Effects of low-level laser irradiation on the rate of orthodontic tooth movement and associated pain with self-ligating brackets

Irfan Qamruddin,[a] Mohammad Khursheed Alam,[b] Verda Mahroof,[a] Mubassar Fida,[c] Mohd Fadhli Khamis,[d] and Adam Husein[e]
Karachi, Pakistan, Sakaka, Kingdom of Saudi Arabia, and Kota Bharu, Kelantan, Malaysia

Introduction: The aim of this study was to evaluate the effect of low-level laser irradiation applied at 3-week intervals on orthodontic tooth movement and pain associated with orthodontic tooth movement using self-ligating brackets. **Methods:** Twenty-two patients (11 male, 11 female; mean age, 19.8 ± 3.1 years) with Angle Class II Division 1 malocclusion were recruited for this split-mouth clinical trial; they required extraction of maxillary first premolars bilaterally. After leveling and alignment with self-ligating brackets (SmartClip SL3; 3M Unitek, St Paul, Minn), a 150-g force was applied to retract the canines bilaterally using 6-mm nickel-titanium closed-coil springs on 0.019 x 0.025-in stainless steel archwires. A gallium-aluminum-arsenic diode laser (iLas; Biolase, Irvine, Calif) with a wavelength of 940 nm in a continuous mode (energy density, 7.5 J/cm^2/point; diameter of optical fiber tip, 0.04 cm^2) was applied at 5 points buccally and palatally around the canine roots on the experimental side; the other side was designated as the placebo. Laser irradiation was applied at baseline and then repeated after 3 weeks for 2 more consecutive follow-up visits. Questionnaires based on the numeric rating scale were given to the patients to record their pain intensity for 1 week. Impressions were made at each visit before the application of irradiation at baseline and the 3 visits. Models were scanned with a CAD/CAM scanner (Planmeca, Helsinki, Finland). **Results:** Canine retraction was significantly greater (1.60 ± 0.38 mm) on the experimental side compared with the placebo side (0.79 ± 0.35 mm) ($P < 0.05$). Pain was significantly less on the experimental side only on the first day after application of LLLI and at the second visit (1.4 ± 0.82 and 1.4 ± 0.64) compared with the placebo sides (2.2 ± 0.41 and 2.4 ± 1.53). **Conclusions:** Low-level laser irradiation applied at 3-week intervals can accelerate orthodontic tooth movement and reduce the pain associated with it. (Am J Orthod Dentofacial Orthop 2017;152:622-30)

Orthodontic treatment with fixed appliances is a lengthy and painful process. Numerous techniques to reduce the treatment duration and the level of discomfort have evolved over the time. A few of them shorten the treatment duration by accelerating the velocity of orthodontic tooth movement (OTM) by increasing bone remodeling, whereas other methods are intended to make the mechanical force delivery system more efficient.[1-4]

Low-level laser irradiation (LLLI) has been reported to enhance the velocity of tooth movement by accelerating bone remodeling.[4-7] It induces a photochemical reaction (biostimulation) at the cellular level in which the light energy is absorbed by the cellular photoreceptors and converted into adenosine triphosphate by mitochondria. This subsequently increases the cellular activities such as DNA, RNA, and protein synthesis. Some electromagnetic energy increases the local tissue temperature causing

[a]Orthodontic Department, Baqai Medical University, Karachi, Pakistan.
[b]Orthodontic Department, College of Dentistry, Al Jouf University, Sakaka, Kingdom of Saudi Arabia.
[c]Section of Dental Surgery, Department of Surgery, Aga Khan University, Karachi, Pakistan.
[d]Forensic Dentistry Unit, School of Dental Science, Universiti Sains Malaysia, Health Campus, Kota Bharu, Kelantan, Malaysia.
[e]Prosthodontic Unit, School of Dental Sciences, Universiti Sains Malaysia, Health Campus, Kota Bharu, Kelantan, Malaysia.
Irfan Qamruddin and Mohammad Khursheed Alam are joint first authors and contributed equally to this work.
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Address correspondence to: Mohammad Khursheed Alam, Orthodontic Department, College of Dentistry, Aljouf University, Sakaka, Saudi Arabia. Irfan Qamruddin, Orthodontic Department, Baqai Dental College, Baqai Medical University, 51 Deh tor Plaza, Gadap Road Superhighway, Karachi, Pakistan; e-mail, drirfan_andani@yahoo.com; dralam@gmail.com.
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vasodilation, eventually inducing cellular proliferation, differentiation, and tissue healing.[8-10]

