Journal of the World Federation of Orthodontists 7 (2018) 134–140

Contents lists available at ScienceDirect

Journal of the World Federation of Orthodontists

journal homepage: www.jwfo.org

Research Article

The effects of brief daily vibration on clear aligner orthodontic treatment

Sarah Alansari [a], Maria Isabel Atique [b], Juan Pablo Gomez [c], Mohammad Hamidaddin [a], Soumya Narayani Thirumoorthy [a], Chinapa Sangsuwon [a], Edmund Khoo [d], Jeanne M. Nervina [a,d,*]

[a] Consortium for Translational Orthodontic Research, Hoboken, New Jersey
[b] Private Practice Orthodontist, San Antonio, Texas
[c] Department of Orthodontics, University of Autonoma Manizales, Caldas, Colombia
[d] Department of Orthodontics, New York University College of Dentistry, New York, New York

ARTICLE INFO

Article history:
Received 28 September 2018
Accepted 16 October 2018
Available online 3 November 2018

Keywords:
Clear aligner
Inflammation
Orthodontics
Vibration

ABSTRACT

Background: Tooth movement with clear aligners does not always follow the computer-generated treatment plan. The deficiency in tracking increases when the aligners are changed more frequently. Recently, it has been shown that high-frequency acceleration (vibration) increases the rate of tooth movement by targeting the periodontal ligament (PDL). Here we hypothesize that brief, daily application of vibration will increase the efficiency of clear aligner treatment by stimulating cytokines and bone remodeling factors in PDL without increasing pain or discomfort.

Methods: Sixty subjects were recruited and divided into five groups changing clear aligners at different time intervals with or without vibration application for 5 minutes per day. After four aligners, scanned intraoral images and the digital simulation software (ClinCheck) images were superimposed and the rate of anterior-posterior movement of one lower anterior tooth was measured. We evaluated the level of cytokines in the gingival crevicular fluid (GCF) at the end of the second aligner, and assessed pain using a numeric rating scale at days 1 and 3 after each aligner change.

Results: The present study demonstrated that short daily vibration treatment significantly reduced the time intervals between aligners and the tooth movement tracked more closely to the ClinCheck prediction. This effect was accompanied by higher levels of cytokines and bone remodeling markers in the GCF and lower levels of pain and discomfort.

Conclusion: Daily vibration treatment produced clinically significant shortening of the time needed for mandibular incisor anterior-posterior correction with clear aligners.

1. Introduction

Clear aligners have become a common treatment option for many adults and teens seeking to improve their smiles and occlusion while avoiding traditional braces therapy. The approach uses a series of clear aligners to slowly move each tooth into the desirable position. Although this approach significantly improves quality of care for patients, the limitations, such as regimented compliance, requiring 22 hours of aligner wear per day, leads to poor patient compliance. Considering that this discipline needs to be maintained during the duration of treatment, the length of treatment becomes a critical decision factor for prospective patients [1].

The length of clear aligner treatment is controlled by how fast patients progress from one aligner to another. Most of the clinicians recommend that patients change their aligners every 2 weeks. This is based on clinical experience showing that any attempt to increase the speed of treatment, whether by increasing the magnitude of tooth movement per aligner, or decreasing the time interval between aligners, is prone to failure because planned tooth

Funding: The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.
Competing interests: Authors have completed and submitted the ICMJE Form for Disclosure of potential conflicts of interest. None declared.
Provenance and peer review: Non-commissioned and internally peer reviewed.
* Corresponding author: New York University College of Dentistry, Department of Orthodontics, 345 East 24th Street, New York, NY 10010.
E-mail address: j.nervina@nyu.edu (J.M. Nervina).

2212-4438/
https://doi.org/10.1016/j.ejwf.2018.10.002

movement will become difficult to achieve. Failure to follow the computer-generated movement is manifested clinically by poor-fitting aligners that prevent treatment from progressing. This, otherwise known as "nontracking," can be attributed to several factors, such as (1) patients not wearing the aligners for a full 22 hours per day, (2) individual variations in tooth movement, (3) increased tooth movement demands per aligner, (4) patients progressing to the next aligner too soon, (5) a suboptimal force delivery system in the aligners, and (6) varying rates of tooth movement (from a biological perspective) from person to person, which current improvements in material science tried to overcome. Even if all these factors are addressed, delays in the rate of tooth movement will prevent progression from one aligner to the next.

Recently, it has been shown that vibration increases the rate of tooth movement by targeting the periodontal ligament [2,3]. It is hypothesized that brief, daily application of vibration will increase the efficiency of clear aligner treatment by altering periodontal ligament (PDL) metabolism without increasing pain or discomfort.

