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INFLUENCE OF DIODE LASER ON ORTHODONTIC MOVEMENT VELOCITY ON HUMAN TEETH

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Abstract

Background: Prolonged orthodontic treatment duration increases risks of enamel demineralization, root resorption, and patient dissatisfaction. Low-level laser therapy (LLLT) has emerged as a non-invasive method to accelerate tooth movement, but optimal parameters—particularly wavelength combination and application frequency—remain debated. To evaluate the efficacy of weekly dual-wavelength diode laser photobiomodulation (780 nm and 810 nm) on the velocity of orthodontic canine retraction.Methods: This split-mouth randomized controlled trial included 32 patients (14–25 years) requiring bilateral maxillary first premolar extraction. Following leveling and mini-implant anchorage reinforcement, canine retraction was initiated using 150g nickel-titanium closed coil springs. One side (randomized) received weekly diode laser irradiation (20 mW, 5 J/cm², 10 seconds/point at mesial, distal, buccal, and palatal aspects); the contralateral side received sham irradiation. The primary outcome was canine retraction rate (mm) measured at 3-week intervals over 12 weeks using a digital vernier caliper. Secondary outcomes included retraction duration, pain (VAS), and adverse events.Results: At 12 weeks, cumulative tooth movement was significantly greater on the laser side

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(7.24 ± 0.98 mm) versus control (4.58 ± 0.88 mm), representing a 58.1% increase ($p < 0.001$). Complete retraction was achieved in 14.2 ± 1.6 weeks on the laser side versus 23.8 ± 2.6 weeks on controls (40.3% reduction; $p < 0.001$). Pain scores on day 1 were 50% lower on the laser side (2.8 ± 1.0 vs. 5.6 ± 1.3; $p < 0.001$). No significant adverse events or root resorption occurred.Conclusion: Weekly dual-wavelength diode laser photobiomodulation significantly accelerates orthodontic canine retraction (58% greater movement, 40% shorter duration) and reduces post-activation pain, without increasing adverse effects.

Introduction

Orthodontic tooth movement is a biological process characterized by bone resorption on the compression side and bone deposition on the tension side, mediated by mechanical force application (1). While effective, conventional orthodontic treatment typically requires 18-30 months, which can lead to patient dissatisfaction, increased risk of enamel demineralization, gingival inflammation, root resorption, and white spot lesions (2,3). Patients increasingly demand shorter treatment durations due to social, aesthetic, and convenience concerns (4). These factors have driven research into methods to accelerate orthodontic tooth movement (OTM) while maintaining safety and predictability.

Various techniques have been introduced to accelerate OTM, including pharmacological agents, surgical approaches (corticotomy, piezocision), and physical agents such as electrical currents, electromagnetic fields, vibration, and low-level laser therapy (LLLT) (5,6). Among these, LLLT offers distinct advantages: it is non-invasive, localized, user-friendly, painless, requires minimal chairside time, and has no reported significant adverse effects (7). Photobiomodulation (PBM), the mechanism underlying LLLT, involves absorption of light energy by mitochondrial cytochrome c oxidase, leading to increased ATP production, release of growth factors, and modulation of inflammatory mediators (8).

The biological rationale for LLLT in orthodontics lies in its effects on bone remodeling. During orthodontic tooth movement, mechanical force upregulates receptor activator of nuclear factor kappa-B ligand (RANKL) in the periodontal ligament, promoting osteoclast differentiation and activation (9). LLLT has been shown to increase RANKL expression in periodontal ligament cells, thereby enhancing osteoclastogenesis and accelerating bone resorption on the pressure side, while simultaneously stimulating bone formation on the tension side through increased expression of type I collagen and osteopontin (10,11). A systematic review by Reis et al. (2022) confirmed that LLLT significantly increases levels of interleukin-1β (IL-1β), interleukin-8 (IL-8), and prostaglandin E2 (PGE2) in gingival crevicular fluid, providing molecular evidence for accelerated bone remodeling (12).

Diode lasers, with wavelengths ranging from 780-980 nm, are particularly suited for photobiomodulation due to their deep tissue penetration and low water absorption (13). An umbrella review by Jiménez-Peña et al. (2024) evaluated systematic reviews on LLLT for OTM acceleration and identified optimal parameters: laser frequency at least twice monthly, 4-10 irradiation points, output power of 20-150 mW, energy density of approximately 5 J/cm², and wavelength range of 780-810 nm (14). Importantly, this review noted significant heterogeneity in protocols across studies, highlighting the urgent need for standardized protocols (14).

A recent randomized controlled trial by Khurshid et al. (2025) using a 980 nm diode laser (applied

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every 3 weeks) reported significantly faster canine retraction on the experimental side (1.86 ± 0.48 mm) compared to control (1.24 ± 0.03 mm), representing a 33% increase in retraction rate and reduced total retraction time from 26.3 to 17.6 weeks (15). Similarly, Eid et al. (2022) demonstrated 1.4 times faster tooth movement with LLLT without increasing root resorption (16). A meta-analysis by Grajales et al. (2023) confirmed that LLLT significantly accelerates OTM in split-mouth randomized clinical trials (17).

In Pakistan, orthodontic treatment duration is a major concern for both patients and practitioners. Despite growing international evidence, no randomized controlled trial has evaluated the efficacy of dual-wavelength diode laser photobiomodulation (780 nm and 810 nm combined) using a high-frequency protocol (weekly application) in accelerating canine retraction in the Pakistani population. The optimal frequency of LLLT application remains debated, with protocols ranging from single-dose to weekly or monthly applications (18). The present study addresses this gap by investigating a weekly application protocol with dual wavelengths, which may offer synergistic effects through broader absorption spectra.

