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High and low frequency vibration in orthodontic tooth movement

Romeïssa Imène Touat

Dissertação conducente ao Grau de Mestre em Medicina Dentária (Ciclo Integrado)

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Trabalho realizado sob a Orientação da Mestre Selma Pascoal e Co-orientação da Mestre Sofia Oliveira

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AGRADECIMENTOS

First of all I wanted to thank my parents. I wanted to thank them for everything they have done for me since I was born because it is clearly thanks to them that I am where I am today. I wanted to thank them from the bottom of my heart and dedicate this diploma to them because it is for them. I will never forget all your sacrifices and I hope, if God allows me, to repay you a hundredfold. I adore you and I will never have enough words to express my gratitude. I also dedicate it to my beloved late grandmother (may she rest in peace), who often prayed for my success. My gratitude to my sister Sarah and my brother Jazil for their unconditional support during these five years of study. You are the extension of my being and I love you. My thanks to my brother-in-law and my best friend: Mehdi and Carole whom I consider as full members of my family. My thanks also for my friends who are really dear to my heart: Asnat, Madina, Ahlem, Celia and Kamila. Thank you for all your encouragement. A little thought for my friends who shared this adventure with me : the Ramadan team with Younes, Florian, Aurélien, Andy and Valentin, I already miss our ftours! Thank you also to the wonderful people I met here, special mention to my Laura, Apolline and Sarah but without forgetting my neighbours and friends Sybel, Syma, Ozgul, Katia, and Kenza. My thanks to my partners, first of all Emilie, who shared her first years with me and then finished her studies at Madrid University. But I would also like to thank my partner at the end of the course: Gwendoline, with whom I spent some very good times and thanks to whom I took up sport again and discovered stretching! Thanks to all of you.

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RESUMO

Introdução: Ortodontia é uma área da medicina dentária em que a evolução das técnicas é omnipresente e que tem como um dos mais recentes objetivos acelerar e optimizar o movimento dentário. Nos últimos anos, assistimos ao surgimento de várias técnicas de aceleração do movimento ortodôntico como, por exemplo, a vibração que é um método não invasivo e que pode ser aplicado em conjunto com o tratamento ortodôntico de forma a aumentar a taxa de movimento dentário.

Objectivos: Avaliar os efeitos das vibrações de alta e baixa frequência no movimento ortodôntico.

Método: Foi realizada uma pesquisa bibliográfica na seguinte base de dados PubMed em Fevereiro de 2022, usando palavras-chave específicas: (((orthodontics[MeSH Terms])) OR (orthodontic movement[MeSH Terms])) OR (tooth movement[MeSH Terms])) AND (vibration[MeSH Terms]) OR (((high frequency[MeSH Terms]) OR (low frequency[MeSH Terms]))).

Resultados: A pesquisa identificou 4945 artigos, dos quais 15 foram seleccionados tendo em conta os critérios de inclusão e exclusão. Sete estudos utilizaram as vibrações de baixa frequência, são até 30 Hz e não parecem afectar o movimento dentário. Oito estudos utilizaram as vibrações de alta frequência, excedem 30 Hz e parecem potenciar o movimento dentário.

Conclusão: As vibrações de baixa frequência não parecem ter efeito na aceleração do movimento dentário, enquanto as vibrações de alta frequência parecem acelerar consideravelmente o movimento ortodôntico. No entanto, os mecanismos exactos necessários para a sua utilização optimizada permanecem pouco claros e são necessários mais estudos para melhor definição dos parâmetros de estimulação.

Palavras-Chave: Ortodontia; Movimento Ortodôntico; Movimento Dentário; Alta frequência; Baixa frequência; Vibração.

ABSTRACT

Introduction: Orthodontics is an area of dental medicine in which the evolution of techniques is omnipresent, and one of its most recent objectives is to accelerate and optimize tooth movement. In recent years, we have witnessed the emergence of various techniques for accelerating orthodontic movement such as vibration, which is a non-invasive method that can be applied in conjunction with orthodontic treatment in order to increase the rate of tooth movement.

Objectives: To evaluate the effects of high and low frequency vibration on orthodontic tooth movement.

Material and Methods: A literature search was conducted in the following PubMed database in February 2022, using specific keywords: (((orthodontics[MeSH Terms])) OR (orthodontic movement[MeSH Terms])) OR (tooth movement[MeSH Terms])) AND (vibration[MeSH Terms]) OR (((high frequency[MeSH Terms]) OR (low frequency[MeSH Terms]))).

Results: The search identified 4945 articles, of which 15 were selected taking into account the inclusion and exclusion criteria. Seven studies used low-frequency vibration, are up to 30 Hz and does not appear to affect dental movement. Eight studies used high-frequency vibration that exceed 30 Hz and seems to be beneficial on the acceleration dental movement.