2. Materials and methods

This randomized, single blinded, multicenter study was approved by Chesapeake Institutional Review Board, Columbia, MD (Protocol ID Pro00020519 from February 3, 2016 to February 3, 2018). The study enrolled 75 subjects divided into five groups of 15 subjects each composed of both men and women within the age range of 18 and 45 years, with no racial or ethnic predilection, from four study centers. Sample size calculation was based on previously published studies [4,5] (with mean of planned tooth movement being 57% with 20% SD). A sample size of 12 was required to achieve a power of 90% at $P = 0.05$, and to detect minimal clinically relevant differences of 25% in the planned tooth movement of the experimental group versus control (57% of planned tooth movement for standard Invisalign [Align Technology, Inc., Santa Clara, CA] treatment vs. 83% of planned tooth movement for improved tracking in presence of VPro5 [Propel, Brooklyn, NY]). It was decided to enroll 15 subjects per group to allow for approximately 20% dropouts from the study.

All subjects were in good general health, and none had received periodontal therapy during the previous 6 months. Table 1 details the complete inclusion-exclusion criteria followed in the present study. All subjects completed routine orthodontic records, including lateral cephalograph and panoramic radiograph, and facial and intraoral photographs, and received a periodontal evaluation and caries clearance before and during each clinical visit. Periodontal evaluation of subjects included (based on American Association of Periodontists guidelines) full mouth probing depth, plaque index, and gingival index assessment. In addition, at the start and end of the study period, intraoral photographs and digital scans were obtained. The study participants were diagnosed and found eligible for aligner treatment with Class I or mild Class II/III malocclusion. Subjects had at least one lower anterior tooth that required anteroposterior movement of 1 mm, which was not blocked by adjacent teeth. The target tooth did not receive any extrusion, intrusion, or rotation correction during the duration of the study. For the duration of the study period, only the target tooth was moved with the aligners, as predesigned in the ClinCheck software (Align Technology Inc., Santa Clara, CA). After identifying subjects who met the inclusion criteria, the informed consent form was reviewed and signed. Subjects were randomly assigned to one of the five groups of 15 subjects using block randomization (Table 2): 14-day control (changed aligners every 14 days, no vibration treatment); 7-day sham (changed aligners every 7 days, no vibration treatment); 7-day vibration (received vibration treatment and changed aligners every 7 days); 5-day sham (changed aligners every 5 days, no vibration treatment); 5-day vibration (received vibration treatment and changed aligners every 5 days). All subjects used four aligners for the study. The aligners were programmed with 0.25 mm of anterior-posterior movement on the target incisor and all were made with the (Smart-Track) material from Align Technology, Inc (Santa Clara, CA). Subjects who were randomly assigned to groups that included vibration were instructed to use the VPro5 appliance 5 minutes per day, based on a previous study showing the osteogenic effect with this applied time duration [6]. Subjects who did not receive vibration were instructed to bite on the Vpro5 without turning on the machine. The variables in this study were the time intervals between aligners in the presence and absence of vibration application. Only the investigators analyzing the data were blinded to group assignment. At the end of data collection, all subjects continued to receive aligner treatment until treatment was completed.

2.1. Application of vibration and compliance

Subjects assigned to the experimental groups using the VPro5 tool were asked to bite comfortably onto the wafer with aligners in place for a total of 5 minutes per day before sleeping, or for the longest time that aligners would be in their mouth without removal, with or without activating the VPro5 tool depending on assigned group. Subjects reported daily compliance by completing "compliance forms" that were collected and reviewed at each office

Table 1
Inclusion and exclusion criteria for study participation

Inclusion criteria	Exclusion criteria
(1) Subject must be 18–45 years of age.	(1) Subjects who have received periodontal treatment in the previous 6 months.
(2) Subject is willing and able to comply with all study procedures and sign Informed consent/HIPAA forms.	(2) Subjects who are taking medication that could affect the level of inflammation, such as chronic antibiotics, phenytoin, cyclosporin, ant-inflammatory drugs, systemic corticosteroids, or calcium channel blockers.
(3) Subject must have complete adult dentition (excluding third molars).	(3) Subjects with severe Class II or Class III malocclusion.
(4) Subjects must have Class I malocclusion or mild Class II/III malocclusions.	(4) Subjects with skeletal Class I but extreme dental malocclusion.
(5) Subject is at least 1 month into aligner treatment.	(5) Severe crowding that requires extraction.
(6) Subject has history of and currently healthy oral hygiene (probing depth is <4 mm, gingival index <1, and plaque index = 1).	(6) Subjects with more than 4 mm positive overjet or more than 2 mm negative overjet.
	(7) Subjects with extreme deep bite (more than 90%).
	(8) Subjects with severe openbite (more than 2 mm).
	(9) Pregnant women.
	(10) Subjects with any systemic diseases affecting bone metabolism.
	(11) Smoking.
	(12) Subjects with active, untreated caries.
	(13) Subjects who require interproximal reduction or attachments during the study period.
	(14) Subjects who are noncompliant regarding aligner wear or VPro5 recommended daily usage.

