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ORIGINAL ARTICLE

Evaluation of the efficacy of laser-assisted flapless corticotomy in accelerating canine retraction: a split-mouth randomized controlled clinical trial

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Abstract

Objective To evaluate the efficacy of laser-assisted flapless corticotomy in the acceleration of canine retraction compared with the conventional technique and to evaluate patients' pain and discomfort levels after corticotomy.

Materials and methods A single-center randomized controlled trial was conducted on 18 class II division 1 patients (7 males, 11 females; age range: 16 to 24 years) who required the first-upper-premolar extraction followed by canine retraction. A split-mouth design was used in which the Er:YAG laser-assisted flapless corticotomy was randomly allocated to one side, whereas the other side served as the control side. The primary outcome measure was the canine retraction rate which was assessed immediately after laser application, 1, 2, 4, 8, and 12 weeks after laser application. Also, the levels of pain and discomfort during the first week following laser application were assessed. Paired *t*-tests or Wilcoxon matched-pairs signed-rank tests were used to detect significant differences.

Results All of the selected eighteen patients entered the statistical analysis stage. Significant differences were observed ($P < 0.001$) in canine retraction rates between the experimental and control sides at the baseline to 1st-week, 1st- to 2nd-week, 2nd- to 4th-week, and 4th- to 8th-week intervals. No significant difference was found between the two sides at the 8th- to 12th-week interval. A significant reduction was seen in the mean score of pain during eating at all assessment times when compared to the baseline data ($P = 0.002$ at day 2, $P < 0.001$ at days 5 and 7).

Conclusion Er:YAG laser-assisted flapless corticotomy appears to be an effective treatment method for accelerating canine retraction and was accompanied by a mild degree of pain and discomfort.

Trial registration ClinicalTrials.gov (No.: NCT04316403), retrospectively registered on the 20th of March 2020. URL: https://clinicaltrials.gov/ct2/show/NCT04316403

Keywords Acceleration · Laser-assisted · Flapless · Corticotomy · Canine retraction

Introduction

Comprehensive orthodontic treatment with fixed appliances usually takes more than 18 months in mild and severe cases [1]. Prolonged treatment time can cause many adverse effects such as pain, discomfort, external root resorption, white spots, and dental caries [2, 3]. Decreasing the treatment time for tooth movement has been the focus of both the clinicians and the patients [4]. For the last few decades, investigators have recommended many treatment approaches intending to reduce overall treatment time such as low friction and self-ligating bracket systems [5], low-level laser irradiation [6, 7], electrical currents [8], pharmacological approaches [9], local platelet-rich plasma (PRP) injection [10], and surgical approaches like dentoalveolar

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distraction [11] and selective alveolar decortication or corticotomy [12, 13].

Alveolar corticotomies initiate a deciduous demineralization process called regional acceleratory phenomenon (RAP) [14, 15], which activates the fusion and differentiation of pre-osteoclast into mature multi-nucleated osteoclasts, which resorb bone for about 2 weeks. The speed and intensity of the RAP increase with increasing the insult [16].

Although the surgical approaches accelerate teeth movement effectively [11, 12], it has not been widely embraced by the patients or dental communities due to its aggressive nature. These techniques require full mucoperiosteal flap elevations. They have the potential to generate post-surgical discomforts such as pain and swelling [12] as well as postoperative complications like crestal bone loss, bone necrosis, edema, and gingival recession [17, 18].

Therefore, many different techniques with minimally surgical procedures have been proposed in the literature [19]. These include corticision [20], piezocision [21], microosteoperforations [22, 23], and laser-assisted flapless corticotomy [21, 24] have been proposed.

Recently, using lasers in dental treatments has become very popular [25]. Er:YAG lasers are the commonly used lasers in dentistry since 1988 [25]. They emit light at 2.49 µm and it can be operated up to pulse repetition of 40 Hz and power of 20 W at pulse energies of 1 J [26]. The Er:YAG lasers do not require physical contact with the bone, cut the bone with minimal thermal damage and precise control of bone-cutting [24, 27], and the bone healing following their use appeared to occur faster than mechanical bur drilling [28].

