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Original Article

CBCT-based assessment of apical root resorption and alveolar bone height following orthodontic treatment of Class I moderate crowding with labial vs. lingual fixed appliances in young adults: A randomized controlled trial

Jehad M. Kara-Boulad [1], Ahmad S. Burhan [2], Mohammad Y. Hajeer [2], Fehmieh R. Nawaya [3], Samer T. Jaber [4]

Available online:

1. Department of Orthodontics, Faculty of Dentistry, Al-Hawash Private University, Homs, Syria
2. Department of Orthodontics, Faculty of Dentistry, University of Damascus, Damascus, Syria
3. Department of Pediatric Dentistry, Faculty of Dentistry, Syrian Private University, Damascus Countryside, Syria
4. Department of Orthodontics, Faculty of Dentistry, Al-Wataniya Private University, Hama, Syria

Correspondence:
Mohammad Y. Hajeer, Department of Orthodontics, Faculty of Dentistry, University of Damascus, Damascus, Syria.
myhajeer@gmail.com

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Summary

Objectives > Apical root resorption and alveolar bone loss are potential complications associated with orthodontic treatment. This study aimed to assess apical root resorption and alveolar bone height following orthodontic treatment of moderate crowding with labial vs. lingual fixed appliances using CBCT imaging.

Subjects and methods > All patients meeting the eligibility criteria were included from March 2022 to June 2022 at the University of Damascus Faculty of Dentistry, Department of Orthodontics. The study involved patients diagnosed with Class I malocclusion and moderate crowding in both arches that could be treated on a non-extraction basis. Participants were randomly divided into two groups. One group was treated using lingual appliances (DTC® IN-Tendo JK-SL, DTC Medical Apparatus Co., Hangzhou, China) with a 0.018-inch slot. The sequence of archwires used included 0.012″, 0.014 0.016″ nickel-titanium, 0.016″ × 0.022″ TMA, 0.016″ × 0.022″ stainless steel, and 0.017″ × 0.025″ stainless steel. The other group received treatment with labial straight-wire appliances (AO Mini Master® – MBT System, metal brackets, Sheboygan, WI, USA) also featuring a 0.018-inch slot. The sequence of archwires used was 0.012″, 0.014″, 0.016″ nickel-titanium, 0.016″ × 0.022″ nickel-titanium, 0.016 and 0.017″ × 0.025″ stainless steel. The CBCT images were taken before the commencement of treatment (T0) and one day following the end of treatment (T1). The apical root resorption and alveolar bone height of the upper and lower teeth

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were assessed at these assessment times. Paired-sample *t*-test used to analyse the intergroup differences, while a two-sample *t*-test was employed to assess intragroup changes. The significance level was set at $P < 0.004$ after adjustment using Bonferroni's correction.

Results > Out of forty patients, nineteen patients in each group were included in the statistical analysis (16 men and 24 women; mean age: 21.3 years). In both groups, there was a significant decrease in the lengths of all studied teeth at T1 ($P < 0.004$). The apical resorption was significantly greater in the lingual appliance group for lower central and lateral incisors compared to the labial appliance group (0.64 mm, 0.7, respectively). The mean lingual bone loss in the lingual appliances was statistically greater than that in the labial appliances for lower central incisors (0.53 mm), while the mean buccal bone loss in the labial appliance group was statistically greater than that in the lingual appliance group for the lower lateral incisors (0.52 mm).

Conclusions > The use of DTC® lingual or AO Mini Master® labial brackets with archwire sequences is associated with clinically acceptable mild to moderate root resorption and clinically insignificant alveolar bone loss when treating moderate crowding. The record resorption in both cases is less than 1.34 mm. The lingual appliances cause greater resorption of lower incisors than labial appliances. Lingual bone loss is greater with lingual orthodontic appliances for lower central incisors, while vestibular bone loss is greater with labial orthodontic appliances for the lower later al incisors.

List of abbreviations

CEJ cementoenamel junction
CBCT cone beam computed tomography
DICOM digital imaging and communication in medicine
IPR interproximal reduction

Introduction

Labial fixed appliances are commonly used to correct cases of malocclusion, it has been traditionally employed to move teeth into their desired positions and have been effective in achieving optimal alignment of the teeth [1]. However, lingual fixed appliances have gained popularity due to their aesthetic advantages by being virtually invisible. It has provided a competitive substitute for the majority of adult and adolescent patients' effective treatment [2].

Recently the therapeutic results of lingual orthodontics have become similar and comparable to those produced by labial orthodontics [3,4]. However, lingual appliances act differently. The application of force near the centre of resistance and the distance between the lingual brackets leads to an increase in friction and thus an increase in the force applied during treatment [5]. In addition, the contact of the lower incisors with the brackets of the upper incisors in the lingual technique can lead to the intrusion of these incisors [6]. Therefore, these factors can be potential risks for apical root resorption and alveolar bone height in lingual orthodontics.

Apical root resorption is an undesirable side effect in orthodontic treatment, and it has a multifactorial aetiology [7]. It occurs as a result of physiological or pathological causes that lead to a loss in the structure of the teeth, and the most important factors are orthodontic treatment, trauma, periodontitis around the apex, dental cysts, internal bleaching, or for unknown reasons [8].

Different aspects of orthodontic treatment can affect root resorption such as the duration of the orthodontic treatment, the distance travelled by the moved tooth, and the amount, frequency, and type of the applied force [9,10].

In the literature, the root resorption observed after orthodontic treatment is seen to be unavoidable, and it is expected to occur in 80% of patients. Orthodontically induced root resorption is usually less than 2.5 mm and is classified as minor to moderate while severe root resorption, which can be defined as exceeding a third of the ordinary root length, is observed in 1–5% of the orthodontically treated teeth [11].