Conclusion: Vibrations in the low frequency range did not have any effect on the acceleration of tooth movement, whereas high frequency vibrations considerably enhanced and accelerated orthodontic movement. However, the exact mechanisms required for their successful use remain unclear and further studies are needed to better define the stimulation parameters.

Keywords: Orthodontics; Orthodontic Movement; Tooth Movement; High frequency; Low frequency; Vibration.

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INDEX OF ABBREVIATIONS AND ACRONYMS

LFMV: Low-Frequency Mechanical Vibration

HFV: High Frequency Vibration

OTM: Orthodontic tooth movement

GCF: Gingival Crevicular Fluid

PDL: Periodontal ligament

IL: Interleukin

TNF: Tumor necrosis factor

NF: Nuclear Factor

RANKL: Receptor Activator of Nuclear factor Kappa-B Ligand

1 INTRODUCTION

Orthodontic treatment improves oral and facial aesthetics, occlusion and masticatory function. The duration of the treatment is estimated to average between 24 and 36 months and is one of the main concerns in the patient's decision-making process. (1)
Moreover, undesirable effects are directly proportional to the duration of the treatment: dental caries, root resorption, periodontal problems. (2,3) Therefore, it's beneficial for the patient and the orthodontist to accelerate tooth movement to reduce the duration of treatment and any associated secondary risks. (3) Science has developed many techniques for accelerating orthodontic tooth movement (OTM) which can be divided into two main approaches: surgical and non-surgical. (1) The surgical approach is illustrated by the techniques of alveolar corticotomies, rapid canine retraction, dental distraction. (2) Nevertheless, potential morbidity, the rather invasive character, the high cost and the post-operative discomfort make patients and parents very dubious about the use of these surgical procedures. This explains the rather limited clinical application. (2,4) Therefore, research is moving towards other non-surgical approaches that aim to accelerate tooth movement in a less invasive manner with minimal side effects and low costs that would be more acceptable to the patient. (2) Various noninvasive methods have been tried such as laser therapy, electric current, pulsed electromagnetic fields, and pharmacological intervention with prostaglandin injection or vitamin E2. However, undesirable side effects such as root resorption and local pain have been associated with these methods. (3,4)
The use of high frequency vibration (HFV) or low frequency mechanical vibration (LFMV) is a non-surgical method that can be applied in addition to orthodontic treatment to increase the speed of movement. This method is based on the direct application of vibratory stimuli complementary to orthodontic treatment. (5) It is based on the established principles that orthodontic movement is based on the remodelling capacity of the alveolar bone and that the use of vibratory forces can assist osteoclastic and periodontal remodelling activity without damaging the periodontium or causing pathologies as root resorption. However, all the biological mechanisms involved in bone remodelling when these vibratory forces are applied are still not fully understood. (3)

2 OBJECTIVES

This systematic review aims to highlight and compare the effects of high and low frequency vibrations on dental movement fulfilling the following objectives:

1- To assess whether HFV would induce acceleration on OTM.

2- To assess whether LFMV frequencies would induce acceleration on OTM.

3- Compare the effects of LFMV versus the effects of HFV on OTM.

3 METHODS

3.1 Protocol and registration

The systematic review followed the PRISMA "Preferred Reporting Items for Systematic Reviews and Meta-Analyzes" protocol. (6)

3.2 Formulation of Research Question

The "PICO" [Patient Population (P), Intervention (I), Comparison (C), and Outcomes (O)] was used to structure and answer a research question more precisely and provide more relevant and specific research findings. The PICO question answers the following criteria in the table below.

Table 1- PICO

Population	Orthodontics patients
Intervention	HFV and LFMV vibration exposition
Comparison	Orthodontics patients subjected to HFV/LFMV in comparison to control (orthodontics patients without any vibration treatment)
Outcomes	HFV are involved in acceleration on OTM. LFMV do not seem to induce variations in OTM. Analysis of OTM by measuring the distance of alignment of the space at several points over several time intervals.

3.3 Research strategy and study selection process

To carry out this systematic review a literature search was conducted on PubMed using the following combination of search terms: (((orthodontics[MeSH Terms]) OR (orthodontic movement[MeSH Terms])) OR (Tooth Movement[MeSH Terms])) AND (vibration[MeSH Terms]) OR (((high frequency[MeSH Terms]) OR (low frequency[MeSH Terms]))).

