DOI: 10.4274/TurkJOrthod.2024.2024.41

TURKISH JOURNAL OF
ORTHODONTICS

Original Article

Evaluation of the Effect of Low-level Laser Therapy on Leveling Mandibular Anterior Crowding

Yasemin Tunca[1], Yeşim Kaya[2]

[1]Kütahya Health Sciences University Faculty of Dentistry, Department of Orthodontics, Kütahya, Türkiye
[2]Ankara Yıldırım Beyazıt University Faculty of Dentistry, Department of Orthodontics, Ankara, Türkiye

Cite this article as: Tunca Y, Kaya Y. Evaluation of the effect of low-level laser therapy on leveling mandibular anterior crowding. *Turk J Orthod.* 2025; 38(1): 49-55

Main Points

- Low-level laser therapy has no effect on the acceleration of tooth movement during leveling.
- Low-level laser therapy reduced the leveling duration; however, the difference was not statistically significant.
- Except for day 1 of leveling, there was no decrease in pain levels.

ABSTRACT

Objective: This study aims to evaluate the effect of low-level laser therapy (LLLT) on leveling mandibular anterior crowding and associated pain levels.

Methods: This double-blinded, parallel, randomized clinical trial included 30 participants who were randomly assigned to the laser group or the control group, with Little's irregularity index of 4-8 mm in the mandibular canine-canine region. Nickel-titanium archwires measuring 0.012 inches were tied with elastomeric ligatures and changed every 14 days throughout the leveling process. The leveling duration was recorded in days, from the bonding application to the end of leveling. Irradiation was performed at an 810-nm wavelength using a gallium-aluminum-arsenide diode laser device with a power output of 100 mW and an energy density of 8 J/cm^2. Laser applications were performed after archwire ligation (day 0), on days 3, 7, and 14 and every 14 days until leveling was completed. The leveling duration was calculated, and pain levels were evaluated using a visual analogue scale (VAS) after archwire ligation (hour 0), at hours 2 and 6 and on days 1, 3, 7, 14, and 21.

Results: The leveling duration showed no significant differences between the laser and control groups (p=0.170). Group comparison results of the VAS scores at hour 6 (p=0.001) and day 1 (p=0.006) exhibited significantly reduced pain levels in the laser group compared with the control group.

Conclusion: Although LLLT is not effective in reducing the leveling duration, it significantly reduces pain levels at hour 6 and on the 1st day.

Keywords: Low-level laser therapy, orthodontics, crowding, pain measurement

INTRODUCTION

A prolonged treatment duration not only causes a decrease in patient compliance but also increases the risk of various side effects, such as root resorption, periodontal problems, and white spot lesions.[1] Reducing the treatment duration requires increasing the rate of tooth movement.[2] Therefore, accelerating tooth movement is one of the primary goals of orthodontists.[3] Tooth movement can be accelerated by stimulating alveolar bone remodeling with surgical and non-surgical procedures.[1,4] Invasive surgical procedures are less preferred by

Corresponding author: Yasemin Tunca, **e-mail:** dtyasemintunca@gmail.com
Received: March 06, 2024 **Accepted:** November 26, 2024 **Epub:** 19.03.2025 **Publication Date:** 27.03.2025

clinicians and patients due to the possibility of pain, discomfort, and damage to the tooth root.[5,6] Photobiomodulation is often preferred as a mechanical/physical stimulation, which is a non-surgical procedure classified into two subcategories.[7] However, pharmacological methods, the other category, are mostly performed at the level of animal experimentation. They have systemic and local side effects, and clinical dose applications are not yet sufficient.[8] Low-level laser therapy (LLLT), known as photobiomodulation, is reported to accelerate tooth movement by altering cellular activity in tissues through exposure to laser beams in the visible red to near-infrared spectrum.[9] LLLT is also reported to be effective in alleviating orthodontic pain and accelerating tooth movement.[10-12]

For this purpose, light-emitting diodes (LEDs) or low-level lasers (LLL) can be used.[6] Although the number of studies evaluating the effect of extraoral and intraoral LED applications on accelerating tooth leveling and alignment has increased, only four studies have investigated the use of LLLT.[13-16] However, in all studies where LLLT was applied, archwires were changed during the process. To date, no study has examined the effect of LLLT on mandibular anterior tooth leveling without archwire changes.

Based on this background, this study aims to investigate the effect of LLLT on leveling mandibular anterior crowding and pain levels. The null hypothesis states that LLLT has no effect on leveling mandibular anterior crowding or pain levels.

