Original Article

Impact of photobiomodulation and low-intensity pulsed ultrasound adjunctive interventions on orthodontic treatment duration during clear aligner therapy: *A retrospective study*

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ABSTRACT

Objective: To assess the efficiency of low-intensity pulsed ultrasound (LIPUS) and photobiomodulation (PBM) interventions in accelerating orthodontic tooth movement during clear aligner therapy (CAT).

Materials and Methods: This retrospective study was carried out on the records of 84 subjects who were treated using CAT. Twenty-eight patients were treated using CAT with a daily use of LIPUS for 20 minutes, 28 patients were treated using CAT with a daily use of PBM for 10 minutes, and 28 patients were treated using CAT alone. The total duration of treatment was recorded for all patients. One-way analysis of variance and post hoc Tukey test were used to assess whether there was any significant difference in total treatment duration among the three groups ($P < .05$).

Results: The mean treatment durations in days were 719 ± 220, 533 ± 242, and 528 ± 323 for the control, LIPUS, and PBM groups, respectively. The LIPUS group showed a 26% reduction, on average, in treatment duration when compared with the control group, whereas the PBM group showed an average 26.6% reduction in the treatment duration when compared with the control group. The results showed that there were statistically significant differences among the groups ($P = .011$). Treatment durations were significantly reduced in the LIPUS and PBM groups as compared with the control ($P = .027$ and $P = .023$, respectively), with no statistically significant differences between the LIPUS and PBM groups ($P = .998$).

Conclusions: Daily use of LIPUS or PBM as adjunctive interventions during CAT could reduce the duration of orthodontic treatment. (*Angle Orthod.* 2021;91:619–625.)

KEY WORDS: Clear aligner therapy; Accelerated orthodontic treatment; LIPUS; Photobiomodulation

INTRODUCTION

The duration of standard orthodontic treatment ranges between 12 and 24 months.[1] Orthodontic treatment could lead to negative side effects, such as the development of white spot lesions,[2] gingivitis,[3] gum recession,[4] and external root resorption.[5] Lengthy orthodontic treatment makes the patient more prone to developing these side effects and can negatively affect patient compliance.[6] Sometimes lengthy orthodontic treatment may deter patients from undergoing treatment, especially adults.[7] Reducing the treatment duration is a major concern for both the orthodontist and patient. Several appliances and techniques, both surgical and nonsurgical, have been claimed to accelerate tooth movement and thereby shorten orthodontic treatment time.[8] Recently, several intraoral noninvasive, nonpharmacologic, nonsurgical adjunctive interventions aimed toward accelerating orthodontic tooth movement (OTM) have been introduced to orthodontic practice. These interventions include me-

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chanical vibration,[9] photobiomodulation (PBM),[10] low-level laser therapy (LLLT),[11] and low-intensity pulsed ultrasound (LIPUS).[12] Unlike physiological tooth movement, OTM is a complex process of bone remodeling that occurs in response to externally applied mechanical forces through wires and brackets or clear aligners.[12] Several types of cells are involved in OTM, and they are targeted by intraoral nonsurgical adjunctive interventions to accelerate OTM.[13] These cells include osteoblasts, osteoclasts, and periodontal ligament fibroblasts.[13] The ratio of receptor activator of nuclear factor-kappa ligand (RANKL)/osteoprotegerin during bone remodeling plays an important role in OTM.[14] As this ratio increases, the osteoclastogenesis process is induced, which leads to accelerated OTM.[14] Ultrasound, an acoustic pressure wave at frequencies greater than the limit of human hearing, is transmitted through and into biologic tissues. It has been used widely in medicine as a therapeutic, operative, and diagnostic tool.[15,16] Therapeutic ultrasound intensity ranges from 30 to 70 W/cm^2, operative ultrasound (shock waves) intensity ranges from 0.05 to 27,000 W/cm^2, and diagnostic ultrasound intensity ranges from 5 to 50 mW/cm^2 to avoid excessive heating of the tissues.[16] The LIPUS output is of low enough intensity to be considered neither thermal nor destructive.[17] It is generally accepted that LIPUS has no deleterious or carcinogenic effects.[18] LIPUS exposure has no thermal effects to produce biological changes in living tissues.[16,18] It was reported that LIPUS exposure stimulates various types of cells in the dentofacial region, including those in the gingiva,[19] periodontal ligament,[20] cementum,[21] as well as odontoblast-like cells[22] and bone cells.[23] LIPUS accelerates OTM through stimulating osteoclastogenesis by upregulation of the receptor activator of nuclear factor-kappa/RANKL pathway and signaling molecules such as mitogen-activated protein kinase.[18,24]

