

Decrowding of lower anterior segment with and without photobiomodulation: a single center, randomized clinical trial

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Abstract The aim of this study was to evaluate the effect of low-level light therapy using light-emitting diodes (LEDs) on the speed of tooth movements that were required for the leveling and aligning of the lower anterior segment during non-extraction orthodontic treatment. The sample was comprised of patients ($n = 40$) with lower anterior crowding who were treated with self-ligating orthodontic brackets and a standardized wire sequence. A test group of patients ($n = 20$) who were treated with extraoral infrared light therapy for 20 min daily with at least 80 % compliance was compared to a control group ($n = 20$). The date of the first arch wire placement was recorded as T1, and the date of the completion of the lower anterior segment decrowding was recorded as T2. A final impression was also taken at T2. The time between T1 and T2 was significantly reduced by 22 % in the test group compared to the control group (68.3 vs. 87.8 days, respectively, $p < 0.043$). The use of photobiomodulation for 20 min daily at a wavelength of 850 nm might reduce the time required to resolve lower anterior crowding. This trial and its protocol were not registered on a publicly accessible registry.

Keywords Low-intensity laser therapy (LILT) · Light-emitting diode (LED) · Accelerated tooth movement · Faster tooth movement · Leveling and aligning · Self-ligating brackets

Background

Treatment duration is a primary patient concern when orthodontic treatment is suggested [1]. Reductions in active treatment time can result in reductions in patient discomfort and fatigue and improvements in patient compliance. Furthermore, reducing active treatment time might also reduce treatment complications such as caries, periodontal diseases [2], and root resorption [3].

Different therapies have been advocated to accelerate orthodontic tooth movement. Yamasaki et al. reported on the local injection of prostaglandins, Verna et al. altered alveolar calcium metabolism, Wilcko et al. advocated full flap surgical bur stimulation of the cortical alveolar bone to increase bone turnover, Dibart et al. advocated piezoelectric-based surgical corticotomy, Kim et al. introduced scalpel blade injury to the alveolar cortical bone, and Nishimura et al. described the application of cyclical vibration. All of these techniques resulted in increased rates of tooth movement and reductions in active treatment time. In a recent systematic review, Long et al. concluded that corticotomy is effective and safe for accelerating orthodontic tooth movement and that low-intensity laser therapy (LILT) is unable to achieve similar movement [4–12].

Infrared light therapy, also known as photobiomodulation, is a technique that does not involve invasive surgery but rather depends upon the exposure of the tissue to therapeutic wavelengths of light, particularly in the near and far infrared ranges (600 to 1200 nm). Photobiomodulation has a potential impact on ATP production [13]. Cytochrome oxidase c—a

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mitochondrial enzyme—mediates ATP production, and it is upregulated by infrared light [14]. The increase in ATP levels at a localized site will induce cells to undergo a remodeling process due to elevated metabolic activity [15]. The increased energy levels within the bone cells can enhance cell proliferation and differentiation to create a favorable environment for tooth movement.

Light therapy can be administered with two main types of light source, i.e., low-intensity lasers and light-emitting diodes (LEDs). The difference between these two sources is that lasers produce coherent light, while the light from LEDs is incoherent [16]. Compared to lasers, LEDs are light weight and cost effective. LEDs can be made to produce multiple wavelengths and can be arranged in large, flat arrays that allow for the treatment of a large area; thus, LEDs can easily be constructed based on the field to be irradiated [17].