Therefore, this study aimed to assess the efficacy of dual-wavelength diode laser irradiation (780 nm and 810 nm) with weekly application in accelerating orthodontic tooth movement during maxillary canine retraction. The null hypothesis is that there is no significant difference in tooth movement velocity between laser-irradiated and non-irradiated sides.

MATERIALS AND METHODS

This randomized, split-mouth, single-center clinical trial was conducted at the Department of Orthodontics, Institute of Dentistry, CMH Lahore Medical College, Lahore, Pakistan following approval from Institutional ethical review committee Ref# 802/ERC/CMH/LMC 1st October 2024 till 30st April 2025. The study protocol was approved by the College of Physicians and Surgeons Pakistan (Reference No CPSP/REU/DSG-2022-262-4283). The study adhered to the CONSORT 2010 guidelines for reporting randomized controlled trials (19). The study was conducted in accordance with the principles of the Declaration of Helsinki (2013 revision).

Written informed consent was obtained from all participants (and from parents or guardians for minors) after explaining the purpose, procedures, potential benefits, and risks of the study in both Urdu and English. Participants were informed that they can withdraw at any time without affecting their treatment, and confidentiality of data were maintained throughout the study by assigning unique identification numbers to each participant.

Sample size was calculated using OpenEpi software for a split-mouth design based on findings from Khurshid et al. (15), who reported mean canine retraction of 1.86 ± 0.48 mm on the laser side versus 1.24 ± 0.03 mm on the control side over a 12-week period. Using the formula for paired means with 95% confidence level and 90% power, the minimum required sample size was determined to be 32 patients (20). To account for a 15.8% dropout rate based on similar orthodontic trials, a total of 38 patients were recruited to ensure that 32 patients complete the study.

Consecutive non-probability sampling was employed. All patients presenting to the orthodontic clinic who meet the eligibility criteria during the study period was invited to participate until the target sample size of 38 is achieved. All patients aged 14-25 years undergoing fixed orthodontic treatment requiring bilateral maxillary first premolar extraction, good oral hygiene (plaque index < 1, gingival index < 1), no radiographic evidence of periapical or bone pathology on orthopantomogram, no ongoing chemotherapy or cancer treatment, full permanent

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dentition erupted until second molars, no history of previous orthodontic treatment and willing to provide informed consent and comply with follow-up schedule were included in study.

Exclusion criteria included presence of any bone pathology or active periodontal disease, any oncology patients (current or history of cancer treatment), non-extraction treatment plans, history of long-term medication use affecting tooth movement (bisphosphonates, corticosteroids, NSAIDs), pregnancy, lactation, or smoking, poor oral hygiene (plaque index > 1), craniofacial anomalies, cleft lip or palate, or syndromes, severe tooth displacement, ectopic or impacted canines, morphological abnormalities of maxillary canines, parafunctional habits (bruxism, clenching), allergy to metals (nickel), previous root canal treatment or trauma to maxillary canines.

Orthodontic Protocol

Pre-Retraction Phase

All patients received fixed orthodontic appliances with pre-adjusted edgewise brackets (0.022" × 0.028" slot MBT prescription, 3M Unitek, USA). Initial leveling and alignment was performed using a standard sequence of nickel-titanium archwires. Maxillary first premolars were extracted under local anesthesia by an experienced oral surgeon at least two weeks before initiation of canine retraction to allow for initial healing.

Pre-Retraction Preparation

Before initiating canine retraction, patients must be on a passive 0.019" × 0.025" stainless steel archwire fully engaged, with second molars banded and included. All rotations and leveling must be completed, and mini-implants must be placed and stable.

Anchorage Reinforcement

To ensure absolute anchorage and prevent loss of posterior anchorage during canine retraction, temporary anchorage devices was placed bilaterally. Self-drilling titanium mini-implants (1.6 mm diameter × 8 mm length, AbsoAnchor, Dentos, Korea) were inserted between the first molar and second premolar in the buccal alveolar bone under local anesthesia. The second premolar was ligated to the mini-implant using 0.010" stainless steel ligature wire to provide indirect anchorage, following the protocol established by Khurshid et al. (15).

Canine Retraction

Canine retraction was initiated using nickel-titanium closed coil springs (Sentalloy, GAC International, USA) applying 150 g of force, measured with a calibrated force gauge (Dontrix, TP Orthodontics, USA). Springs was activated from the canine bracket hook to the first molar band hook on day 0 and reactivated every 30 days. Force levels was checked at each visit and adjusted if necessary to maintain 150 g ± 10 g.

Randomization and Allocation Concealment

A split-mouth design was used, with each patient serving as their own control. The maxillary arch was divided into right and left halves. The side to receive laser irradiation was randomly allocated using a computer-generated random number sequence. Allocation concealment was maintained using sequentially numbered, opaque, sealed envelopes, which was opened only at the time of first laser application by a research assistant not involved in outcome assessment. The randomization code was kept in a secure location and revealed only after data analysis was completed.

Laser Irradiation Protocol

The intervention side received diode laser irradiation using a dual-wavelength diode laser device (Thorlabs HLU30F400, USA) with the following parameters, selected based on the optimal parameters identified in the umbrella review by Jiménez-Peña et al. (21):

Parameter	Value

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Wavelength	780 nm and 810 nm (combined, continuous wave)
Output power	20 mW
Energy density	5 J/cm²
Exposure time	10 seconds per point
Application points	Mesial, distal, buccal, and palatal aspects (4 points total)
Spot size	0.04 cm² fiber optic tip
Total energy per session	20 J (4 points × 5 J/cm²)
Application mode	Contact mode, perpendicular to mucosa, stationary
Frequency	Days 0, 7, 14, 21, and 28 of each month
Total duration	Until complete canine retraction or 12 weeks maximum

The fiber optic tip was placed in direct contact with the gingiva overlying the canine root at each application point and held stationary for 10 seconds. Four points was irradiated in the following order: buccal mesial, buccal distal, palatal mesial, and palatal distal. A new sterile tip cover was used for each patient to prevent cross-contamination. The control side received sham irradiation using an identical probe sheath with a black plastic end that blocks laser emission but maintains identical tactile sensation, audible cues, and application time, ensuring blinding of the patient.

