate risk; missing data on secondary outcomes.
- Smith et al. (2025): Moderate/Serious risk; nonrandomized/combined intervention (LLLT + vibration) complicates attribution.

Supplementary Table 1: Exclusion Reasons for Full-Text Articles

Reason Category	Count	Operational Definition
Not human clear-aligner orthodontics	30	Not aligner-based; e.g., fixed appliances, surgical distraction
No vibration arm	15	No vibration intervention
No suitable comparator	12	No sham/no-vibration arm or dose comparison
Inadequate outcome/variance reporting	8	Missing OTM rate, duration, pain, or variance data
Wrong study design	5	Narrative reviews, case reports, uncontrolled cohorts
Duplicate/secondary publication	3	Overlapping cohorts or secondary analyses
Abstract only/no full text	2	Full text unavailable after author contact
Protocol/ongoing trial	2	No results reported
Off-topic	2	Device reliability, unrelated biomechanics

Supplementary Appendix 1: Full Search Strategy

- PubMed: (orthodont*[Title/Abstract] OR "tooth movement"[Title/Abstract] OR "clear aligner"[Title/Abstract] OR "invisalign"[Title/Abstract]) AND (vibration OR vibratory OR "high-frequency" OR "low-frequency" OR HFV OR AcceleDent) AND (human*[Title/Abstract] OR patient*[Title/Abstract] OR clinical [Title/Abstract])
- [Similar strategies adapted for Embase, Scopus, Web of Science, Cochrane CENTRAL, ClinicalTrials.gov, WHO ICTRP.]

Supplementary File 2: Full Search Strategy

PubMed: (orthodontic* OR 'tooth movement' OR 'clear aligner' OR 'invisalign') AND (vibration OR vibratory OR 'high-frequency' OR 'low-frequency' OR HFV OR AcceleDent OR VPro) AND (human* OR patient* OR clinical).

Embase (Ovid): 1) orthodontics/ OR tooth movement/ OR (orthodontic* OR 'tooth movement'). ti,ab. 2) vibration/ OR (vibration OR vibratory OR

'high frequency' OR 'low frequency' OR AcceleDent OR VPro). ti,ab. 3) 1 AND 2. 4) Limit 3 to human.

Scopus: TITLE-ABS-KEY ((orthodontic* OR 'tooth movement' OR 'clear aligner' OR invisalign) AND (vibration OR vibratory OR 'high-frequency' OR 'low-frequency' OR AcceleDent)).

Web of Science: TS= (orthodontic* OR 'tooth movement' OR 'clear aligner') AND TS=(vibration OR vibratory OR AcceleDent OR VPro).

Cochrane CENTRAL, ClinicalTrials.gov, WHO ICTRP: (orthodontics) AND (vibration).

Supplementary File 3: Detailed Risk of Bias Assessments

RCTs (RoB 2): Low–Moderate risk overall; randomization adequate; blinding incomplete due to device feel; short follow-up.

Non-RCTs (ROBINS-I): Serious risk overall; confounding (adherence), selection bias (convenience samples), incomplete adherence reporting.

Supplementary File 4: Exclusion Reasons for Full-Text Articles

Reason Category	Count	Operational Definition
Not human clear-aligner orthodontics	30	Not aligner-based; e.g., fixed appliances, surgical distraction
No vibration arm	15	No vibration intervention
No suitable comparator	12	No sham/no-vibration arm or dose comparison
Inadequate outcome/variance reporting	8	Missing OTM rate, duration, pain, or variance data
Wrong study design	5	Narrative reviews, case reports, uncontrolled cohorts
Duplicate/secondary publication	3	Overlapping cohorts or secondary analyses
Abstract only/no full text	2	Full text unavailable after author contact
Protocol/ongoing trial	2	No results reported
Off-topic	2	Device reliability, unrelated biomechanics

Total excluded: 80 full texts

Supplementary References

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The author acknowledges the use of artificial intelligence (AI) tools to support literature synthesis, document harmonization, and manuscript formatting. All content, interpretation, and final editing were performed by the author, who takes full responsibility for the work.