Erbium lasers have been suggested to accomplish corticotomy without flap reflection due to their attractive advantages. Seifi et al. [27] found that flapless cortication accomplished by ER:CR:YSGG laser on rabbits is a useful way to accelerate orthodontic tooth movement. Salman and Ali [24] and Alfawal et al. [21] used Er:YAG laser to perform selective flapless corticotomy to accelerate canine retraction. Both studies found that canine retraction with laser-assisted flapless corticotomy was 1.5–2 times faster than the traditional method of canine retraction during the first 6 weeks of observation. However, these two studies employed four laser-induced perforations in the alveolar bone adjacent to the first-premolar extraction site without any intervention close to the canine region where most of the tooth movement usually occurs. Also, they only reported orthodontist-oriented outcomes instead of exploring patient-centered outcomes such as pain and discomfort associated with laser application.

Recent systemic reviews have stated that the scientific evidence about the efficiency of the minimally invasive surgical procedures in accelerating tooth movement is still limited [19] and there is a great need for new RCTs in this field.

The current trial aimed to evaluate the efficacy of laser-assisted flapless corticotomy in accelerating orthodontic tooth movement. The secondary aim was to evaluate the patients' responses to laser application. It was postulated that canine retraction after laser-assisted flapless corticotomy would be accomplished within a shorter period compared with the conventional canine retraction method, with no significant degree of pain and discomfort.

Materials and methods

Setting and study design

A split-mouth design single-center randomized controlled trial was conducted at the Department of Orthodontics, University of Hama Dental School. This study was approved by the Research Ethics Committee of the University of Hama Dental School, Syria (Approval no. UHDS-3101_2015PG) and was funded by the University of Hama Postgraduate Research Budget (Reference number: UHDS-6057_2015DENRB). No important changes to the methods was done after trial commencement. This trial was locally registered, and registered retrospectively on the 20th of March 2020 with clinicaltrials.gov, URL: https://clinicaltrials.gov/ct2/show/NCT04316403 No.: (NCT04316403).

Sample size calculation

The sample size was calculated using Minitab Version 17 (Minitab Inc., State College, PA, USA) and the intended test was "paired-samples *t*-test." The smallest difference requiring detection in canine movement velocity was assumed to be 0.25 mm/week. With an alpha level of 0.05, a power of 80%, and a standard deviation of 0.248 mm/week from a previous study [12], it was found that a sample of 18 patients was required.

Subjects and inclusion criteria

An evaluation of 120 patients referred to the Department of Orthodontics for treatment was performed. Routine orthodontic records were collected and analyzed for 51 patients whose primary diagnosis was class II division 1. Patients who fulfilled the following inclusion criteria were invited to participate in the study: (1) class II division 1 patients requiring orthodontic treatment with fixed appliances and a need for upper first-premolar extraction using a two-step retraction technique; (2) permanent dentition with an age range from 16 to 24 years; (3) healthy with no systemic conditions; (4) adequate oral hygiene and healthy periodontal tissues; (5) no previous orthodontic treatment, and (6) absence of canine endodontic treatment. The information sheets were provided

and the research protocol was explained to 25 patients who fulfilled the inclusion criteria, 3 patients of them refused to undergo Er:YAG laser application and 22 patients accepted the entry to the trial. However, according to the prior sample size calculation, 18 patients were required. Therefore, simple random sampling was employed to obtain a sample of 18 patients. All the selected patients signed informed consent. Figure 1 shows the CONSORT flow diagram of patients' recruitment and follow-up.

Randomization

Randomization was performed by one of the academic staff not involved in this research at the Orthodontic Department. A computer-generated list of random numbers was exported by Minitab (version 17, Minitab, LLC, State College, Pa, USA) assigning each side of the upper jaw (left or right) to the experimental group in an allocation ratio of 1:1. The right side of half of the patients served as the experimental side, whereas the left side served as the control side. In the same time, the right side of the other half of the patients served as the control side, whereas the left side served as the experimental side. Blinding of personnel and participants were not applicable. Therefore, blinding was applied only for the outcomes' assessor.

