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A comparative study of laser-assisted orthodontic treatment versus conventional methods in accelerating tooth movement

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Abstract:
Prolonged orthodontic treatment remains a major clinical challenge, increasing the risk of root resorption, periodontal complications and poor patient compliance. Therefore, it is of interest to evaluate the effect of 940-nm low-level laser therapy on canine retraction and pain in 40 adults undergoing bilateral maxillary first premolar extraction. Canine movement was significantly greater on the laser side than on the control side (4.62 ± 0.58 mm vs. 3.05 ± 0.52 mm), reducing retraction time by 50.3 ± 16.4 days ($p < 0.001$). Pain scores were significantly lower with laser therapy during the first week, with no significant differences in anchorage loss, canine tipping, rotation, or external root resorption. Thus, data shows that adjunctive low-level laser therapy safely accelerates orthodontic tooth movement while preserving treatment quality, supporting its integration into conventional fixed-appliance therapy.

Keywords: Low-level laser therapy (LLLT), photobiomodulation (PBM), orthodontic tooth movement, canine retraction, accelerated orthodontics, diode laser

Background:
Comprehensive fixed orthodontic treatment typically lasts 18-30 months, with the canine retraction phase frequently constituting one of the longest and least predictable stages of treatment. Prolonged treatment duration is associated with increased risk of external apical root resorption, white-spot lesions, periodontal breakdown and declining patient compliance, particularly in adult patients **[1]**. As a result, both surgical and non-surgical adjunctive interventions aimed at accelerating orthodontic tooth movement have received substantial attention over the past two decades **[2].** Surgical methods such as conventional corticotomy, piezocision and micro-osteoperforations exploit the regional acceleratory phenomenon (RAP) to increase the rate of tooth movement. While effective, these techniques are invasive, may cause patient discomfort and carry risks of post-operative pain, swelling and rarely periodontal injury **[3]**. Among less invasive options, laser-based interventions have emerged in two main forms: laser corticotomy using erbium-doped yttrium aluminium garnet (Er:YAG) or erbium-chromium yttrium scandium gallium garnet (Er, Cr:YSGG) lasers to elicit a controlled RAP and low-level laser therapy (LLLT), also referred to as photobiomodulation (PBM), which uses sub-thermal doses of red or near-infrared light to modulate cellular activity without ablative tissue effects **[4]**. The biological rationale for LLLT in orthodontics is well established. Photobiomodulation in the 600–1000 nm range is absorbed primarily by mitochondrial cytochrome c oxidase, leading to enhanced ATP synthesis, modulation of reactive oxygen species and activation of transcription factors that influence osteoblast and osteoclast activity **[5]**. Animal and human studies have shown that LLLT increases RANKL expression, reduces OPG and accelerates alveolar bone remodelling on the compression side, while supporting osteoblast proliferation on the tension side **[4].** Clinically, these effects translate into faster tooth movement, reduced pain perception and unchanged or improved periodontal parameters compared with controls **[6]**. Despite a growing body of randomized controlled trials and systematic reviews, the literature on laser-assisted acceleration of orthodontic tooth movement remains heterogeneous. Reported acceleration factors range from approximately 1.2 to 2.0, depending on laser wavelength (most commonly 660–980 nm), power output, energy density, irradiation schedule and the type of orthodontic mechanics used **[7]**. Recent umbrella reviews continue to emphasize that, although the overall direction of

effect favors LLLT, the magnitude of acceleration and the optimal dosimetric parameters are still being defined **[8, 9]**. Therefore, it is of interest to compare the rate of orthodontic tooth movement, pain perception and side-effects between quadrants treated with adjunctive 940-nm diode LLLT.

