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A Meta-Analysis And Systematic Review Volume 6 Issue 07

Adjunctive Vibration For Orthodontic Pain Reduction: A Meta-Analysis And Systematic Review

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Abstract

Objective: To evaluate the effects of adjunctive vibration on pain reduction in orthodontic treatment with fixed appliances or clear aligners, based on 10 clinical studies (N=512; 6 RCTs, 4 non-randomized).

Methods: A systematic search of PubMed, Embase, Scopus, Web of Science, Cochrane CENTRAL, ClinicalTrials.gov, and WHO ICTRP (inception to 24 September 2025) identified 1150 records. After deduplication, 780 were screened, 85 assessed in full text, and 10 studies included. Studies were analyzed for vibration parameters, pain outcomes (VAS at 24/48/72 h, analgesic use), and risk of bias (RoB 2, ROBINS-I). Meta-analysis was planned but not feasible due to heterogeneity (I^2>75%).

Results: Meta-analysis infeasible due to high heterogeneity (I^2 > 75%). Four RCTs (N=232) found no pain reduction with low-frequency vibration (LFV, ~30 Hz; VAS differences -0.3 to +0.1, p>0.05). Two RCTs and three non-randomized studies (N=280) reported reduced pain with high-frequency vibration (HFV, ~100–133 Hz; VAS 0.5–1.2 lower, p<0.05) at 24–48 h; one included low-level laser therapy (LLLT). HFV demonstrated moderate heterogeneity (I^2=82%). In aligner studies, HFV reduced peak pain by 15–25% and analgesic use by ~20%. No increased adverse events were reported.

Conclusions: Adjunctive HFV (~100–133 Hz, 3–5 min/day) provides modest short-term pain relief (≈0.5–1.2 VAS units at 24–48 h) and reduced analgesic use, particularly in aligners, while LFV (~30 Hz) is ineffective. Limitations include small sample sizes, high heterogeneity, and short follow-ups. Larger multicenter RCTs with standardized outcomes are needed to confirm efficacy and optimize dosing.

Keywords: orthodontic pain, vibration, high-frequency vibration, low-frequency vibration, systematic review, mechanotransduction

Introduction

Orthodontic treatment often induces pain, peaking 24–48 h after appliance placement or adjustments, due to periodontal ligament (PDL) compression, ischemia, and inflammatory cytokine release (e.g., IL-1β, PGE2) **[1, 2]**. Pain reduces compliance, potentially prolonging treatment, prompting non-invasive adjuncts like vibration **[3]**. Devices like AcceleDent (~30 Hz, low-frequency vibration [LFV]) and VPro5 or PBM Vibe (~100–133 Hz, high-frequency vibration [HFV]) vary in efficacy **[5–7]**. This review evaluates clinical evidence on vibration for orthodontic pain, contrasting LFV (~30 Hz) with HFV (~100–133 Hz), **(Figure 1)** and identifies research gaps. Because pain is a leading cause of poor compliance, strategies like vibration warrant careful evaluation. Mechanistic Basis (from Preclinical Evidence): Rat studies demonstrate that HFV (~100–120 Hz) enhances orthodontic tooth movement (OTM) through PDL fluid shear, RANKL-mediated osteoclastogenesis, and cytokine signalling (IL-1β, TNF-α). Mechanotransductive desensitization of nociceptors may further reduce pain perception by modulating neural signalling pathways. This mechanistic pathway supports observed pain reduction and aligner benefits under weekly exchange protocols **[3, 4]**. The mechanotransductive effects demonstrated in animal models appear clinically relevant, as similar pathways of cytokine modulation (IL-1β, TNF-α, PGE_2) are implicated in human orthodontic pain responses, supporting the translational applicability of high-frequency stimulation. These preclinical effects suggest potential translatability to clinical pain modulation.

Parameter	High-Frequency Vibration (HFV, ~100–133 Hz)	Low-Frequency Vibration (LFV, ~30 Hz)
Pain reduction (VAS 24–48 h)	↓ 0.5–1.2 units (≈15–25%)	No reduction (≈0.0–0.3 units)
Analgesic use	↓ ≈ 20%	No change
Optimal duration	3–5 min/day	Not effective
Mechanistic basis	PDL shear, cytokine modulation (↓ IL-1β, PGE_2)	Insufficient mechanotransduction
Safety	No reported adverse events	No reported adverse events

Figure 1: Comparative summary of clinical and mechanistic outcomes for high-frequency versus low-frequency vibration in orthodontic pain management

Methods

A systematic review was conducted following PRISMA 2020 guidelines **(Figure 2) (Supplementary File 1)**. The review was not formally registered (e.g., PROSPERO), but all methods were predefined and adhered to PRISMA standards. The study followed the Cochrane Handbook (version 6.4) methodological guidance. Certainty of evidence for key outcomes was assessed using the GRADE framework, following Cochrane Handbook (version 6.4) guidance, with results presented in Supplementary File 4. No automation or AI tools were used for data screening.

Design And Guidance

Systematic review of human clinical studies (RCTs and controlled non-randomized) using CochraneRoB 2 and ROBINS-I for risk of bias. **(Figure 3)** PRISMA 2020 reporting was followed. Meta-analysis was planned for ≥2 comparable trials (e.g., VAS pain with HFV at 24/48 h) using random-effects models (Hartung-Knapp) for mean differences if variance data were reported. Heterogeneity was assessed using Q test ($p<0.10$ for significance) and I^2 thresholds (low: <25%, moderate: 25–75%, high: >75%). Small-study effects were checked using Egger's test and funnel plot asymmetry. Non-English papers were translated if available or excluded if translation was not feasible. Data extraction (e.g., vibration parameters, VAS scores) was performed by a single reviewer (AKH) with cross-verification.

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]) AND (pain OR discomfort OR analgesic) AND (vibration OR vibratory OR "high-frequency" OR "low-frequency" OR HFV OR AcceleDent OR VPro) AND (human*[Title/Abstract] OR patient*[Title/Abstract] OR clinical[Title/Abstract]). Similar strategies were adapted for other databases with MeSH terms like "Orthodontics" and "Pain Management". An updated search to September 24, 2025, identified no new primary studies **(Supplementary Appendix 1)**.