Leveling and alignment for the entire sample

The orthodontic treatment and surgical intervention by Er:YAG laser were performed by the same principal researcher (STJ). The treatment plan for all patients involved the extraction of bilateral maxillary first premolars. At the beginning of treatment and before appliance fitting, extraction of premolars was done in order to allow for leveling and alignment without causing additional proclination for the anterior teeth and to ensure that the extraction would not affect canines' movement velocity. Pre-adjusted edgewise MBT brackets of 0.022-in slot (Master Series, American Orthodontics, Sheboygan, USA) bonded on the teeth in both maxillary and mandibular arches. Self-drilling miniscrew implants (1.3 mm diameter and 8 mm length, Dewimed®, Tuttlingen, Germany) were used as skeletal anchorage. They were placed bilaterally between the maxillary second premolar and the first molar, approximately 8–10 mm above the archwire at the mucogingival junction, and they were checked for primary stability (mechanical retention). After that, the leveling and alignment stage was initiated using the following archwire sequence: 0.014-in. NiTi, 0.016-in. NiTi, 0.016*0.022-in. NiTi, 0.017*0.025-in. NiTi, 0.017*0.025-in. SS, and 0.019*0.025-in. SS which was considered the basal archwire [29]. During the whole treatment stages, an indirect

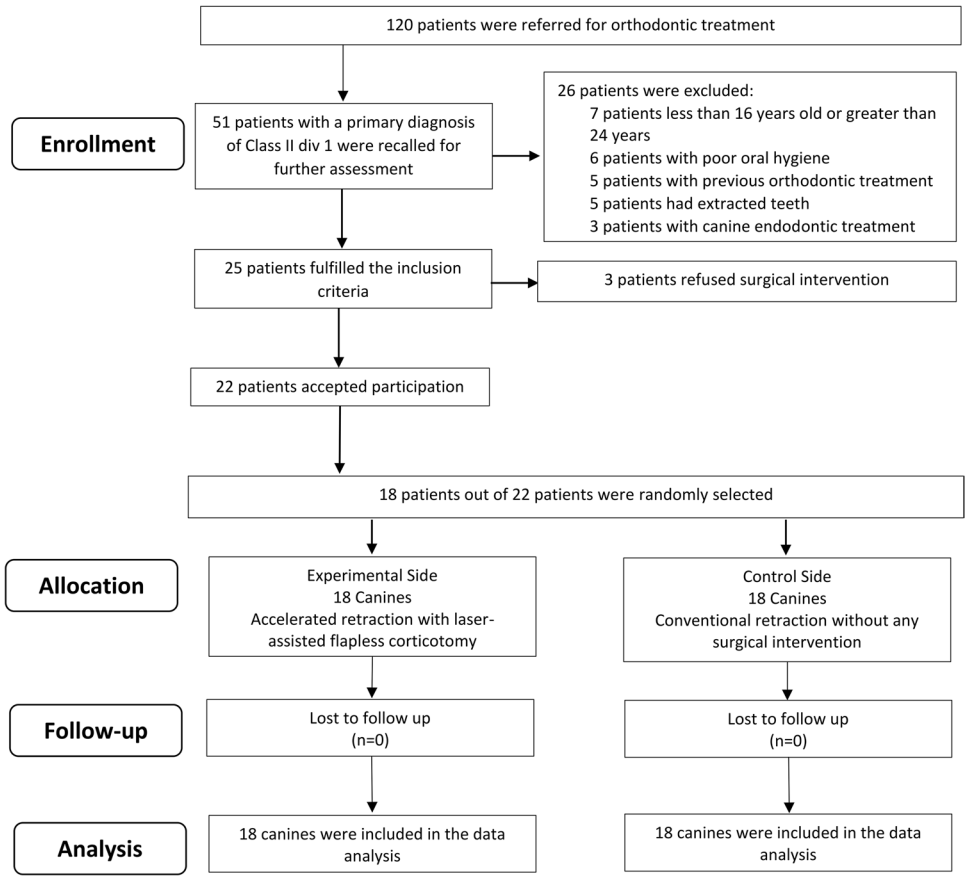

Fig. 1 CONSORT flow diagram of patients' recruitment and follow-up

molar anchorage was employed by tightening a ligature wire between the molar tubes and miniscrews' exposed heads.

Surgical intervention

After finishing the leveling and alignment stage, eight small perforations were made in the buccal gingiva, 4 of them were made at the first-premolar extractions sites while the other four perforations were made around the area of the evaluated canine using Er:YAG laser apparatus (Keylaser III 1243, Kavo, Biberach an der Riss, Germany) at the Laser Department, University of Hamah Dental School. First, patients were asked to rinse with chlorhexidine 0.12% for 1 min, and the peri-buccal area was cleaned with gauze soaked in chlorhexidine, then all safety precautions for the patient and the operator were followed according to the manufacture's recommendations. Laser application was started on the attached gingiva using a 2062 handpiece with the program (10 frenectomy 2062) with the following parameters (energy: 200 mJ; frequency: 10 Hz (Fig. 2a)). The goal of this procedure is to make a path through the gingiva to the cortical bone surface.