PBM, also known as low-level light/laser therapy, attempts to use low energy lasers or light-emitting diodes to modify cellular biology by exposure to light in the red to near-infrared range (600–1000 nm).[25] Exposure to near-infrared light activates cytochrome c oxidase inside the cells,[26] which in turn induce mitochondrial adenosine triphosphate (ATP) production.[27] The increased production of ATP may accelerate bone remodeling by stimulating metabolic activity.[25]

To date, no study has been conducted to compare the effects of LIPUS and PBM on the duration of orthodontic treatment during clear aligner therapy (CAT) in humans. The purpose of this retrospective study was to determine the efficiency of these adjunctive interventions in accelerating OTM by comparing the orthodontic treatment duration of patients who were treated using CAT with either LIPUS or PBM interventions to a matched control group who were treated using CAT alone. The null hypothesis was that there would be no difference in orthodontic treatment duration among CAT with LIPUS, CAT with PBM, and CAT alone.

MATERIALS AND METHODS

This was a retrospective study carried out using the records of subjects with full permanent dentition (age range 18–59 years) who were treated using CAT (Invisalign, Align Technology, Santa Clara, Calif) by the same orthodontist (Dr El-Bialy) at their private orthodontic clinic in Edmonton, Canada, during a period of 5 years (2016–2020). The patients signed an informed consent form allowing the use of their data for scientific purposes. The study was approved by the Health Research Ethics Board at the University of Alberta, Canada (Pro00091339). We collected data regarding gender, age, type of malocclusion, Little's index of irregularity,[28] Invisalign insertion date, retainer insertion date, and total number of aligners for each patient (Table 1). Patients included in this study were presented with information about tooth movement–accelerating methods during the orthodontic treatment-planning stage using brochures, videos, and personalized discussions. The decision to receive the LIPUS device, PBM device, or no accelerating device was made by the patient and his or her family depending on the desire to shorten treatment time and considering the extra cost of the adjunctive device. LIPUS was applied to the first intervention group using an ultrasound device (Aevo system, SmileSonica Inc, Edmonton, AB, Canada) concurrently with CAT. The LIPUS device was used by patients at home for 20 min/d during treatment with the parameters shown in Table 2. PBM was applied to the second intervention group using the Orthopulse device (Biolux Research Ltd, Vancouver, BC, Canada). The PBM device was used by the patient at home for 10 min/d during treatment with the parameters shown in Table 2. The third group, which served as a control group, was treated using CAT alone.

We calculated the sample size using G*Power version 3.1.9.2 based on an alpha level of significance of .05 and a beta of .2 to achieve a power of (power = 1 − beta) of .8, assuming a medium effect size difference (.35) between groups. The results showed that a minimum total sample size of 84 patients (28 patients in each group) was necessary to detect significant differences among the three groups (28 patients in each group). Records were collected retrospectively based on the detailed inclusion and exclusion criteria shown in Table 1. A control group treated using CAT only was randomly selected to match the LIPUS and

Table 1. Characteristics of Included Patients in the Groups With Inclusion and Exclusion Criteria[a]

