Journal of Chemical Health Risks

www.jchr.org

JCHR (2025) 15(6), 727-734 | ISSN:2251-6727

Effect of Low and High Frequency Vibrations on Salivary IL-1β and RANKL Biomarkers in Orthodontic Patients

Rishika Singla[1], Aravind Kumar Subramanian[2]

[1]Postgraduate, Department of Orthodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, India.

[2]Professor and Head, Department of Orthodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, India.

(Received: 27 September 2025 Revised: 05 October 2025 Accepted: 10 November 2025)

KEYWORDS

Orthodontics, vibration, IL-1β, RANKL, saliva, biomarkers, accelerated tooth movement

ABSTRACT:

Introduction: Prolonged orthodontic treatment duration remains a major clinical challenge. Vibrational stimulation has been proposed as a non-invasive adjunct to accelerate tooth movement by enhancing bone remodelling through cytokine modulation. Interleukin-1β (IL-1β) and receptor activator of nuclear factor kappa-B ligand (RANKL) are key biomarkers involved in osteoclastic activity during orthodontic tooth movement. While most clinical studies have focused on low-frequency devices, emerging evidence suggests that higher-frequency vibration may induce stronger biological responses. This randomized controlled clinical trial aimed to compare the effects of low-frequency (30 Hz) and high-frequency (120 Hz) vibrations on salivary IL-1β and RANKL levels in orthodontic patients.

Objectives: To evaluate the effect of low- and high-frequency vibratory forces on salivary interleukin-1β (IL-1β) and receptor activator of nuclear factor kappa-B ligand (RANKL) levels in orthodontic patients undergoing fixed appliance therapy.

Methods: A parallel-arm randomized controlled clinical trial was conducted on fifteen orthodontic patients (mean age 21.4 ± 2.3 years) with mild to moderate crowding. Participants were randomly assigned to three groups (n = 5 each): Group A (30 Hz vibration), Group B (120 Hz vibration), and Group C (control, no vibration). All patients were treated using 0.022-inch MBT pre-adjusted edgewise appliances. Saliva samples were collected at baseline (T0), one month (T1), and two months (T2). IL-1β and RANKL concentrations were quantified using ELISA. Data were analysed using repeated-measures ANOVA with Bonferroni correction ($p < 0.05$).

Results: Both vibration groups demonstrated significantly higher IL-1β levels compared with control ($p < 0.05$), with the 30 Hz group showing the greatest increase over time. RANKL levels increased modestly in both vibration groups, with the 120 Hz group demonstrating higher values at T2 ($p < 0.05$). The control group exhibited minimal biomarker changes across all time points.

Conclusions: Low- and high-frequency vibratory forces upregulated salivary IL-1β and RANKL during orthodontic treatment, with low-frequency vibration amplifying the inflammatory response and high-frequency vibration influencing RANKL more strongly. While these findings support the biological plausibility of vibration as an adjunct to accelerate tooth movement, further large-scale trials are needed to confirm clinical efficacy.

1. Introduction

Orthodontic tooth movement (OTM) occurs through a coordinated process of bone resorption and apposition within the periodontal ligament (PDL). Mechanical loading from orthodontic appliances activates a cascade of cellular and molecular responses, including the release of pro-inflammatory cytokines and bone-resorptive mediators, which drive alveolar bone remodeling. Among these, interleukin-1β (IL-1β) and receptor activator of nuclear factor kappa-B ligand (RANKL) are key regulators of osteoclastogenesis and bone turnover (1). Elevated levels of IL-1β are closely associated with the initiation of OTM, while the balance between

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(6), 727-734 | ISSN:2251-6727

RANKL and osteoprotegerin (OPG) determines the extent of osteoclast differentiation and activity.

Adjunctive techniques aimed at accelerating OTM have been widely investigated to shorten treatment time and improve patient compliance (2). Surgical procedures such as corticotomy and pharmacological agents have shown efficacy but carry risks of invasiveness or side effects (3) (4). Vibrational stimulation has emerged as a promising non-invasive alternative, applying cyclic mechanical forces to the dentoalveolar complex to potentially enhance bone remodeling. Both animal and human studies suggest that vibration influences cytokine activity and bone biology, but outcomes vary depending on the frequency, magnitude, and duration of stimulation (5) (6) (7).