Additionally, LLLI has also been shown to have analgesic effects in various clinical and therapeutic applications.[11-13] It is believed that LLLI minimizes pain perception by inhibiting the release of arachidonic acid, which decreases the levels of prostaglandin E2.[14-16] Also, it induces the release of an endogenous opioid neuropeptide (beta-endorphin) that produces potent analgesic effects.[17] Moreover, LLLI stabilizes the membrane potential and henceforth inhibits activation and transmission of the pain signal.[10]

Since pain and longer duration of orthodontic treatment are among the worst aspects of fixed appliance therapy, LLLI could be an ideal modality to address both concerns. Various authors have investigated the biostimulating and analgesic effects of LLLI in relation to OTM in animals and humans. In-vivo animal studies have shown that low-energy laser irradiation can induce the proliferation and activation of both osteoblasts and osteoclasts through the expression of RANK and RANKL, accelerating the remodeling of bone and eventually increasing the velocity of OTM.[18-20] However, recently, some authors have observed no acceleration in OTM after application of LLLI.[21,22]

Several clinical trials involving the use of LLLI in human subjects have shown different outcomes. Some authors have reported positive effects on the speed of OTM, whereas others did not support any enhancement in velocity.[5,23-26] A few studies that evaluated the effects of LLLI on OTM and associated pain simultaneously also showed divergent results.[27,28] The role of LLLI in decreasing the perceived pain levels for the first few days after separator placement and initial archwire insertion has been reported by a number of studies; however, consistent reports of the effectiveness of LLLI on relieving the pain related to OTM are still not available.[7,29-33]

So far, the application of LLLI to investigate the acceleration of tooth movement was either on a daily basis or with a short interval between the visits, which became unmanageable for the patients because of forgetfulness or time constraints (Table I).[34] Therefore, the purpose of this study was to evaluate the effects of LLLI applied at 3-week intervals on the velocity of OTM and the pain associated with it using self-ligating brackets. It was hypothesized that the application of LLLI at 3-week intervals would expedite OTM and reduce the pain effectively.

MATERIAL AND METHODS

This single-blind, randomized clinical trial was conducted at the Orthodontic Department in Baqai Medical University, Pakistan. The study was approved by the ethics committee of Baqai Medical University, Pakistan. Twenty-two healthy orthodontic patients of Pakistani ethnic background (11 male, 11 female) with ages between 12 and 25 years (19.8 ± 3.1 years) were selected for the study.

The sample size was determined using power analysis, based on the tooth movement objective. Having 80% power, an alpha that indicates the significance level was set at 0.05, with a standard deviation of 0.99 mm and considering a 1-mm mean difference as clinically meaningful.[27] The minimum sample size calculated with this method was 19. Including expected dropouts, 22 patients were recruited for the study (Fig 1).

Selection criteria were Angle Class II Division 1 malocclusion requiring extraction of first premolars bilaterally in the maxillary arch only. Patients with moderate-to-severe crowding who required extractions of premolars for alignment were not included in the sample. Patients on long-term medication, or with parafunctional habits, temporomandibular joint dysfunction, craniofacial malformation, multiple missing teeth, and impacted teeth except for third molars, or periodontally compromised patients were excluded from the study. The informed consents of the patients were taken, after explaining the procedure verbally. Legal guardians signed the consent form if the age of the patient was below 18 years.