	LIPUS (n = 28)	PBM (n = 28)	Control (n = 28)	*P* Value*
Age, mean ±SD, y	37.3 ± 12.3	31.9 ± 8.9	31.5 ± 8.7	.06
Men, n	8	8	8	NA
Women, n	20	20	20	
Aligners (trays), mean ± SD	82 ± 25.4	78 ± 37.7	81.5 ± 26	.871
Little's irregularity index,[28] mean ± SD	3.5 ± 1.6	3.6 ± 1.3	3.37 ± 1.47	.825
Class I malocclusion, n	6	6	6	NA
Class II malocclusion, n	13	13	13	
Class III malocclusion, n	9	9	9	
• Inclusion criteria:				
• Patients with full permanent dentition treated using clear aligner therapy				
• Mild to moderate crowding (0–6 mm) based on Little's irregularity index[28]				
• No history of orthodontic treatment				
• No periodontal diseases				
• No significant medical history				
• No craniofacial anomalies				
• No missing teeth				
• Nonextraction treatment and nonsurgical treatment				
• Exclusion criteria:				
• Patients with severe crowding (>7 mm) in the anterior area				
• Pregnant women				
• Chronic use of medications affecting orthodontic tooth movement as bisphosphonate				
• History of parafunctional habits				

[a] LIPUS indicates low-intensity pulsed ultrasound; NA, not applicable; PBM, photobiomodulation.
* Statistically significant ($P < .05$) based on 1-way ANOVA test.

PBM groups for age, gender distribution, baseline malocclusion, number of aligners, and Little's index of irregularity[28] (mild to moderate crowding) as measured on digital orthodontic study models using OrthoCad software (Cadent, Inc, Fairview, NJ). The LIPUS group comprised 28 subjects (mean age 37.3 ± 12.3 years, 8 men and 20 women). The PBM group comprised 28 subjects (mean age 31.9 ± 8.9 years, 8 men and 20 women). The control group comprised 28 patients (mean age 31.5 ± 8.7 years, 8 men and 20 women).

Statistical analysis of the data was performed using the Statistical Package for Social Sciences, version 25.0 (SPSS for Windows, SPSS Inc, Chicago, Ill) at the significance level of $P < .05$. We used the Shapiro-Wilk test to verify the normal distribution of the data. Descriptive analysis was performed for all categorical variables. One-way analysis of variance (ANOVA) was used to test the matching among the groups. One-way ANOVA and Tukey post hoc analysis were used to determine whether there were significant differences in the total treatment durations among the three groups ($P < .05$).

RESULTS

Characteristics of the patients included in the three groups are shown in Table 1. All included patients were treated to Class I canine and molar relationships. A total of 84 patients were included in this study (60 women, 24 men) with different types of malocclusions (Class I = 18, Class II = 39, Class III = 27). The patients were equally distributed among the three groups, with 28 patients in each group. No statistically significant differences were found among the groups at baseline in terms of gender, age, or baseline malocclusion distributions as well as Little's irregularity index[28] scores. No statistically significant difference was recorded in terms of the number of aligners that were used in treating all patients, which ensured controlling this possible confounding factor that could affect the orthodontic treatment duration. The results (Figure 1;

Table 2. Specifications of the LIPUS and PBM Devices[a]

Device	Brand Name	Manufacturer	Specifications
LIPUS device	Aevo system	SmileSonica Inc, Edmonton, AB, Canada	Ultrasonic pulse frequency of 1.5 MHz, a pulse duration of 200 μs, a pulse repetition rate of 1 kHz (1 ms), and spatial average-temporal average (SATA) intensity of 30 mW/cm^2
PBM device	Orthopulse device	Biolux Research Ltd, Vancouver, BC, Canada	Low levels of light with a near-infrared wavelength of 850 nm and intensity of 60 mW/cm^2 continuous wave

[a] LIPUS indicates low-intensity pulsed ultrasound; PBM, photobiomodulation.