Materials and Methods:

The study was carried out in accordance with the principles of the Declaration of Helsinki and informed consent was obtained from all patients at the time of treatment for participation and for the use of anonymized records in research. Ethical approval was obtained from the institutional ethics committee prior to enrolment. Adult patients attending the orthodontic clinic between February 2022 and March 2025 who required bilateral maxillary first premolar extraction and canine retraction were screened for eligibility. A sample size calculation, based on a previous split-mouth trial reporting a mean inter-side difference in canine retraction of 0.5 mm with a standard deviation of 0.7 mm, indicated that a minimum of 36 subjects was required to detect a clinically meaningful difference at $\alpha = 0.05$ and power = 0.80. To allow for potential dropouts, 40 patients were finally included. Inclusion criteria were: (i) age ≥ 18 years at treatment start; (ii) Class II Division 1 malocclusion or maxillary protrusion requiring bilateral maxillary first premolar extraction and en-masse or two-step canine retraction; (iii) good general and periodontal health; (iv) no previous orthodontic treatment; and (v) availability of complete records including pre-treatment study models, panoramic radiographs and lateral cephalograms. Exclusion criteria were: (i) systemic conditions or medications known to affect bone metabolism (*e.g.,* bisphosphonates, corticosteroids, NSAIDs on a chronic basis); (ii) craniofacial syndromes or cleft lip/palate; (iii) moderate-to-severe periodontitis or significant alveolar bone loss; (iv) marked asymmetry in extraction site anatomy on the panoramic radiograph; (v) pregnancy or lactation; and (vi) any history of photosensitivity or contraindication to laser irradiation. All patients were treated by the same operator using readjusted edgewise fixed appliances (MBT prescription, 0.022 × 0.028-inch slot). Following standard levelling and alignment, working archwires of 0.019 × 0.025-inch stainless steel were placed in both arches. Canine retraction was initiated using nickel-titanium (NiTi) closed-coil springs delivering 150 g of force per side, anchored to mini-screws (1.6 × 8 mm) placed bilaterally between the second premolar and first molar to provide maximum anchorage. A split-mouth design was used. Within each patient, the side to receive LLLT was determined by computer-generated randomization in a 1:1 ratio; the contralateral quadrant served as the conventional (non-laser) control. The laser used was a 940-nm gallium-aluminium-arsenide diode laser (continuous-wave mode, 100 mW output power, 8 J/cm² energy density per point). Irradiation was performed at eight points per canine root (four buccal: cervical, mesial, distal, apical; four palatal: cervical, mesial, distal, apical) for 10 seconds per point, with the fiber tip held perpendicular to and in light contact with the attached gingiva. Irradiation was applied on days 0, 3, 7 and 14 and then every 14 days throughout the 3-month retraction phase. The control quadrant received an identical clinical handling sequence with the laser tip switched off (sham irradiation) and both patient and outcomes assessors were blinded to side allocation; the operator could not be blinded due to the nature of the intervention. Tooth movement was measured using digital scans of alginate study models taken at baseline (T0) and at the end of months 1, 2 and 3. Scans were superimposed on stable palatal rugae using three-dimensional surface-matching software and the linear displacement of the canine cusp tip relative to a stable transverse palatal reference was recorded bilaterally in millimeters. Anchorage loss was quantified as the mesial movement of the first molar and canine tipping and rotation were measured from the same superimposed scans. Pain perception was assessed using a 0–10 visual analog scale (VAS) on days 1, 3 and 7 after each laser session in the first month and at corresponding time points on the control side. External apical root resorption of both canines was assessed on pre- and post-retraction periapical radiographs taken with a parallel-cone technique and individualized bite blocks, by measuring the difference in root length between time points and applying standard correction for radiographic distortion. To assess intra-examiner reliability, 20 randomly selected pairs of digital scans were re-measured two weeks after the initial measurement. The interclass correlation coefficient (ICC) exceeded 0.94 for all linear and angular variables, indicating excellent reliability. Data were analyzed using SPSS version 28.0 (IBM Corp., Armonk, NY, USA). The Shapiro-Wilk test was used to assess normality. Paired t-tests were used for normally distributed variables and the Wilcoxon signed-rank test was used for non-normally distributed data, to compare laser and control sides within patients. The acceleration ratio was calculated as (laser-side movement / control-side movement). Pearson correlations were used to examine relationships between cumulative tooth movement and pain scores. Statistical significance was set at $p < 0.05$.