The search conducted until 14-02-2022 with the above detailed keyword combination. After applying the inclusion criteria, 4945 articles were Identified and 36 were selected for reading the abstracts, of which 24 articles were considered relevant to this work after reading the title and abstract. Finally, 15 articles were selected after analyzing the full-texts.

3.4 Eligibility criteria

The selection criteria were documented as follows:

Inclusion criteria:

- Articles with a publication date between 2012 and 2022;
- Articles published in English;
- Prospective, retrospective studies, randomised controlled clinical studies, *in vivo* and *in vitro* studies.

Exclusion criteria:

- Articles whose publication date was before 2012;
- Articles published in languages other than English;
- Systematic review, integrative systematic review and meta-analysis;
- Article with a title or abstract that is irrelevant to the objectives.

3.5 Data collection and extraction

All data related to study characteristics and outcomes of the included studies were extracted into an excel spreadsheet. Data related to the study characteristics were collected: author, year, type of study, participating population, type of orthodontic appliance, dental location and associated movement, vibration parameters (device type, frequency type, frequency, force and irradiation time) and results.

4 RESULTS

According to the inclusion and exclusion criteria, 15 articles were selected from the literature search in PubMed.

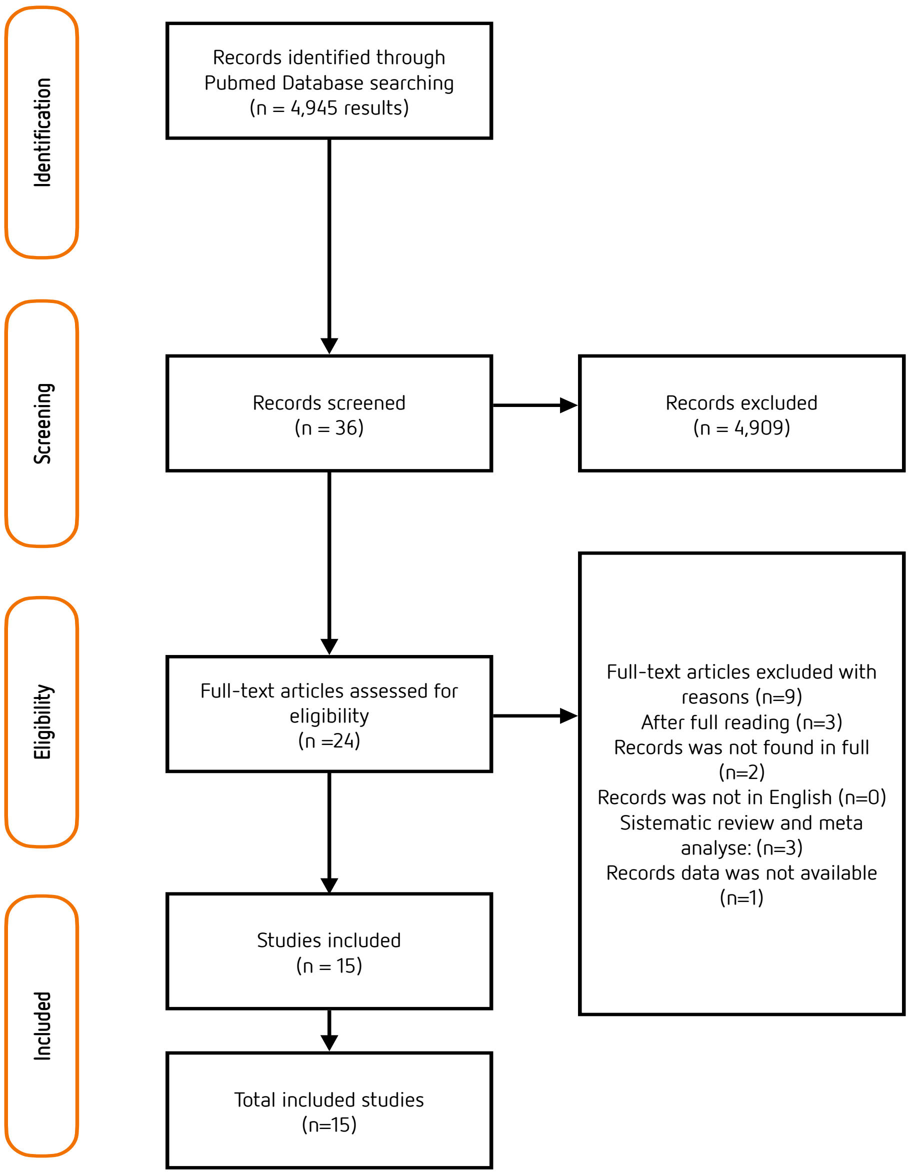

Figure 1- Flow diagram PRISMA

From the included studies, eight studies (53.3%) used fixed orthodontics, while seven (46.7%) applied aligners. Regarding the vibration stimuli, LFMV was explored in seven studies (46.7%), whereas eight studies (53.3%) used HFV. For the studies applying LFMV, five (33,3%) used the AcceleDent® appliance. Considering the HFV, four studies (26.7%) applied the VPRO5® appliance and only one study (6.7%) used an Oral B® (USA) Humming Bird appliance. The following table summarises the included studies characteristics.