The orthodontic treatment was initiated with a banding procedure followed by bonding passive self-ligating MBT brackets having a 0.022-in slot (SmartCli SL3; 3M Unitek, St Paul, Minn). After alignment and leveling with 0.014-in nickel-titanium wires, and following the sequence of wires (0.016-in, 0.017 × 0.025-in, and 0.019 x 0.025-in), which took approximately 6 months (each archwire was placed for 6 weeks), a final working wire of 0.019 × 0.025-in stainless steel was placed. Twenty-one days after the working wire placement, extractions were performed, and a silicone impression was made (before the experiment) a week after the extractions. Canine retractions were started bilaterally using 6-mm nickel-titanium closed-coil springs, placed from the first molar band hook to the power arm of the canine brackets secured through the ligature wire. The incisors were consolidated using 0.010-in steel ligature wires so that spaces did not appear between them during canine retraction. A constant retraction force of 150 g was exerted for canine retraction measured with an orthodontic dynamometer (Forestadent, Pforzheim, Germany).

The maxillary arch was divided into experimental and placebo groups randomly by flipping a coin. LLLI was applied on the experimental side immediately after the retraction force. LLLI was applied on a total of 10 points, 5 on the buccal side and 5 on the palatal side (T0). The points to be irradiated on the buccal sides were mesial and distal to the apical area of the canine, and mesial

Table I. Comparison of our study with previous studies that used LLLT to accelerate OTM

Study	*Number of patients*	*Laser specifications*	*Energy density and intervention schedule*	*Conclusion*
Cruz et al[5] (2004)	11	Ga-Al-As 780 nm Continuous mode 20 mW	5 J/cm2/point 50 J/cm2/session 200 J/cm2/month Days 0, 3, 7, 14, 33, 37, 44 Total 60 days	Tooth movement accelerated.
Limpanichkul et al[45] (2006)	12	Ga-Al-As 860 nm Continuous mode 100 mW	25 J/cm2/point 204 J/cm2/session 612 J/cm2/month Days 0, 1, 2, 28, 29, 30, 58, 59, 60, 88, 89, 90 Total 90 days	No significant results. Author stated that energy input was too low.
Sous et al[24] (2011)	10	Ga-Al-As 780 nm Continuous mode 20 mW	5 J/cm2/point 50 J/cm2/session 150 J/cm2/month Days 0, 3, 7, 30, 33, 37, 60, 63, and 67 Total 90 days	Rate of tooth movement accelerated twice.
Youssef et al[25] (2008)	15	Ga-Al-As 809 nm 100 mW	1 J/point on 4 areas and 2 J/point on 2 areas 8 J/session Days 0,3,7,14	Tooth movement accelerated.
Doshi-Mehta and Bhad-Patil[27] (2012)	20	Ga-Al-As 800 nm Continuous mode 250 mW	8J/session Days 0,3,7,14 then every 15 days until the canines are retracted completely	Tooth movement accelerated.
Herav et al[28] (2014)	20	Ga-Al-As 810 nm Continuous mode 200 mW	10 points 21.4 J/cm2/point Days 0, 3, 7, 11 15	No significant difference in canine movement velocity and pain. Pertaining to different dosage and point of application and interval between applications.
Genc et al[26] (2013)	20	Ga-Al-As 808 nm Continuous mode 200 mW	10 points around maxillary lateral incisor 0.71 J/cm^2/point Days 0, 3, 7, 14, 21,28, 35	Significant acceleration in movement. No significant difference in nitric oxide levels in GCF.
Fujiyama et al[29] (2008)	90	CO_2 laser 2 W	5 pulses per 1000 s Applied once immediately after separation 60 s/tooth	Reduction in pain was reported, but there was no significant difference in movement of molars.
This study	20	Ga-Al-AS 940 nm Continuous mode 100 mW	5 points buccally, 5 points palatally 3 s each point 7.5 J/cm^2 each point Days 0, 21,42	Rate of tooth movement accelerated twice. Significant reduction in pain associated with movement.