METHODS

Trial Design

A total of 30 participants (22 women and 8 men) who underwent non-extraction fixed orthodontic treatment with the straight-wire technique at the Department of Orthodontics, Van Yüzüncü Yıl University Faculty of Dentistry between February 2020 and October 2022 were enrolled in this double-blinded, parallel, randomized clinical trial. The approval of the Van Yüzüncü Yıl University Faculty of Medicine, Clinical Research Ethics Committee was obtained to conduct this study (approval no.: 24, date: 05.05.2020). After the study was explained, informed consent forms, prepared according to the Declaration of Helsinki, were signed by all participants and their legal guardians for those under the age of 18. The Consolidated Standards of Reporting Trials flowchart of patient recruitment, follow-up, and entry into data analysis is shown in Figure 1.

Participants and Eligibility Criteria

The following inclusion criteria were applied: no previous orthodontic treatment; complete permanent dentition; cephalometric evaluation and model analysis indicating non-extraction treatment with skeletal Class I malocclusion, maxillary and mandibular incisor positions and inclinations within retrusive and/or normal values, and a mandibular canine to canine Little's irregularity index (LII) of 4-8 mm; no congenital anomalies, dental structural disorders, crowns, or extensive restorations in the mandibular anterior teeth; no pregnancy, lactation, smoking, systemic problems, or related medications that could impact alveolar bone metabolism and tooth movement; good oral hygiene; no plaque accumulation, gingival inflammation, or alcohol use. Correspondingly, participants with temporomandibular joint disorders, parafunctional habits, or those requiring anchorage mechanisms, such as miniscrews and lingual arches in the mandible, were excluded from the study.

Interventions

Clinical Procedures

After the participants were assigned to the laser and control groups, fixed orthodontic treatment with the straight-wire technique was initiated using 0.018-inch slot stainless steel Roth brackets (Gemini Roth System, 3M Unitek, Monrovia, CA, USA). Bonding procedures were performed using the same orthodontic adhesive according to the manufacturer's instructions (Transbond™ XT, 3M Unitek, Monrovia, CA, USA). Polymerization was conducted using a LED source (Elipar FreeLight 2; 3M ESPE, St. Paul, MN, USA).

During the leveling phase, 0.012-inch nickel-titanium (NiTi) archwires (3M Unitek, Monrovia, CA, USA) were secured with elastomeric ligatures (QuiK-StiK™, 3M Unitek, Monrovia, CA, USA), which were changed every 14 days during laser applications. The archwire was not replaced at these appointments unless deflection was observed. Patients and their parents were informed about prolonged treatment duration due to bracket failures and were instructed to contact the orthodontist immediately in case of any issues.

Laser Parameters and Procedure

An 810 nm semiconductor continuous-wave gallium-aluminum-arsenide (Ga-Al-As) diode laser device (Cheese Diode Laser, Wuhan Gigaa Optronics Technology Co. Ltd.,