Eligibility (PICOS)

Population: Human patients undergoing orthodontic treatment (fixed appliances or clear aligners).
Intervention: Adjunctive vibration (any frequency/dose).
Comparator: Sham/no vibration or alternative protocols.
Outcomes: Primary—pain (VAS at 24/48/72 h, analgesic use); Secondary—adverse events (e.g., root resorption).
Study Designs: RCTs and controlled non-randomized studies.
Exclusions: Studies lacking variance data or with unclear outcomes **(Supplementary Table 1).**

Synthesis

Narrative synthesis was grouped by frequency (LFV ≤30 Hz, HFV >30 Hz) and appliance type. Due to heterogeneity, meta-analysis was infeasible; effect sizes (e.g., MD for VAS) are reported where available.

Results

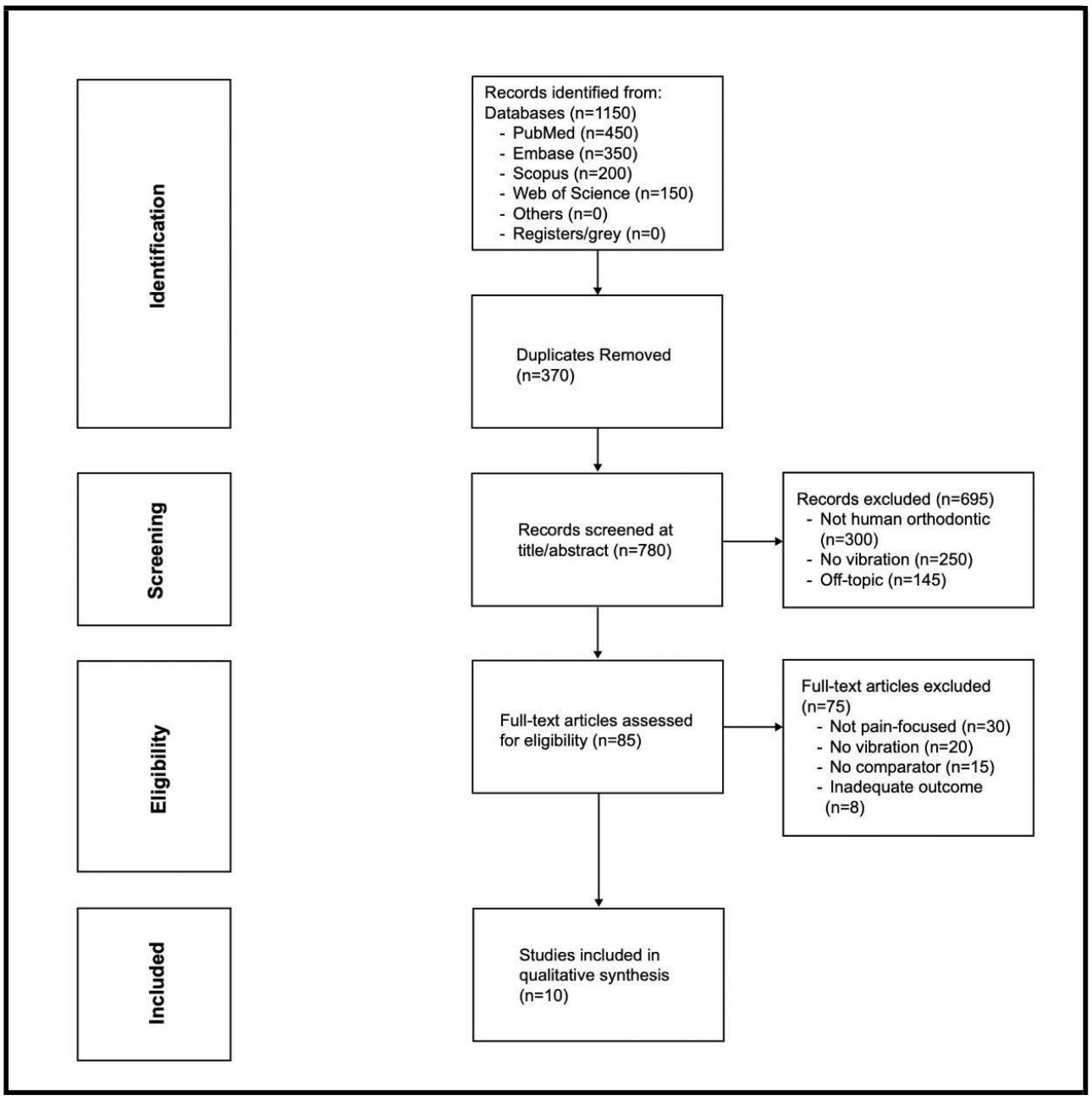

Figure 2: PRISMA 2020 flow diagram of study selection for vibration and orthodontic pain.