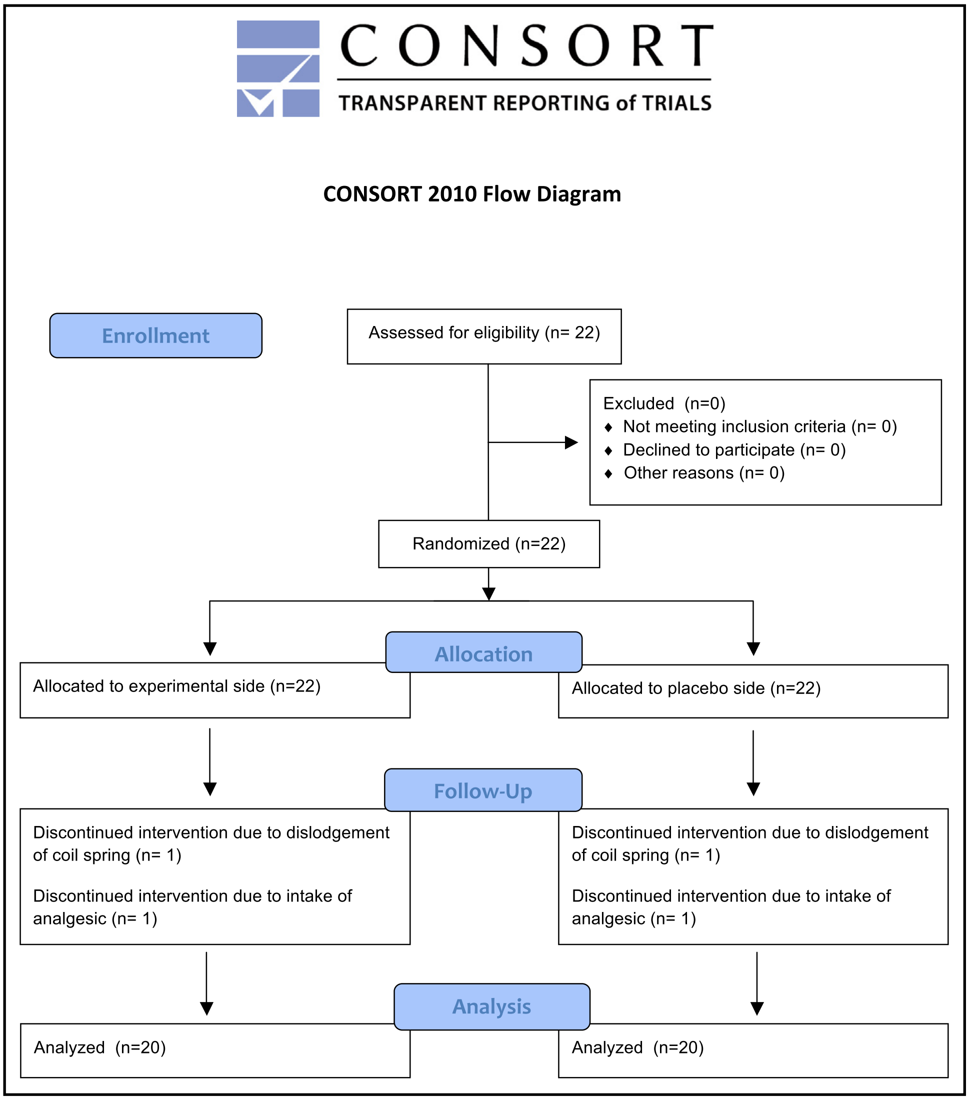

Fig 1. Consort flow diagram.

and distal to the cervical area of the canine, and 1 point was approximately at the middle of the root.

The same areas on the palatal side were also irradiated. Irradiation was performed by keeping the optical fiber tip perpendicular and in direct but light contact with the mucosa. The laser was also held the same way on the placebo side, but the laser unit was not turned on. The procedure was performed in an isolated room, using protective eyewear for the patient, operator, and dental assistant. To prevent a carry-across effect of the laser beam on the placebo side, a plastic shield was used as a barrier having the same wavelength as the laser.

A gallium-aluminum-arsenic diode laser (iLas; Biolase, Irvine, Calif) with a wavelength of 940 nm in a continuous mode of operation was used with the power set at 100 mW. The diameter of the optical fiber tip was 0.04 cm^2. Irradiation was applied for 3 seconds at each point; therefore, the energy density calculated at each point was 7.5 J per square centimeter.