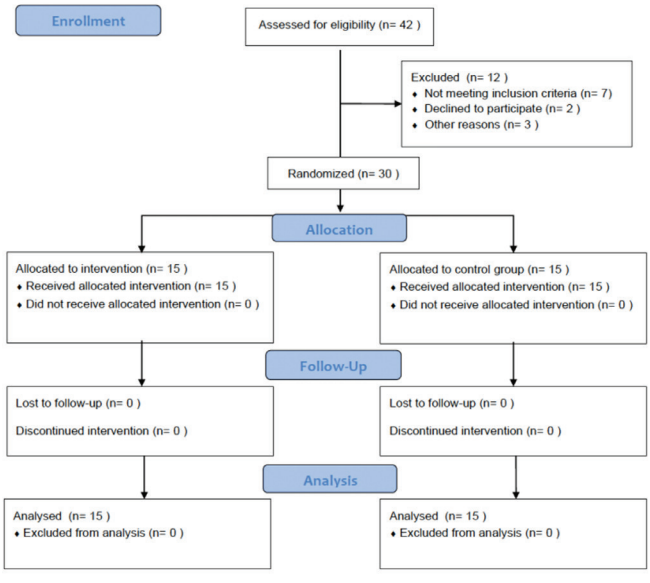

Figure 1. Consolidated Standards of Reporting Trials flowchart

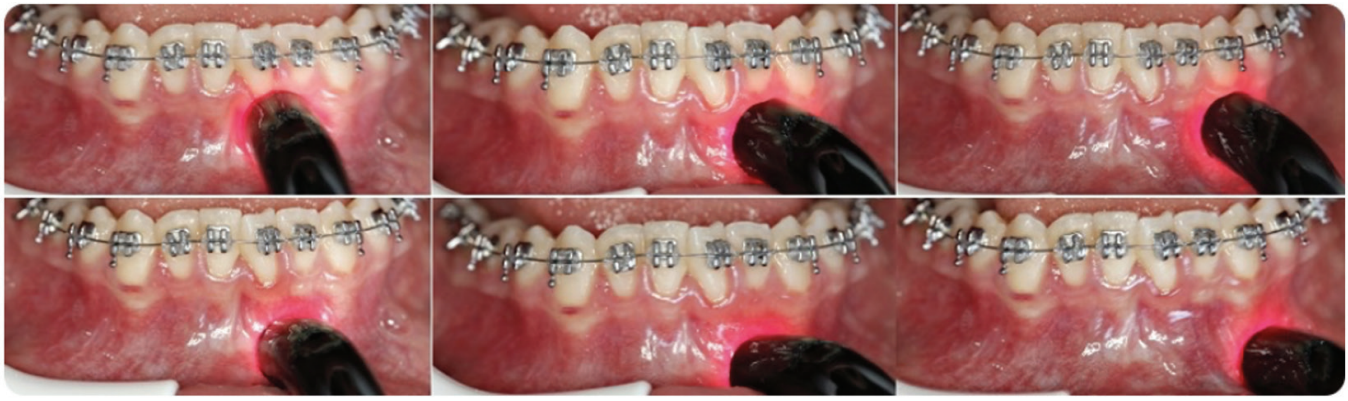

Figure 2. The application of LLL onto the cervical and apical midpoint of the mandibular anterior teeth roots
LLL, low-level lasers

Wuhan, China) was used in this study. The laser operated at a power output of 100 mW, an energy density of 8 J/cm^2, and an exposure time of 10 seconds was used in this study. The laser tip, held perpendicularly and in contact with the mucosa, had a radius of 4 mm and a spot area of approximately 0.125 mm^2.

A total of 12 irradiations, each lasting 10 seconds, were applied to two areas on the vestibular surfaces of the mandibular anterior teeth, one on the cervical third and one on the apical third (Figure 2). These applications were conducted immediately after archwire ligation (day 0) and subsequently on days 3, 7, and 14 and then every 14 days until leveling was completed.

Both the participants and the clinician wore protective goggles during the application to protect against the possible adverse effects of the laser beam. All laser applications were performed by the same investigator (Y.T.). In the control group, a placebo procedure was conducted by the same researcher on the indicated days, without pressing the pedal of the laser device. This approach ensured an effective assessment of individual pain levels (Y.T.). The second researcher, who determined whether the leveling was complete, and the participants in the study were blinded to group assignments.

Leveling Assessment

The leveling of mandibular anterior crowding was assessed using the objective grading system of the American Board of Orthodontics Phase III clinical examination by an orthodontist with 5 years of experience (Y.K.).[17] To evaluate the treatment outcomes, mandibular alginate impressions of the participants were taken to obtain plaster models before treatment and at the end of leveling. After these plaster models were scanned using iTero intraoral scanner (iTero Element 2, Align Technology, San Jose, CA, USA) and the digital orthodontic models were exported as stereolithography (STL) files and imported into OrthoCAD software (Align Technology, San Jose, CA, USA) to calculate LII by another investigator (Y.T.). To assess the measurement reliability, 10 pre-treatment STL files were remeasured 1 month after the first measurement. The reliability was evaluated using the intraclass correlation coefficient (ICC) and showed strong intraexaminer reliability (ICC =0.997).

When LII was 0.5 mm or less, the date of completing the leveling of mandibular anterior crowding was noted on the patient card. The leveling duration was calculated and recorded in days, from the bonding application to the end of leveling.

Pain Assessment

The participants' pain experiences were measured using a questionnaire containing the visual analogue scale (VAS), a 10 cm horizontal line with 0 representing no pain and 10 representing the worst pain possible. The patients were asked to consider the most severe pain they had experienced in the past, accept this as 10, and place a mark on the scale reflecting their current pain. The pain assessment was conducted immediately after the bonding procedure and ligation of 0.012-inch NiTi archwires (hour 0), at hours 2 and 6, and on days 1, 3, 7, 14, and 21. All individuals were given detailed information about when and how to fill in the forms (Y.T.). However, to prevent any issues during the completion of the forms, a timetable indicating which form should be filled out at what time and on which day was prepared.