Table 2
Status of subject enrollment and demographic characteristics of participants groups

	Control	7Sham	7HFA	5Sham	5HFA
Subject enrollment					
Patient recruited	15	15	15	5	15
Completed studies	13	13	14	0[a]	13
Sex					
Male	5	4	6	2	7
Female	8	9	8	3	6
Age					
Mean (SD)	30.8 (6.9)	28.6 (8.1)	31.8 9 (7.6)	24.7 (6.9)	29.9 (6.8)
Median	28.55	25.7	30.1	23.95	30.65
Range	22.6–44.1	18.5–42.7	19.8–44.7	18.7–33.1	21.3-41-2
Race					
White	7	5	7	3	4
Black	1	2	1	0	2
Hispanic	4	2	3	1	5
Asian	1	4	3	1	2
Malocclusion					
Class I	10	11	9	5	10
Class II	2	2	3	0	3
Class III	1	0	2	0	1
Initial Mandibular anterior Irregularity (mm) mean (SD)	4.1 (2.4)	4.3 (2.2)	4.9 (2.1)	4.3 (1.8)	4.6 (2.3)

HFA, high-frequency acceleration.
[a] Discontinued due to nontracking. "Nontracking" refers to actual tooth movement lagging when compared with the digital prediction. As a result, aligner changes were not possible because of improper fit.

visit. Subjects with questionable compliance (less than 22 hours of aligner wear per day or 1 day of no VPro5 application) were dismissed from the study. The VPro5 delivered vibration at a frequency of 120 Hz and an acceleration of 0.03 g.

2.2. Pain assessment

Subjects were asked to report their level of discomfort at days 1 and 3 after aligner use with a numeric rating scale, which is a high reliability tool comparable with a visual analog scale [7–9]. The subjects were instructed to choose a number (from 0 to 10) that best described their pain: 0 indicated "no pain" and 10 indicated "worst possible pain."

2.3. Gingival crevicular fluid sampling and protein analysis

Gingival crevicular fluid (GCF) samples were collected from each subject before the start of aligner treatment (baseline) and at the end of the second tray, to evaluate different inflammatory and bone remodeling markers as previously described [8]. From each side of the target lower incisor, 1.0 to 1.5 μL GCF was collected and diluted in phosphate-buffered saline to obtain the 30 μL of sample required for MILLIPLEX@MAP assay (MiliporeSiGMa, Billerica, MA) according to manufacturer instructions. Briefly, GCF samples were incubated with antibody-coupled magnetic beads in 96-well microplates for 2 hours, washed to remove unbound protein, incubated with biotinylated antibodies specific for different inflammatory and bone remodeling markers (30 minutes), and detected using fluorescently labeled reporter molecules. Inflammatory and bone remodeling marker concentrations in the samples were calculated by Luminex MAGPIX xPONENT software (Luminex, Austin, TX) using a standard curve derived from a recombinant markers standard, included in the 96-well plate.

2.4. Measurement of digital images and evaluation of tracking

Digital intraoral scans (iTero Element; Align Technology Inc., Santa Clara, CA) were taken at the beginning and end of the study to assess tracking during treatment using the Invisalign ClinCheck 3.0 software (Align Technology Inc.). Image measurements were performed by investigators blinded to the group assignment of each subject. Aligner tracking, as a measure of tooth movement, was examined using the "Progress assessment" feature on the iTero Intraoral scanner. Software error was assessed by comparing the initial scan with ClinCheck at the beginning of the study to measure the margin of error, and confirmed to be less than 0.2 mm. At the end of the study, scanned images and their corresponding ClinCheck images for that stage were superimposed using the software's "Automated Superimposition at Best Fit Image" function. Superimposed images were saved in an image viewer program and magnified 300%. A line tangent to the labial surface of the current position of the tooth and the ClinCheck prediction was drawn. Contact points between the tangent line and labial surface of tooth at both the mesial and distal were marked. The distance between marked points and counterpart points in the prediction image (ClinCheck) was measured (Fig. 1). The average of these two numbers was used to measure the percentage tooth movement in comparison with the predicted movement.

Two examiners completed all image quantifications. Both intraobserver and interobserver errors were evaluated. Intraobserver error was evaluated by individual investigators who measured five