Table 2- Details gathered from the selected studies

Autor	Type of Study	Participating population	Type of orthodontic appliance	Dental location and associated movement	Vibration parameters	Results
Pavlin *et al* (2015)	Double-blind, randomized controlled trial	Human patients (n=45); - Vibration group (n=23): + vibrations; - Control group (n=23): No vibration.	Orthodontic fixed appliances: - Brackets	Maxillary canine retraction (translation)	- Low frequency; - AcceleDent®; - Frequency: 30Hz; - Force: 0.25N; - Duration: 20 min/day.	The average rate movement was considerably more significant for the AcceleDents group with 1.16mm/month compared to control group with0.79mm/month with the mean difference of 0.37 mm/month.
Lombardo *et al* (2019)	Single-centre, randomized controlled clinical trial	Humans patients (n= 45); - Group A (conventional protocol) (n=15): aligners substituted every 14 days; - Group B (n=15): aligners substitued every 14 days + LFMV for 20 min/day; - Group C (n=15): aligners substituted every 7 days + LFMV 20 min / day.	Aligners	All tooth and movement	- Low frequency; - AcceleDent®; - Frequency: 30Hz; - Force: 0.25N; - Duration: 20 min/day.	- Mandibula: no statistically significant differences between groups A, B and C; - Maxila: no statistically significant differences between groups A and C; Group B displayed significantly greater: • Maxillary incisor rotation with respect to group A (B= 0.72> A= 0.62); • In vestibulolingual (B=0.67> C= 0.54) and mesiodistal (B= 0.65 > C= 0.49) tipping of maxillary canines respect to group C; • In vestibulolingual (B= 0.71> C= 0.55) of maxillary molars respect to group C.
Katchooi *et al* (2018)	Randomized Clinical trial	Humans patient (n=27); - (A) Active AcceleDent Aura device ; - (B) Sham AcceleDent Aura device. For all: • 1-week aligner change regimen; • Evaluated every 3 weeks.	Aligners	Maxillary and mandibular incisors	- Low frequency; - AcceleDent®; - Frequency: 30Hz; - Force 0,25N; - Duration: 20min/day.	No significant difference in rates between the 2 groups (Group A = 77%; Group B = 85%). T-tests indicated no meaningful difference in the irregularity index or change in irregularity index between the 2 groups. The Wilcoxon rank sum test showed minor differences in pain intensity. Compliance was comparable in both groups.

Miles *et al.* (2018)	Single-blind randomized clinical trial	Humans, patients (n=40); - Control Group (n=20): no vibrations; - VibrationGroup (n=20): + vibrations.	Aligners	Closure of space of 1st PM maxillary extraction	- Low frequency; - AcceleDent®; - Frequency: 30Hz; - Force: 0,25N; - Duration: 20min/day.	There was no statistical difference (P5 0.74) and clinical (0.05 mm/month) in the rate of tooth movement during space closure with LFMV.
Reiss *et al* (2020)	Pilot study	Humans patients (n=40); - Control group (n=20): brackets + no vibration; - Vibration group (n=20): brackets + vibration. To analyse the concentration of specific biomarkers of bone remodelling: a salivary multiplex test was conducted before treatment (T0) and at 3 subsequent time points (T1, T2, T3), 4-6 weeks interval.	Orthodontic fixed appliances: - Brackets	Mandibular anterior alignment rate (RMAA)	- Low frequency; - AcceleDent®; - Frequency: 30Hz; - Force: 0.25N; - Duration: 20min/day.	No differences were observable in the changes in salivary biomarkers among the groups at any time point in the experiment. No correspondence was detected in irregularity and biomarkers at any time-point. Lastly, there was no correlation with RMAA and AcceleDent compliance. RMAA and bone remodelling biomarkers are not affected by LFMV during orthodontic treatment.
Kumar *et al* (2020)	Randomized controlled trial	Humans patients (n=65); - Control group: conventional MBT brackets + any vibrations; - Group 1: passive self-ligating brackets + LF vibration; - Group 2: Conventionally ligated appliances (MBT brackets) + LF vibration.	Orthodontic fixed appliances: - Brackets - Passive self-ligating - Conventionally ligated appliances	Closure of the space between canines (distal) and 2nd Premolar (PM) 2nd PM(mesial) maxillary	- Low Frequency; - Frequency: 30Hz; - Force: 150gms (in total); - Duration: 20min/day.	The results of the closure measurement of the space (mm/month) between the canines and the 2nd PM showed that there were no statistically differences between the 3 groups. There was no difference between control group and the experimental groups P>0.05, but also between the experimental groups themselves.
Yadav *et al* (2015)	Single-centre, randomized controlled clinical trial	Animals (n=64) male CD1 mice; - Control groups: • Baseline • no spring +5 Hz; • no spring +10 Hz; • no spring +20 Hz. - Experimental groups: • spring + no vibration; • spring + 5 Hz; • spring +10 Hz; spring + 20 Hz.		Maxillary first molar (mesial displacement)	- Low Frequency; - Frequency: 5Hz; 10Hz; 20Hz; - Force: 10g; - Duration: 15min / 3days (1,4,7,10,13).	LFMV has not raise the completion the rate of OTM.