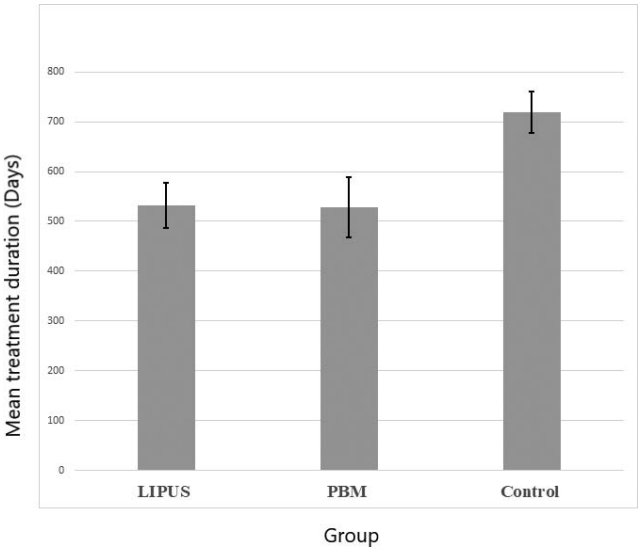

Figure 1. Mean treatment duration (days) with standard error bars for the LIPUS, PBM, and control groups.

Table 3) showed that the mean treatment durations in days were 719 ± 220, 533 ± 242, and 528 ± 323 for the control, LIPUS, and PBM groups, respectively. The large standard deviations may be attributed to variations in the treatment complexity (and consequently the treatment duration) among the patients included. The LIPUS group showed an average 26% reduction in treatment duration as compared with the control group, whereas the PBM group showed an average 26.6% reduction in treatment duration as compared with the control group. Based on one-way ANOVA (Table 4), there were statistically significant differences among the groups ($P = .011$). Based on the post hoc Tukey test (Table 5), the treatment durations were significantly reduced in the LIPUS and PBM groups as compared with the control group ($P = .027$, $P = .023$, respectively), with no statistically significant differences between the LIPUS and PBM groups ($P = .998$). The small sample size of each type of malocclusion precluded evaluating the effect of type of malocclusion on the treatment duration while using the intraoral nonsurgical interventions with CAT.

DISCUSSION

The aim of this retrospective study was to assess the possible orthodontic treatment acceleration efficiency of LIPUS and PBM when used as intraoral nonsurgical adjunctive interventions during CAT.

Orthodontic treatment is associated with different adverse effects such as root resorption, pain, pulpal changes, periodontal disease, and decalcification.[29] As the treatment duration increases, the risk for developing these adverse effects becomes greater. Lengthy orthodontic treatment is considered one of the major causes of patient dissatisfaction.[30] In addition, patients' quality of life and self-esteem can be harmed as a result of fixed appliance use, because the presence of appliances may lead to discomfort and trouble relative to patients' daily routine, which in turn makes lengthy treatment unfavorable for patients.[31] The duration of orthodontic treatment is influenced by many factors. Some of these factors are related to the orthodontic patient, such as complexity of the baseline malocclusion,[32] the need for extraction to align the teeth,[33] orthognathic surgery treatment modality to correct skeletal discrepancies, and patient compliance.[31] Other factors that could affect orthodontic treatment duration are related to the treating orthodontist's experience and knowledge, shorter intervals between appointments, and standards of care.[31] Reduction of orthodontic treatment duration would be beneficial to both patients and their treating professionals. Orthodontists and patients alike are interested in interventions that can accelerate tooth movement.[34] Most orthodontists were willing to pay only up to 20% of their treatment fee to companies for the use of interventions that could reduce treatment time, and most patients and parents were willing to pay only up to a 20% increase in fees for these interventions.[34]

Accordingly, recent intraoral nonpharmacologic adjunctive orthodontic procedures that aim to accelerate orthodontic treatment and reduce its side effects have been proposed. This study found that both LIPUS and PBM as intraoral interventions resulted in accelerating the OTM and that both reduced the total orthodontic duration by 26% on average. The results were consistent with previously published research that

Table 3. Descriptive Statistics of the Mean Duration of Orthodontic Treatment Among the Three Groups[a]

					95% CI for Mean			
	n	Mean	SD	SE	Lower Bound	Upper Bound	Minimum	Maximum
Control	28	719.3929	220.37499	41.64696	633.9404	804.8454	296.00	1170.00
LIPUS	28	532.6429	242.05558	45.74421	438.7835	626.5022	107.00	1281.00
PBM	28	528.3214	322.70329	60.98519	403.1902	653.4527	92.00	1210.00
Total	84	593.4524	277.06175	30.22992	533.3263	653.5785	92.00	1281.00

[a] LIPUS indicates low-intensity pulsed ultrasound; PBM, photobiomodulation.