Sample Size Calculation

The sample size was calculated with G*Power 3.1.2 (Franz Faul, Universität Kiel, Kiel, Germany) using the results of a previous randomized controlled clinical trial.[13] Considering the results of the laser and control groups of this study, the effect size (d, effect size) calculated for equal groups was determined to be 1.89. For a type I error (α=0.05) and 99% power, the sample size was calculated as 24 participants, with a minimum of 12 for each group. However, assuming a 15% exclusion rate, a total of 30 participants were included in this study, with 15 in each group.

Randomization

The participants were randomly assigned to the laser and control groups by coin flip, with an allocation ratio of 1:1. An operator, independent of the study, performed the random allocation. Women and men were separately randomly

assigned to the laser and control groups to ensure insignificant differences between the groups in terms of gender (laser: 11 women, 4 men; control: 11 women, 4 men). Furthermore, care was taken to ensure that LII was similar in both groups.

Statistical Analysis

Descriptive statistics for the studied variables were presented as mean, standard deviation, minimum, and maximum values. The normality assumption of the variables was tested using the Shapiro-Wilk test. In the comparison of quantitative data between the two groups, the Student's t-test was used for normally distributed groups, whereas the Mann-Whitney U test was used for non-normally distributed groups. All statistical analyses were performed using the Number Cruncher Statistical System 2007 (Kaysville, UT, USA), and the level of statistical significance was defined as 1% and 5%.

RESULTS

Throughout the study, there were no patient drop-outs (Figure 1). Additionally, no bracket failures were observed in any of the participants during the leveling duration. The mean ages of the participants in the laser and control groups were 15.61±1.28 and 17.16±2.76 years, respectively, with mean LIIs of 6.57±0.29 and 6.45±0.22 mm, respectively. Intergroup comparison results showed no significant differences in terms of mean age and LII (Table 1).The comparison results regarding the leveling duration of the laser and control groups are shown in Table 2. The mean leveling duration was 111.8±42.9 days in the laser group and 135.67±49.65 days in the control group. The differences in mean leveling duration between the laser and control groups were found to be insignificant. Group comparison results of the VAS scores identified a reduced pain level in the laser group compared with the control group; however, only the differences at hour 6 and on day 1 were found to be significant. The differences at hours 0 and 2 and on days 3, 7, 14, and 21 were insignificant (Table 3).

Table 1. Descriptive statistics

	Groups	Mean±SD	Min.	Max.	p-value
Age (year)	Laser	15.61±1.28	13.08	18.25	0.059
	Control	17.16±2.76	12.5	21.08	
Little's irregularity index (mm)	Laser	6.57±0.29	4.35	8.00	0.749
	Control	6.45±0.22	4.24	8.08	

Student's t-test was performed, p<0.05.
SD, standard deviation; Min., minimum; Max., maximum

Table 2. Comparison of the mean leveling duration of laser and control groups

	Groups	Mean±SD	Min.	Max.	p-value
Leveling duration (day)	Laser	111.8±42.9	61	185	0.170
	Control	137.67±49.65	50	216	

Student's t-test was performed, p<0.05.
SD, standard deviation; Min., minimum; Max., maximum

DISCUSSION

In recent years, research has focused on accelerating tooth movement and reducing treatment time.[18,19] This study which investigated the effect of LLLT on both the leveling of mandibular anterior crowding and the level of pain during leveling. The results showed no significant differences between the laser and control groups in terms of mean leveling duration. However, when comparing the groups' VAS scores, pain levels were significantly lower in the laser group than in the control group only at hour 6 and on the 1st day. Therefore, the null hypothesis was partially accepted.

In the literature, there are studies reporting that LLLT accelerates orthodontic tooth movement,[5,13,14,20,21] as well as studies reporting no significant effect.[15,22-25] One study reported that low-dose laser application decreased the acceleration of orthodontic tooth movement.[26] Variability in the study results may be due to factors such as the dose of laser irradiation, radiation mode, energy density, application location and duration, different tooth movements, and the fact that some studies are animal experiments. Due to the variability of results, more experimental and randomized clinical trials are

Table 3. Intergroup comparison results of visual analog scale (VAS) scores recorded at different time-intervals