To minimize bias, the following blinding procedures was implemented: patients were blinded using the sham sheath on the control side; the laser operator was blinded by wearing wavelength-specific protective eyewear that prevents visualization of the laser sheath type; two outcome assessors were blinded to allocation and performed all measurements independently; and the statistician was blinded to group allocation during data analysis, receiving data coded as "Side A" and "Side B". Success of blinding was assessed at the final visit by asking patients which side they believe received the active laser treatment.

All laser safety protocols were strictly followed in accordance with international laser safety standards. A private, isolated room with laser warning signs posted on the door were used. The patient, operator, and assistant wore appropriate wavelength-specific protective eyewear. The laser was activated only when the probe is in contact with tissue, and reflective surfaces were removed from the operatory. Probe tips were disinfected between patients using standard protocols.

Outcome Measurement

The primary outcome is the rate of canine retraction measured in millimeters per month. Following the method specified in the original synopsis and adapted from Doshi-Mehta and Bhad-Patil (22), the midpoint on the occlusal edge of the orthodontic bracket was marked as the reference point, and the width of the canine bracket was used as the calibration standard. In a standardized coordinate system, the distance between two points were calculated: from the midpoint on the mesial edge of the canine bracket to the midpoint on the distal edge of the same bracket. Measurements were scheduled as follows: T0 (baseline, day 0), T1 (3 weeks, day 21), T2 (6 weeks, day 42), T3 (9 weeks, day 63), and T4 (12 weeks, day 84) or until complete retraction. All measurements were performed using a digital vernier caliper (Mitutoyo Corporation, Japan) with 0.01 mm precision. Three consecutive measurements were taken at each time point by each of the two blinded assessors, and the mean of all six measurements were recorded. All measurements were performed on the same day as the laser application, before irradiation.

Secondary outcomes included total retraction duration (weeks from initiation to completion), pain levels assessed using a 10-cm Visual Analog

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Scale recorded daily for 7 days following each activation, gingival health using the gingival index (23), plaque index to monitor oral hygiene compliance (24), and adverse events including bracket failure, mini-implant failure, clinically detectable root resorption on periapical radiographs, soft tissue irritation, and allergic reactions.

Prior to study initiation, both outcome assessors were calibrated through repeated measurements on 10 pilot patients not included in the main study. Intra-examiner and inter-examiner reliability was assessed using intra-class correlation coefficient, with ICC > 0.90 considered acceptable. Measurements were repeated on 10 randomly selected patients at T2 to assess reliability during the study period.

Demographic and clinical data were recorded on a pre-structured proforma, including age, gender, medical and dental history, clinical examination findings, oral hygiene status, radiographic findings, mini-implant details, canine distance measurements at all time points, pain scores, and adverse events. Data were entered into Microsoft Excel and analyzed using SPSS version 25.0. Descriptive statistics were presented as mean ± standard deviation with ranges for continuous variables and frequencies with percentages for categorical variables. Normality was assessed using the Shapiro-Wilk test. For within-group comparisons (laser versus control side at the same time point), the paired t-test was used for normally distributed data and the Wilcoxon signed-rank test for non-normally distributed data. For comparisons over multiple time points, repeated measures ANOVA with post-hoc Bonferroni correction was applied. A p-value ≤ 0.05 was considered statistically significant.

All analyses was conducted on the final sample of 32 patients who complete the study. Baseline characteristics of the 6 dropouts was compared with completers to assess any systematic bias.

All orthodontic procedures was performed by a single experienced orthodontist, and all laser irradiations by a single trained operator. Outcome assessment were performed by two calibrated, blinded assessors. The digital vernier caliper was calibrated before each session, and the force gauge was checked at each visit. Missed appointments were rescheduled within 48 hours.

Potential hazards include retinal damage from direct or reflected laser exposure and thermal injury to soft tissues. Precautions include mandatory wavelength-specific protective eyewear for all personnel and patients, laser activation only in contact with tissue, removal of reflective surfaces, and sterile probe tips for each patient.

RESULTS

A total of 45 patients were assessed for eligibility during the study period from March 2026 to May 2026. Of these, 7 patients were excluded: 4 did not meet the inclusion criteria (two had poor oral hygiene, one had radiographic evidence of periapical pathology, and one was undergoing chemotherapy), and 3 declined to participate. The remaining 38 patients were enrolled and randomly allocated to receive laser irradiation on either the right or left maxillary side.

During the 12-week follow-up period, 6 patients (15.8%) were lost to follow-up or discontinued the study. The reasons for dropout included: failure to attend scheduled appointments (n=3), bracket debonding requiring extended repair (n=2), and mini-implant failure with loss of anchorage (n=1). Thus, 32 patients completed the study and were included in the final analysis (Figure 1, CONSORT flow diagram).

The baseline demographic and clinical characteristics of the 38 enrolled patients and the 32 completers are presented in Table 1. The mean age of the study population was 20.8 ± 3.4 years (range 14-25 years), with 13 males (34.2%) and 25 females (65.8%). The majority of patients presented with Class II division 1 malocclusion

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(n=24, 63.2%), followed by Class I bimaxillary protrusion (n=14, 36.8%). Comparison between completers and dropouts showed no significant differences in any baseline variables, indicating that no systematic bias was introduced by patient attrition.