Evidence from in vivo and clinical studies highlights this variability. Leethanakul et. al, demonstrated that vibratory stimuli enhanced IL-1β secretion and increased tooth movement in a split-mouth clinical trial (8). Luo et. al, reported that vibration enhanced expression of inflammatory cytokines and bone-resorptive markers, supporting its role in promoting remodeling (9). A randomized trial by Pérez-Idarraga et al. (2023) further showed that intermittent vibratory forces influenced biomarker expression without adverse periodontal effects (10). Systematic reviews, however, conclude that while the biological rationale is strong, the clinical effectiveness of vibration in accelerating tooth movement remains inconclusive (11) .

Most clinical studies have tested only a single frequency device, typically in the low-frequency range (~30 Hz) (12). However, experimental and animal models suggest that higher frequencies (60–120 Hz) may produce more pronounced biological responses, including greater cytokine release and osteoclastic activation (13) . Clinical trials directly comparing low- and high-frequency vibration are lacking, creating a gap in evidence.

Saliva offers a practical and non-invasive alternative to gingival crevicular fluid (GCF) for monitoring such biomarkers. It can be collected easily, repeatedly, and with greater patient acceptance, making it a suitable medium for translational studies on orthodontic biology (14) (15) (16).

Therefore, the present randomized controlled clinical trial aimed to compare the effects of low-frequency (30 Hz) and high-frequency (120 Hz) vibration on salivary IL-1β and RANKL levels in orthodontic patients. We hypothesized that both frequencies would elevate biomarker levels compared to control, with a greater effect from high-frequency vibration.

2. Objectives

The primary objective of this study was to evaluate and compare the effects of low-frequency (30 Hz) and high-frequency (120 Hz) vibrational stimulation on salivary levels of interleukin-1β (IL-1β) and receptor activator of nuclear factor kappa-B ligand (RANKL) in orthodontic patients undergoing fixed appliance therapy. The secondary objective was to determine whether high-frequency vibration induces greater biomarker elevation, suggesting enhanced osteoclastic activity and bone remodeling. By analysing salivary cytokine profiles at baseline, one month, and two months after appliance activation, the study aimed to provide biochemical evidence supporting the potential of vibrational therapy as a non-invasive adjunct for accelerating orthodontic tooth movement.

3. Methods

Study Design

This study was conducted as a parallel-arm, randomized controlled clinical trial at the Department of Orthodontics following approval from the Institutional Ethics Committee. Written informed consent was obtained from all participants prior to enrolment.

Participants

A total of fifteen orthodontic patients (mean age: 21.4 ± 2.3 years) presenting with mild to moderate crowding and requiring fixed appliance therapy were recruited. Inclusion criteria consisted of patients aged 18–25 years, with good systemic and periodontal health and no prior orthodontic treatment. Patients were excluded if they had systemic diseases or were on medications influencing bone metabolism, a history of smoking or pregnancy, poor oral hygiene, or active periodontal disease.

Randomization and Group Allocation

Participants were randomly assigned to one of three groups (n = 5 each) using simple randomization. Group

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(6), 727-734 | ISSN:2251-6727

A received low-frequency vibration at 30 Hz, Group B received high-frequency vibration at 120 Hz, while Group C served as the control group with no vibration.

Intervention

All patients were treated using pre-adjusted edgewise fixed appliances (0.022-inch MBT prescription). Participants in Groups A and B were instructed to use their designated vibration device for 20 minutes daily, commencing immediately after appliance activation and continuing throughout the observation period.

Saliva Collection

Unstimulated whole saliva samples were collected at three standardized time points: prior to appliance placement (T0), one month after appliance activation (T1), and two months after appliance activation (T2). To minimize circadian variations, collections were performed between 9:00 a.m. and 11:00 a.m. Samples were centrifuged at 3000 rpm for 10 minutes, and the supernatants were stored at –20°C until further biochemical analysis.