Next, perforations in the cortical bone were prepared using a 2060 handpiece with the program (27 apicectomy 2060) after setting the parameters at 200 mJ of energy and 15 Hz of frequency. The laser beam directed through the pilot beam on the previously prepared perforations in the attached gingiva, which allows the laser beam from the 2060 handpiece to reach the cortical bone surface (Fig. 2b). The width of the holes prepared was 1 mm, and the depth was 3 mm to approximate the width of the buccal cortical bone, and that was confirmed with a UNC-15 probe (Fig. 3a). No local anesthesia was used during the surgical intervention. Nonsteroidal anti-inflammatory drugs were not allowed to be taken after surgery. The patients were allowed to take analgesics (paracetamol, 500-mg tablets) only when they believed the pain was severe, but after completing their questionnaires.

Canines' retraction

Canines' retraction was started after the surgical intervention at the same time on both sides in all patients using elastic chains (American Orthodontics, Sheboygan, USA) which were stretched between the hooks on the labial surface of the first molar bands and the canine brackets. The retraction force on each canine was 150 g measured intraorally (Fig. 3b) by a force gauge (Hag-striet, Bern, Switzerland). Follow-up appointments were every 2 weeks to take the maximum advantage of the RAP [21, 30]. In each appointment, the force was calibrated and elastic chains were changed when needed to maintain a 150 g of force during the whole retraction phase.

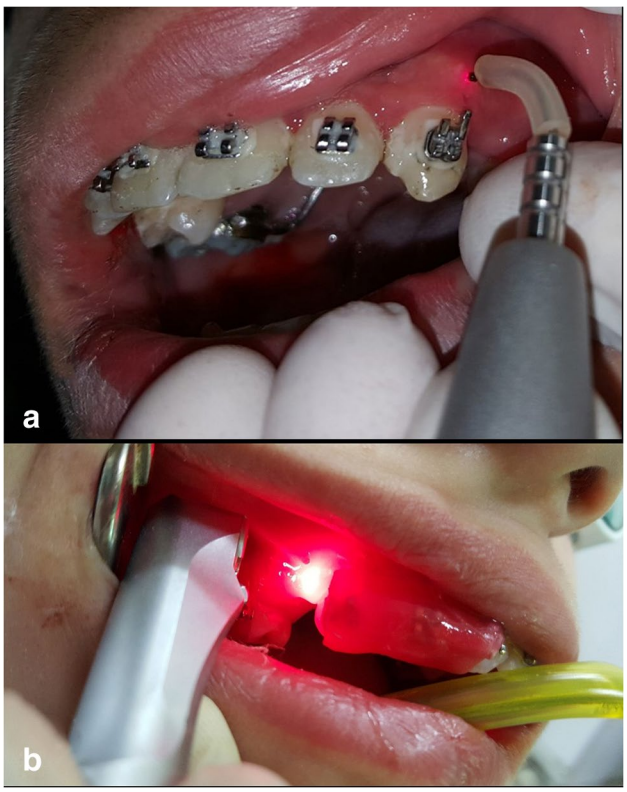

Fig. 2 Perforating the attached gingiva using 2062 handpiece (**a**), corticotomy using 2060 handpiece (**b**)

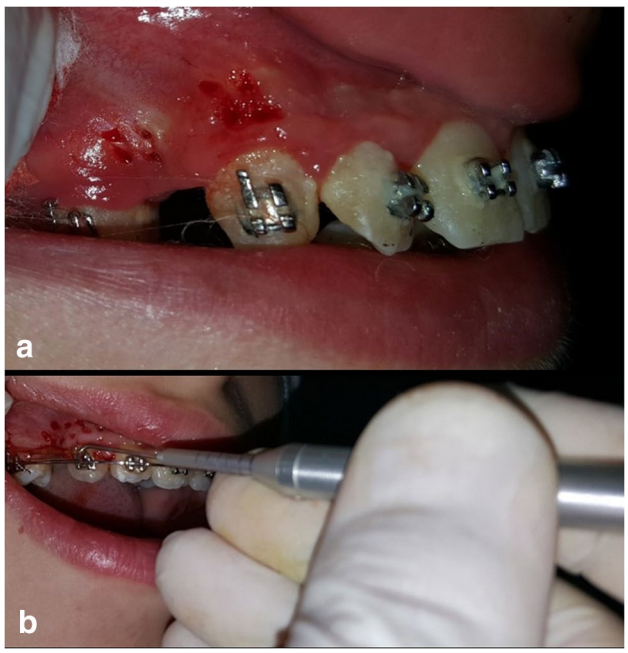

Fig. 3 Perforations at the end of surgical intervention (**a**), retraction force calibration using a force gauge (**b**)