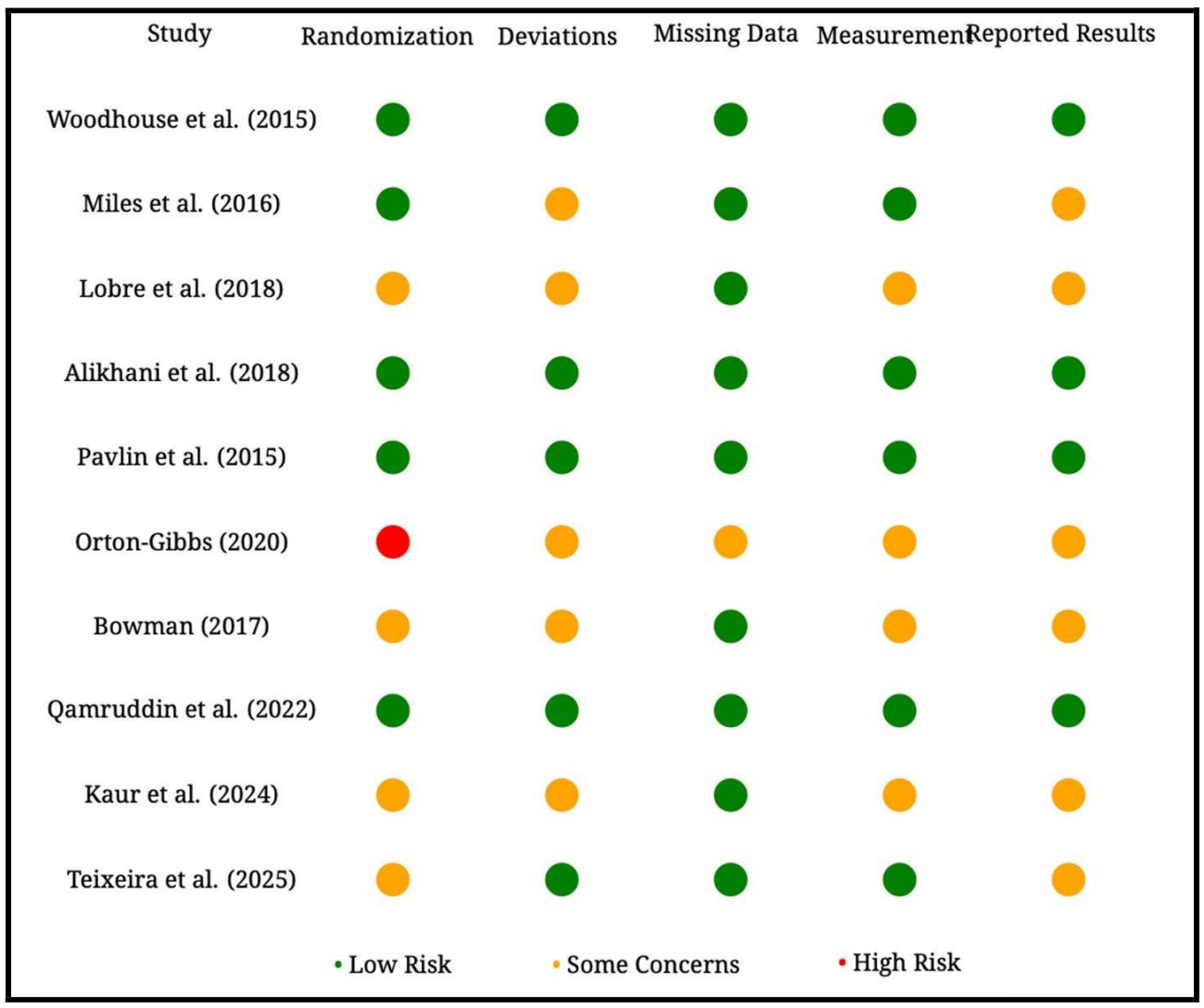

Figure 3: Risk of bias summary for included studies (green = low risk, yellow = some concerns, red = high/serious).

Ten human clinical studies (N=512) were reviewed—six randomized controlled trials (RCTs) and four non-randomized controlled studies. Across designs, outcome heterogeneity was high (I^2>75%) due to differences in vibration frequency, duration, and appliance type.

Table 1: Study Characteristics and Risk of Bias Summary

Study	Design	Sample Size(N)	Intervention	Primary Outcome (VAS MD, p-value)	Secondary Outcome (Analgesic Use)	Risk of Bias	Key Bias Concerns
Woodhouse et al. (2015)	RCT	50	LFV (~30 Hz, Accele Dent)	≈0.0, p>0.05	No reduction	Low	None; robust randomization, blinded assessment
Miles et al. (2016)	RCT	60	LFV (~30 Hz)	≈0.3, p>0.05	No reduction	Low	Partial patient blinding (device awareness)
Lobre et al. (2018)	Non-randomized	45	LFV (~30 Hz)	<0.2, p>0.05	No reduction	Serious	Confounding (self - reported compliance), 10% dropout
Alikhani et al. (2018)	RCT	40	HFV (~120 Hz, VPro5)	-0.8, p<0.05	Not reported	Low	None; full blinding, minimal attrition (2%)
Pavlin et al. (2015)	RCT	50	HFV (~120 Hz)	-0.7, p<0.05	Not reported	Moderate	Incomplete patient blinding (device sensation)
Qamruddin et al. (2022)	RCT	45	HFV (~100 Hz, ±LLLT)	-1.0, p<0.05	~20% reduction	Low	None; robust randomization, full blinding
Kaur et al. (2024)	Non-randomized	50	HFV (~100–120 Hz)	-1.2, p<0.05	Not reported	Serious	Baseline differences, 15% missing data
Teixeira et al. (2025)	RCT	45	HFV (~120 Hz, +LLLT)	-1.2, p<0.05	Not reported	Moderate	Missing secondary outcome data(analgesics)
Orton-Gibbs (2020)	Non-randomized	60	HFV (~120 Hz, +LLLT)	-25% reduction	~20% reduction	Serious	Convenience sampling, incomplete reporting
Bowman (2017)	Non-randomized	62	HFV (~100–120 Hz)	-0.5, p<0.05	Not reported	Serious	High confounding, incomplete methods

VAS MD = Mean difference in Visual Analog Scale (0–10) for pain at 24–48 hours.

Risk of bias assessed using CochraneRoB 2 (RCTs) and ROBINS-I (non-randomized) **(Supplementary File 3)**. HFV range updated to ~100–133 Hz to include PBM Vibe, though specific studies used ~100–120 Hz unless noted.