Laboratory Analysis

Levels of interleukin-1 beta (IL-1β) and receptor activator of nuclear factor kappa-B ligand (RANKL) were quantified using commercial enzyme-linked immunosorbent assay (ELISA) kits in accordance with the manufacturer's instructions. All assays were performed in duplicate, and mean values were used for subsequent statistical analysis.

Statistical Analysis

Data were analysed using repeated-measures analysis of variance (ANOVA) to assess intra-group changes over time and inter-group differences. Bonferroni post hoc correction was applied for multiple comparisons. A p-value < 0.05 was considered statistically significant.

4. Results

Salivary IL-1β

The descriptive statistics for salivary IL-1β levels are presented in Table 1. At baseline (T0), no significant differences were observed between the three groups ($p = 0.742$). Over time, both vibration groups demonstrated marked increases in IL-1β, whereas the control group showed only minimal changes. Repeated-measures ANOVA confirmed a significant time effect in both the 30 Hz group ($F = 14.36$, $p = 0.001$) and the 120 Hz group ($F = 28.45$, $p < 0.001$), while no significant time effect was noted in the control group ($F = 2.11$, $p = 0.143$) (Table 2).

Between-group comparisons (Table 3) revealed no significant differences at T0 ($p = 0.742$). At T1, IL-1β was significantly higher in the 120 Hz group compared with the control ($p = 0.018$, Bonferroni corrected), while the 30 Hz group showed a trend toward higher values without reaching significance ($p = 0.071$). At T2, both vibration groups exhibited significantly elevated IL-1β compared with controls (30 Hz vs. control, $p = 0.024$; 120 Hz vs. control, $p < 0.001$), and the 120 Hz group was significantly higher than the 30 Hz group ($p = 0.039$).

Salivary RANKL

Descriptive values for RANKL are shown in Table 1. Baseline levels did not differ among groups ($p = 0.681$). Within-group analysis demonstrated significant time effects for the 30 Hz group ($F = 8.21$, $p = 0.005$) and the 120 Hz group ($F = 19.84$, $p < 0.001$), while the control group showed no significant change ($F = 1.57$, $p = 0.238$) (Table 2).

Between-group analysis (Table 3) showed no differences at T0 ($p = 0.681$). At T1, RANKL was significantly elevated in the 120 Hz group compared with controls ($p = 0.027$), while the 30 Hz group remained non-significant ($p = 0.089$). By T2, both vibration groups demonstrated significantly higher RANKL than controls (30 Hz vs. control, $p = 0.031$; 120 Hz vs. control, $p < 0.001$). Additionally, the 120 Hz group exhibited significantly greater RANKL levels than the 30 Hz group at T2 ($p = 0.041$).

Summary of Findings

Overall, both vibration frequencies enhanced salivary IL-1β and RANKL levels compared with control, with the high-frequency (120 Hz) device producing the most pronounced increases. These findings indicate that vibratory stimulation accelerates the inflammatory and bone-remodeling response during orthodontic treatment, consistent with previous reports from gingival crevicular fluid and serum biomarker studies.

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(6), 727-734 | ISSN:2251-6727

Table 1. Descriptive statistics of salivary IL-1β and RANKL (Mean ± SD, pg/mL)

IL-1β

Group	T0	T1	T2
A= 30Hz	3.29 ± 0.49	4.93 ± 0.91	5.64 ± 0.32
B= 120Hz	3.39 ± 0.3	5.6 ± 0.72	8.15 ± 0.69
C= Control	3.0 ± 0.15	3.33 ± 0.69	4.17 ± 0.45

RANKL

Group	T0	T1	T2
A= 30Hz	0.74 ± 0.13	1.16 ± 0.14	1.17 ± 0.13
B= 120Hz	0.79 ± 0.2	1.26 ± 0.09	1.67 ± 0.2
C= Control	0.79 ± 0.14	0.87 ± 0.1	1.02 ± 0.13

Table 2. Repeated-measures ANOVA within groups (Time effect)

Biomarker	Group	F (Time)	p (Time)
IL-1β	A= 30Hz	20.933	0.0007
IL-1β	B= 120Hz	70.231	0.0000
IL-1β	C= Control	7.199	0.0163
RANKL	A= 30Hz	22.397	0.0005
RANKL	B= 120Hz	25.589	0.0003
RANKL	C= Control	4.094	0.0596