Results:

A total of 40 patients (24 females, 16 males; mean age 22.8 ± 4.1 years; range 18–34 years) were included in the final analysis. All patients completed the 3-month observation period; no patient was lost to follow-up and no treatment-related adverse events (burns, mucosal irritation and mini-screw failure attributable to laser irradiation) were recorded. Mean treatment time for full canine retraction, projected from the first 3 months, was 118.4 ± 14.2 days on the laser side and 168.7 ± 17.9 days on the control side. Rate of tooth movement and treatment time statistically significant inter-side differences were observed for all primary outcome variables **(Table 1).** Cumulative canine retraction was significantly greater on the laser side at every time point: 1.62 ± 0.34 mm vs 1.04 ± 0.29 mm at month 1 ($p < 0.001$), 3.18 ± 0.46 mm vs. 2.07 ± 0.41 mm at month 2 ($p < 0.001$) and 4.62 ± 0.58 mm vs 3.05 ± 0.52 mm at month 3 ($p < 0.001$). The mean rate of tooth movement was 1.54 ± 0.21 mm/month on the laser side versus 1.02 ± 0.18 mm/month on the control side ($p < 0.001$),
corresponding to an overall acceleration ratio of approximately 1.51 in favour of LLLT. Total retraction time was reduced by a

mean of 50.3 ± 16.4 days on the laser side ($p < 0.001$), representing roughly a 30% reduction relative to the control quadrant. VAS pain scores were significantly lower on the laser side at day 1 (3.6 ± 1.1 vs 5.8 ± 1.3, $p < 0.001$), day 3 (1.8 ± 0.9 vs. 3.7 ± 1.1, $p < 0.001$) and day 7 (0.6 ± 0.5 vs. 1.4 ± 0.8, $p = 0.002$). No statistically significant differences were observed between the two sides for anchorage loss (1.21 ± 0.38 mm vs. 1.18 ± 0.41 mm, $p = 0.742$), canine tipping (5.4°C ± 2.3°C vs. 5.7°C ± 2.4°C, $p = 0.618$), canine rotation (3.8°C ± 1.9°C vs. 4.1°C ± 2.0°C, $p = 0.547$), or external root resorption (0.42 ± 0.21 mm vs. 0.46 ± 0.23 mm, $p = 0.483$) **(Table 1).** Cumulative tooth movement per month and the corresponding acceleration ratios are summarized in **Table 2**. The acceleration ratio remained remarkably stable across the three months (1.56 at month 1, 1.54 at month 2 and 1.51 at month 3), suggesting a sustained rather than transient biological response to repeated photobiomodulation under the dosimetric protocol used. On the laser side, cumulative tooth movement at 3 months correlated significantly with patient age ($r = –0.36$, $p = 0.022$), indicating slightly slower movement in older patients and weakly with baseline overjet ($r = 0.21$, $p = 0.193$). A modest negative correlation was found between cumulative movement and VAS pain score at day 1 on the laser side ($r = –0.31$, $p = 0.048$), suggesting that the analgesic and pro-remodelling effects of LLLT may be biologically linked. No significant correlation was observed between cumulative tooth movement and external root resorption on either side (laser: $r = 0.14$, $p = 0.389$; control: $r = 0.18$, $p = 0.265$), suggesting that the increased rate of tooth movement on the laser side did not translate into increased radiographic root damage over the observation period.

Table 1: Clinical, kinematic and side-effect variables on the laser and control sides during the 3-month canine retraction phase (n = 40 patients, split-mouth design).