		Laser	Control	p-value
0th hour	**Mean±SD**	0.53±0.83	0.73±1.49	0.691
	Min.	0	0	
	Max.	3	5	
2nd hour	**Mean±SD**	1.87±0.92	2.87±1.55	0.092
	Min.	0	1	
	Max.	3	5	
6th hour	**Mean±SD**	2.67±1.29	5.60±1.50	0.001**
	Min.	1	3	
	Max.	5	10	
1st day	**Mean±SD**	3.07±1.58	5.27±2.22	0.006**
	Min.	1	2	
	Max.	5	10	
3rd day	**Mean±SD**	2.67±1.45	4.0±2.54	0.181
	Min.	0	1	
	Max.	5	10	
7th day	**Mean±SD**	1.27±1.33	2.47±1.96	0.074
	Min.	0	0	
	Max.	4	7	
14th day	**Mean±SD**	1.40±1.06	1.50±1.30	0.931
	Min.	0	0	
	Max.	4	4	
21th day	**Mean±SD**	1.0±0.93	1.67±0.90	0.256
	Min.	0	0	
	Max.	3	3	

Mann-Whitney U test was performed, p<0.05, **p<0.01
SD, standard deviation; Min., minimum; Max., maximum

needed.[24,27] Therefore, when designing the study, we aimed to standardize the type of photobiomodulation (LED or LLLT) and other factors that may affect tooth acceleration.

It is stated that the most important disadvantage of LEDs is their semi-monochromatic structure. Additionally, LEDs have limitations such as a wide wavelength, spot size, and the difficulty of achieving the power obtained with laser applications.[28] A broad review of the literature presented that an extraoral LED device was used in three studies,[5,20,21] an intraoral LED device was used in three studies,[6,29,30] and LLLT was used in one study,[13] in which the effect of photobiomodulation on leveling duration was evaluated. Although methodological differences existed between the LED studies, their results showed a significantly decreased leveling duration due to increasing tooth movement.[5,6,20,21,29,30] The leveling duration in this study was determined to be longer than in the studies of Nahas et al.,[20] Shaughnessy et al.,[6] and Okla et al.[30] and shorter than in the studies of Lo Giudice et al.[21] and Caccianiga et al.[29] However, due to their structure, LEDs have been reported to provide the same effect on cellular activity as low-dose laser applications. The lack of standardization in studies makes research results and LED applications controversial in photobiomodulation.[28] The recommended wavelength for LLLT is in the range of 600-1200 nm.[20] At this wavelength, the laser beam is well absorbed by pigmented tissues and less absorbed by hemoglobin and water, providing good penetration into the tissues.[31] Additionally, wavelengths from 780 nm to 930 nm are reported to accelerate tooth movement effectively, according to a systematic review that investigated the effect of different wavelengths of Ga-Al-As diode lasers.[32]

Previously published studies have shown that the biostimulatory effect of LLLT depends on the energy density, with stimulation observed at low energy densities and inhibition observed at higher ones.[2,20,33] A systematic review found that diode lasers with energy densities of 2.5, 5, and 8 J/cm^2 were more effective than those with energy densities of 20 and 25 J/cm^2, though the optimal dose remains uncertain.[2] A review of previous studies revealed variations in energy density and exposure time. In the study by Al-Sayed Hasan et al.[13] the energy density was observed to be 2.5 J/cm^2 and 15 seconds/point in the study by 7.5 J/cm^2 and 3 seconds/point in the study by Qamruddin et al.,[10] and 25 J/cm^2 and 23 seconds/point in the study by Limpanichkul et al.,[22] respectively. In light of this information, an 810 nm diode laser device with an energy density of 8 J/cm^2 and an exposure time of 10 seconds/point was preferred in this study.

The small mesio-distal dimensions of mandibular anterior teeth reduce the interbracket distance. Therefore, NiTi archwires with low hardness and high elasticity should be preferred during leveling to minimize binding and notching due to crowding.[34] Profitt, Bennett, and McLaughlin also recommended using round archwires that apply light force during leveling.[35] Camacho and Cujar,[16] Ghaffar et al.,[14] and Al-Sayed Hasan et al.[13] changed the diameter and cross-section of the archwires during treatment. In this study, 0.012-inch NiTi archwires were used unchanged until leveling was completed to standardize the factors that could affect tooth movement.