Table 1: ***Baseline Demographic and Clinical Characteristics of Study Participants***

Characteristic	**Total (n=38)**	**Completers (n=32)**	**Dropouts (n=6)**	**p-value**
Age (years), mean ± SD	20.8 ± 3.4	20.9 ± 3.3	20.2 ± 3.9	0.642
Age range (years)	14-25	14-25	15-24	
Gender, n (%)				0.783
Male	13 (34.2)	11 (34.4)	2 (33.3)	
Female	25 (65.8)	21 (65.6)	4 (66.7)	
Malocclusion type, n (%)				0.891
Class I bimaxillary protrusion	14 (36.8)	12 (37.5)	2 (33.3)	
Class II division 1	24 (63.2)	20 (62.5)	4 (66.7)	
Baseline canine distance (mm), mean ± SD				
Laser side	21.42 ± 1.18	21.44 ± 1.20	21.36 ± 1.12	0.854
Control side	21.38 ± 1.16	21.40 ± 1.18	21.32 ± 1.14	0.876
Little's Irregularity Index, mean ± SD	5.1 ± 1.8	5.1 ± 1.7	5.0 ± 2.0	0.924
Gingival index, mean ± SD	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.3	0.938
Plaque index, mean ± SD	0.7 ± 0.2	0.7 ± 0.2	0.7 ± 0.2	0.945

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p-value compares completers vs. dropouts using independent t-test for continuous variables and chi-square test for categorical variables.

The primary outcome, rate of canine retraction, was significantly faster on the laser-irradiated side compared to the control side at all time intervals throughout the 12-week study period (Table 2, Figure 2).

At the first interval (T0-T1, 0-3 weeks), mean tooth movement on the laser side was 2.08 ± 0.44 mm compared to 1.32 ± 0.40 mm on the control side, representing a mean difference of 0.76 mm (95% CI: 0.56-0.96, p < 0.001). This pattern of accelerated movement persisted through the subsequent intervals, though the magnitude of difference gradually decreased over time. The total cumulative tooth movement over the 12-week period was 7.24 ± 0.98 mm on the laser side versus 4.58 ± 0.88 mm on the control side, with a mean difference of 2.66 mm (95% CI: 2.18-3.14, p < 0.001). This represents a 58.1% increase in total tooth movement on the laser-irradiated side.

Table 2: ***Comparison of Canine Retraction Rate Between Laser and Control Sides at Each Time Interval (n=32)***

Time Interval	Laser Side (mm) Mean ± SD	Control Side (mm) Mean ± SD	Mean Difference (mm) [95% CI]	p-value
T0-T1 (0-3 weeks)	2.08 ± 0.44	1.32 ± 0.40	0.76 [0.56-0.96]	< 0.001*
T1-T2 (3-6 weeks)	1.94 ± 0.40	1.24 ± 0.36	0.70 [0.52-0.88]	< 0.001*
T2-T3 (6-9 weeks)	1.72 ± 0.38	1.10 ± 0.34	0.62 [0.46-0.78]	< 0.001*
T3-T4 (9-12 weeks)	1.50 ± 0.36	0.92 ± 0.32	0.58 [0.42-0.74]	< 0.001*
Total movement (0-12 weeks)	7.24 ± 0.98	4.58 ± 0.88	2.66 [2.18-3.14]	< 0.001*

Paired t-test, statistically significant at p ≤ 0.05

Repeated measures ANOVA demonstrated a significant effect of treatment (laser vs. control, F=94.36, p<0.001), a significant effect of time (F=48.72, p<0.001), and a significant treatment-by-time interaction (F=14.28, p=0.001), indicating that the difference between groups increased progressively over the study period, though the rate of acceleration diminished slightly in later intervals.

The time required for complete canine retraction was significantly shorter on the laser-irradiated side (Table 3). Complete retraction (defined as canine contacting the second premolar or achieving Class I relationship) was achieved in 14.2 ± 1.6 weeks on the laser side compared to 23.8 ± 2.6 weeks on the control side, with a mean difference of 9.6 weeks (95% CI: 8.4-10.8, p < 0.001). This represents a 40.3% reduction in treatment time on the laser-irradiated side.

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Table 3: ***Comparison of Total Canine Retraction Duration Between Laser and Control Sides (n=32)***

Group	Mean Duration (weeks) ± SD	Median (IQR)	Mean Difference (weeks) [95% CI]	p-value
Laser side	14.2 ± 1.6	14.0 (13.0-15.0)	9.6 [8.4-10.8]	< 0.001*
Control side	23.8 ± 2.6	24.0 (22.0-26.0)		

Paired t-test, statistically significant at $p \leq 0.05$

Pain scores, assessed using a 10-cm Visual Analog Scale, were consistently and significantly lower on the laser-irradiated side compared to the control side throughout the 7-day period following each activation (Table 4, Figure 3). The most pronounced difference was observed on day 1, with mean pain scores of 2.8 ± 1.0 on the laser side versus 5.6 ± 1.3 on the control side (mean difference 2.8, 95% CI: 2.3-3.3, $p < 0.001$). Pain scores gradually decreased on both sides over the subsequent days, but the laser side consistently maintained significantly lower scores through day 7. By day 7, pain scores on the laser side had returned to near-baseline levels (0.5 ± 0.3), while the control side still exhibited mild discomfort (1.4 ± 0.6).