The application of LILT to increase the rate of tooth movement has increased in the past few years [18]. Most of studies in the LILT literature have reported on the effects related to improvements in cellular function. However, the results that have been reported regarding responses to LILT in orthodontic treatment are inconsistent. Dominguez et al. [19] reported that human osteoblast cells are sensitive to low-intensity laser irradiation and that such irradiation increases bone remodeling in a manner that could be clinically applied to accelerate orthodontic movement and enhance bone neo-formation in the field of periodontal surgery. Altan et al. [20] confirmed that LILT accelerate the bone remodeling process by stimulating osteoblast and osteoclast cell proliferation and function during orthodontic tooth movement. Yoshida et al. [21] found that LILT accelerates the velocity of tooth movement via the stimulation of alveolar bone remodeling. Yamaguchi et al. [22] reported that LILT enhances the velocity of tooth movement; these authors observed a significant increase in the amount of tooth movement in an irradiated group compared with a non-irradiated group at the end of their experiment. Kawasaki et al. [18] concluded that LILT can accelerate tooth movement and associated alveolar bone remodeling in a rat model. Fujita et al. [23] reported that LILT increases the velocity of tooth movement via the induction of RANK and RANKL. Saito et al. [24] found that LILT accelerates bone regeneration in the mid-palatal suture following palatal expansion in a rat model. Kim et al. [25] observed increases in the expressions of fibronectin and type I collagen in a LILT group and concluded that irradiation facilitated connective tissue turnover during orthodontic tooth movement in rats. Youssef et al. [26] reported a rate of canine retraction that was nearly twice that of control canines following the application of a total energy of 8 J/cm² per irradiation. Da Silvia Sousa et al. [27] reported a statistically significant increase in the movement speed of irradiated canines to the extraction space following the application of a total energy of 5 J/cm² per irradiation.

In contrast, Markezan et al. [28] reported that a protocol of daily laser application promoted an increase of the number of osteoclasts after 7 days but inhibited the expression of immature collagen on the tension side; thus, low-level laser therapy was unable to accelerate tooth movement.

The scholarly literature reveals a wide variety of methods, irradiation light sources, and total amounts of energy used. It is clear that further research is needed to establish standardized guidelines for low-level light therapy in orthodontics. According to Karu [29], there is no significant difference between the use of a laser or an incoherent light source when the same wavelength is applied. Furthermore, other studies have concluded that the cellular response primarily depends on the wavelength and the light dose and not the light source [30, 31].

After their introduction, researchers began investigating the effect of LEDs on cellular function. Fujita et al. [23] concluded that low-intensity laser irradiation resulted in an increased rate of tooth movement compared to those observed in LED- and non-irradiated groups. Furthermore, he stated that LED irradiation at the same wavelength and energy density that were effective with laser irradiation did not affect the proliferation or differentiation of fibroblasts and osteoclasts. Elke et al. [32] studied the effects of LILT and LED irradiation at different wavelengths (green, red, and infrared) on fibroblast proliferation and concluded that all irradiated groups exhibited elevated cell counts compared with the non-irradiated groups; the highest cell count was observed in the green LED light-irradiated group. Esper et al. [33] concluded that an LED-irradiated group exhibited a significant reduction in post-orthodontic pain compared with the LILT and control groups.

The literature is inconclusive regarding the treatment durations required by self-ligating and non-self-ligating brackets. Pandis et al. [34] observed no difference in the time required to correct mandibular crowding in a comparison of self-ligating and conventional brackets. Fleming et al. [35] reported that bracket type did not influence the duration of treatment or the number of visits required. In contrast, Abdulwahab et al. [36] concluded that the use of self-ligating appliances resulted in a statistically significant reduction in treatment time in the leveling and aligning stage compared with the use of conventional appliances.

The purpose of this study was to examine whether the use of photobiomodulation therapy (utilizing an OrthoPulse machine from Biolux® Ltd. (Vancouver, Canada) that produced light at a wavelength of 850 nm and a had power output of 90 mW/cm²) could decrease the treatment duration of the leveling and aligning phase of orthodontic therapy. A secondary objective was to investigate the effectiveness of a compliance-dependent extraoral irradiation method in accelerating tooth movement.

Material and methods

Ethical approval was obtained from the European University College (EUC) Institutional Review Board. The study subjects were EUC patients (Dubai, UAE) and were fully informed about the research study and the treatment protocol. The patients were asked to sign an informed consent form prior to the participation in the study.

The inclusion criteria were the following: permanent dentition requiring comprehensive orthodontic treatment, non-extraction treatment plan, a Little's irregularity index of ≥ 2 mm and ≤ 10 mm score (lower anterior crowding), and medically fit patients with good oral hygiene and healthy periodontal status; patients with active periodontal disease were excluded from the study along with patients taking any medication that might affect bone metabolism.