The patients were called for their follow-ups every 3 weeks for 3 more consecutive visits (T1, T2, and T3). Laser therapy was repeated at T1 and T2, and silicone impressions were made at T0, T1, T2, and T3. Questionnaires to record the pain were also given to each patient after the application of the LLLI. Patients were advised to fill in the questionnaire and bring it back at their next follow-up visit.

For canine retraction (OTM), a CAD/CAM scanner (Planmeca, Helsinki, Finland) was used to scan all models

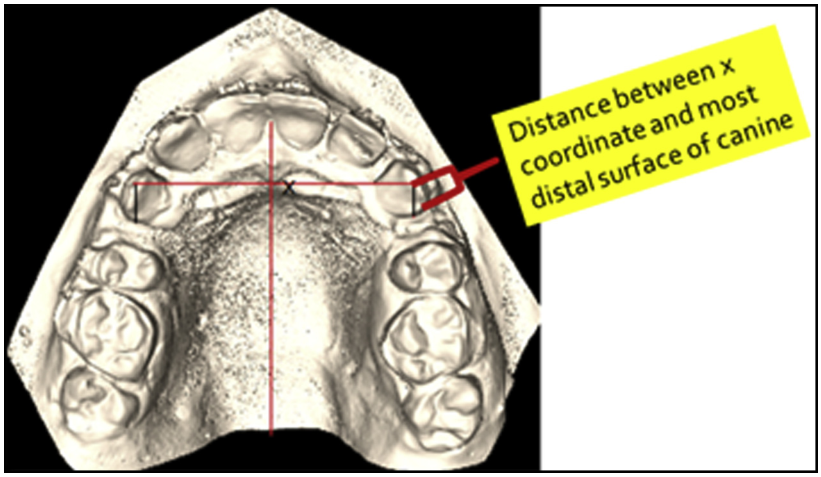

Fig 2. Scanned model with measurements to compare the velocity of canine movement on experimental and placebo sides.

3 dimensionally, and the software used to measure the movements was Romexis viewer (Planmeca). To evaluate the effect of LLLI on the rate of tooth movement, the experimental sides were compared with the placebo sides for the displacement of the canines on the dental casts (at T0, T1, T2, and T3). The following method was used to measure canine displacement as elaborated by Gebauer[35] (Fig 2).

The x- and y-coordinates were made on scanned images of the dental casts. The midpalatal raphe line was used to draw the y-axis of the coordinate system, which was made by using distinct points in the anterior and posterior median parts of the palate, whereas the x-axis was perpendicular to the y-axis, made at the mesial end of the most prominent palatal rugae (Fig 2).

The distance between the most distal surface of the canine to the x-coordinate was measured on both sides of all dental casts to compare the velocity of canine movement.

An 11-point numeric rating scale was used to formulate a questionnaire to record the pain intensity associated with canine retraction: 0 indicated no pain, and 10 indicated an intolerable pain. Questionnaires were given to all patients to fill out at home and bring back on their next visit. Patients were told to record their pain intensity 4 hours after the procedure and then after every 24 hours for the next 7 days. They were also advised to record the most severe pain they experienced in the past 24 hours, so that the intense episode was not missed even if the pain subsided by the time of recording. Reminders to fill in the questionnaire were also given to the patients by daily phone calls. Patients were also discouraged from taking analgesics; if taken in case of severe pain, then they were advised to note it.

Statistical analysis

SPSS software (version 20.0; IBM, Armonk, NY) was used to record and analyze the data. Descriptive analyses were performed to obtain the mean values for OTM and pain. Since the distribution of data was not normal, the Mann-Whitney U test was applied to compare the rate of canine retraction and the level of pain between the experimental and placebo sides. The same test was applied to compare the sex-based differences in the rate of canine retraction and pain.

RESULTS

The total duration of the study was 15 months (July 2014 to September 2015). Twenty-two patients were recruited for the study, of whom 2 were dropped because of dislodgement of the coil spring prematurely in 1 patient and analgesics taken by the other. Therefore, the sample size was 20 patients (10 male, 10 female) with a mean age of 19.80 years. There was no difference in the rate of OTM among the sexes at T1, T2, and T3 ($P = 0.64$, $P = 0.79$, $P = 0.85$, respectively). Similarly, no significant sex-based variation in pain perception was found at any stage of the study.