Shipley T (2018)	Pilot Study	Humans patients (n=16); - Group 1 experimental (n = 8): aligners substituted every 5 days + HFV; - Group 2 control (n=8): conventional protocol with aligners substituted every 14 days.	Aligners	All tooth and movement	- High frequency; - VPRO5®; - Frequency: 120Hz; - Duration: 5min/day.	HFV resulted in: - Faster tooth movement (treatment duration in weeks: G1=19.25; G2=96.75); - Much faster exchange (66% more mfaster than control group); - Far fewer aligners were required than the control group (Number of aligners: G1=25.63; G2=45); - Required any adjustments while the control subjects (adjustments made G1=0/8; G2=6/8).
El-Bialy T (2020)	Case report	Humans patients (n=4); - Orthodontics patients without growth; - Class II skeleton; - Exposed to HFV in addition to orthodontic treatment.	Aligners	- Intrusion of the posterior teeth (vertical control + forward rotation of the mandible); - Lingual tilt of the lower incisors + palatal root torque of the upper incisors (dental decompensation).	- High frequency; - VPRO5®; - Frenquency: 120Hz; - Duration: 5min/day.	HFV helped: - Intrusion movement of the posterior teeth; - Decompensation of the incisors; - Forward mandible projection; - Labial bone formation at the mandibulary incisors.
Shipley *et al* (2019)	Retrospective study	Humans patients (n=30); - Control group (n=15): no vibration; - HFV group (n = 15): high-frequency vibration; • Aligners should be replaced when they become loose. • Evaluation of bone density with cone beam computed tomography (CBCT).	Aligners	All tooth and movement	- High frequency; - VPRO5®; - Frenquency: 120Hz; - Duration: 5min/day.	The average time to aligner change was 8,7 days in the control group and 5,2 days in the HFV group. A substantial elevation of HU values in the maxilla and mandibula was observed in the HFV group but not in the control group at the commencement of the retention phase.
Alansari *et al* (2018)	Randomized, single blinded, multicenter study	Humans patients (n=75); - 14 day control (n=15): replaced aligners every 14 days + no vibration;	Aligners	Mandibular incisor anterior-posterior movement	- High frequency; - VPRO5®; - Frequency: 120Hz; - Duration: 5 min/day.	HFV accelerated tooth movement, which significantly reduced the time gaps between aligners. HFV increased levels of cytokines and bone remodelling markers in the gingival crevicular fluid (GCF) and

		- 7 day sham (n=15): replaced aligners every 7 days + no vibration; - 7 day vibration (n=15): replaced aligners every 7 days + vibration; - 5 day sham (n=15): replaced aligners every 5 days + no vibration; - 5 day vibration (n=15): replaced aligners every 5 days + vibration. 4 aligners were used by all subjects + measurement of rate movement + assessment of cytokine levels in the GCF				decreased levels of pain and discomfort.
Mayama *et al* (2022)	Double blind prospective randomized controlled trial	Humans patients (n=46); - Non vibration control group (n=23): TM; - Vibration group (n=23): TM + V.	Orthodontic fixed appliances: - Brackets	Canine	- High Frequency; - Frequency: 102.2Hz; - Force: 0.5g; - Duration: 3min/day.	The rate of canine movement was higher in the vibration group than the control group: 1.21 mm > 0.89 mm. There was no significant difference in pain, discomfort and root resorption between the two groups.
Alikhan *et al* (2018)	Randomized clinical trial	Animals (n=206) Sprague Dawley rats; - Baseline group: not receive spring nor HFV; - Control group: spring with no activation; - Experimental groups were exposed to different: • Acceleration: 0.01g; 0.05g; 0.1g; • Frequency: 30Hz; 60Hz; 120Hz; • Duration: 5; 10 min.	Orthodontic fixed appliances: - Sentalloy closing coils that were custom-made by GAC International	Maxillary right first molar	- High frequency; - Frequency: 30Hz; 60Hz; 120Hz; - Acceleration: 0.01g; 0.05g; 0.1g; - Duration: 5; 10 min/day.	HFV produced: - Significant changes in speed of maxillary right first molar movements - Increases inflammation-dependent catabolic cascade during orthodontic movement; - Increases inflammatory mediators and osteoclastogenesis; - Decreased alveolar bone density; - Effect was Periodontal ligamento (PDL)-dependent.
Liao *et al* (2017)	Randomized controlled trial	Humans patients (n=13); Each subject was randomly assigned a "vibration" and	Orthodontic fixed appliances: - Brackets	Distal retraction of upper canines	- High frequency; - Oral B (USA) Hamming Bird Vibrating; - Frequency: 50Hz;	- Space closure on canine distalization were statistically higher in vibration group than the control group;