The Little's irregularity index is a score in millimeters of the horizontal overlapping (crowding) between the anatomical contact points of lower anterior teeth (canine to canine); our inclusion criteria was to include patients who have a score of 2–10 mm Little's irregularity index score and the alignment was considered complete when the score was down to 0–1 mm measured on a T2 model.

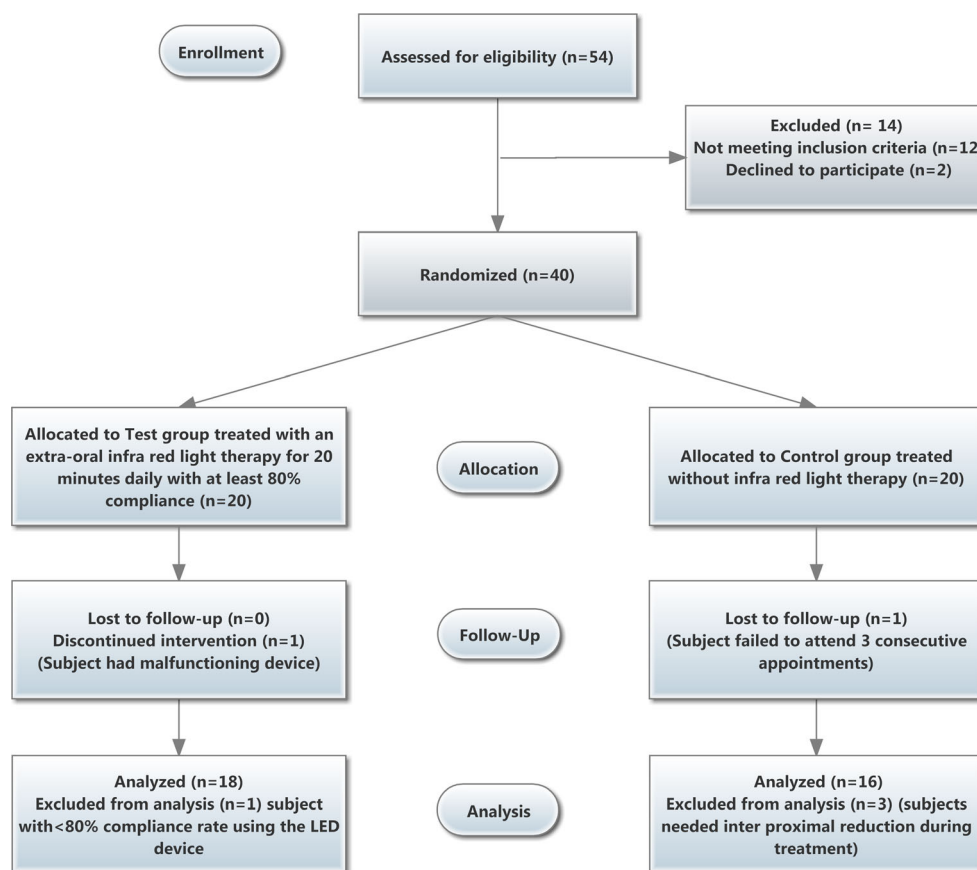
The patients were recruited in the period of March to December 2012. The patients were randomly assigned to

one of the two groups utilizing simple randomization by asking them to draw a sealed envelope ($n = 40$) that indicated their allocation to a test group ($n = 20$) in which LED photobiomodulation was delivered from an OrthoPulse device (Biolum® Ltd., Vancouver, Canada) or a control group ($n = 20$) (Fig. 1). The patients allocated to the test group were informed that a compliance rate below 80 % regarding the use of the light therapy device would result in their exclusion from the study, and the patients in both groups were informed that unreported bracket breakage that was not repaired within 36 h would also exclude them from the study.