The null hypothesis was rejected because a significant difference was found in the rates of canine retraction between the experimental and placebo groups at T1, T2, and T3 as depicted in Table II ($P < 0.05$). The mean values for canine retractions after 9 weeks were 1.60 ± 0.38 mm on the experimental side and 0.79 ± 0.35 mm on the placebo side. The overall movement of the canines on the experimental side was 2.02 times greater compared with the placebo side.

Table II. Mean values (SD) of canine movement in experimental and placebo groups with confidence intervals, mean differences, and *P* values (Mann-Whitney U test)

		95% Confidence interval			95% Confidence interval			
	Experimental side (mm)	Lower bound	Upper bound	Placebo side (mm)	Lower bound	Upper bound	Mean difference (mm)	P value
T0-T1	1.81 ± 0.26	1.68	1.93	0.79 ± 0.40	0.60	0.98	1.01	0.00*
T1-T2	1.40 ± 0.51	1.16	1.64	0.80 ± 0.40	0.61	0.99	0.60	0.00*
T2-T3	1.59 ± 0.38	1.41	1.77	0.79 ± 0.25	0.67	0.91	0.80	0.00*

*Significant at $P < 0.05$.

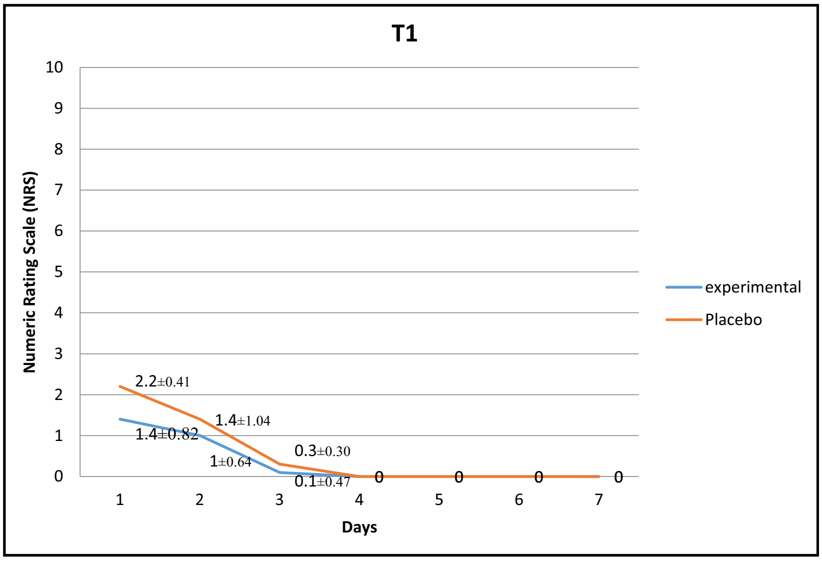

Fig 3. Comparison of pain experienced at experimental and placebo sides for a week at T1.

The alternate hypothesis was accepted, since the pain was significantly less on the experimental side on the first day after the application of LLLI at T1 and at T2 (1.4 ± 0.82 and 1.4 ± 0.64) compared with the placebo side (2.2 ± 0.41 and 2.4 ± 1.53, respectively), whereas the difference in pain perception on the remaining days of the week was insignificant at T1, T2, and T3 (Figs 3-5).

DISCUSSION

We evaluated the effect of LLLI applied at 3-week intervals on the velocity of canine retraction and the pain associated with retraction using self-ligating brackets. The rate of tooth movement and associated pain are both subject to individual anatomic and biologic variations; therefore, the split-mouth design was used in this study.[36,37] To prevent the carry-across effect that is a possible drawback of split-mouth designs, a plastic shield was placed at the midline to limit the laser beam's penetration to the placebo side. Moreover, loud music was played in the operating room so that the patient did not hear the beeping sound of the laser unit and spoil the placebo design. No patients reported any discomfort or heat during treatment; this shows that the energy output of laser was too low to cause any rise in temperature of the target tissues above normal body temperature: ie, above 36.5°C.