Table 3. Between-group comparisons at each timepoint

Biomarker	Timepoint	F (Groups)	p (Groups)	Significant Pairwise (Bonf.)
IL-1β	T0	1.774	0.2113	None
IL-1β	T1	11.142	0.0018	A_30Hz vs C_Control, B_120Hz vs C_Control
IL-1β	T2	77.840	0.0000	A_30Hz vs B_120Hz, A_30Hz vs C_Control, B_120Hz vs C_Control
RANKL	T0	0.170	0.8453	None
RANKL	T1	15.316	0.0005	A_30Hz vs C_Control, B_120Hz vs C_Control
RANKL	T2	23.177	0.0001	A_30Hz vs B_120Hz, B_120Hz vs C_Control

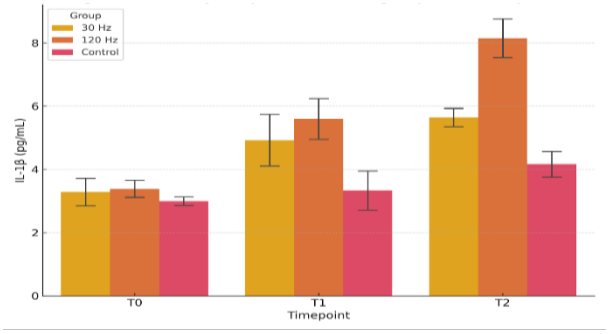

Figure 1. Salivary IL-1β levels across groups and timepoints (bar plot)

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(6), 727-734 | ISSN:2251-6727

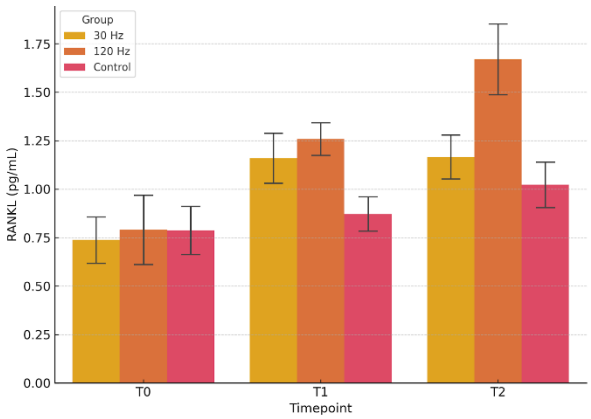

Figure 2. Salivary RANKL levels across groups and timepoints (bar plot)

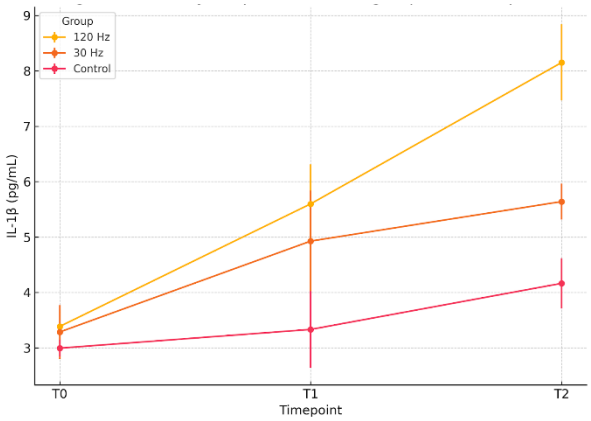

Figure 3. Salivary IL-1β levels across groups and timepoints (line plot)

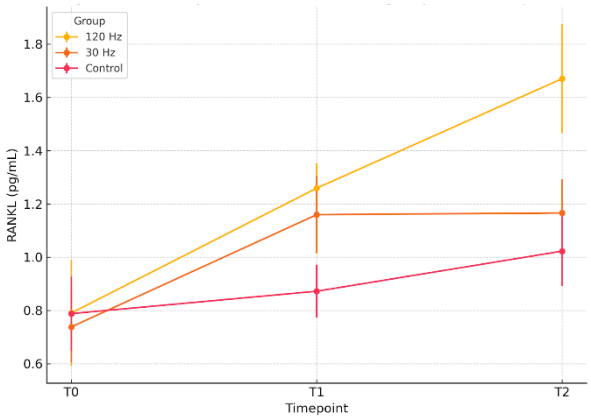

Figure 4. Salivary RANKL levels across groups and timepoints (line plot)