Following full-mouth scaling and polishing and oral hygiene instructions, both groups received a self-ligating bracket appliance (Empower; American Orthodontics, Inc.) with an MBT prescription and slot size of 0.022×0.028 in. All patients were treated non-extraction. In both groups, the patients were recalled every 2 weeks until good alignment of the lower six anterior teeth was achieved.

Initial study casts from both groups were coded and then pooled. The amounts of lower anterior crowding were evaluated from the initial study casts by a single operator who was blinded to the allocation of the study casts to either group. The evaluations were performed by measuring the Little's irregularity index using digital calipers (CEN-TECH Model 47256) with an accuracy of 0.001.

Fig. 1 Flowchart of the study



The bonding procedure was standardized for both groups and performed by a single operator using a light cure adhesive paste (Transbond™ XT, 3M Unitek, USA). After bonding and placement of the initial arch wire, the date was recorded as a part of the T1 data. The arch wire sequence was standardized across groups. A 0.016-in Heat Activated NiTi (HANT) was initially placed and followed by a 0.018-in NiTi until alignment of the lower anterior teeth was achieved (Fig. 2a–c).

The test group received an OrthoPulse device from Biolux® Ltd. (Vancouver, Canada) and was instructed to

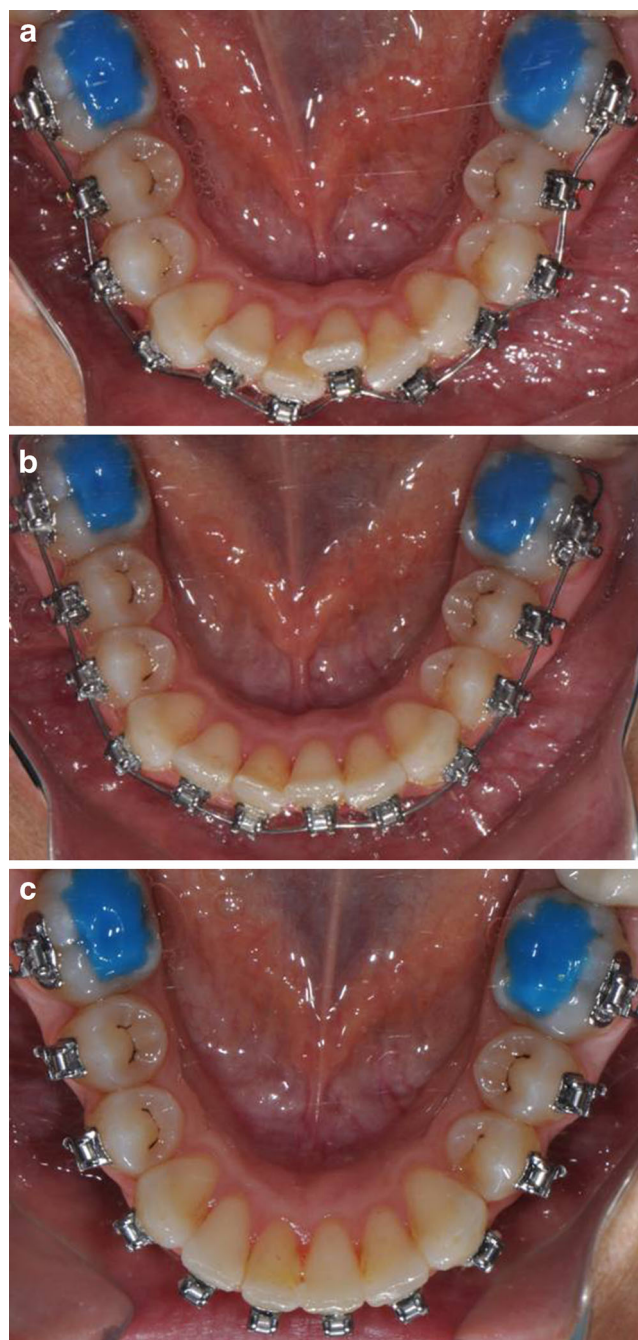


Fig. 2 Arch wire sequence. **a** 0.016-in HANT. **b** 0.018-in NiTi. **c** Final alignment

use it daily for 20 min. The fitting procedures were performed by a single operator (Fig. 3). The OrthoPulse device produced light at a wavelength of 850 nm and a power output of 90 mW/cm². The estimated irradiation dose per session on the surface of the cheek was 108 J/cm². The tracking software was integrated into the LED device to evaluate the compliance rate based on recordings of the numbers of sessions performed by each patient. A minimum compliance rate of 80 % was required.