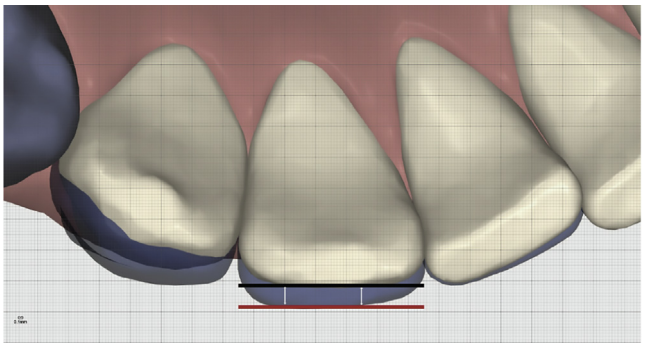

Fig. 1. Schematic of method used to evaluate tracking. Scanned images at the end of treatment and their corresponding ClinCheck images were superimposed using the "Automated Superimposition at Best Fit Image" function on ClinCheck software. Superimposed images were magnified 300%. A line tangent to the labial surface of the current position of the tooth (red line on gray tooth) and the ClinCheck prediction (black line on white tooth) were drawn. Contact points between the tangent line and labial surface of the tooth at both the mesial and distal were marked. The distance between marked points and counterpart points in the prediction image (ClinCheck) was measured (white arrows). The average of these two numbers was used to measure the percentage of tooth movement in comparison with the predicted movement.

Table 3
Percentage of tracking in each group (mean ± SD)

Group	Tracking (percentage), Mean ± SD	*P*
Control	84 ± 13[a]	0.022
7-sham	70± 16	N/A
7-HFA	90 ± 14[a]	0.003
5-sham	N/A	N/A
5-HFA	84 ± 12[a]	0.022

HFA, high-frequency acceleration; N/A, not applicable.
[a] Statistically significant differences compared with the 7-sham group.

superimposed images twice at least 2 weeks apart. Interobserver error was evaluated using the same set of five superimposed images measured by a second investigator. The Dahlberg [9] formula was applied to estimate the random errors and the paired *t* test was applied to identify systematic errors according to Houston [10]. Random error for intraobserver evaluation was 0.09 mm and 0.11 mm for the interobserver evaluation, and not statistically significant. Systematic errors were also small and not statistically significant ($P = 0.88$ for intraobserver and $P = 0.86$ for interobserver).

2.5. Statistical analysis

After confirming the normal distribution of samples by the Shapiro-Wilk test, group comparisons were assessed by ANOVA. Pairwise multiple comparison analysis was performed with the Tukey post hoc test. In some experiments, paired and unpaired *t* tests were used to compare the two groups. Two-tailed *P* values were calculated, and $P < 0.05$ was set as the level of statistical significance.

3. Results

3.1. Enrollment

Based on the sample size calculations, the plan was to recruit 75 subjects for five study groups; however, due to nontracking and reports of significant discomfort in 5-sham subjects; this group was discontinued after five subjects. Therefore, in addition to those five subjects, only 60 subjects were enrolled in the study and assigned to control or the remaining three experimental groups, by block randomization. During the trial, seven subjects were disqualified due to lack of proper follow-up (two forgot to use the VPro5 as prescribed, three did not wear the aligners enough hours per day, and two did not follow instructions on changing aligners at specific time intervals based on their group assignment) (Table 2).

3.2. Effect of vibration on pain perception

Using the numerical rating scale, a statistically significant decrease in reported pain and discomfort was observed between the first day of treatment in the 7-vibration group in comparison with the 7-sham ($P < 0.020$) and control ($P < 0.034$) groups. No significant differences were observed on the first day of aligner wear among the remaining groups, including the 5-vibration group. On day 3 of aligner wear, the 7-vibration group reported lower pain and discomfort levels compared with the 7-sham group, which was statistically significant ($P < 0.026$). No difference among the other groups, including the 5-vibration group, was observed ($P > 0.05$) (Table 3).

3.3. Markers of inflammation and bone remodeling

The markers, evaluated through MILLIPLEX@MAP assay, showed a very striking pattern of expression for cytokines (interleukin [IL]-1b, tumor necrosis factor alpha, IL-6, IL-1a, IL-7, FLT-3L, and IL-12P70; Fig. 2A), chemokines (CCL2, CCL3, CCL4, CCL5, and CCL7; Fig. 2B), factors that participate in control and progress of inflammation (IL-10, IL-8, IL-13, IL-1ra, and IL-4; Fig. 2C), osteoclastogenesis and matrix degradation markers (granulocyte colony-stimulating factor, granulocyte-macrophage colony-stimulating factor, SCD40L and Receptor activator of nuclear factor kappa-B ligand; Fig. 2D), and growth factors (epidermal growth factor, platelet-derived growth factor AA/BB, platelet-derived growth factor AA; Fig. 2E). In comparison with baseline (concentration of markers before treatment), the concentration of all these markers increased significantly in control and 7-sham groups ($P < 0.05$) with no significant differences observed between the groups ($P > 0.05$). Statistically significant increases in the concentration of these markers were also observed in 5-vibration and 7-vibration in comparison with baseline, control, and 7-sham ($P < 0.05$). No significant differences were observed between 5-vibration and 7-vibration groups ($P > 0.05$).