The laser unit with the wavelength (940 nm) at the beginning of the infrared electromagnetic spectrum was chosen for the study because of the deeper tissue penetration associated with this spectrum of light.[38] It has been established that a laser has biostimulatory effects at low doses; therefore, the energy dose applied at each point was 7.5 J per square centimeter in this study.[4,39]

Patients with Angle Class II Division 1 malocclusions with mild crowding were selected for the study so that the extractions were not required initially to align and level the arches. Moreover, all patients required extractions in the maxillary arch only so that the mandibular arch occlusion did not interfere with our results. Direct comparison of our study with previous studies was limited because no previous researchers used self-

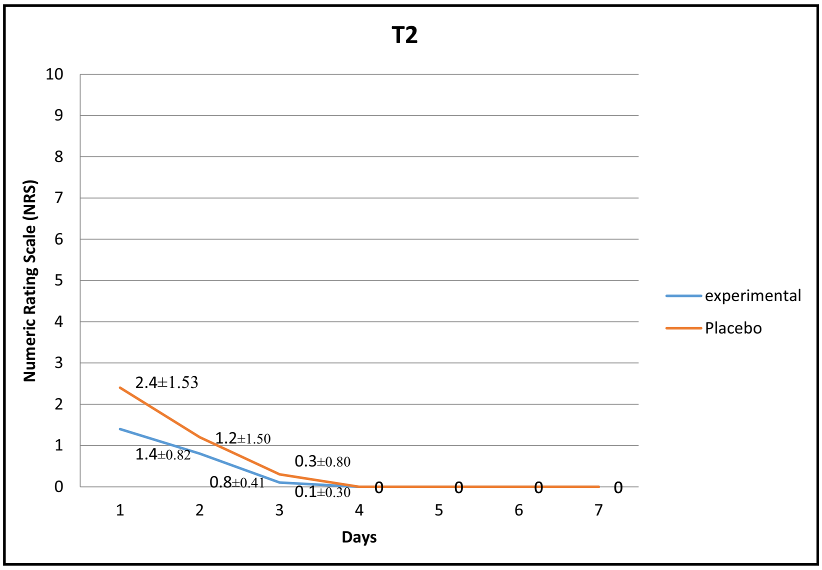

Fig 4. Comparison of pain experienced at experimental and placebo sides for a week at T2.

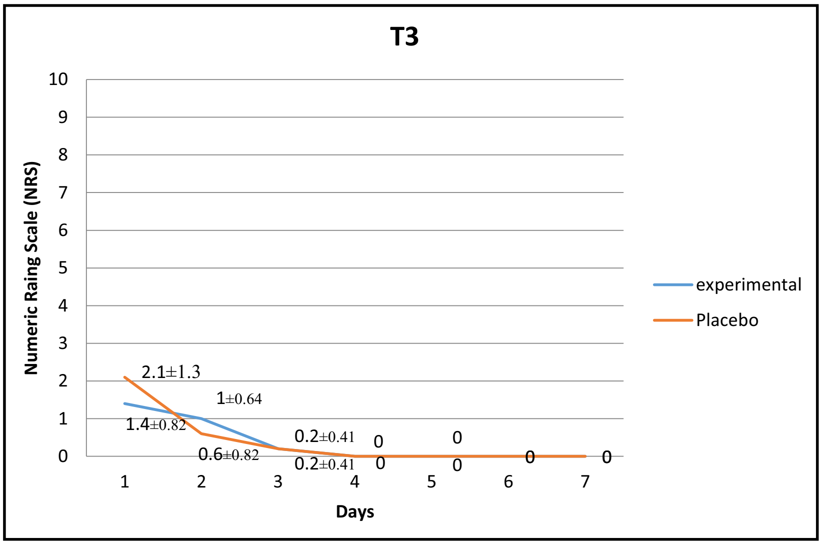

Fig 5. Comparison of pain experienced at experimental and placebo sides for a week at T3.

ligating brackets; furthermore, the laser application in other studies was applied with much shorter intervals, whereas we applied LLLI at 3-week intervals.