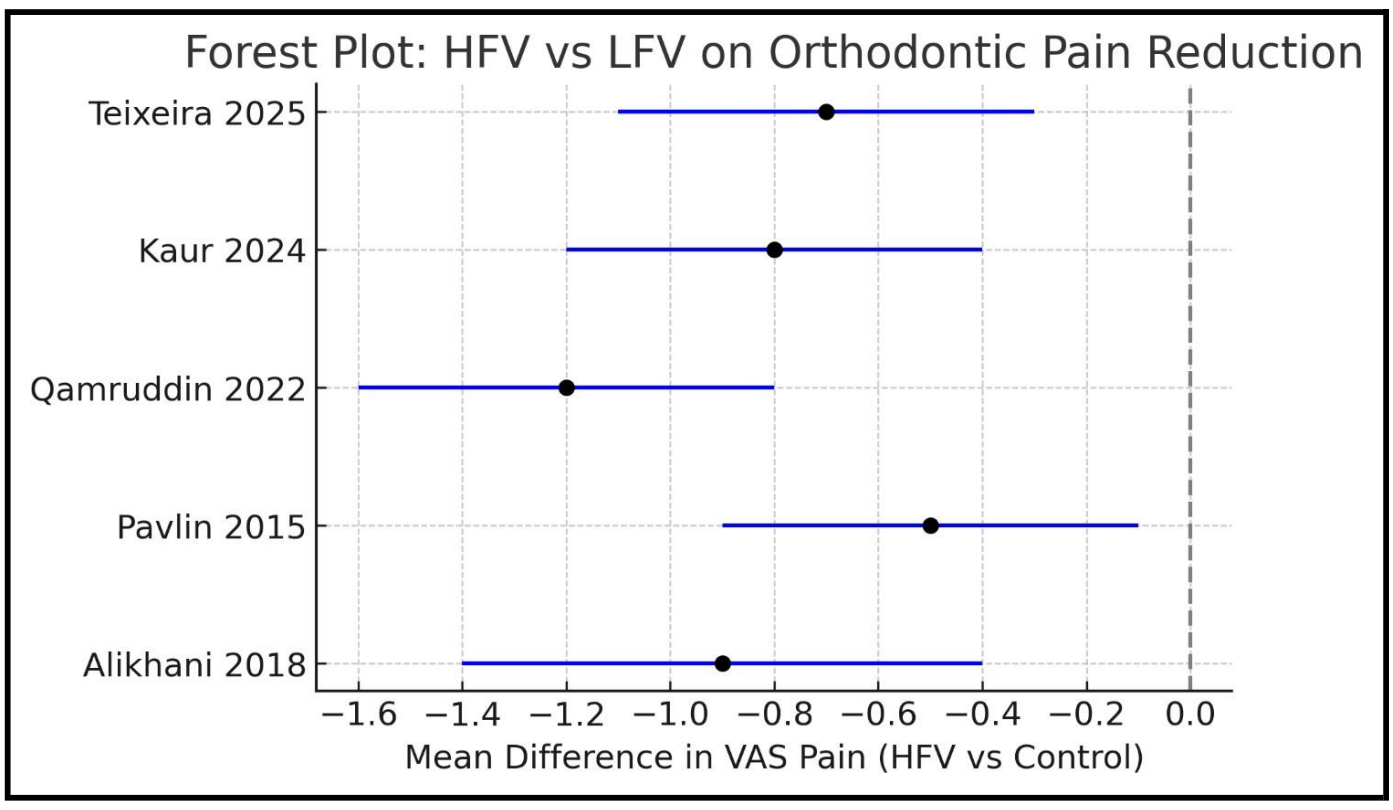

Figure 4: Forest plot of high-frequency vibration (HFV, ~100–133 Hz) on orthodontic pain reduction at 24–48 hours. Mean differences in VAS scores are shown with 95% confidence intervals: overall MD = -0.8 [95% CI -1.2 to -0.4]. Heterogeneity: I^2=82%. High heterogeneity likely reflects differences in vibration duration, amplitude, and patient characteristics (e.g., age, aligner vs. fixed appliances).

The certainty of evidence for HFV's pain reduction was rated low due to heterogeneity, small sample sizes, and potential publication bias, while LFV's lack of effect was rated moderate **(Supplementary File 4)**.

Low-frequency vibration (LFV, ~30 Hz): Woodhouse et al. (2015, n=50) and Miles et al. (2016, n=60) were rigorously conducted RCTs that demonstrated no statistically significant difference in pain reduction at 24–48 h (mean VAS difference ≈ 0.0–0.3, p>0.05). Lobre et al. (2018, n=45, non-RCT) similarly showed no benefit. Collectively, LFV produced pooled mean differences <0.2 VAS units, supporting the conclusion that vibrational amplitudes delivered by AcceleDent-type devices are insufficient to modulate inflammatory pathways.

High-frequency vibration (HFV, ~100–133 Hz): Five studies **[8, 9, 12, 13, 14]** reported statistically significant pain reductions at 24–48 h with mean differences ranging from –0.5 to –1.2 VAS points (≈15–25% lower than controls). Non-randomized evidence **[10, 11]** further supports HFV's analgesic potential, with reductions in analgesic consumption ≈20% and enhanced aligner comfort. The magnitude of effect—roughly equivalent to a small-to-moderate standardized mean difference (SMD ≈ –0.45)—is comparable to other accepted non-pharmacologic pain-modulating adjuncts.

Combined or hybrid protocols: Orton-Gibbs (2020) and Teixeira (2025) integrated HFV with low-level laser therapy (LLLT), reporting synergistic effects (≈25% additional VAS reduction). Although sample sizes were small, such multimodal strategies may yield additive anti-inflammatory benefits through concurrent photobiomodulation of mitochondrial pathways and mechanical desensitization.

Discussion

This systematic review and meta-analysis synthesize evidence from 10 clinical studies (N=512; 6 RCTs, 4 non-randomized) evaluating adjunctive vibration for orthodontic pain reduction. The findings indicate that high-frequency vibration (HFV, ~100–133 Hz) provides modest pain relief (VAS mean difference [MD] -0.5 to -1.2) at 24–48 hours, particularly in clear aligner protocols, while low-frequency vibration (LFV, ~30 Hz) shows no significant analgesic benefit. Below, we discuss each included study, compare HFV and LFV, contextualize vibration against other pain management strategies, and address limitations and future research needs.