3.4. Aligner tracking

The control group (no vibration, aligners changed every 14 days) demonstrated 84% of predicted tooth movement. The 7-sham group showed lower tracking of 70%, which was statistically significant ($P < 0.022$) when compared with the control group. However, when subjects changed aligners every 7 days and received vibration (7-vibration), tracking improved significantly to 90% ($P < 0.003$), but it was not significantly higher than the control group ($P > 0.05$). When the interval between aligners was reduced to 5 days (5-sham), teeth did not move according to the ClinCheck prediction and progress in treatment was not possible due to poor aligner fitting when attempting to change to the second and third aligners. Therefore, for the subjects' benefit, their participation in the trial was suspended. However, when the 5 days group received vibration stimulation (5-vibration), good tracking was observed (84%) that was statistically significant than the 7-sham group ($P < 0.022$) but insignificant statistically from the control or 7-vibration groups ($P > 0.05$) (Table 4).

4. Discussion

For years, clinicians have recommended 2-week intervals between aligner changes, considering that shorter interval of change would cause nontracking and prevent progress from one aligner to another. This poor performance could be related to two main factors: inefficient force delivery system by ill-fitting aligners and limited biological response. The force delivery system can be analyzed from two aspects: (1) biomechanically, the efficiency of creating proper couples and forces to produce different types of movement, and (2) material properties, the ability of the plastic aligner material to generate proper force magnitudes. Biomechanically, aligners have demonstrated poor performance in producing certain types of tooth movement, such as extrusion, intrusion, and rotation [10], while showing better results with regard to tipping movements, with reported success in the range of 41% to 62% [5,6]. Therefore, to prevent the biomechanical limitation as a variable in our study, only tipping movement was compared among groups. Further studies to investigate the effect of vibratory stimulus using VPro5 along with aligner treatment on other types of tooth movement are required.

The switch of the aligner material to Smart-Track has greatly improved the efficiency of force delivery. This study used aligners made of this material and found that the change significantly improved tooth movement to 84% of the ClinCheck prediction when the aligners were changed every 14 days in comparison with previous reports [5,6]. Yet, it was found that even in the presence of the best force delivery system, the rate of movement, and therefore