		''non-vibration'' to each subject on the buccal surface of upper canine			- Force: 0,2N; - Duration: 10min/day.	- The volume-average hydrostatic stress was higher with vibration in the PDL for upper teeth and for all linguo-buccal and mesio-distal orientations; - An acceleration in vibratory frequency increase the PDL response.
Takano-Yamamoto *et al* (2017)	Prospective clinical trial	Animal (n=70) rats; 1st group: - C group: 1st molar left side was used as control; - TM group: right side to tooth movement by activated Ni-Ti appliance; 2nd group: - V group: 1st molar left side was subjected to vibration; - TMV group: right side to tooth movement by activated Ni-Ti appliance and vibration (TMV1, TMV3, TMV50).	Orthodontic fixed appliances: **-** Ni-Ti appliance	Right maxillary first molar palatally moved	- High frequency; - Frequency/Force: • 58hz; 1gf; • 70hz, 3gf; • 268Hz, 50gf; - Duration: 3min/week.	- 3 gf at 70 Hz, 3 minutes per week is the optimal frequency in the movement of the right maxillary 1st molar palatally; - No adverse effects were recorded, (not root resoption); Biologically, it induced: - Induces Nuclear Factor (NF)-kB activation in osteoclasts, osteoblasts and osteocytes; - Increases PDL volume via osteoclastic bone resorption; - Promotes bone resorption in the deep alveolar bone during tooth movement.

LFMV: Low-frequency Mechanical Vibration; **HFV**: High Frequency Vibration; **OTM**: Orthodontic Tooth Movement **RMAA**: Rate of Mandibular Anterior Aligment; **PDL**: Periodontal Ligament; **PM**: Premolar; **GCF**: Gingival Crevicular Fluid.

5 DISCUSSION

Vibration has long been used in medicine to promote fracture healing and strengthen bones in the treatment of osteoporosis. (7) More recently, they have been applied in orthodontics to induce periodontal cell proliferation and differentiation in order to accelerate tooth movement. (8)

5.1 Effect of low frequency vibratory on dental movement

AcceleDent® device was mainly used in more than half of the studies applying LFMV. The AcceleDent® (OrthoAccel Technologies, Houston, Texas, USA) is a commercial orthodontic vibration device that uses low frequency pulsating forces operating at a frequency of 30Hz and a force of 0.25N using SoftPulse® technology. These micro-impulses are transmitted through the roots of the teeth to the surrounding bone. These forces are intended to stimulate cellular activity, influencing the rate of bone remodelling during orthodontic treatment when patients gently bite on the device for 20 minutes per day, which is expected to reduce the duration of orthodontic treatment. (8)