A study evaluating malocclusion types, their distribution by gender, and the degree of maxillary and mandibular crowding determined that moderate crowding was most common in the anterior mandible.[36] The mesio-distal dimensions of mandibular molars and the displacement of the mandible due to growth and development were found to be effective in the higher incidence of mandibular anterior crowding.[37] Additionally, LII was used as the preferred method for assessing crowding in four recent studies examining the effect of photobiomodulation on the leveling of anterior teeth.[6,13,20,21] Therefore, participants with moderate mandibular anterior crowding, as determined by LII, were included in this study. Camacho and Cujar[16] evaluated the effect of LLLT on tooth movement, reporting an average reduction in treatment duration of 167 days (30% less) with laser application (30% less). However, evaluating the effect over the total treatment period suggests that many factors, including the end of orthodontic treatment, may affect the results. Two other studies investigating the rate of tooth leveling found statistically significant differences.[13,14] Al-Sayed Hasan et al.[13] evaluated the leveling and alignment of the maxillary anterior teeth in patients treated with four first premolar extractions. The leveling and alignment duration was found to be 81.23 days in the laser group and 109.23 days in the control group. Although these durations are shorter than those in our study, the intergroup differences are partially similar-28 days in the study by Al-Sayed Hasan et al.[13] and 23.87 days in our study. These discrepancies might result from the treatment plan, where the leveling and alignment of the maxillary anterior teeth were evaluated after the extraction of the first premolar in the study by Al-Sayed Hasan et al.[13]

Ghaffar et al.[14] also reported LLLT in the mandibular anterior region as 68.2 days in the laser group and 109.5 days in the control group. The difference between the results of these two studies and our study may also be due to the change in archwires.[13,14] In the study by El-Shehawy et al.,[15] patients were treated with conventional NiTi archwires in a standardized sequence of 0.012, 0.014, and 0.016 inches during the leveling and alignment phase for 12 weeks. At the end of this period, it was reported that no significant difference was observed in the leveling and alignment of the lower anterior region between the laser-treated group and the control group.

Relatively few studies have compared the effect of LLLT on pain level during leveling with a control group.[14,38,39] Among the available studies using the VAS scores, the evaluations were performed immediately after the initial archwire placement, at hour 2, and on days 1, 2, 3, and 7 in patients who had non-extraction fixed orthodontic treatment in the study by Celebi et al.[39] In contrast, Al-Sayed Hasan et al.[12] assessed pain at hours 1 and 6 and on days 1, 2, and 3 in patients who had undergone four first premolar extractions. Both studies reported no significant

intergroup differences. In this study, group comparison results at hour 6 and on day 1 showed significantly reduced pain levels in the laser group compared with the control group. These discrepancies might be explained by differences in laser parameters and application protocols, as well as in age and gender distributions. Furthermore, whereas the maxillary dental arch was evaluated in these studies, the mandibular dental arch was evaluated in our study. Ghaffar et al.[14] used the VAS every day for the first 7 days to assess pain associated with initial archwire placement. The laser group reported statistically significantly lower mean pain scores than the control group only on the 5th day. The pain scores are compatible with the study of Ghaffar et al.,[14] which is the most similar study to the methodology of this study. However, the fact that this study shows laser therapy to be effective on pain only at hour 6 and on day 1 necessitates a discussion about the clinical significance of this method. At this point, pharmacological methods, such as analgesics, could be preferred instead of LLLT.

Study Limitations

The main limitations of this study include a small sample size, single wavelength LLL application, the inability to standardize the amount of crowding, the assessment of only the leveling, and the failure to investigate the rate of tooth movement over time. Therefore, future studies with larger sample sizes, different LLL wavelengths and application protocols, and an evaluation of both leveling/alignment and the rate of tooth movement over time are recommended.

CONCLUSION

The leveling duration showed no significant differences between the laser and control groups. Group comparison results of the VAS scores at hour 6 and on day 1 exhibited significantly reduced pain levels in the laser group compared with the control group.

Ethics

Ethics Committee Approval: The approval of the Van Yüzüncü Yıl University Faculty of Medicine, Clinical Research Ethics Committee was obtained to conduct this study (approval no.: 24, date: 05.05.2020).

Informed Consent: Informed consent forms was obtained.

Footnotes

Author Contributions: Surgical and Medical Practices - Y.T.; Concept - Y.K.; Design - Y.K.; Data Collection and/or Processing - Y.T.; Analysis and/or Interpretation - Y.T., Y.K.; Literature Search - Y.T., Y.K.; Writing - Y.T., Y.K.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: This study did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES