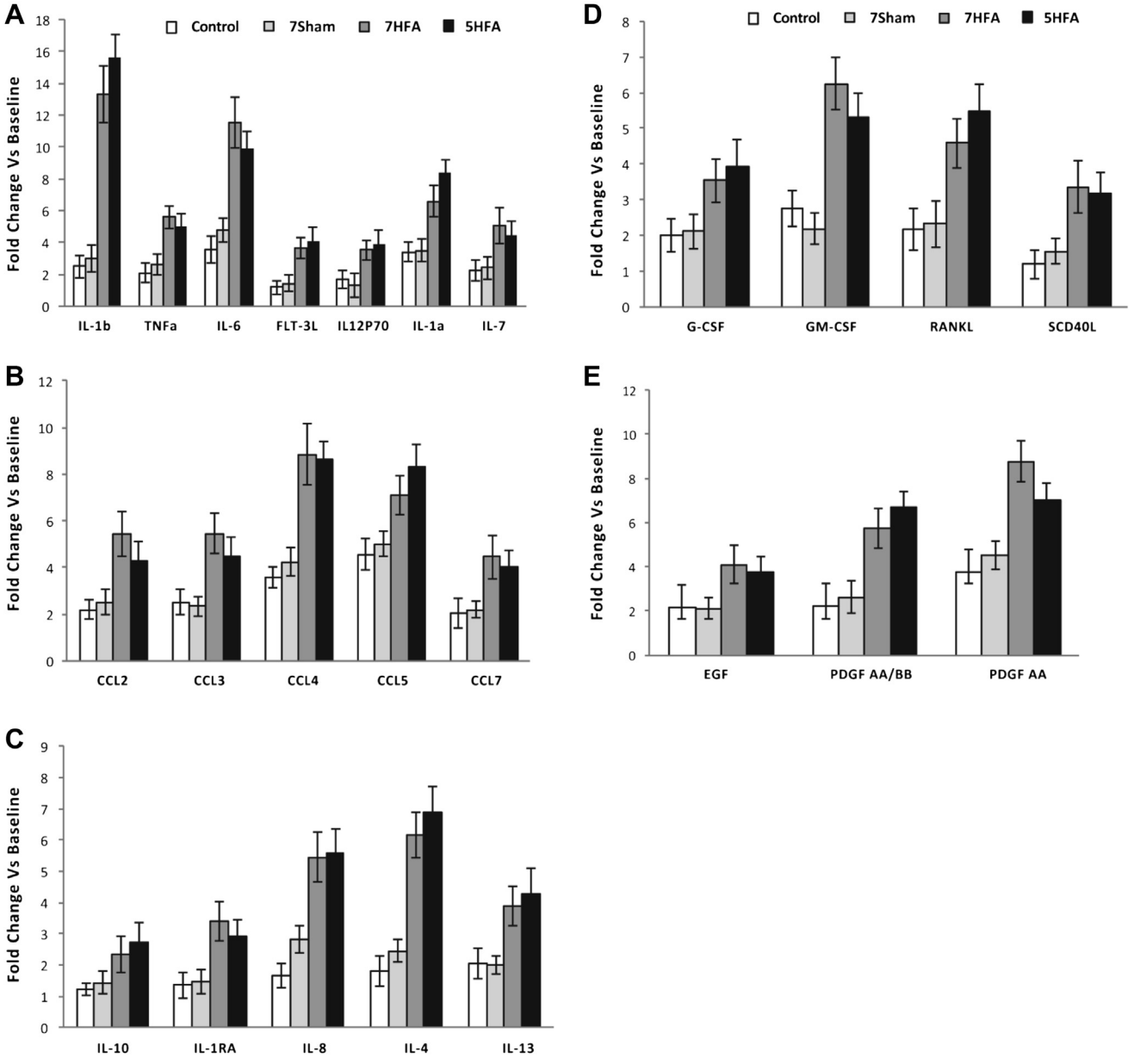

Fig. 2. Expression of inflammatory markers in gingival crevicular fluid. GCF samples were collected at the last day of second aligner usage. Samples were collected from mesial and distal of the target lower incisor. Mean "fold" increase in concentration of different (A) cytokines, (B) chemokines, (C) factors that participate in progression of inflammation, (D) osteoclastogenic factors, and (E) growth factors, was compared with baseline (before start of treatment). Each experiment was repeated three times and data are expressed as the average ± SEM of all experiments. * Significantly different from control ($P < 0.05$).

progress to the next aligner, was significantly controlled by the subject's biological response. If the rate of tooth movement is slow, it is not possible to progress to the next aligner without increasing the risk of nontracking. It is known that the rate of movement depends on cytokine activation, which stimulates osteoclasts, increasing bone resorption facilitating tooth movement [11,12]. It has also been shown that the rate of cytokine activation and bone resorption does not always increase linearly with the magnitude of force, but shows a biological saturation point beyond which a larger force magnitude will not increase the rate of movement [13]. Based on these observations, any attempts to decrease the interval between aligners will not necessarily increase the rate of tooth movement. This can explain why in our study, decreasing the intervals of aligners to 7 days decreased the magnitude of tooth movement to 71% of planned movement. This lack of tracking can

Table 4
Reported pain and discomfort (mean ± SD)

Group	Discomfort 1st day	Discomfort 3rd day
Control	4.19 ± 0.71	2.42 ± 0.64
7-sham	4.6 ± 1.13	2.98 ± 1.18
7-HFA	3.39 ± 1.35[ab]	1.96 ± 0.9[c]
5-sham	N/A	N/A
5-HFA	3.7 ± 0.95	2.21 ± 0.91

HFA, high-frequency acceleration; N/A, not applicable.
[a] Statistically significant difference compared with first day of the 7-sham group ($P < 0.020$).
[b] Statistically significant difference compared with the first day of control group ($P < 0.034$).
[c] Statistically significant difference compared with the third day of the 7-sham group ($P < 0.026$).

accumulate from one aligner to the next aligner and, if the treatment duration increases, it may be accompanied by a significant discrepancy from the ClinCheck tooth prediction. Based on this observation, one may suggest that to improve tracking, it is better to decrease the magnitude of tooth movement incorporated into each aligner. In this study, to be able to compare the rate of movement between the groups, the planned movement in all groups was 0.25 mm of target movement per aligner. While decreasing the magnitude of tooth movement per aligner may allow better tracking in shorter intervals between aligners, it would increase the number of aligners significantly, which ultimately result in increasing the total treatment duration. Therefore, a better solution would be to optimize the rate of tooth movement.

Recently, it has been shown that vibration increases the rate of tooth movement by directly targeting the PDL and increasing cytokine and chemokine levels, facilitating activation of osteoclasts, which then increase the rate of bone resorption and accelerate tooth movement [2]. The results of the present study agree with previous results demonstrating that vibrational forces facilitate orthodontic tooth movement [14]. However, some studies did not find any change in the rate of tooth movement when using certain vibrational devices because of difference in properties [15–17], which cautions us to evaluate the literature on this topic carefully. It has been shown that acceleration and frequency delivered from vibrational devices significantly alter the rate of tooth movement [2]. Similarly, our study demonstrates that the use of vibration (VPro5) for at least 5 minutes per day was accompanied by higher levels of inflammatory and bone remodeling markers (Fig. 2). More interestingly, using the VPro5 device leads to decrease in the interval of aligner wear from 14 days to 7 or 5 days without affecting the efficiency of the aligners. Indeed, 7-day intervals with vibration produced slightly better results than 14 days alone, although not statistically significant. The 5-day with vibration group produced results similar to the 14 days alone, suggesting that this interval may be an option for rapid anterior-posterior movement of mildly misaligned lower incisors.