AcceleDent® device is a pioneer in the LFMV appliance market and has been used in several studies, including Pavlin et *al.* (2015), Lombardo *et al.* (2019), Katchooi *et al.* (2018), Miles *et al.* (2018) and Reiss *et al.* (2020). These studies were all conducted on human patients undergoing orthodontic treatment. However, Lombardo *et al.* (2019), Katchooi *et al.* (2018) and Miles *et al.* (2018) applied LFMV on human patients wearing aligners, while Pavlin *et al.* (2015) and Reiss *et al.* (2020) used this therapy on human patients wearing fixed orthodontic appliances. Pavlin *et al.* (2015) concluded that the AcceleDent® appliance in addition to orthodontic treatment increased the rate of maxillary canine retraction in orthodontic patients. Thus, this study seems to give hope for the use of LFMV in accelerating orthodontic movement. (7) Lombardo *et al.* (2019) also concludes that the AcceleDent® device appears to improve the accuracy of a conventional aligner protocol in terms of upper incisor rotation by 10% in patients treated with LFMV. Nevertheless, this study also reported no difference in accuracy between replacing aligners with LFMV every 7 days and every 14 days without vibration. (8) While Pavlin *et al.* (2015) reported that the AcceleDent® device would be effective on fixed appliances (7), Lombardo *et al.* (2019) showed a less effect on aligners. (8) However, Reiss *et al.* (2020) also used the AcceleDent® device along with fixed orthodontic appliance and demonstrated that the rate of anterior mandibular alignment and biomarkers of bone remodelling were not affected by the LFMV during orthodontic treatment. (11) Katchooi *et al.* (2018) also indicated that the vibratory device had no impact on the acceleration of the movement of the maxillary and mandibular incisors on aligners. (9) This was confirmed by Miles *et al.* (2018) which reported that the LFMV had no effect on the speed of OTM during the closure of the extraction space of the maxillary first premolars in adolescents wearing aligners. (10) Therefore, contradictory results on the potential effects of LMFV in accelerating the tooth movement were observed since most studies demonstrated that AcceleDent® device does not appear to accelerate OTM when used in conjunction with fixed orthodontic treatment or in patients wearing aligners. Other studies have also used a LFMV device (table 2). The study by Kumar *et al.* (2020) showed that LFMV did not significantly increase the closure of the space between maxillary canines and second premolars, regardless of the mode of ligation. (12) While Yadav *et al.* (2015) reported no effect of LFMV on increasing the mesial displacement of the maxillary first molar compared to the control groups in rats (13). Regardless the type of appliance and the orthodontics or ligature mode, LFMV did not appear to have a significant effect on the acceleration of orthodontic movement in humans, or rats.

5.2 Effect of high frequency vibratory on dental movement

The application of vibrations, particularly at HFV, would promote stimulation, differentiation and cell maturation, accelerating the alveolar bone remodelling and, thus, the dental movement. More specifically, daily application of a vibratory device will induce the production of cytokines (a biological factor known to be involved in bone remodelling) and other biological markers implicated in bone remodelling processes of periodontal ligament (PDL) that will ultimately promote the acceleration of tooth movement. (19)

Currently, propel VPRO5® is a commonly known HFV device available in the market. It is programmed at a frequency of 120 Hz with a force of 0.36 N and requires only 5 minutes of use once a day. (14) Four studies have employed this device on patients with aligners. In the study conducted by Shipley T. (2018), the VPRO5® device not only increased the speed of orthodontic movement, but also reduced the number of aligners by 43%, and, consequently, reduced the treatment time by 66%. The treatment time was 96.75 weeks for the control group compared to 19.25 weeks for the group stimulated with HFV, the HFV also reduced the number of adjustments required. (14) In the same vein, El-Bialy T*.* (2020)

concluded that HFV assisted dental movements such as incisor decompensation and posterior dental intrusion. It also helped to project the mandible forward and increased labial bone formation in the mandibular incisors in skeletal class II patients. (15) In addition, the study by Shipley *et al.* (2019) indicated an accelerated OTM, faster tray changes, reduced treatment time and increased bone density in the HFA group at the start of retention. (16) VPRO5® also accelerated the anteroposterior correction of the mandibular incisors which significantly reduced the time intervals between aligners and, consequently, produced a decrease in orthodontic treatment time in the study by Alansari *et al.* (2018). HFV also increased levels of cytokines and bone remodelling markers in the gingival crevicular fluid (GCF) and decreased levels of pain and discomfort in the same study. (17). In all these studies, VPRO5® HFV device induced faster dental movements, faster tray changes, reducing the treatment time. (14,15,16,17) The acceleration was also observed on the most complex dental movements (15), but also increased bone formation (15,16) by having enhanced levels of cytokines and bone remodelling markers in the GCF. (17) The reduction in the required adjustment (14) and in pain and discomfort levels were also enabled. (17)

The following studies by Mayama *et al.* (2022), Alikhan *et al.* (2018), Liao *et al.* (2017) and Takano-Yamamoto *et al.* (2017) also reported the effectiveness of HFA in accelerating OTM. The study by Mayama *et al.* (2022) accelerated canine movement with a higher rate of movement in the vibration group (1.21 mm) than in the control group (0.89 mm) in patients with fixed orthodontic appliances without causing side effects (*e.g.*, pain, discomfort and root resorption). (18) Alikhan *et al.* (2018) also reported an increase in the rate of movement of the maxillary first molar during the catabolic phase and also facilitated retention during the anabolic phase of remodelling (end of treatment) in patients undergoing HFV with fixed orthodontic appliances. (19) On the other hand, Liao *et al.* (2017) employed the Oral B® (USA) Humming Bird appliance with frequency of 50Hz and force of 0.2N for 10min per day, being beneficial in maxillary canine retraction in patients with fixed orthodontic appliances. (20) In rat models, similar findings were also observed with Takano-Yamamoto *et al.* (2017) study reporting the acceleration of maxillary first molar tooth movement at an optimal frequency and force of 3 gf at 70 Hz. (21) Therefore, HFV has demonstrated to accelerate tooth movement in both rats and humans, and in patients with aligners and/or fixed orthodontic appliances.