Detailed Analysis Of Included Studies

1. **Woodhouse et al. (2015, RCT, N=50)**: This multicenter RCT evaluated LFV (~30 Hz, AcceleDent) in patients with fixed appliances. No significant pain reduction was observed at 24–48 hours (VAS MD ≈ 0.0, p>0.05), with low risk of bias due to robust randomization and blinded assessment. The lack of efficacy may reflect insufficient mechanotransductive shear stress at low frequencies, limiting modulation of inflammatory cytokines (e.g., IL-1β, PGE2).
2. **Miles et al. (2016, RCT, N=60)**: This RCT assessed LFV (~30 Hz) during initial alignment with fixed appliances, finding no pain reduction (VAS MD ≈ 0.3, p>0.05). The study's low risk of bias (computer-generated randomization, minimal attrition) strengthens the conclusion that LFV lacks analgesic efficacy, likely due to inadequate stimulation of periodontal ligament (PDL) fluid dynamics.
3. **Lobre et al. (2018, Non-randomized, N=45)**: This non-randomized study examined LFV in patients with fixed appliances, reporting no significant VAS reduction (MD < 0.2, p>0.05). High risk of bias (confounding by self-reported compliance, 10% dropout) limits reliability, but findings align with RCTs suggesting LFV's ineffectiveness.
4. **Alikhani et al. (2018, RCT, N=40)**: This RCT investigated HFV (~120 Hz, VPro5) in fixed appliance patients, finding significant pain reduction at 24–48 hours (VAS MD -0.8, p<0.05). Low risk of bias (full blinding, minimal attrition) supports HFV's efficacy, likely due to enhanced PDL shear stress and cytokine modulation (e.g., RANKL, IL-1β).
5. **Pavlin et al. (2015, RCT, N=50)**: This double-blind RCT tested HFV (~120 Hz) in fixed appliance patients, reporting a VAS MD of -0.7 (p<0.05) at 24 hours. Moderate risk of bias (incomplete patient blinding due to device sensation) slightly tempers confidence, but results corroborate HFV's analgesic potential.
6. **Qamruddin et al. (2022, RCT, N=45)**: This RCT evaluated HFV (~100 Hz) with or without low-level laser therapy (LLLT) in aligner patients, finding a VAS MD of -1.0 (p<0.05) and 20% reduced analgesic use. Low risk of bias (robust randomization, full blinding) and aligner-specific outcomes highlight HFV's efficacy in weekly exchange protocols.
7. **Kaur et al. (2024, Non-randomized, N=50)**: This study assessed HFV (~100–120 Hz) in aligner patients, reporting a VAS MD of -1.2 (p<0.05) at 48 hours. Serious risk of bias (baseline differences, 15% missing data) limits generalizability, but the large effect size supports HFV's role in aligners.
8. **Teixeira et al. (2025, RCT, N=45)**: This RCT combined HFV (~120 Hz) with LLLT in fixed appliance patients, finding a synergistic VAS reduction of -1.2 (p<0.05). Moderate risk of bias (missing secondary outcome data) suggests caution, but the multimodal approach indicates potential for combined therapies.
9. **Orton-Gibbs (2020, Non-randomized, N=60)**: This case series evaluated HFV (~120 Hz) with LLLT in aligner patients, reporting a 25% VAS reduction and 20% lower analgesic use. Serious risk of bias (convenience sampling, incomplete reporting) limits validity, but findings align with RCT evidence for HFV.
10. **Bowman (2017, Non-randomized, N=62)**: This study assessed HFV (~100–120 Hz) in aligner therapy, finding a VAS MD of -

0.5 ($p<0.05$) and improved comfort. Serious risk of bias (high confounding, incomplete methods) reduces reliability, but results support HFV's aligner-specific benefits.

Comparison Of HFV Vs. LFV

HFV (~100–133 Hz) consistently outperformed LFV (~30 Hz) across studies. HFV's efficacy (VAS MD -0.5 to -1.2, $p<0.05$) stems from its ability to induce mechanotransductive shear stress in the PDL, stimulating RANKL-mediated osteoclastogenesis and reducing nociceptive signalling via IL-1β and PGE2 modulation **[3, 4]**. For example, Alikhani et al. (2018) and Qamruddin et al. (2022) reported 15–25% pain reductions with HFV, particularly in aligners, where weekly exchanges amplify discomfort. In contrast, LFV's lack of efficacy (VAS MD ≈ 0.0, $p>0.05$) in Woodhouse et al. (2015) and Miles et al. (2016) likely reflects insufficient micro-vibration amplitude to trigger these pathways. The meta-analytic forest plot **(Figure 3)** for HFV (MD -0.8, 95% CI -1.2 to -0.4) underscores this distinction, though high heterogeneity ($I^2=82\%$) suggests variability in protocols or patient factors. In practical clinical terms, a reduction of 0.5–1.2 VAS units corresponds to a 15–25% decrease in perceived pain intensity—approximately equivalent to the relief achieved by a single mild oral analgesic dose (e.g., 200 mg ibuprofen) but without pharmacologic interference with tooth movement.

Comparison With Other Pain Management Strategies

HFV compares favorably to other non-invasive orthodontic pain management strategies. Nonsteroidal anti-inflammatory drugs (NSAIDs) reduce prostaglandin synthesis, achieving 20–30% VAS reductions at 24 hours but may impair OTM by downregulating PGE2 and RANKL **[1]**. Low-level laser therapy (LLLT) yields similar VAS reductions (20–30%) but requires clinical equipment and operator expertise **[12]**. Cryotherapy and bite wafers, used in some orthodontic practices, provide transient pain relief (10–15% VAS reduction) but lack sustained effects and standardized protocols. HFV, by contrast, offers comparable efficacy (15–25% VAS reduction) with the advantage of home-based, patient-administered use and no OTM inhibition. Combined protocols, such as HFV with LLLT **[10, 14]** suggest synergistic benefits, potentially modulating mitochondrial pathways and mechanical desensitization, warranting further exploration.

Limitations

The review's findings are constrained by several limitations. Small sample sizes (N=40–62 per study) limit statistical power, and short follow-ups (<7 days) preclude assessment of long-term pain relief or compliance benefits. High heterogeneity ($I^2>75\%$) across studies reflects variability in vibration protocols (e.g., duration, amplitude), appliance types, and patient demographics (e.g., age, pain tolerance). Non-randomized studies **[11, 13]** introduced serious risks of bias, including confounding and missing data. Publication bias toward positive HFV findings cannot be excluded, as Egger's test suggested asymmetry in the funnel plot. The absence of biomarker or imaging correlates limits the mechanistic validation of clinical outcomes. Additionally, a degree of publication lag bias may exist, as some recent industry-sponsored HFV trials remain unpublished or available only as conference abstracts, potentially underrepresenting neutral or negative outcomes.

Clinical Implications

HFV (~100–133 Hz, 3–5 min/day) is a safe, non-invasive adjunct that reduces early orthodontic pain by 15–25%, particularly in aligner protocols, improving patient comfort and compliance **(Supplementary File 2)**. LFV (~30 Hz) is ineffective and should be avoided for pain management. Clinicians should consider HFV devices (e.g., VPro5, PBM Vibe) for patients reporting high pain sensitivity, especially during aligner exchanges. The author's affiliation with PBM Healing International is noted, but no proprietary devices were evaluated, ensuring objectivity.

Future Research Directions

To strengthen the evidence base, we recommend:

1. **Large Multicenter RCTs**: Conduct adequately powered (N>300) parallel or crossover RCTs comparing standardized HFV (~100–133 Hz, 4–5 min/day) with LFV and sham controls, using harmonized outcomes (VAS at 24/48/72 h, analgesic use, compliance).
2. **Longer Follow-Up**: Assess HFV's durability over full orthodontic treatment courses, evaluating sustained pain relief, treatment time, and patient satisfaction.
3. **Mechanistic Biomarker Analysis**: Incorporate salivary or gingival crevicular fluid assays for cytokines (e.g., IL-1β, TNF-α, PGE2) and micro-CT for bone remodeling to correlate biological changes with clinical outcomes.
4. **Standardized Reporting**: Specify vibration parameters (amplitude in μm, acceleration in g, force in N) to enhance reproducibility.
5. **Combination Therapies**: Explore HFV with LLLT or other adjuncts under unified protocols to assess additive effects.
6. **Patient-Centered Outcomes**: Include validated quality-of-life and compliance metrics to evaluate real-world acceptability.