Although improving the aligner force delivery and improving the biological response are key factors in optimizing the rate of movement, the aligner fit on the dentition is also important. This agrees with the observation of clinicians and recommendation of aligner companies for patients to chew on “Chewies,” small cylinders made of a spongy plastic-like material, for few minutes per day to promote fully seating the aligners to allow efficient delivery of the predicted forces. In our study, subjects who did not receive vibration were biting on the rubber wafer of VPro5 for a similar length of time, to eliminate this variable. The success of VPro5 may be related to the effect that it may have on fitting the aligner on the dentition. This may partly explain why the group that changed the aligners every 5 days in the absence of VPro5 (5-sham), could not progress through the aligners and had to be dropped from the study.

For clinicians and patients, decreasing the time needed between aligners by 50% represents a welcome improvement in treatment efficiency. The data presented here demonstrate equal magnitudes of tooth movement in the subjects treated conventionally (aligners changed after 14 days) and the subjects treated with vibration for 7 days. Whether this increased efficiency is due to the impact of vibration on the biological response or on aligner seating, or both, the data from the present study suggest that adding 5 minutes of vibration treatment per day is a viable modification to the treatment plan of aligner patients that will shorten treatment while producing the expected outcome.

Another aspect of aligner therapy that makes the appliance more attractive for patients is its association with less pain and discomfort. Although pain is perceived differently from one individual to another, this study looked at general perceptions of pain related to the use of aligners alone or in combination with vibration. Comparative studies have shown that adults treated with aligners experienced less pain and fewer negative impacts on their lives during the first week of treatment than did those treated with fixed appliances [18]. In fact, the patients with fixed appliances took more pain medication during days 2 and 3 of treatment [19]. In our study, we used a “Numeric Rating Scale” to evaluate the impact of VPro5 stimulation on pain and discomfort during aligner therapy. Our results showed that vibration application for only 5 minutes a day reduced pain and discomfort levels during the first 3 days of treatment, which is the critical period during which patients are more likely to take medication. In our study, none of the enrolled subjects took any medication during the duration of the study. This is in agreement with previous studies that have recommended vibrational forces for reduction of sinus [20], dental [21], musculoskeletal [22], and tooth pain during orthodontic treatment [23]. However, some studies reported no change in the perception of pain with a particular vibrational device, which emphasizes the differences in vibration produced by these devices [15,17]. The pain-relieving effects of vibrational forces including vibration may be achieved by increasing vascularity and reducing areas of ischemia and through activation of large-diameter sensory nerve fibers [2,24].

Different adjunct techniques have been suggested to have varied effects on the speed of treatment by Invisalign. Although some surgical intervention, such as micro-osteoperforation, piezocision, and corticotomy, have been reported to significantly improve the outcome of Invisalign treatment [25–27], other techniques, such as photobiomodulation, did not change the outcome or the results had no clinical significance [28,29]. Based on our knowledge, this is the first time that a noninvasive approach, such as vibration, was able not only to significantly reduce the time of appliance usage but to also improve the treatment outcome with clear aligners.

5. Conclusion

The present study, which evaluated the efficacy of vibrational stimulus in patients treated with clear aligners while performing mandibular incisor alignment, could observe that

1. Vibration stimulation using VPro5 for 5 minutes a day can reduce the interval between aligner change without affecting the efficiency of treatment.
2. Vibration stimulation can increase the cytokine and bone remodeling markers in gingival crevicular fluid.
3. Using VPro5 for 5 minutes per day significantly reduced the pain and discomfort during the first 3 days of clear aligner treatment.

The results of this study might have significant clinical implications by introducing a noninvasive tool that can overcome some of the limitations of clear aligner treatment. Further studies are necessary to understand how stimulating the patient’s biological response may change the efficacy of different force systems or facilitate the most difficult movements with aligner therapy.

References

[1] Uribe F, Padala S, Allareddy V, Nanda R. Patients', parents', and orthodontists' perceptions of the need for and costs of additional procedures to reduce treatment time. Am J Orthod Dentofacial Orthop 2014;145(4 Suppl):S65–73.
[2] Liao Z, Elekdag-Turk S, Turk T, et al. Computational and clinical investigation on the role of mechanical vibration on orthodontic tooth movement. J Biotech 2017;60:57–64.
[3] Alikhani M, Alansari S, Hamidaddin MA, et al. Vibration paradox in orthodontics: anabolic and catabolic effects. PLoS One 2018;13:e0196540.