5.3 Biological mechanisms involved in high frequency vibration effects on dental movement

The study by Alikhan *et al.* (2018) highlighted that the HFV effect on orthodontic movement is dependent on the PDL. HFV are thought to increase the rate of orthodontic movement and this response is believed to be dependent on inflammatory mediators and osteoclasts presented in the PDL. HFV increased chemokines and cytokines such as interleukin (IL)-1ß and tumor necrosis factor (TNF)$-\alpha$ in the GCF, which led to the recruitment of osteoclasts and increased osteoclagenesis. Osteoclagenesis would enhance the bone resorption phenomenon, being responsible for the acceleration of dental movement. Thus, the acceleration of orthodontic movement would be achieved by improving the release of inflammatory mediators in the PDL. (19)

It was also observed in the studies Alikhan *et al.* (2018) and Liao *et al.* (2017) that the application of HFA increased the concentration of the osteoclast differentiation receptor activator of nuclear factor kappa-B ligand (RANKL). HFV promoted the recruitment of osteoclasts to their application site which increased osteoclastogenesis and, thus, bone resorption during OTM. (19,20) Therefore, HFV not only enhanced proinflammatory mediators, but also the differentiation factor RANKL, which in turn promoted the recruitment of osteoclasts and osteoclastogenesis, improving the bone resorption phenomenon that would be at the origin of the acceleration of dental movement. (19,20)

Takano-Yamamoto *et al.* (2017) demonstrated that HFV increased activation of the nuclear Factor (NF)-kB cell signalling pathway in osteoclasts, osteoblasts and osteocytes during tooth movement. The NF-kB signalling pathway plays an important role in the adaptive response to physiological stimuli, including mechanical stress such as HFV. HFV enhance osteoclastogenesis and osteoclast function via activation of the NF-KB signalling pathway, thereby leading to alveolar bone resorption and, ultimately, to accelerated OTM. HFV also promoted an increase in PDL volume via osteoclastic bone resorption during tooth movement. (21)

In summary, tooth movement occurs through bone resorption and formation in response to compression and tension. Pressure exerted on the PDL by orthodontic forces induces changes that lead to the activation of cell signalling pathways and the release of pro-inflammatory molecules. In combination with orthodontic force, vibratory stimuli enhanced the activation of these pathways and the secretion of pro-inflammatory molecules into the GCF that appeared to increase bone resorption activity and, consequently, to accelerate the OTM. (19,20,21)

5.4 High frequency versus low frequency vibratory movements on dental movement

The LFMV, at 30Hz, improved the precision of the upper incisor rotation, the speed of tooth movement and reduced the treatment time. (7,8) However, in most cases, these effects were inconsistent, not always producing favourable results. (9,10,11,12,13) Vibration at 120 Hz (HFV) resulted in premature change of aligners, reduced treatment time (14,15,16,17), and exhibited an increase in the concentration of bone remodelling markers and alveolar bone density. (19,20,21) Thus, HFV seemed to be more effective in accelerating OTM than the LFMV ones in rats (19,21) or human patients (14,15,16,17,18,20) with fixed appliances (18,19,20,21) and/or aligners. (14,15,16,17)

5.5 Limitations of the study

Our findings have certain limitations. All the included studies did not employ the same vibratory device neither the same vibratory parameters. Furthermore, the results herein reported are based on the application of vibrations by the patient, which might be problematic as this factor may be influenced by the patient's attendance and seriousness, and the number of participants involved in the studies is mainly limited. The considered target area and the associated treatment also varied among studies, while the results were interpreted by different statistical methods depending on the study. All these factors may be limiting variables that may compromise the strength of our conclusions.

6 CONCLUSION

Vibrations can be either high or low frequency and can be applied in conjunction with orthodontic treatment. LFMV vibrations are up to 30 Hz, while HFV exceed 30 Hz. LFMV do not appear to have any effect on accelerating OTM, but HFV potentiated and significantly accelerated the OTM. However, further studies are required to better define the stimulation parameters of HFV and to improve the knowledge of the underlying mechanisms.

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