An ideal intervention schedule for LLLI has not been established; however, it has been reported that the application should be at the beginning of OTM.[9]

Acceleration in the rate of OTM in our study was more than what previous studies reported (2.02 times). Sousa et al[24] and Youssef et al[25] also reported twice as much acceleration, whereas Doshi-Mehta and Bhad-Patil[27] found 1.3 times acceleration in the rate of canine retraction. The reason could relate to the application of LLLI immediately after the activation of the spring in our study and the use of self-ligating brackets, which have never been investigated. Genc et al[26] also reported increased velocity of movement of the lased teeth; however, they investigated movement of lateral incisors.

Measurements of OTM in all previous studies were subject to errors due to anchorage losses associated with tooth movement that was not considered. Doshi-Mehta and Bhad-Patil[27] and Youssef et al[25] measured canine retraction directly on the models with digital calipers from the tip of the canine to the mesiobuccal cusp tip of the permanent first molar, whereas Genc et al[26] measured from the mesial surface of the central incisor to the distal surface of the lateral incisor. To eliminate this error in our study, reference lines were drawn using the mesial part of the most prominent palatal rugae.[35] It has been established that the position of the mesial end of the palatal rugae is a stable landmark and is not affected by orthodontic treatment, but the lateral end may follow tooth movement in premolar extraction cases.[40] The same method for measurements of canine movement was also used by Heravi et al,[28] but they photographed the dental casts with standard settings; in our study, the dental models were scanned using a CAD/CAM scanner. No significant difference in the velocity of canine movement was reported by Heravi et al after multiple applications of LLLI pertaining to the high energy density used in that clinical trial.

To investigate the effects of LLLI on pain associated with canine retraction, a questionnaire was formulated based on a numeric rating scale. Unlike many previous studies that used a visual analog scale, a numberic rating scale was preferred for this study so that even younger patients comprehended the method well.[29,41]

No difference was found in the perception of pain among male and female subjects at T1, T2, and T3. This was in contrast with the findings of Turhani at el,[42] who reported a speedy recovery from pain in female patients. In our study, the patients were advised to record their pain 4 hours after the activation of the spring, since it has been established that orthodontic pain starts usually within 4 hours, becomes more intense over 24 hours, and then subsides within 7 days.[43]

In this study, the pain ratings were low in the lased and placebo groups. The maximum pain score reported by patients was on the placebo side, which was 3, denoted as mild discomfort in the 11-point numeric rating scale. This was in contrast to the previous studies that found severe pain in the control group after force activation.[25,32,44] This could be explained by the difference in subjective responses that depend on a number of factors including individual pain threshold, emotional status, psychological condition, and even cultural differences.[44] Another explanation could be the use of LLLI with self-ligating brackets; this has never been investigated before. Maximum pain was reported on the first day after the activation of the coil spring; this agreed with previous studies.[32,33,44]

A significant difference was found in the level of pain between the experimental and placebo sides on the first day at T1 and at T2, whereas there was no significant difference on the remaining days of the week. LLLI reduced the levels of pain on the experimental sides effectively on the following days, but pain scores on the placebo sides were also reduced enough to make the differences insignificant. Previous studies also endorsed the analgesic effect of LLLI on pain associated with canine retraction.[25,27] Few studies validated the analgesic effects of LLLI; however, they investigated the effects on pain associated with initial archwire insertion.[32,33,44] A few studies did not support our results and found no significant difference in pain associated with canine retraction between the lased and control groups.[28,45]

Both null hypotheses were rejected, since our study statistically supported the rate of acceleration and the analgesic effects of LLLI on OTM and associated pain,\ when applied at 3-week intervals using self-ligating brackets. Further studies should be conducted with conventionally ligated brackets so that the influence of ligation methods on the tested variables can be determined.

CONCLUSIONS

LLLI is a beneficial modality that can double the rate of OTM if applied at 3-week intervals. The pain associated with OTM can also be significantly reduced with LLLI. This 3-week pattern of LLLI goes well with conventional orthodontic appointment scheduling and thus may be easily implemented in the clinical practice.

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