Variable	Laser group (mean ± SD)	Control group (mean ± SD)	Δ (Laser–Control)	p-value
Canine retraction at 1 month (mm)	1.62 ± 0.34	1.04 ± 0.29	+0.58 ± 0.31	< 0.001*
Canine retraction at 2 months (mm)	3.18 ± 0.46	2.07 ± 0.41	+1.11 ± 0.43	< 0.001*
Canine retraction at 3 months (mm)	4.62 ± 0.58	3.05 ± 0.52	+1.57 ± 0.55	< 0.001*
Total retraction time (days)	118.4 ± 14.2	168.7 ± 17.9	–50.3 ± 16.4	< 0.001*
Mean rate of tooth movement (mm/month)	1.54 ± 0.21	1.02 ± 0.18	+0.52 ± 0.20	< 0.001*
VAS pain score at day 1	3.6 ± 1.1	5.8 ± 1.3	–2.2 ± 1.2	< 0.001*
VAS pain score at day 3	1.8 ± 0.9	3.7 ± 1.1	–1.9 ± 1.0	< 0.001*
VAS pain score at day 7	0.6 ± 0.5	1.4 ± 0.8	–0.8 ± 0.7	0.002*
Anchorage loss (mm)	1.21 ± 0.38	1.18 ± 0.41	+0.03 ± 0.40	0.742
Canine tipping (°C)	5.4 ± 2.3	5.7 ± 2.4	–0.3 ± 2.3	0.618
Canine rotation (°C)	3.8 ± 1.9	4.1 ± 2.0	–0.3 ± 1.9	0.547
External root resorption (mm)	0.42 ± 0.21	0.46 ± 0.23	–0.04 ± 0.22	0.483

**Statistically significant ($p < 0.05$). VAS, visual analog scale; SD, standard deviation. Δ = laser side – control side.*

Table 2: Cumulative canine retraction per month on laser and control sides, with acceleration ratios (n = 40).

Time point	Laser group (mm, mean ± SD)	Control group (mm, mean ± SD)	Acceleration ratio (Laser/Control)
Month 1	1.62 ± 0.34	1.04 ± 0.29	1.56
Month 2	3.18 ± 0.46	2.07 ± 0.41	1.54
Month 3	4.62 ± 0.58	3.05 ± 0.52	1.51
Overall (3 months)	4.62 ± 0.58	3.05 ± 0.52	1.51

Acceleration ratio = mean laser-side displacement / mean control-side displacement at each time point.

Discussion:

This split-mouth randomized clinical study compared the efficiency of adjunctive 940-nm diode LLLT with conventional mechanics during the canine retraction phase of fixed-appliance orthodontic treatment. The null hypothesis was rejected, as statistically significant differences in favour of laser-assisted treatment were observed for the rate of tooth movement, total retraction time and pain perception, while side-effects including anchorage loss, tipping, rotation and root resorption did not differ significantly between sides. The observed acceleration ratio of approximately 1.51 over three months is consistent with the 1.3-1.7 range reported in recent randomized trials and split-mouth analyses of LLLT during canine retraction by Eid *et al.* (2022) **[10]** and Zheng and Yang (2021) **[11]**. The pattern of a roughly 50% faster rate on the laser side is also in agreement with the systematic review and meta-analysis by Grajales *et al.* (2023) **[5]**, which reported a significant but heterogeneous Overall effect of LLLT on orthodontic tooth movement across split-mouth designs. Acceleration in our study appeared sustained rather than confined to the early weeks of treatment, with similar ratios at months 1, 2 and 3. This contrasts with some earlier reports of a more pronounced early effect and gradual attenuation over time and supports the hypothesis that repeated photobiomodulation sessions every 14 days are sufficient to maintain the biological stimulus on alveolar bone remodelling. The mechanistic basis-up-regulation of RANKL, modulation of OPG, increased osteoclast recruitment on the pressure side and enhanced osteoblastic activity on the tension side-has been reviewed in detail by Wang *et al.* (2023) **[6]** and Yong *et al.* (2023) **[7]**. Reduction in pain perception is a clinically meaningful secondary outcome. Mean VAS scores on the laser side were approximately 2 points lower at day 1 and remained significantly lower at days 3 and 7. This finding aligns with the randomized controlled trial by Kharat *et al.* (2023) **[12]**, who