Outcome measures

Primary outcome measure: canine retraction rate The distance between the first molar labial hook and the canine bracket hook was recorded using Digital Boely gauge in the following times: immediately after laser application, 1, 2, 4, 8, and 12 weeks after laser application. These measurements were used to calculate canine retraction speed.

Secondary outcome measure: levels of pain and discomfort during the first week after laser application A questionnaire was administered at the 1st, 3rd, 5th, and 7th day after laser application. The questionnaire contained 5 questions (using 4-point Likert ordinal scales) to collect patients' responses towards the perceived pain during the daytime, during overnight, during mastication at mealtimes, as well as his/her perception of swelling on the surgical side. Besides, one question based on a nominal scale was to identify the procedure that caused more discomfort and annoyance to patients (extraction of premolars, laser application, or both).

Statistical analysis

The data were analyzed using SPSS version 20 (IBM Corporation., Chicago, IL, USA). Intra- and intergroup differences were analyzed by using paired *t*-tests or Wilcoxon matched-pairs signed-rank tests. Alpha level was set at 5%.

The error of the method

The systemic error was evaluated from double measurements of 10 randomly chosen tooth movement measurements in each group using paired *t*-tests. The measurements were repeated after a 20-min interval for the selected patients. The intraclass correlation coefficients (ICCs) were calculated to assess intra-observer reliability, whereas Bland and Altman plots were also used to determine the agreement between repeated measurements.

Results

Eighteen patients were enrolled in the present split-mouth RCT (7 males, 11 females) with a mean age of 16.9 ± 2.5. The basic characteristics of the sample are given in Table 1. No patient was lost to follow-up. Therefore, all 18 patients entered the statistical analysis.

The error of the method Paired sample *t*-tests results revealed that there were no significant differences between the first and second measurements in both groups ($p > 0.05$); hence, small and insignificant systemic errors. The ICCs showed high intra-observer reliability between the repeated measurements (Table 2). Also, the Bland and Altman plots demonstrated very good repeatability (i.e., agreement) between the two measurements (Supplementary Figs. 1 and 2).

Table 1 Basic characteristics of the sample

Characteristics	Value
Sample	18
Gender (male/female)	7/11
Mean age ± SD (years)	16.9 ± 2.5
Crowding (no/minimal)	5/13
Posterior crossbite (yes/no)	0/18
Overjet increased (moderate/severe)	6/12
Facial height (normal/increased)	9/9

Data presented as *n* or mean ± standard deviation (SD)

Canine retraction rate There were statistically significant differences ($p < 0.001$) in the rate of canine retraction rate between the experimental and control sides at the baseline to 1st week of assessment, and the movement velocity in the experimental side was 2.5 times higher than that of the control side. When comparing the movement velocity at 1-to-2-week, 2-to-4-week, and 4-to-8-week intervals, there were significant differences ($p < 0.001$) between the experimental and control sides and the retraction velocity was approximately 1.8 times faster on the experimental side. No significant difference between the two sides was found at the 8-to-12-week interval (Table 3). When the retraction speed was calculated for the whole observation period, the retraction speed on the experimental side was faster by 1.6 times than the control side thought the experiment.

Levels of pain and discomfort Regarding the subjective assessment of pain on the experimental side, 16.7% of patients reported extreme pain during eating on the first day while 66.7% of the patients did not report any pain. A significant reduction was seen in the mean score of pain during eating at all assessment times when compared to the baseline data ($p = 0.002$ at day 2, $p < 0.001$ at days 5 and 7) with no patients reporting moderate or severe pain at the fifth-day and the seventh-day assessments. When evaluating daytime pain, 11.1% of the patients reported that the pain was extreme, while 44.4% of the patients reported a mild degree of pain. A reduction was also seen in the mean score, but the differences were not statistically significant ($p > 0.05$). The levels of pain in the overnight were low and acceptable at all assessment times (Table 4).