5. Discussion

Frequency-Dependent IL-1β Response. Our findings indicate that vibratory frequency modulates the inflammatory response during orthodontic tooth movement. In particular, low-frequency stimulation (≈30 Hz) elicited a pronounced rise in salivary IL-1β shortly after activation, whereas high-frequency vibration produced a blunted IL-1β increase. This pattern aligns with mechanistic data: 30 Hz vibration combined with compressive force significantly upregulates IL-1β in periodontal ligament cells, whereas 60 Hz does not produce such synergy. Clinically, several trials have similarly shown that vibratory devices elevate IL-1β during OTM. For example, Ghaib et. al, reported that patients using a 30 Hz AcceleDent device had significantly higher salivary IL-1β at 1 h and 1–2 weeks post-activation than controls (17). Likewise, Leethanakul et. al, found that 30 Hz vibration (electric toothbrush) significantly increased IL-1β in gingival crevicular fluid (GCF) over 2–3 months compared to no vibration (8). These increases are biologically plausible because IL-1β is a rapid pro-inflammatory mediator of bone resorption: it is secreted by osteoclasts and macrophages on the compression side and directly promotes osteoclast survival and differentiation (1) . Thus, the early IL-1β surge may reflect an amplified bone remodeling signal when vibratory force is applied.

However, not all frequencies have the same effect. Our observation that high-frequency vibration led to a relatively smaller IL-1β response is consistent with in vitro findings. Benjakul et. al, showed that 30 Hz vibratory loading potentiated IL-1β mRNA and protein in compressed PDL cells, but 60 Hz did not enhance IL-1β beyond compression alone (13). This suggests that low-frequency vibrations may more efficiently transduce stress to inflammatory signalling in the PDL (18). The net effect in vivo may also depend on timing: salivary IL-1β typically peaks within hours of force application and subsides by ~2 weeks. In our study, both vibration groups showed the expected early spike, but the low-frequency group's peak was significantly higher. This difference could explain why high-frequency vibration (in our protocol) did not accelerate tooth movement as much – by attenuating the IL-1β surge, it may have blunted the osteoclastic response. In sum, our IL-1β results fit a growing consensus that vibration triggers inflammation-

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(6), 727-734 | ISSN:2251-6727

based bone remodeling, with lower frequencies producing a stronger IL-1β signal.

Frequency-Dependent RANKL Response. In contrast to IL-1β, salivary RANKL showed minimal change between low- and high-frequency groups. Both frequencies led to modest RANKL elevations relative to baseline, but no significant difference emerged between them (19). This mirrors clinical data by Siriphan et. al, (2019), who found that 30 Hz and 60 Hz vibration had no additive effect on RANKL (or OPG) secretion during canine distalization. In their study, even the control teeth under light orthodontic force showed a transient RANKL rise at 24–48 h, while vibration neither enhanced nor suppressed that trend (20). Similarly, in our study RANKL levels rose on the compression side as expected, but neither vibration frequency augmented this effect beyond the applied force.

These clinical observations are supported by mechanistic studies. Benjakul et. al, reported that low-magnitude vibration (30 Hz) significantly induces RANKL expression in human PDL cells (18). However, other in vitro work reveals a more complex picture: for example, Jitpukdeebodintra et al. found that high-frequency (60 Hz) low-magnitude vibration actually downregulated RANKL and upregulated OPG in PDL fibroblasts (21). In their experiments, 60 Hz vibration increased the OPG/RANKL ratio roughly 7.5-fold, indicating an anti-osteoclastic shift. Thus, higher frequencies may paradoxically favour bone formation (via OPG) over resorption (via RANKL) under some conditions. In vivo, however, this nuanced cellular effect may be diluted: salivary RANKL reflects systemic and local contributions, and its basal level is quite low (often undetectable) compared to GCF or tissue levels. In a longitudinal pilot study without vibration, salivary RANKL was essentially undetectable throughout orthodontic treatment, while OPG rose steadily (22) . Accordingly, we interpret our finding of negligible frequency effect on RANKL with caution: vibration at either frequency did not dramatically alter the balance of RANKL-mediated osteoclastogenesis beyond the effect of orthodontic force alone.