The alignment of the lower six anterior teeth was evaluated by a single investigator who was blinded regarding the patients' group allocations. The alleviation of crowding was clinically determined based on visual inspection, and at the time alignment was achieved, an impression was taken for a study cast (T2). Little's irregularity indices were measured from the T2 casts by a single operator who was blinded regarding the patient group allocation. A score between 0 and 1 mm was considered to indicate a complete resolution of the lower anterior crowding, and irregularity indices greater than 1 mm resulted in the continuation of the alignment until complete resolution of the crowding was achieved. The elapsed time from T1 to T2 was calculated in days.

Measurement error

The measurement error was evaluated by re-measuring the irregularity indices of ten randomly selected casts on two occasions separated by a 2-week interval. Both measurements were performed by a single operator. A Dahlberg test for reliability revealed no significant differences between the two measurements ($p > .05$).

Statistical analyses

The data were analyzed with SPSS software (version 20.0.0; Chicago, USA). Descriptive statistics were computed for the study variables and included the means and standard deviations. Independent sample *t* tests were used to compare the two groups. A *p* value of <0.05 was considered to indicate statistical significance.



Fig. 3 Fitting of the OrthoPulse LED device

Table 1 Comparison of the test and control groups including descriptive statistics

	Group	N	Mean	SD	P value
Age	Cont.	16	21.1	10.2	0.079
	Test	18	21.8	5.3	
Treatment time/days	Cont.	16	87.8	24.7	0.043*
	Test	18	68.3	28.7	
Irregularity index (initial)	Cont.	16	5.62	1.79	0.098
	Test	18	5.64	2.55	

N number, SD standard deviation, Cont. control group. P values by independent *t* test

* $P < 0.05$ indicates statistical significance

Results

During the treatment, a total of four patients were dropped out from the control group, three required inter-proximal reduction of the lower anterior teeth, and one failed to attend more than three consecutive appointments. In the test group, two patients were excluded from the study; the first patient did not commit to using the LED device with a compliance rate of above 80 % and the second patient experienced a malfunction with his LED device (Fig. 1).

There were no significant differences between the two groups in terms of the baseline data including age and the Little's irregularity index. The test group exhibited a significant reduction in the treatment time required to align the lower anterior teeth by 22 %. The treatment duration for the test group (mean age 21.8 years) was 68.3 days (SD 28.7), and for the control group (mean age 21.1 years), this time was 87.8 days (SD 24.7; Table 1).

Discussion

Photobiomodulation has a potential impact on ATP production [13]. Cytochrome oxidase c—a mitochondrial enzyme—mediates ATP production, and it is upregulated by infrared light [14]. The increase in ATP levels at a localized site will induce cells to undergo a remodeling process due to elevated metabolic activity [15]. The increased energy levels within the bone cells can enhance cell proliferation and differentiation to create a favorable environment for tooth movement.

In the present study, the test group experienced a reduction in treatment duration required to complete the leveling and aligning stage of the lower anterior segment compared to the

control group. In this study, irradiation performed on a daily basis by the patients was different from previous studies in which the irradiation was performed at chair side at intervals ranging from a few days to 2 weeks via hand-held laser devices with questionable reliability regarding the anatomy actually irradiated [26, 37–39].

Our findings are in agreement with those of previous clinical trials, Cruze et al. [37] reported a 1.34-fold increase in the tooth movement rate in his experimental group that was exposed to a total energy of 5 J/cm² per irradiation compared to a control group. Gauri Doshi-Metha et al. [38] reported a 30 % increased tooth movement speed on the irradiated side during the canine retraction-to-extraction spaces following exposure to 8 J/cm² total energy per irradiation. However, Limpanichkul et al. [39] reported no significant difference in the velocity of extraction space closure between the irradiated and control sides with a total energy of 25 J/cm² per irradiation.