When the perception of swelling was evaluated (Table 4), patients did not report severe swelling during the first week. No significant difference was found between the first and second days ($p = 0.157$), but a significant reduction was

Table 2 Intra-observer reliability of the measurements between the first molar labial hook and the canine bracket hook and the error of the method ($n = 10$)

Variable	Mean (SD) of the 1st measurement	Mean (SD) of the 2nd measurement	Mean difference (95% CI)	*t*-value	*P*-value†	ICCs†† (95% CI)
Experimental	19.20 (2.79)	19.22 (2.79)	−0.014 (−0.06, 0.03)	−0.68	0.515	1.000 (0.999, 1.000)
Control	21.34 (1.51)	21.29 (1.52)	0.05 (−0.06, 0.16)	1.02	0.336	0.997 (0.989, 0.999)

†Systemic error was assessed using paired *t*-tests. ††Random error was assessed using intraclass correlation coefficients (ICCs); *SD*, standard deviation; *CI*, confidence interval

observed at days 5 and 7 compared to the baseline data ($p < 0.05$). When patients were asked to choose the most annoying experience between premolars' extraction and laser application, the majority of them indicated that both procedures bothered them equally.

Discussion

This RCT was undertaken to evaluate the effectiveness of laser-assisted flapless corticotomy in accelerating canine retraction and to explore patient-centered outcomes associated with laser application. The present RCT used a simple split-mouth design, i.e., the measurements for both techniques are taken from the same patients which resulted in reduced variance and higher study power compared to conventional parallel-group designs.

In orthodontics, anchorage reinforcement is of prime importance when the extraction of the premolars is involved. Based on the recommendations of Aboul-Ela et al., miniscrews were used as skeletal anchorage because of their simpler placement technique and the possibility of eliminating the reliance on patient compliance. The miniscrews selected had a diameter of 1.3 mm and a length of 8 mm, which optimized mechanical retention of the screws and eliminated any risks of root proximity or contact that may have contributed to failure during treatment [13, 31]. The miniscrews were placed buccally between the maxillary second premolar and the first molar to ensure a safe placement for the miniscrews in the maxillary arch [32].

The cortical perforations were made in the buccal cortical bone without flap elevation, vertical or subapical cuts, and without interfering with the palatal bone. In this study, 8 perforations were made: four of them in the first-premolar extraction site and the other 4 perforations were made around the canine region. This was the main difference in this study compared to the previous studies which did not involve the canine area [21, 33].

The rates of upper canines' retraction were significantly higher in the experimental sides than in the control sides during all evaluation times except at the 8th–12th-week interval. During the first week after corticotomy, the average rate of canine retraction was significantly higher: approximately 2.5 times than that of the control side. The retraction movement in the experimental side reached its peak at the end of the first month and started to decrease during the second month. During the third month, the retraction rate on the experimental side was equal to its rate on the control side. This acceleration might be explained by the induced RAP and reduced alveolar bone resistance during canine retraction [15, 21]. So, the present findings corroborate the results of Wilcko et al. [15], Hajji [34], Aboul-Ela et al. [13], and Al-Naoum et al. [12] who reported a significant reduction in treatment time when using corticotomy during teeth movement. However, these studies used relatively invasive techniques during cortication in addition to flap reflection and suturing. Moreover, the recent studies which used minimally invasive flapless techniques for corticotomy during canine retraction like piezocision [21] or laser-assisted corticotomy [21, 33] have shown that the tooth movement increased 2 times which is similar to what was seen in this study.

Table 3 Descriptive statistics of the canine retraction rate (mm/week) and the results of significance tests

Time	Experimental side		Control side		Mean difference (95% CI)	*P*-value†
	Mean	SD	Mean	SD		
0–1 week	0.85	0.21	0.34	0.16	0.51 (0.38, 0.65)	< 0.001**
1–2 weeks	0.72	0.20	0.38	0.15	0.34 (0.22, 0.46)	< 0.001**
2–4 weeks	1.21	0.35	0.69	0.34	0.52 (0.30, 0.76)	< 0.001**
4–8 weeks	0.40	0.18	0.22	0.08	0.18 (0.09, 0.28)	< 0.001**
8–12 weeks	0.23	0.10	0.26	0.10	−0.03 (−0.09, 0.04)	0.427

†Using two-sample *t*-test; **significant at $P < 0.001$; *SD*, standard deviation; *CI*, confidence interval