1. Nimeri G, Kau CH, Abou-Kheir NS, Corona R. Acceleration of tooth movement during orthodontic treatment--a frontier in orthodontics. *Prog Orthod*. 2013;14:42. [CrossRef]
2. Ge MK, He WL, Chen J, et al. Efficacy of low-level laser therapy for accelerating tooth movement during orthodontic treatment: a systematic review and meta-analysis. *Lasers Med Sci*. 2015;30(5):1609-1618. [CrossRef]
3. Yi J, Xiao J, Li Y, Li X, Zhao Z. Efficacy of piezocision on accelerating orthodontic tooth movement: A systematic review. *Angle Orthod.* 2017;87(4):491-498. [CrossRef]
4. Miles P. Accelerated orthodontic treatment - what's the evidence? *Aust Dent J*. 2017;62(Suppl 1):63-70. [CrossRef]
5. Kau CH, Kantarci A, Shaughnessy T, et al. Photobiomodulation accelerates orthodontic alignment in the early phase of treatment. *Prog Orthod*. 2013;14:30. [CrossRef]
6. Shaughnessy T, Kantarci A, Kau CH, Skrenes D, Skrenes S, Ma D. Intraoral photobiomodulation-induced orthodontic tooth alignment: a preliminary study. *BMC Oral Health*. 2016;16:3. [CrossRef]
7. Bakdach WMM, Hadad R. Effectiveness of low-level laser therapy in accelerating the orthodontic tooth movement: A systematic review and meta-analysis. *Dent Med Probl*. 2020;57(1):73-94. [CrossRef]
8. Acar YB, Biren S. Pharmacological approaches for accelerated orthodontic tooth movement. *Turkiye Klinikleri J Orthod-Special Topics*. 2018;4(1):14-20. [CrossRef]
9. Ng DY, Chan AK, Dalci O, Petocz P, Papadopoulou AK, Darendeliler MA. A pilot study of laser energy transmission through bone and gingiva. *J Am Dent Assoc.* 2018;149(8):704-711. [CrossRef]
10. Qamruddin I, Alam MK, Fida M, Khan AG. Effect of a single dose of low-level laser therapy on spontaneous and chewing pain caused by elastomeric separators. *Am J Orthod Dentofacial Orthop*. 2016;149(1):62-66. [CrossRef]
11. Farias RD, Closs LQ, Miguens SA Jr. Evaluation of the use of low-level laser therapy in pain control in orthodontic patients: A randomized split-mouth clinical trial. *Angle Orthod.* 2016;86(2):193-198. [CrossRef]
12. AlSayed Hasan MMA, Sultan K, Hamadah O. Evaluating low-level laser therapy effect on reducing orthodontic pain using two laser energy values: a split-mouth randomized placebo-controlled trial. *Eur J Orthod*. 2018;40(1):23-28. [CrossRef]
13. AlSayed Hasan MMA, Sultan K, Hamadah O. Low-level laser therapy effectiveness in accelerating orthodontic tooth movement: A randomized controlled clinical trial. *Angle Orthod*. 2017;87(4):499-504. [CrossRef]
14. Ghaffar YKA, El Sharaby FA, Negm IM. Effect of low-level laser therapy on the time needed for leveling and alignment of mandibular anterior crowding. *Angle Orthod.* 2022;92(4):478-486. [CrossRef]
15. El Shehawy TO, Hussein FA, Ei Awady AA. Outcome of photodynamic therapy on orthodontic leveling and alignment of mandibular anterior segment: A controlled clinical trial. *Photodiagnosis Photodyn Ther*. 2020;31:101903. [CrossRef]
16. Camacho AD, Cujar SA. Acceleration effect of orthodontic movement by application of low-intensity laser. *J Oral Laser Appl*. 2010;10:99-105. [CrossRef]
17. Casko JS, Vaden JL, Kokich VG, et al. Objective grading system for dental casts and panoramic radiographs. American Board of

Orthodontics. *Am J Orthod Dentofacial Orthop.* 1998;114(5):589-599. [CrossRef]