Table 4. Analysis of Variance Comparison of Duration of Orthodontic Treatment by Intervention

	Sum of Squares	*df*	Mean Square	*F*	Significance
Between groups	666,423.595	2	333,211.798	4.731	.011
Within groups	5,704,923.214	81	70,431.151		
Total	6,371,346.810	83			

found both interventions effective in accelerating OTM and reducing total treatment duration.[10,12,25,35–38]

Studies on rat models found that LIPUS enhanced OTM and bone remodeling during mesial and lateral tooth movements.[24,39] Kaur and El-Bialy[12] found that cases treated with LIPUS and Invisalign aligners finished their orthodontic treatment with an average reduction in duration of 49% when compared with cases treated with Invisalign aligners only. El-Bialy et al.[35] found that LIPUS increased the rate of canine retraction during space closure.

One study using a rat model showed that LLLT could accelerate tooth movement that accompanied alveolar bone remodeling.[40] Kawasaki et al.[40] found that LLLT increased bone formation and cellular proliferation on the tension side while increasing the number of osteoclasts on the pressure side. The results of three clinical studies that assessed the effects of LLLT on canine retraction showed that the velocity of irradiated canines was significantly greater than that of nonirradiated canines.[36–38] Two recent studies found that PBM resulted in a clinically significant decrease in the alignment phase of orthodontic treatment.[10,25] On the contrary, one study found that LLLT did not affect canine movement velocity during space closure.[41]

Although the average number of total aligners was similar among the control, LIPUS, and PBM groups, the shorter duration of treatment in the LIPUS and PBM groups was due to being able to change aligners more frequently in those groups. LIPUS and PBM patients changed aligners every 4 to 5 days depending on the fit of the new aligners and the complexity of tooth movement, which sometimes took longer or shorter periods of time. In the control group, new aligners normally would not fit before 7 to 9 days, depending on the stage of treatment, with greater complexity of tooth movement resulting in longer treatment duration. In addition, in all groups, there was some lag time between sets of aligners (finishing one set and ordering a new set of additional aligners/refinement aligners).

A limitation of this study was that the patient compliance reports of wearing the intraoral interventions were not recorded, which precluded the authors from evaluating the effect of the active wearing duration of these interventions on orthodontic treatment duration. The large standard deviations recorded can also be a limitation of this study, which may be attributed to the variability in the treatment complexity (and consequently the treatment duration) among the patients included; this should be addressed in future studies. The small size of each malocclusion sample hindered performing a powerful statistical analysis to assess any possible effect of the type of malocclusion on the results.

CONCLUSIONS

- The null hypothesis was rejected.
- Within the limits of this study and based on the parameters of the devices used, daily use of LIPUS and PBM during CAT could result in a shorter orthodontic treatment duration.
- Both LIPUS and PBM were effective to a similar extent in accelerating OTM.

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Table 5. Post Hoc Tukey Test Results[a]

					95% CI	
(I) Intervention	(J) Intervention	Mean Difference (I − J)	SE	Significance	Lower Bound	Upper Bound
Control	LIPUS	186.75000*	70.92811	.027	17.4058	356.0942
	PBM	191.07143*	70.92811	.023	21.7272	360.4156
LIPUS	Control	−186.75000*	70.92811	.027	−356.0942	−17.4058
	PBM	4.32143	70.92811	.998	−165.0228	173.6656
PBM	Control	−191.07143*	70.92811	.023	−360.4156	−21.7272
	LIPUS	−4.32143	70.92811	.998	−173.6656	165.0228

[a] LIPUS indicates low-intensity pulsed ultrasound; PBM, photobiomodulation.
* Mean difference is significant at the .05 level.

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