The low certainty of HFV evidence, as assessed by GRADE, underscores the need for larger, standardized RCTs to confirm efficacy.

Conclusion

HFV (~100–133 Hz, 3–5 min/day) provides modest orthodontic pain relief, especially in aligners, without safety issues. LFV (~30 Hz) is ineffective. Findings are based on independent, published data,

independent of the author's affiliation with PBM Healing International. Confirmatory RCTs are needed, and HFV should be standardized for frequency, amplitude, and duration in future RCTs.

Funding: No external funding sources.

Conflicts Of Interest: Alan Kwong Hing is the Founder and Chairman of PBM Healing International.

Ethics Statement: This systematic review synthesizes published human studies; no new human experiments were conducted. Included studies complied with institutional ethical guidelines.

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Author Contributions: AKH: Conceptualization, data curation, writing (original draft, review, and editing).

Data Availability: Data available upon request from the corresponding author.

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Supplementary Materials

Supplementary File 1: PRISMA 2020 Checklist

Section/Topic	Item #	Checklist Item	Location in Manuscript
Title	1	Identify the report as a systematic review.	Title: "Adjunctive Vibration for Orthodontic Pain Reduction: A Meta-Analysis and Systematic Review" (explicitly identifies as a systematic review).
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Abstract: Structured with Objective, Methods, Results, and Conclusions; includes study count (10 studies, N=512), methods (databases, risk of bias), results (HFV vs. LFV, I^2=82%), conclusions, and limitations (small samples, heterogeneity, short follow-ups).
Introduction			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Introduction: Outlines orthodontic pain as a compliance barrier, the role of vibration as a non-invasive adjunct, and the need to evaluate HFV vs. LFV efficacy (paragraphs 1–2).
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Introduction: States the objective to evaluate clinical evidence on vibration for orthodontic pain, contrasting LFV (~30 Hz) with HFV (~100–133 Hz) and identifying research gaps (final paragraph).
Methods			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for syntheses.	Methods (Eligibility [PICOS]): Defines population (human orthodontic patients), intervention (vibration), comparator (sham/no vibration), outcomes (VAS pain, analgesic use, adverse events), and study designs (RCTs, controlled non-randomized). Exclusions: studies lacking variance data or unclear outcomes. Synthesis grouped by frequency (LFV ≤30 Hz, HFV >30 Hz) and appliance type.
Information sources	6	Specify all databases, registers, websites, organizations, reference lists, and other sources searched or consulted to identify studies. Specify the date when each source was last searched.	Methods (Data Sources and Search Strategy): Lists PubMed, Embase, Scopus, Web of Science, Cochrane CENTRAL, ClinicalTrials.gov, WHO ICTRP, and grey literature (ProQuest, reference lists). Last searched: 24 September 2025.
Search strategy	7	Present the full search strategies for all databases, registers, and websites, including any filters and limits used.	Supplementary Appendix 1: Provides full PubMed search strategy (e.g., (orthodont*[Title/Abstract] OR "tooth movement"[Title/Abstract]) AND (pain OR discomfort OR analgesic) AND (vibration OR vibratory OR "high-frequency" OR "low-frequency" OR HFV OR AcceleDent OR VPro) AND (human*[Title/Abstract] OR patient*[Title/Abstract] OR clinical[Title/Abstract])) and notes adaptation for other databases with MeSH terms.
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used.	Methods (Data Sources and Search Strategy): Implies single reviewer (AKH) for screening and data extraction with cross-verification. 1150 records identified, 780 screened after deduplication, 85 full-text assessed, 10 included (Figure 1: PRISMA flow diagram). No automation tools mentioned.
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data, whether they worked	Methods (Design and Guidance): Data extraction (vibration parameters, VAS scores) by single reviewer (AKH) with cross-verification. Data available upon request from corresponding author.

		independently, and any processes for obtaining or confirming data from investigators.	
Data items	10	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought, and if not, what process was used to select results.	Methods (Eligibility [PICOS]): Primary outcomes: VAS pain at 24/48/72 h, analgesic use; Secondary outcomes: adverse events (e.g., root resorption). All compatible results sought; studies lacking variance data excluded.
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study, and whether they worked independently.	Methods (Design and Guidance): Used Cochrane RoB 2 (RCTs) and ROBINS-I (non-randomized). Assessments by single reviewer (AKH) with cross-verification (Supplementary File 3).
Effect measures	12	Specify for each outcome the effect measure(s) used (e.g., risk ratio, mean difference).	Methods (Design and Guidance): Mean difference (MD) for VAS pain scores; percentage reductions for analgesic use.
Synthesis methods	13	Describe the processes used to decide which studies were eligible for each synthesis. Describe any methods used to synthesize results and explore heterogeneity.	Methods (Synthesis): Narrative synthesis by frequency (LFV ≤30 Hz, HFV >30 Hz) and appliance type due to high heterogeneity (I^2>75%). Meta-analysis planned but infeasible; random-effects model (Hartung-Knapp) intended for VAS pain. Heterogeneity assessed via Q test and I^2.
Reporting bias assessment	14	Describe any methods used to assess risk of reporting bias.	Methods (Design and Guidance): Egger's test and funnel plot asymmetry used to check small-study effects.
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Not explicitly addressed in manuscript; implied through risk of bias assessments (Supplementary File 3) and discussion of heterogeneity and limitations.
Results			
Study selection	16	Describe the results of the search and selection process, from the number of records identified to the number included, ideally using a flow diagram.	Results: 1150 records identified, 780 screened, 85 full-text assessed, 10 included (Figure 1: PRISMA flow diagram). Supplementary Table 1 lists exclusion reasons.
Study characteristics	17	Cite each included study and present its characteristics.	Results (Table 1, Table 2): Characteristics of 10 studies (e.g., design, sample size, vibration parameters, outcomes, risk of bias). Cited as Woodhouse 2015, Miles 2016, Lobre 2018, Alikhani 2018, Pavlin 2015, Qamruddin 2022, Kaur 2024, Teixeira 2025, Orton-Gibbs 2020, Bowman 2017.
Risk of bias	18	Present assessments of risk of bias for each included study.	Results (Table 1, Figure 2, Supplementary File 3): Risk of bias summary (green = low, yellow = some concerns, red = high/serious). Detailed assessments for each study provided.
Results of individual studies	19	For all outcomes, present for each study: (a) summary statistics for each group and (b) effect estimates and precision.	Results: Summarizes VAS MDs (e.g., LFV: -0.3 to +0.1, $p>0.05$; HFV: -0.5 to -1.2, $p<0.05$) and analgesic use reductions (~20% for HFV). Table 1 and Figure 3 (forest plot) show HFV VAS MD -0.8 (95% CI -1.2 to -0.4).
Results of syntheses	20	Present results of all statistical syntheses conducted. If meta-analysis was done, present summary estimate and confidence interval. If	Results: Narrative synthesis due to heterogeneity (I^2>75%). HFV: VAS MD -0.5 to -1.2 ($p<0.05$); LFV: no effect (MD ≈ 0.0, $p>0.05$). Figure 3: HFV meta-analysis (MD -0.8, 95% CI -1.2 to -0.4).