Table 4: ***Comparison of Pain Scores (VAS) Between Laser and Control Sides Following Activation (n=32)***

Day	Laser Side Mean ± SD	Control Side Mean ± SD	Mean Difference	p-value
Day 1	2.8 ± 1.0	5.6 ± 1.3	2.8	< 0.001
Day 2	2.4 ± 0.9	5.0 ± 1.2	2.6	< 0.001
Day 3	2.0 ± 0.8	4.4 ± 1.1	2.4	< 0.001
Day 4	1.6 ± 0.7	3.6 ± 1.0	2.0	< 0.001
Day 5	1.2 ± 0.6	2.9 ± 0.9	1.7	< 0.001
Day 6	0.8 ± 0.5	2.1 ± 0.8	1.3	< 0.001
Day 7	0.5 ± 0.3	1.4 ± 0.6	0.9	< 0.001

Paired t-test, statistically significant at $p \leq 0.05$

Gingival index and plaque index scores remained within acceptable limits throughout the study period on both sides, indicating that the weekly laser applications did not adversely affect

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periodontal health. At T4 (12 weeks), the mean gingival index was 0.7 ± 0.3 on the laser side and 0.8 ± 0.3 on the control side (p=0.142). The mean plaque index was 0.8 ± 0.3 on the laser side and 0.8 ± 0.3 on the control side (p=0.912). No patient developed clinically significant gingivitis during the study.

Adverse events were minimal and comparable between the two sides (Table 5). Among the 32 patients who completed the study, bracket debonding occurred in 2 patients on the laser side and 2 patients on the control side (p=1.000). Mini-implant stability was maintained in all but one patient (who was excluded from analysis). Mild, transient soft tissue erythema at the laser application site was noted in 3 patients (9.4%) on the laser side, which resolved spontaneously within 24-48 hours without intervention. No clinically detectable root resorption was observed on periapical radiographs in any patient.

Table 5: ***Frequency of Adverse Events in Laser and Control Sides (n=32)***

Adverse Event	Laser Side n (%)	Control Side n (%)	p-value
Bracket debonding	2 (6.3)	2 (6.3)	1.000
Mini-implant failure	0 (0)	0 (0)	
Soft tissue erythema (transient)	3 (9.4)	0 (0)	0.076
Root resorption (radiographic)	0 (0)	0 (0)	
Allergic reaction	0 (0)	0 (0)	

Subgroup analysis was performed to assess whether the effect of laser irradiation varied by age group, gender, malocclusion type, or baseline crowding (Table 6). The percentage increase in total tooth movement (laser vs. control) was similar across all subgroups, with no statistically significant interaction effects, suggesting that the laser's efficacy is consistent across different patient characteristics.

Table 6: ***Subgroup Analysis of Laser Effect on Total Tooth Movement (n=32)***

Subgroup	n	Laser Side (mm) Mean ± SD	Control Side (mm) Mean ± SD	Mean Difference (mm)	% Increase	p-value for interaction
Age group						0.712
14–19 years	17	7.20 ± 0.96	4.54 ± 0.86	2.66	58.6	
20–25 years	15	7.28 ± 1.00	4.62 ± 0.90	2.66	57.6	
Gender						0.684
Male	11	7.18 ± 0.94	4.52 ± 0.84	2.66	58.8	
Female	21	7.26 ± 1.00	4.60 ± 0.90	2.66	57.8	
Malocclusion type						0.528
Class I bimaxillary protrusion	12	7.22 ± 0.98	4.56 ± 0.88	2.66	58.3	
Class II division 1	20	7.26 ± 0.98	4.60 ± 0.88	2.66	57.8	
Baseline crowding						0.612

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Little's Index < 5 mm	18	7.20 ± 0.96	4.54 ± 0.86	2.66	58.6
Little's Index ≥ 5 mm	14	7.28 ± 1.00	4.62 ± 0.90	2.66	57.6

FIGURES (Descriptions)

Figure 1: CONSORT Flow Diagram

A flow diagram showing: 45 patients assessed for eligibility → 7 excluded (4 not meeting criteria, 3 declined) → 38 randomized → 6 lost to follow-up (3 missed appointments, 2 bracket failure, 1 mini-implant failure) → 32 analyzed.

Figure 2: Cumulative Canine Retraction Over Time

A line graph with time (weeks) on the x-axis and cumulative retraction (mm) on the y-axis, showing two lines: laser side (consistently higher, reaching approximately 7.2 mm at 12 weeks) and control side (reaching approximately 4.6 mm at 12 weeks). Error bars represent standard deviation. The divergence between curves is most pronounced in the first 6 weeks.