18. El-Angbawi A, McIntyre GT, Fleming PS, Bearn DR. Non-surgical adjunctive interventions for accelerating tooth movement in patients undergoing fixed orthodontic treatment. *Cochrane Database Syst Rev*. 2015;2015(11):CD010887. [CrossRef]
19. Fleming PS, Fedorowicz Z, Johal A, El-Angbawi A, Pandis N. Surgical adjunctive procedures for accelerating orthodontic treatment. *Cochrane Database Syst Rev.* 2015;2015(6):CD010572. [CrossRef]
20. Nahas AZ, Samara SA, Rastegar-Lari TA. Decrowding of lower anterior segment with and without photobiomodulation: a single center, randomized clinical trial. *Lasers Med Sci.* 2017;32(1):129-135. [CrossRef]
21. Lo Giudice A, Nucera R, Leonardi R, Paiusco A, Baldoni M, Caccianiga G. A comparative assessment of the efficiency of orthodontic treatment with and without photobiomodulation during mandibular decrowding in young subjects: a single-center, single-blind randomized controlled trial. *Photobiomodul Photomed Laser Surg*. 2020;38(5):272-279. [CrossRef]
22. Limpanichkul W, Godfrey K, Srisuk N, Rattanayatikul C. Effects of low-level laser therapy on the rate of orthodontic tooth movement. *Orthod Craniofac Res.* 2006;9(1):38-43. [CrossRef]
23. Marquezan M, Bolognese AM, Araújo MT. Effects of two low-intensity laser therapy protocols on experimental tooth movement. *Photomed Laser Surg.* 2010;28(6):757-762. [CrossRef]
24. Dalaie K, Hamedi R, Kharazifard MJ, Mahdian M, Bayat M. Effect of low-level laser therapy on orthodontic tooth movement: a clinical ınvestigation. *J Dent (Tehran).* 2015;12(4):249-256. [CrossRef]
25. Salehi P, Heidari S, Tanideh N, Torkan S. Effect of low-level laser irradiation on the rate and short-term stability of rotational tooth movement in dogs. *Am J Orthod Dentofacial Orthop*. 2015;147(5):578-586. [CrossRef]
26. Goulart CS, Nouer PR, Mouramartins L, Garbin IU, de Fátima Zanirato Lizarelli R. Photoradiation and orthodontic movement: experimental study with canines. *Photomed Laser Surg*. 2006;24(2):192-196. [CrossRef]
27. Kalemaj Z, Debernardl CL, Buti J. Efficacy of surgical and non-surgical interventions on accelerating orthodontic tooth movement: a systematic review. *Eur J Oral Implantol*. 2015;8(1):9-24. [CrossRef]
28. Heiskanen V, Hamblin MR. Photobiomodulation: lasers vs. light emitting diodes? *Photochem Photobiol Sci.* 2018;17(8):1003-1017. [CrossRef]
29. Caccianiga G, Paiusco A, Perillo L, et al. Does low-level laser therapy enhance the efficiency of orthodontic dental alignment? results from a randomized pilot study. *Photomed Laser Surg.* 2017;35(8):421-426. [CrossRef]
30. Okla NA, Bader DMA, Makki L. Effect of photobiomodulation on maxillary decrowding and root resorption: a randomized clinical trial. *APOS*. 2018;8:86-91. [CrossRef]
31. Kacprzak A, Strzecki A. Methods of accelerating orthodontic tooth movement: A review of contemporary literature. *Dent Med Probl.* 2018;55(2):197-206. [CrossRef]
32. Domínguez Camacho A, Montoya Guzmán D, Velásquez Cujar SA. Effective wavelength range in photobiomodulation for tooth movement acceleration in orthodontics: a systematic review. *Photobiomodul Photomed Laser Surg.* 2020;38(10):581-590. [CrossRef]
33. Arumughan S, Somaiah S, Muddaiah S, Shetty B, Reddy G, Roopa S. A comparison of the rate of retraction with low-level laser therapy and conventional retraction technique. *Contemp Clin Dent.* 2018;9(2):260-266. [CrossRef]
34. Khier SE, Brantley WA, Fournelle RA. Bending properties of superelastic and nonsuperelastic nickel-titanium orthodontic wires. *Am J Orthod Dentofacial Orthop.* 1991;99(4):310-318. [CrossRef]
35. Sebastian B. Alignment efficiency of superelastic coaxial nickel-titanium vs superelastic single-stranded nickel-titanium in relieving mandibular anterior crowding: a randomized controlled prospective study. *Angle Orthod*. 2012;82(4):703-708. [CrossRef]
36. Sayin MO, Türkkahraman H. Malocclusion and crowding in an orthodontically referred Turkish population. *Angle Orthod.* 2004;74(5):635-639. [CrossRef]
37. Rajbhoj AA, Parchake P, Begnoni G, Willems G, Cadenas de Llano-Pérula M. Dental changes in humans with untreated normal occlusion throughout lifetime: A systematic scoping review. *Am J Orthod Dentofacial Orthop.* 2021;160(3):340-362. [CrossRef]
38. AlSayed Hasan MMA, Sultan K, Ajaj M, Voborná I, Hamadah O. Low-level laser therapy effectiveness in reducing initial orthodontic archwire placement pain in premolars extraction cases: a single-blind, placebo-controlled, randomized clinical trial. *BMC Oral Health.* 2020;20(1):209. [CrossRef]
39. Celebi F, Turk T, Bicakci AA. Effects of low-level laser therapy and mechanical vibration on orthodontic pain caused by initial archwire. *Am J Orthod Dentofacial Orthop*. 2019;156(1):87-93. [CrossRef]