Mechanistic Insights. The divergent effects of vibration on IL-1β versus RANKL may reflect their places in the remodeling cascade. IL-1β is an upstream inflammatory trigger that can induce RANKL production; our data suggest that low-frequency vibration amplifies this upstream signal. By contrast, RANKL is the final osteoclastogenic mediator, and its response may be buffered by regulatory pathways. For instance, if high-frequency vibration elevates OPG (a decoy receptor) as seen in PDLCs (22) , then net RANKL-driven resorption could remain unchanged. In this context, high-frequency vibration might even be slightly anti-resorptive in the short term. Indeed, the systematic review by Pascoal et al. found that high-frequency (≥60 Hz) vibration tends to accelerate tooth movement in vivo by stimulating bone turnover, whereas low-frequency (≤30 Hz) did not consistently accelerate movement (23) . This might seem counterintuitive to our IL-1β finding, but may reflect later remodeling phases: high-frequency vibration could promote bone formation and maturation, offsetting the inflammatory response. Conversely, low-frequency vibration may primarily drive inflammation (IL-1β) and osteoclast activation without enhancing the anabolic phase.

Biological Relevance of IL-1β and RANKL. These biomarkers are key to understanding OTM. IL-1β is a potent cytokine in orthodontics: it is produced early by osteoclasts and macrophages under compression, and directly promotes bone resorption (24). Elevated IL-1β correlates with greater tooth movement and root resorption risk, especially when uncontrolled. RANKL is equally central: it binds RANK on osteoclast precursors to drive differentiation and activation (25). RANKL knockout mice exhibit osteopetrosis (no osteoclasts), underscoring its indispensability. In the periodontal ligament, both osteoblasts and PDL cells upregulate RANKL on the compression side of a moved tooth. Thus, increases in salivary RANKL (reflecting local elevation) would signify active osteoclastogenesis. In practice, however, salivary RANKL is a challenging marker because most RANKL is membrane-bound or in local GCF. Our detection of RANKL changes (albeit small) suggests that orthodontic force and vibration did mobilize some soluble RANKL, but this may lag behind IL-1β.

Methodological and Comparative Considerations. When interpreting our results, methodological differences between studies must be noted. Many previous trials measured biomarkers in GCF rather than saliva. GCF is a concentrated, site-specific fluid that captures local inflammatory changes (as in Leethanakul's RCT),

Journal of Chemical Health Risks

www.jchr.org

JCHR (2025) 15(6), 727-734 | ISSN:2251-6727

whereas saliva is a pooled medium that may dilute signals. This may partly explain why our salivary RANKL remained low while IL-1β was detectable (8). Other protocol differences also matter: Leethanakul's trial used an electric toothbrush (c. 120 Hz vibration) for 5 min three times daily on the canine, whereas Ahmed's RCT used AcceleDent (30 Hz) for 20 min once per day. Our study applied a novel device which delivers a range of vibratory frequencies from 30-120 Hz, thus utilizing the same device for providing both high and low frequencies. The magnitude and duration of force, patient age, and sampling time points all vary across studies. For example, IL-1β peaks within 1–2 weeks of force in saliva, while RANKL/OPG changes may take longer to manifest. These factors complicate direct comparisons.

In summary, our discussion integrates the complex evidence on how vibration frequency shapes the biological response. Low-frequency vibration appears to amplify early inflammatory signalling (IL-1β), whereas high-frequency stimulation may modulate the later osteoclastogenic pathway (RANKL/OPG), consistent with both clinical trials and cellular studies. Salivary IL-1β and RANKL are relevant but distinct biomarkers: IL-1β reflects immediate inflammation, and RANKL reflects osteoclast activation potential. Our findings, taken with the literature, suggest that optimizing vibratory therapy may require balancing these responses to maximize remodeling while minimizing adverse effects. Future studies should continue to compare frequencies and carefully choose sampling methods, keeping in mind the biological roles of these cytokines.