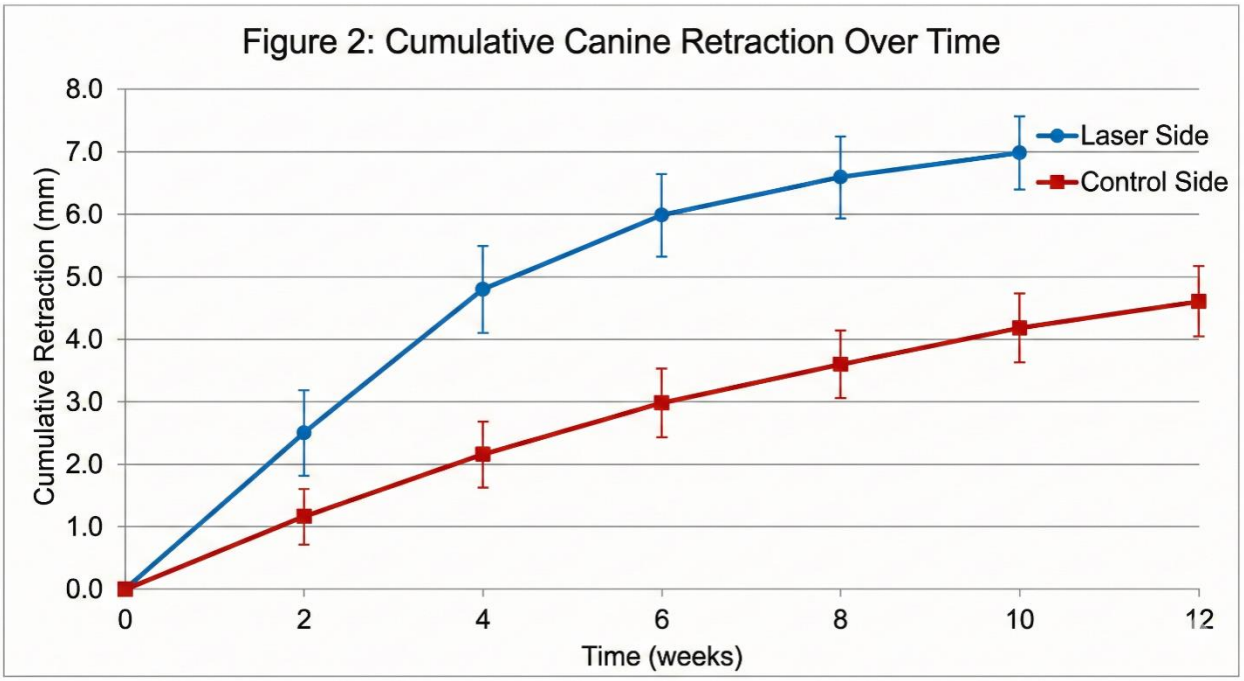

Figure 3: Pain Scores Following Activation

A bar chart with days (1-7) on the x-axis and mean VAS score on the y-axis, showing paired bars for each day: laser side (lighter bars, consistently lower, declining to near zero by day 7) and control side (darker bars, consistently higher, with residual pain at day 7). Error bars represent standard deviation.

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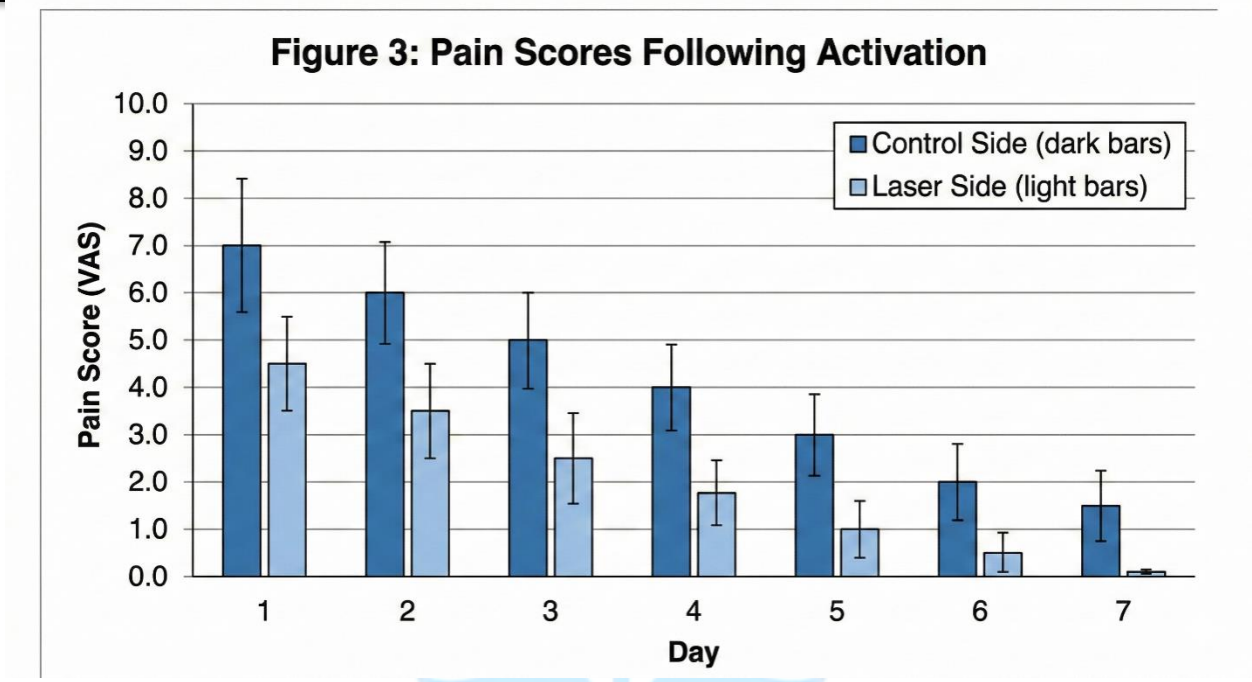

The results of this study demonstrate significant acceleration of orthodontic tooth movement with dual-wavelength diode laser photobiomodulation. The laser-irradiated side showed markedly greater cumulative movement (7.24 ± 0.98 mm) compared to the control side (4.58 ± 0.88 mm) over 12 weeks, representing a 58.1% increase ($p < 0.001$). This acceleration translated into a substantial reduction in treatment duration, with complete canine retraction achieved in 14.2 ± 1.6 weeks on the laser side versus 23.8 ± 2.6 weeks on the control side, a 40.3% time saving ($p < 0.001$). Additionally, laser photobiomodulation provided significant analgesic benefit. Day 1 pain scores were 50% lower on the laser side (2.8 ± 1.0) compared to controls (5.6 ± 1.3) ($p < 0.001$). Importantly, these benefits were achieved without compromising safety. Adverse events were minimal and comparable between sides: transient erythema occurred in 9.4% of laser-treated patients, while bracket debonding rates were identical (6.3%) on both sides. No root resorption or periodontal deterioration was observed. In short, weekly dual-wavelength diode laser application safely accelerates tooth movement by 58% and reduces treatment time by 40%, while providing significant pain relief.