[4] Chisari JR, McGorray SP, Nair M, Wheeler TT. Variables affecting orthodontic tooth movement with clear aligners. Am J Orthod Dentofacial Orthop 2014;145(4 Suppl):S82–91.
[5] McGorray SP, Dolce C, Kramer S, Stewart D, Wheeler TT. A randomized, placebo-controlled clinical trial on the effects of recombinant human relaxin on tooth movement and short-term stability. Am J Orthod Dentofacial Orthop 2012;141:196–203.
[6] Alikhani M, Khoo E, Alyami B, et al. Osteogenic effect of high-frequency acceleration on alveolar bone. J Dent Res 2012;91:413–9.
[7] Cook KF, Keefe F, Jensen MP, et al. Development and validation of a new self-report measure of pain behaviors. Pain 2013;154:2867–76.
[8] Hollen PJ, Gralla RJ, Kris MG, McCoy S, Donaldson GW, Moinpour CM. A comparison of visual analogue and numerical rating scale formats for the Lung Cancer Symptom Scale (LCSS): does format affect patient ratings of symptoms and quality of life? Qual Life Res 2005;14:837–47.
[9] Phan NQ, Blome C, Fritz F, et al. Assessment of pruritus intensity: prospective study on validity and reliability of the visual analogue scale, numerical rating scale and verbal rating scale in 471 patients with chronic pruritus. Acta Derm Venereol 2012;92:502–7.
[10] Rossini G, Parrini S, Castroflorio T, Deregibus A, Debernardi CL. Efficacy of clear aligners in controlling orthodontic tooth movement: a systematic review. Angle Orthod 2015;85:881–9.
[11] Teixeira CC, Khoo E, Tran J, et al. Cytokine expression and accelerated tooth movement. J Dent Res 2010;89:1135–41.
[12] Krishnan V, Davidovitch Z. Cellular, molecular, and tissue-level reactions to orthodontic force. Am J Orthod Dentofacial Orthop 2006;129:469.e1–469.e32.
[13] Alikhani M, Alyami B, Lee IS, et al. Biological saturation point during orthodontic tooth movement. Orthod Craniofac Res 2015;18:8–17.
[14] Kau CH, Littlefield J, Rainy N, Nguyen JT, Creed B. Evaluation of CBCT digital models and traditional models using the Little's Index. Angle Orthod 2010;80:435–9.
[15] Woodhouse NR, DiBiase AT, Johnson N, et al. Supplemental vibrational force during orthodontic alignment: a randomized trial. J Dent Res 2015;94:682–9.
[16] Woodhouse NR, DiBiase AT, Papageorgiou SN, et al. Supplemental vibrational force does not reduce pain experience during initial alignment with fixed orthodontic appliances: a multicenter randomized clinical trial. Sci Rep 2015;5:17224.
[17] Miles P, Smith H, Weyant R, Rinchuse DJ. The effects of a vibrational appliance on tooth movement and patient discomfort: a prospective randomised clinical trial. Aust Orthod J 2012;28:213–8.
[18] Miller KB, McGorray SP, Womack R, et al. A comparison of treatment impacts between Invisalign aligner and fixed appliance therapy during the first week of treatment. Am J Orthod Dentofacial Orthop 2007;131:302.e1–9.
[19] Fujiyama K, Honjo T, Suzuki M, Matsuoka S, Deguchi T. Analysis of pain level in cases treated with Invisalign aligner: comparison with fixed edgewise appliance therapy. Prog Orthod 2014;15:64.
[20] Lundeberg T, Ekblom A, Hansson P. Relief of sinus pain by vibratory stimulation. Ear Nose Throat J 1985;64:163–7.
[21] Ottoson D, Ekblom A, Hansson P. Vibratory stimulation for the relief of pain of dental origin. Pain 1981;10:37–45.
[22] Lundeberg T, Abrahamsson P, Bondesson L, Haker E. Vibratory stimulation compared to placebo in alleviation of pain. Scand J Rehabil Med 1987;19:153–8.
[23] Marie SS, Powers M, Sheridan JJ. Vibratory stimulation as a method of reducing pain after orthodontic appliance adjustment. J Clin Orthod 2003;37:205–8. quiz 3–4.
[24] Lundeberg T, Nordemar R, Ottoson D. Pain alleviation by vibratory stimulation. Pain 1984;20:25–44.
[25] Cassetta M, Altieri F, Barbato E. The combined use of corticotomy and clear aligners: a case report. Angle Orthod 2016;86:862–70.
[26] Dibart S, Yee C, Surmenian J, et al. Tissue response during Piezocision-assisted tooth movement: a histological study in rats. Eur J Orthod 2014;36:457–64.
[27] Nicozisis JL. Applications of controlled local inflammation in aligner treatment. Semin Orthod 2017;23:90–8.
[28] Alwafi A. Inconclusive evidence for the effectiveness of nonconventional methods in accelerating orthodontic tooth movement. J Am Dent Assoc 2017;148:193–4.
[29] Chung S, Milligan M, Gong S-G. Photobiostimulation as a modality to accelerate orthodontic tooth movement. Semin Orthod 2015;21:195–202.