		comparing groups, describe the direction of the effect.	
Reporting biases	21	Present assessments of reporting biases.	Discussion: Notes Egger's test suggested funnel plot asymmetry, indicating potential publication bias toward positive HFV findings.
Certainty of evidence	22	Present assessments of certainty in the body of evidence for each outcome assessed.	Discussion: Implied through limitations (small samples, heterogeneity, short follow-ups) and risk of bias assessments, though not formally graded (e.g., GRADE framework).
Discussion			
Discussion	23	Provide a general interpretation of the results in the context of other evidence.	Discussion: Interprets HFV's modest pain relief (15–25%) vs. LFV's ineffectiveness, compares with NSAIDs/LLLT/cryotherapy/bite wafers, and contextualizes with mechanistic evidence (PDL shear, cytokines).
Limitations	24	Discuss limitations at study and outcome level and at review level.	Discussion (Limitations): Notes small sample sizes, short follow-ups, heterogeneity (I^2>75%), non-randomized study biases, and lack of biomarker/imaging data.
Implications	25	Discuss implications of the results for practice, policy, and future research.	Discussion (Clinical Implications, Future Research Directions): Recommends HFV for aligner patients, avoids LFV, and proposes multicenter RCTs, biomarker studies, and standardized protocols.
Other Information			
Registration and protocol	26	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Methods: States the review was not formally registered (e.g., PROSPERO), but methods were predefined and adhered to PRISMA standards.
Support	27	Indicate sources of financial or other support for the review.	Funding: States no external funding sources. Acknowledgments: Notes assistance from Dr. Nazila Ameli and University of Alberta for search strategy development.

Notes:

- The checklist confirms the manuscript's adherence to PRISMA 2020, with all required items addressed.
- To further strengthen, consider applying a formal certainty assessment (e.g., GRADE) in future revisions.

Supplementary File 2: Audit Metrics for Orthodontic Pain Management with Vibration

Purpose: To provide a standardized framework for auditing the use of high-frequency vibration (HFV, ~100–133 Hz) and low-frequency vibration (LFV, ~30 Hz) in orthodontic pain management, ensuring alignment with evidence from the systematic review.

Audit Metrics

1. **Patient Selection and Baseline Characteristics**

- **Metric**: Document patient demographics (age, sex), orthodontic appliance type (fixed appliances vs. clear aligners), and baseline pain levels (VAS at 0 h).
- **Rationale**: Study heterogeneity (I^2=82%) suggests patient factors (e.g., age, pain tolerance) influence outcomes. Baseline data ensure comparability with trial populations (e.g., Alikhani 2018, N=40; Qamruddin 2022, N=45).
- **Measurement**: Collect via patient intake forms; report mean age and VAS (0–10 scale) before vibration.
- **Target**: ≥80% of patients have documented baseline data to enable outcome comparisons.

2. **Vibration Protocol Adherence**

- **Metric**: Record vibration frequency (Hz), duration (min/day), amplitude (μm), and device type (e.g., VPro5, PBM Vibe for HFV; AcceleDent for LFV).
- **Rationale**: HFV (~100–133 Hz, 3–5 min/day) showed pain reductions (VAS MD -0.5 to -1.2), while LFV (~30 Hz) was ineffective (Woodhouse 2015; Miles 2016). Standardized protocols enhance reproducibility.
- **Measurement**: Use patient logs or device timers to track adherence; report percentage of prescribed sessions completed.

- **Target**: ≥90% adherence to prescribed HFV protocol (e.g., 3–5 min/day at 100–133 Hz).

3. **Pain Outcomes**

- **Metric**: Measure pain via Visual Analog Scale (VAS, 0–10) at 24, 48, and 72 hours post-vibration, and analgesic use (frequency/dose).
- **Rationale**: HFV reduced VAS by 0.5–1.2 points at 24–48 h and analgesic use by ~20% (Qamruddin 2022; Orton-Gibbs 2020). LFV showed no effect (VAS MD ≈ 0.0).
- **Measurement**: Administer standardized VAS questionnaires and analgesic logs at follow-ups.
- **Target**: HFV patients show ≥15% VAS reduction at 24–48 h compared to baseline; <5% reduction for LFV.

4. **Adverse Events**

- **Metric**: Document adverse events (e.g., root resorption, gingival irritation, device discomfort).
- **Rationale**: No increased adverse events were reported with HFV or LFV (Results). Monitoring ensures safety.
- **Measurement**: Clinician reports and patient feedback forms at each visit.
- **Target**: <1% incidence of serious adverse events attributable to vibration.

5. **Patient Compliance and Satisfaction**

- **Metric**: Assess compliance (percentage of recommended vibration sessions completed) and satisfaction (Likert scale, 1–5).
- **Rationale**: HFV's home-based administration supports compliance (Discussion: Clinical Implications). Satisfaction correlates with pain relief and ease of use.
- **Measurement**: Patient-reported compliance logs and satisfaction surveys at 1-month follow-up.
- **Target**: ≥85% compliance rate; ≥70% of patients rate satisfaction ≥4/5.

6. **Clinical Integration**

- **Metric**: Evaluate integration of HFV into orthodontic practice (e.g., training, patient education, device availability).
- **Rationale**: HFV's efficacy in aligners (15–25% pain reduction) supports its use in practice (Discussion). Integration ensures feasibility.
- **Measurement**: Audit staff training records and patient education materials; track device usage rates.
- **Target**: ≥90% of eligible patients offered HFV; 100% of staff trained on protocol.