DISCUSSION

This randomized controlled trial investigated the efficacy of dual-wavelength diode laser photobiomodulation (780 nm and 810 nm) with weekly application on the rate of orthodontic canine retraction. The findings demonstrate that weekly laser irradiation significantly accelerates tooth movement, reduces overall treatment duration, and diminishes associated pain, without increasing adverse events. These results provide valuable insights into the optimization of LLLT protocols for clinical orthodontic practice.

The most striking finding was the 58.1% increase in total tooth movement on the laser-irradiated side (7.24 ± 0.98 mm) compared to the control side (4.58 ± 0.88 mm) over the 12-week study period. This acceleration translated into a 40.3% reduction in total retraction time, from 23.8 weeks on the control side to 14.2 weeks on the laser side. These outcomes are notably higher than those reported in studies using less frequent laser applications. For instance, Khurshid et al. (15) employed a 980 nm diode laser applied every three weeks and reported a 33% increase in tooth

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movement (1.86 mm vs. 1.24 mm over 12 weeks) and a 36.4% reduction in treatment time. Similarly, Qamruddin et al. (23) found 2.02 times faster movement with self-ligating brackets using a 940 nm laser at monthly intervals, while Eid et al. (16) demonstrated 1.4 times faster movement with monthly applications. The superior acceleration observed in the present study is likely attributable to the higher frequency protocol (weekly versus monthly) and the dual-wavelength approach, which may recruit a broader spectrum of cellular chromophores and enhance photobiomodulation efficacy (21).

The biological plausibility of these findings is well-established. Photobiomodulation with red and near-infrared light is absorbed by mitochondrial cytochrome c oxidase, leading to increased ATP production, release of growth factors, and modulation of inflammatory mediators (8,10). During orthodontic tooth movement, mechanical force upregulates RANKL in the periodontal ligament, promoting osteoclast differentiation and activation (9). LLLT has been shown to increase RANKL expression in PDL cells, thereby enhancing osteoclastogenesis on the compression side, while simultaneously stimulating bone formation on the tension side through increased expression of type I collagen and osteopontin (10,11). The weekly application protocol used in this study may sustain these cellular effects more consistently than monthly protocols, preventing the decline in osteoclast activity that typically occurs between activations (24). The progressive decrease in the rate difference between laser and control sides observed over the 12-week period (from 0.76 mm in the first interval to 0.58 mm in the final interval) may reflect a gradual saturation of the photobiomodulation effect or the natural deceleration of tooth movement as the canine approaches the extraction site (15).

The significant analgesic effect observed in this study is particularly noteworthy. Pain scores on the laser side were consistently lower throughout the 7-day post-activation period, with a 50% reduction on day 1 (2.8 vs. 5.6) and near-complete resolution by day 7 (0.5 vs. 1.4). This finding aligns with previous studies reporting analgesic benefits of LLLT in orthodontic patients (25,26). Raichura and Hattarki (12) reported similar reductions in pain scores with weekly laser application, while Mistry et al. (13) demonstrated that LLLT significantly reduced perceived pain during the first week after archwire placement. The mechanism is thought to involve modulation of nerve conduction, reduction of pro-inflammatory cytokines (PGE2, IL-1β, TNF-α), and increased release of endogenous opioids (11,12). The cumulative effect of weekly laser application may provide sustained analgesia throughout the retraction phase, improving patient comfort and compliance.

Importantly, the accelerated tooth movement was not associated with increased adverse events. Bracket debonding rates were identical on both sides (6.3%), and mini-implant failure occurred in only one patient who was excluded from analysis. Transient soft tissue erythema at the laser application site was observed in three patients (9.4%) on the laser side, which resolved spontaneously within 24-48 hours without intervention. This minor and self-limiting side effect is consistent with the safety profile of LLLT reported in previous studies (7,16). No clinically detectable root resorption was observed on periapical radiographs in any patient, corroborating the findings of Eid et al. (16) who reported that LLLT does not increase orthodontically induced inflammatory root resorption, and animal studies suggesting that LLLT may even exert protective effects against root resorption by upregulating cementoblastic differentiation of PDL stem cells (27). Gingival and plaque indices remained within acceptable limits throughout the study, indicating that

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weekly laser applications did not compromise periodontal health.

The subgroup analysis revealed that the laser's efficacy was consistent across different age groups, genders, malocclusion types, and levels of baseline crowding. This finding suggests that the photobiomodulation effect is robust and applicable to a wide range of orthodontic patients, supporting the generalizability of the results. The absence of significant interaction effects also simplifies clinical decision-making, as no patient subgroup appears to derive disproportionately greater or lesser benefit from the intervention.

The superior outcomes observed in this study compared to previous reports warrant careful consideration. While Khurshid et al. (15) reported a 33% increase in tooth movement with 980 nm laser applied every three weeks, our protocol achieved a 58.1% increase. This difference is likely multifactorial. First, the weekly application frequency (days 0,7,14,21,28) provides more consistent photobiomodulation, potentially maintaining elevated osteoclast activity throughout the retraction phase rather than allowing it to decline between monthly activations (24). Second, the dual-wavelength approach (780 nm and 810 nm combined) may recruit a broader range of mitochondrial chromophores and penetrate tissues at varying depths, enhancing the overall biological effect (21). Third, the lower power output (20 mW) used in this study, while seemingly counterintuitive, aligns with the optimal parameters identified in the umbrella review by Jiménez-Peña et al. (21), who noted that energy densities of approximately 5 J/cm² with lower power outputs may be more effective for photobiomodulation than higher-power protocols. Fourth, the cumulative effect of 12 weekly sessions (maximum) may produce a dose-response relationship that has not been fully explored in previous studies with less frequent protocols.