reported significant pain reduction during accelerated canine retraction with low-level laser therapy and with the randomized trial of Pérignon *et al.* (2021) **[13]**, in which 970-nm LLLT applied during Class II intermaxillary elastics treatment was associated with lower analgesic consumption. The analgesic effect of LLLT is biologically plausible: photobiomodulation reduces local prostaglandin and bradykinin release, modulates nerve conduction and decreases inflammatory mediators in the periodontal ligament, all of which contribute to lower nociceptive signaling. Importantly, increased tooth movement on the laser side was not accompanied by greater anchorage loss, tipping, rotation, or root resorption. This is consistent with the findings of Guram *et al.* (2018) **[14]**, who showed that LLLT-induced acceleration did not compromise periodontal or radiographic outcomes and with the systematic review by Olmedo-Hernández *et al.* (2022) **[15]**, which concluded that photobiomodulation can accelerate orthodontic tooth movement without significant adverse effects on root structure or supporting tissues under standard dosimetric parameters. The slightly faster but biologically controlled remodelling induced by LLLT may explain the absence of an excess in root resorption: rather than overstressing the periodontium, the laser appears to make the existing biological response more efficient. The choice of laser parameters in our protocol (940 nm, 100 mW, 8 J/cm², eight points, every 14 days) falls within the effective dose window identified in umbrella reviews. Domínguez *et al.* (2024) **[4]** emphasized that wavelengths between 780 and 980 nm, low-to-moderate power outputs and energy densities in the range of 5–10 J/cm² are most consistently associated with clinical acceleration of orthodontic tooth movement, whereas excessively high or low doses may yield neutral or even inhibitory effects. The stability of our acceleration ratio across months supports the appropriateness of the dosing schedule used. Several limitations should be acknowledged. First, the 3-month follow-up captures the rate of movement during canine retraction but does not extend to overall treatment-time reduction or post-treatment stability; longer-term studies are needed to determine whether the time saved during retraction translates into a proportionally shorter total treatment time. Second, although the split-mouth design controls effectively for inter-patient variables such as bone density, age and biological responsiveness, it cannot rule out systemic effects of laser irradiation acting on the contralateral side; however, such cross-over effects, if present, would tend to underestimate rather than overestimate the laser benefit. Third, comparison was made against conventional mechanics rather than against other accelerating modalities such as micro-osteoperforations or laser corticotomy, both of which have shown comparable or greater acceleration in recent randomized trials including the Er:YAG laser corticotomy split-mouth trial of Toodehzaeim *et al.* (2024) **[3]**. Direct head-to-head comparisons of non-invasive (LLLT) and minimally invasive (laser corticotomy, MOPs) approaches remain a priority for future research. From a clinical standpoint, the present findings suggest that adjunctive LLLT can meaningfully shorten the canine retraction phase while reducing patient discomfort, without adverse effects on movement quality, anchorage, or root integrity **[16, 17]**. These advantages are particularly relevant for adult patients, in whom slower bone remodelling typically prolongs treatment, as well as for non-extraction comprehensive cases in which clinicians and patients seek non-invasive ways to reduce treatment burden **[18-20]**.

Conclusion:

Adjunctive 940-nm diode LLLT significantly accelerated canine retraction (ratio: 1.51), reduced treatment time by approximately 50 days, and minimized pain. No significant differences were observed in anchorage loss, canine tipping, rotation, or external root resorption, supporting its clinical safety. Further randomized trials with standardized dosimetry and longer follow-up are needed to validate its long-term efficacy.

Conflict of interest: The authors declare no conflict of interest related to this study

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