Table 4 Patients' responses in percentages for each of the questions presented 4 times during the first week after corticotomy using 4-point Likert scales

	1 (None)	2 (Mild)	3 (Moderate)	4 (Severe)	*P*-value† (vs day 1)
Q1: pain during eating					
Day 1	66.7	11.1	5.6	16.7	–
Day 3	55.6	27.8	0	16.7	0.002*
Day 5	44.4	55.6	0	0	< 0.001**
Day 7	88.9	11.1	0	0	< 0.001**
Q2: daytime pain					
Day 1	16.7	44.4	27.8	11.1	–
Day 3	72.2	11.1	16.7	0	0.705
Day 5	66.7	33.3	0	0	0.444
Day 7	83.3	16.7	0	0	0.064
Q3: overnight pain					
Day 1	66.7	16.7	16.7	0	–
Day 3	66.7	33.3	0	0	0.083
Day 5	100	0	0	0	0.024*
Day 7	72.2	27.8	0	0	0.046*
Q4: swelling at the surgical side					
Day 1	72.2	11.1	16.7	0	–
Day 3	83.3	0	16.7	0	0.157
Day 5	83.3	16.7	0	0	0.025*
Day 7	100	0	0	0	0.038*

†Comparisons with the baseline data (day 1) were performed using Wilcoxon matched signed-rank tests; *significant at $P < 0.05$; **significant at $P < 0.001$

During the first 3 days after corticotomy, 16.7% of the patients experienced severe pain during eating, and the percentage decreased significantly to 0% at the fifth- and seventh-day assessments. For the daytime pain, 44% of the patients experienced a mild degree of pain during the first day, while 11.1% reported that the pain was high. On the third day, 72.2% of the patients were free of pain, and the percentage increased to 83.3% on the 7th day. For the overnight pain, 16.7% of the patients reported a moderate degree of pain during the first 3 days, and then the percentage decreased significantly during the other assessment points until no pain was recorded by all patients on the last assessment time (i.e., the 7th day).

Immediately following corticotomy, 72.2% of the patients did not experience any swelling in the surgical side, while 16.7% experienced moderate swelling during the first 3 days after corticotomy. On the 7th day, 100% of the patients did not notice any swelling ($p = 0.038$). These findings agree with the findings of Gibreal et al. who reported a mild swelling during the first day after piezocision-assisted flapless corticotomy and decreased after 7 days [35]. In the conventional corticotomy, Al-Naoum et al. mentioned that 80% of the patients experienced severe swelling after corticotomy, whereas 70% of the patients reported mild to moderate swelling after 7 days [12]. This could be explained by the minimally invasive nature of laser-assisted flapless corticotomy conducted in the current study.

Complications

No obvious complications were observed during treatment. But one miniscrew became loose 2 weeks after insertion. Repositioning of the miniscrew was done posteriorly between the maxillary first and second molars, and then canine retraction was resumed.

Limitations and shortcomings

The current study did not evaluate posterior teeth changes as well as anchorage loss during canine retraction. Furthermore, the nature of the canine movement (i.e., tipping, translation, or both) was not evaluated. In future similar clinical trials, a radiographic evaluation would reveal more information about dentoalveolar changes. Additionally, sex-related differences in canine retraction and patient-reported outcome measures should be included.

Conclusions

Within the limits of the current trial, the following conclusions can be given:

- Alveolar bone corticotomy was an effective procedure to accelerate orthodontic tooth movement.
- Laser-assisted flapless corticotomy appeared to be effective in accelerating canine retraction. Canine retraction by this method was 2.5 times faster than the conventional retraction method.
- A mild degree of pain and discomfort was accompanied by laser-assisted flapless corticotomy during canine retraction.

Abbreviations RAP: Regional acceleratory phenomenon; ICCs: Intraclass correlation coefficients; RCT: Randomized control trial

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10006-021-00963-x.

Author contribution STJ treated the recruited patients, did the surgical intervention, analyzed the collected data, interpreted the results, and wrote the first drafts of this manuscript. RAA supervised this trial, planned the study design, and helped in writing up the manuscript. MYH helped in the statistical analysis, in the interpretation of the results, and in the writing up of this manuscript. All authors read and approved the final manuscript.

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate Ethical approval was obtained from the Research Ethics Committee of the University of Hama Dental School, Syria (Approval no. UHDS-3101_2015PG).

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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