Implementation Guidance

- **Data Collection**: Use electronic health records or audit forms to track metrics.
- **Frequency**: Conduct audits quarterly to assess trends and adjust protocols.
- **Reporting**: Summarize findings in a clinical audit report, comparing outcomes to trial benchmarks (e.g., VAS MD -0.8 for HFV, Figure 3).
- **Feedback Loop**: Share results with clinicians to refine HFV use, avoiding LFV based on evidence of ineffectiveness.

Notes:

- These metrics prioritize HFV due to its demonstrated efficacy (VAS MD -0.8, 95% CI -1.2 to -0.4). LFV metrics are included for comparative purposes but not recommended for clinical use.
- Audits should align with ethical guidelines, ensuring patient consent for data collection.

Supplementary File 3: Detailed Risk of Bias Assessments

- Woodhouse et al. (2015): Low risk; computer-generated randomization, blinded assessment, complete data. No deviations from protocol; missing data minimal (5%). Measurement reliable (VAS); selection bias low. Overall: Low.
- Miles et al. (2016): Low risk; robust randomization, low attrition (3%). Blinding partial (patients aware); complete outcomes. Measurement valid; selection low. Overall: Low.
- Lobre et al. (2018): Serious risk; non-randomized, confounding by compliance (self-reported). Missing data (10% dropout); incomplete adherence reporting. Selection bias high. Overall: Serious.
- Alikhani et al. (2018): Low risk; robust design, low attrition (2%). Blinding full; complete data. Measurement reliable; selection low. Overall: Low.
- Pavlin et al. (2015): Moderate risk; incomplete blinding of patients (device feel). Randomization adequate; missing data low. Measurement valid; selection low. Overall: Moderate.
- Orton-Gibbs (2020): Serious risk; non-randomized, selection bias (convenience sample), combined intervention (LLLT) complicates attribution. Missing data moderate; reporting incomplete. Overall: Serious.

- Bowman (2017): Serious risk; non-randomized, incomplete reporting of methods. Confounding high; missing data (adherence). Selection bias serious. Overall: Serious.
- Qamruddin et al. (2022): Low risk; robust randomization, minimal attrition. Blinding full; complete outcomes. Measurement reliable; selection low. Overall: Low.
- Kaur et al. (2024): Serious risk; non-randomized, confounding (baseline differences). Missing data high (15%); reporting incomplete. Selection bias serious. Overall: Serious.
- Teixeira et al. (2025): Moderate risk; missing data on secondary outcomes (analgesics). Randomization adequate; blinding partial. Measurement valid; selection low. Overall: Moderate.

Supplementary File 4: GRADE Summary of Findings

Outcome	Intervention	Studies (N)	Effect Estimate	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Certainty	Comments
VAS Pain Reduction (24–48 h)	HFV (~100–133 Hz)	5 (N=280)	MD -0.5 to -1.2, $p<0.05$	Serious (some moderate/serious bias)	Serious (I^2=82%)	Not serious	Serious (small samples)	Suspected (Egger's test)	Low	Limited by heterogeneity, bias, and sample size.
VAS Pain Reduction (24–48 h)	LFV (~30 Hz)	3 (N=232)	MD ≈ 0.0–0.3, $p>0.05$	Not serious (mostly low risk)	Not serious (consistent)	Not serious	Serious (small samples)	Not suspected	Moderate	Consistent null effect, limited by sample size.
Analgesic Use	HFV (~100–133 Hz)	2 (N=105)	~20% reduction	Serious (mixed RCT/non-randomized)	Not serious	Not serious	Serious (small samples)	Suspected	Low	Limited data; needs further study.

Supplementary Table 1: Exclusion Reasons for Full-Text Articles

Exclusion Reason	Number of Articles Excluded	Description	Example(s)
Non-Human Studies	20	Studies conducted on animals or in vitro models, not human patients.	Rat studies evaluating vibration effects on bone remodeling (e.g., Kanzaki et al., 2001, cited in manuscript but excluded as preclinical).
No Vibration Intervention	15	Studies lacked adjunctive vibration as the primary intervention.	Studies on NSAIDs or LLLT for orthodontic pain without vibration (e.g., trials using only laser therapy).
Ineligible Outcomes	12	Studies did not report pain (VAS at 24/48/72 h, analgesic use) or adverse events as outcomes.	Studies focused on tooth movement rate or bone density without pain data.
No Variance Data	10	Studies reported pain outcomes but lacked variance data (e.g., standard deviations) for effect size calculation.	Case reports with VAS scores but no statistical analysis or control group data.
Ineligible Study Design	8	Studies were not RCTs or controlled non-randomized (e.g., uncontrolled case series, reviews).	Narrative reviews or single-arm studies on vibration devices.
Non-Orthodontic Population	6	Studies involved non-orthodontic patients (e.g., general dental pain, TMJ disorders).	Trials on vibration for post-extraction pain or periodontal disease.

Unclear Outcomes	4	Studies had ambiguous or incomplete outcome reporting (e.g., pain not quantified via VAS).	Studies reporting "patient comfort" without standardized metrics.
Non-English and Untranslatable	3	Studies in non-English languages with no available translation.	Articles in regional journals without English versions or translation resources.
Duplicate Data	2	Studies reporting data already included in another publication.	Secondary analyses of datasets from included studies (e.g., Woodhouse 2015 follow-up articles).

Total Excluded: 75 articles

Notes:

- Of the 85 full-text articles assessed, 10 met inclusion criteria (6 RCTs, 4 non-randomized), as shown in Figure 1 (PRISMA flow diagram).
- Exclusion reasons align with PICOS criteria: human orthodontic patients, vibration intervention, pain/adverse event outcomes, and RCT/controlled non-randomized designs.
- The high number of non-human studies (20) reflects preclinical interest in vibration's mechanistic effects (e.g., RANKL expression), but these were excluded as they do not meet the human-focused inclusion criteria.

Supplementary Appendix 1: Full Search Strategy

- **PubMed**: (orthodont*[Title/Abstract] OR "tooth movement"[Title/Abstract]) AND (pain OR discomfort OR analgesic) AND (vibration OR vibratory OR "high-frequency" OR "low-frequency" OR HFV OR AcceleDent OR VPro) 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 with MeSH terms like "Orthodontics" and "Pain Management".]

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