The biological effects of low-level light therapy are directly caused by very low-light intensity irradiation of the tissue, and the main concern is the ability to deliver a sufficient amount of light energy to the target tissues to induce cell proliferation and differentiation without overheating the tissues. The most effective irradiation lies within the red and near infrared ranges of the spectrum because hemoglobin does not absorb light in this range, and the light can penetrate deep into the living tissues [40]. Abi-Ramia et al. [41] studied the effect of low-level laser therapy and orthodontic tooth movement on dental pulp in a rat model. Orthodontic force was applied in two experimental groups with and without low-level light therapy, and a non-treated control group was used for comparison. Abi-Ramia concluded that orthodontic tooth movement resulted in reversible hyperemia in response to the applied force stimulus, but the low-level laser therapy group exhibited faster repair of the pulpal tissue.

In the present study, an extraoral LED device was used to irradiate the lower anterior segment at a wavelength of 850 nm and a power output of 90 mW/cm² for 20 min daily. The expected irradiation dose on the surface of the cheek per session was estimated to be approximately 108 J/cm² based on the specifications provided by the manufacturer. There is a loss of energy of 80–95 % as the photo beams reach the target tissue (alveolar bone) which results in approximately 12 J/cm² final total energy density at the target tissue, which is comparable to the doses reported in previous human studies [37, 39] in which the dose rate ranged from 5 to 25 J/cm² per

Table 2 Little's irregularity index for subjects included in the final analysis

Control group	3.12	2.89	3.14	8.1	8.15	4.12	5.25	8.1	7.15	5.89	6.22	4.33	7.14	5.13	6.1	5.15		
Test group	4.53	7.71	4.38	2.81	5.83	8.12	2.53	3.35	2.71	5.53	9.36	4.71	5.62	9.25	3.2	7.67	10.61	3.68

application with laser light sources. The initial high dose at the level of the cheek surface is justified because the irradiation method and the utilized light source were different, i.e., LED lights have reduced penetration capacity compared to laser light. Furthermore, this method is an extraoral method, which means that the photo beams need to penetrate the extraoral tissue and the intraoral tissues, which contrasts with the previous studies that have utilized hand-held laser devices that irradiated a specific area of the target quadrant directly on the target tooth [26, 37–39]. In contrast, we irradiated the entire lower anterior segment rather than a specific tooth.

The aim of the present study was to test the treatment duration required to level and align the lower anterior segment during non-extraction therapy. The type of tooth movements expected were tipping and rotation movements, which are simple tooth movements; the time required to achieve such movements might be affected by variations in the morphologies of the contact points between the teeth which might have led to some biases resulting from loose or tight contact points. Severe rotations might lead to an extended treatment time required to align the teeth. This might lead to a considerable bias when comparing the two groups. However, such difficult rotations were experienced equally between the two groups. Table 2 shows the Little's irregularity index for subjects involved in the final analysis. Investigations of the rates of more complex tooth movements, such as extraction space closure, would be interesting subjects for future research. The extraoral approach of the photobiomodulation device might propose some challenges to the patient and the clinician regarding compliance and device fitting and wearing time; continuous efforts are being made to design a photobiomodulation device that has an intraoral approach. An intraoral approach will result in a decreased wearing time due to the fact that the required dose will be delivered to the target tissues without loss of energy to the extraoral tissues.

Conclusion

The use of photobiomodulation for 20 min daily at a 850-nm wavelength might reduce the time required to resolve lower anterior crowding.

LEDs, light-emitting diodes; LILT, low-intensity laser therapy.

Compliance with ethical standards

Competing interests Material support for this study was provided by the Biolux Research Ltd. and the American Orthodontics. None of the sponsors (listed companies) had any role in the design or execution of this study. None of the authors have any financial interest in any of the products or devices mentioned in this manuscript or any competing financial interests.

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