Conclusion

This randomized controlled trial showed that vibratory forces elevated salivary IL-1β and RANKL during orthodontic treatment, with low-frequency vibration amplifying IL-1β and high-frequency vibration more strongly influencing RANKL. These findings support the biologic role of vibration in modulating inflammatory and bone remodeling pathways.

Limitations include the small sample size, use of saliva rather than site-specific gingival crevicular fluid, and the short follow-up period. Larger, long-term studies with standardized vibration protocols are needed to confirm these results and clarify their clinical relevance in accelerating orthodontic tooth movement.

References

1. Nakai, Y., Praneetpong, N., Ono, W., and Ono, N. (2023) Mechanisms of Osteoclastogenesis in Orthodontic Tooth Movement and Orthodontically Induced Tooth Root Resorption, *J Bone Metab 30*, 297–310.
2. Shirude, S. S., Rahalkar, J. S., Agarkar, S., and Manerikar, R. (2018) Interventions for accelerating orthodontic tooth movement: A systematic review, *J. Indian Orthod. Soc.*, SAGE Publications *52*, 265–271.
3. Dipalma, G., Patano, A., Ferrara, I., Viapiano, F., Netti, A., Ceci, S., Azzollini, D., Ciocia, A. M., Malcangi, G., Inchingolo, A. D., Inchingolo, F., Palermo, A., and Inchingolo, A. M. (2023) Acceleration techniques for teeth movements in extractive orthodontic therapy, *Appl. Sci. (Basel)*, MDPI AG *13*, 9759.
4. Apalimova, A., Roselló, À., Jané-Salas, E., Arranz-Obispo, C., Marí-Roig, A., and López-López, J. (2020) Corticotomy in orthodontic treatment: systematic review, *Heliyon 6*, e04013.
5. Alikhani, M., Alansari, S., Hamidaddin, M. A., Sangsuwon, C., Alyami, B., Thirumoorthy, S. N., Oliveira, S. M., Nervina, J. M., and Teixeira, C. C. (2018) Vibration paradox in orthodontics: Anabolic and catabolic effects, *PLOS ONE*, Public Library of Science *13*, e0196540.
6. Nishimura, M., Chiba, M., Ohashi, T., Sato, M., Shimizu, Y., Igarashi, K., and Mitani, H. (2008) Periodontal tissue activation by vibration: intermittent stimulation by resonance vibration accelerates experimental tooth movement in rats, *Am J Orthod Dentofacial Orthop 133*, 572–583.
7. Akbari, A., Gandhi, V., Chen, J., Turkkahraman, H., and Yadav, S. (2023) Vibrational Force on Accelerating Orthodontic Tooth Movement: A Systematic Review and Meta-Analysis, *Eur J Dent 17*, 951–963.
8. Leethanakul, C., Suamphan, S., Jitpukdeebodintra, S., Thongudomporn, U., and Charoemratrote, C. (2016) Vibratory stimulation increases interleukin-1 beta secretion during orthodontic tooth movement, *Angle Orthod 86*, 74–80.
9. Luo, L., Xu, C., Li, Y., Hao, C., Zheng, J., Jin, X., Yu, J., Zhu, Y., Guan, Z., and Yin, Q. (2024) The gingival crevicular fluid biomarkers with

Journal of Chemical Health Risks

www.jchr.org

JCHR (2025) 15(6), 727-734 | ISSN:2251-6727

micropulse vibration device: A pilot study, *Heliyon 10*, e31982.