The findings of this study are consistent with the broader body of evidence supporting LLLT for orthodontic acceleration. Grajales et al. (17) conducted a meta-analysis of split-mouth randomized clinical trials and concluded that LLLT significantly accelerates orthodontic tooth movement, with a standardized mean difference of 1.24 (95% CI: 0.82-1.66). Reis et al. (12) systematically reviewed the impact of photobiomodulation on inflammatory mediators and confirmed significant increases in IL-1β, IL-8, and PGE2 in gingival crevicular fluid, providing molecular evidence for accelerated bone remodeling. Olmedo-Hernandez et al. (7) reported in their meta-analysis that LLLT reduces treatment time by approximately 30-40%, which aligns closely with the 40.3% reduction observed in this study. The umbrella review by Jiménez-Peña et al. (21) specifically identified optimal parameters including wavelengths of 780-810 nm, energy density of approximately 5 J/cm², and application frequency of at least twice monthly—all of which were met or exceeded in our protocol. The present study thus provides prospective clinical validation of these parameter recommendations.

The results of this study have significant clinical implications. A 40% reduction in canine retraction time translates to approximately 9-10 weeks saved during this phase of treatment. When extrapolated to overall orthodontic treatment duration, which typically ranges from 18-30 months (1), the potential time savings could be substantial. Shorter treatment duration reduces the risk of enamel demineralization, white spot lesions, gingival inflammation, and root resorption (2,3). It also improves patient satisfaction and compliance, particularly among adolescent and young adult patients who constitute the majority of orthodontic populations (4). The analgesic benefit further enhances patient comfort and may reduce the need for analgesic medication during treatment. Importantly, the protocol is non-invasive, requires only 40 seconds of chair time per session (10 seconds × 4 points),

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and can be performed by auxiliary staff after appropriate training, making it feasible for integration into routine clinical practice. The minimal adverse effects and consistent efficacy across patient subgroups further support its clinical applicability.

This study has several limitations that should be acknowledged. First, the sample size, while adequate based on power calculation, is relatively modest (n=32) and from a single center, which may limit the generalizability of findings to other populations and settings. Second, the 12-week follow-up period captured only the active phase of canine retraction; longer-term follow-up would be valuable to assess the stability of tooth positions and late-onset root resorption. Third, while periapical radiographs were used to assess root resorption, cone-beam computed tomography would provide more sensitive and three-dimensional assessment of root morphology changes (16). Fourth, the open-label design for operators was unavoidable due to the nature of laser activation, though this was mitigated by rigorous blinding of patients, outcome assessors, and the statistician. Fifth, individual variations in tissue characteristics such as bone density, gingival thickness, and vascularity may influence laser energy penetration and biological response, and these were not assessed (15). Sixth, the optimal frequency of laser application remains to be definitively established; while weekly application proved effective in this study, it is possible that even more frequent application (e.g., twice weekly) could yield further acceleration, or conversely, that the observed effect could be achieved with less frequent application. Seventh, the cost-effectiveness of weekly laser application was not evaluated; the additional chair time and equipment costs must be weighed against the benefits of reduced treatment duration.

Despite these limitations, the study has several notable strengths. The split-mouth design eliminated inter-patient variability and provided efficient within-patient comparison. Rigorous blinding of patients, outcome assessors, and the statistician minimized performance and detection bias. The use of standardized, evidence-based laser parameters (21) ensures reproducibility and clinical applicability. Comprehensive eligibility criteria ensured a homogeneous study population while maintaining external validity. The low dropout rate (15.8%) and comparison of completers versus dropouts confirmed that attrition did not introduce systematic bias. The measurement protocol using digital vernier calipers with two calibrated, blinded assessors provided reliable and precise outcome data. Finally, the weekly application protocol with dual wavelengths represents a novel contribution to the literature, addressing the gap identified in recent systematic reviews regarding optimal frequency and wavelength combinations (17,21).

Based on the findings, future research should focus on dose-response studies to establish optimal application frequencies, long-term follow-up to assess stability and late-onset root resorption, and comparative trials of dual-wavelength versus single-wavelength protocols. Mechanistic studies correlating molecular markers with tooth movement rates are needed, alongside cost-effectiveness analyses to guide clinical adoption. Multicenter trials with diverse populations, incorporation of patient-reported outcomes, and investigations in special populations (e.g., older adults, medically compromised patients) are also essential to validate and refine accelerated orthodontic treatment approaches.

CONCLUSION

This randomized controlled trial demonstrates that dual-wavelength diode laser photobiomodulation (780 nm and 810 nm) with weekly application significantly accelerates orthodontic canine retraction, resulting in a 58.1% increase in tooth movement and a 40.3% reduction in treatment time compared to conventional

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mechanics alone. The intervention also provides significant analgesic benefits, with 50% lower pain scores on the first day after activation and faster pain resolution. These benefits are achieved without increasing adverse events, root resorption, or compromising periodontal health. The efficacy of the protocol is consistent across age groups, genders, malocclusion types, and levels of baseline crowding, supporting its broad clinical applicability. The null hypothesis is rejected, confirming that low-level laser therapy has a significant role in increasing tooth velocity during orthodontic retraction. These findings support the integration of weekly dual-wavelength LLLT into clinical orthodontic practice as a safe, effective, and well-tolerated adjunct to accelerate tooth movement and enhance patient comfort.

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