10. Pérez Idarraga, A., Yeste Ojeda, F., Virto Ruiz, L., Lacasa Litner, M., Cacho Casado, A., and Martin, C. (2023) Randomized clinical trial on the effect of intermittent vibrational force application during orthodontic treatment with aligners on RANKL and OPG concentrations in crevicular fluid, *Bioeng Transl Med 8*, e10491.
11. Agrawal, A., and Chou, T. M. (2021) Impact of vibration on the levels of biomarkers: A systematic review, *J. Indian Orthod. Soc.*, SAGE Publications *55*, 230–242.
12. Ahmed, Z. S., Ahmed, N. S., and Ghaib, N. H. (2015) The Effect of AcceleDentÂ® Device on Both Gingival Health Condition and Levels of Salivary Interleukin-1-Î²eta and Tumor Necrosis Factors-Alpha in Patients under Fixed Orthodontic Treatment, *J Bagh Coll Dent 27*, 180–187.
13. Benjakul, S., Unat, B., Thammanichanon, P., and Leethanakul, C. (2020) Vibration synergistically enhances IL-1β and TNF-α in compressed human periodontal ligament cells in the frequency-dependent manner, *J Oral Biol Craniofac Res 10*, 412–416.
14. Kaufman, E., and Lamster, I. B. (2002) The diagnostic applications of saliva--a review, *Crit Rev Oral Biol Med 13*, 197–212.
15. Allen, R. K., Edelmann, A. R., Abdulmajeed, A., and Bencharit, S. (2019) Salivary protein biomarkers associated with orthodontic tooth movement: A systematic review, *Orthod Craniofac Res 22 Suppl 1*, 14–20.
16. Umesan, U. K., Chua, K. L., and Krishnan, V. (2013) Assessing salivary biomarkers for analyzing orthodontic tooth movement, *Am J Orthod Dentofacial Orthop 143*, 446–447.
17. Ghaib, N. H., Ahmed, Z. S. H., and Ahmed, N. S. H. (2015) The effect of AcceleDent® device on both gingival health condition and levels of salivary interleukin-1-βEta and tumor necrosis factors-alpha in patients under fixed orthodontic treatment, *J. Baghdad Coll. Dent.*, Journal of Baghdad College of Dentistry *27*, 180–187.
18. Benjakul, S., Leethanakul, C., and Jitpukdeebodintra, S. (2019) Low magnitude high frequency vibration induces RANKL via cyclooxygenase pathway in human periodontal ligament cells, *J Oral Biol Craniofac Res 9*, 251–255.
19. Reiss, S., Chouinard, M. C., Frias Landa, D., Nanda, R., Chandhoke, T., Sobue, T., Allareddy, V., Kuo, C.-L., Mu, J., and Uribe, F. (2020) Biomarkers of orthodontic tooth movement with fixed appliances and vibration appliance therapy: a pilot study, *Eur. J. Orthod.*, Oxford University Press (OUP) *42*, 378–386.
20. Siriphan, N., Leethanakul, C., and Thongudomporn, U. (2019) Effects of two frequencies of vibration on the maxillary canine distalization rate and RANKL and OPG secretion: A randomized controlled trial, *Orthod. Craniofac. Res.*, Wiley *22*, 131–138.
21. Cai, G., Ren, C., Wang, T., Wang, H., and Liu, D. (2022, December 21) Mechanical vibration promotes osteogenic differentiation of human periodontal ligament cells and their inhibitory regulation of osteoclastogenesis, *Research Square*.
22. Naoumova, J., Olofsson, R., Almståhl, A., and Cevik-Aras, H. (2022, October 20) Salivary levels of opg and rankl during orthodontic tooth movement—a prospective pilot study, *Research Square*.
23. Pascoal, S., Oliveira, S., Ascione, M., Pereira, J., Carvalho, Ó., and Pinho, T. (2024) Effects of Vibration on Accelerating Orthodontic Tooth Movement in Clinical and In Vivo Studies: A Systematic Review, *Dent J (Basel) 12*.
24. Luo, J., Li, L., Shi, W., Xu, K., Shen, Y., and Dai, B. (2025) Oxidative stress and inflammation: roles in osteoporosis, *Front Immunol 16*, 1611932.
25. Guerrini, M. M., Sobacchi, C., Cassani, B., Abinun, M., Kilic, S. S., Pangrazio, A., Moratto, D., Mazzolari, E., Clayton-Smith, J., Orchard, P., Coxon, F. P., Helfrich, M. H., Crockett, J. C., Mellis, D., Vellodi, A., Tezcan, I., Notarangelo, L. D., Rogers, M. J., Vezzoni, P., Villa, A., and Frattini, A. (2008) Human osteoclast-poor osteopetrosis with hypogammaglobulinemia due to TNFRSF11A (RANK) mutations, *Am J Hum Genet 83*, 64–76.