Changes in alveolar bone height are another potential side effect of orthodontic treatment. The distance between the cementoenamel junction (CEJ) and the marginal bone crest of the alveolar bone consists biologically of the junction of the epithelial and connective tissue [12]. Baysal et al. report that an increase in this distance to more than 2 mm is indicative of alveolar bone dehiscence [13]. Many factors contribute to the occurrence of alveolar bone loss, including the size and position of the teeth, the thickness of the alveolar bone, the orthodontic movement, and the forces applied during orthodontic treatment [14].

Several methods exist for assessing apical root resorption and alveolar bone height after orthodontic treatment, allowing orthodontists to evaluate the severity and progression of these phenomena. In order to monitor root resorption, two-dimensional (2D) radiographs, such as panoramic or periapical radiographs, are typically taken prior to, during, and following orthodontic treatment. However, these 2D radiographs may not accurately depict the true amount of root resorption due to magnification errors and difficulties in obtaining repeatable images [15]. Besides, conventional two-dimensional radiographs cannot accurately assess alveolar bone height in the anterior region [16].

Cone beam computed tomography (CBCT) has been introduced as a three-dimensional imaging technique that can capture detailed images of dental and maxillofacial structures. It gained popularity in dentistry because it offers a lower radiation dose compared to conventional computed tomography [17]. CBCT has proven to be valuable in diagnosing root resorption due to its capability to produce distortion-free images, as well as its ability to maintain a high level of reproducibility despite changes in tooth positions after treatment with high sensitivity and specificity [18,19]. On the other hand, the use of CBCT visualizes the morphology of the tooth root and alveolar bone in three dimensions; thus, CBCT allows for an evaluation of alveolar bone height and alveolar bone defects (such as dehiscence and fenestration) in the anterior region with high accuracy and precision [16,20].

In the literature, few studies evaluated the amount of root resorption after treatment with lingual appliances [5,6,21,22]. These studies mainly used two-dimensional images in evaluating root resorption using periapical radiography [5,6] or panoramic radiography [21,22]. However, these imaging techniques have limitations, including magnification errors, difficulties in obtaining repetitive images, and difficulties in accurately identifying the cementoenamel junction and root apex due to overlapping anatomical structures. Additionally, the accuracy of measuring tooth length is affected by the angle formed between the tooth axis and the radiographic film [23]. Moreover, these clinical studies focused only on the upper and/or lower incisors and did not consider the multi-rooted teeth even though, during orthodontic movement of premolars and molars, varying degrees of root resorption may occur.

The impact of lingual appliances on alveolar bone height is a pressing matter that demands extensive investigation. Surprisingly, there is a lack of clinical studies exploring this issue; there is no published evidence to date regarding the effects of fixed lingual appliances on bone loss.

Understanding the differences in root resorption and alveolar bone height between labial and lingual fixed appliances can help orthodontists make informed decisions when choosing the most appropriate treatment approach for their patients. Furthermore, this knowledge can contribute to improving treatment protocols and minimizing potential complications associated with orthodontic treatment. Therefore, this study aimed to assess apical root resorption and alveolar bone height following orthodontic treatment of moderate crowding with labial vs. lingual fixed appliances using CBCT. Our null hypothesis was that there was no difference in the assessment of apical root resorption and alveolar bone height between labial and lingual fixed appliances.

Material and methods

Trial design and registration

This research was a randomized controlled trial with parallel groups. It was conducted at the Department of Orthodontics, Faculty of Dentistry, University of Damascus (Syria). The Local Research Ethics Committee of the University of Damascus evaluated and approved the study's protocol (Approval No.: UDDS-1978-12122021/SRC-3499). This research project was supported by the University of Damascus (Ref. No.: 501100020595) and was registered in the ClinicalTrials.gov database (NCT06401369). Since the start of the experiment, the study protocol has not been altered. The CONSORT statement's guidelines were followed in the reporting of this study [24].

Sample size calculation

The sample size was calculated using Minitab™ (version 21; Minitab Inc., State College, PA, USA). The "'two-sample *t*-test'' was the proposed statistical test. The ensuing presumptions were applied: the smallest variation in the root resorption that needs to be noticed was 0.5 mm, a standard deviation of 0.49 according to a previous study [25], with a 5% significance level and 80% as the power of the study. The analysis revealed that a sample of 17 patients was required for each group. Tree patients were added to each group to prevent any possible attrition, resulting in 40 as the total study sample.

Participants and eligibility criteria

One hundred patients who first registered from March 2022 to June 2022 at the University of Damascus Faculty of Dentistry, Department of Orthodontics, with a primary diagnosis of crowded teeth and class I malocclusion were called back for additional examination. Subsequent clinical evaluation identified 56 individuals who satisfied the selection criteria. Three patients declined to take part in the trial after being given sufficient details about it. The number of patients who met the inclusion criteria and agreed to participate in the study, after receiving an explanation of the clinical trial design both orally and in written format, was 53. A total of 40 patients were randomly selected by an academic staff member from the Department of Orthodontics (who was not involved in this research) to form the primary sample. The remaining 13 patients, who provided their informed consent but were not included in the trial in order to adhere to the sample size requirement, were treated at the Department of Orthodontics by other MSc students under the direct supervision of one of the co-authors (A.S.B.).

The inclusion criteria included: (1) Class I molar canine relationships on both sides; (2) moderate crowding of both the arches measuring greater than 4 mm but less than 6 mm, according to Little's Index of Irregularity, which could be treated on a non-extraction basis; (3) age from 18 to 25 years; and (4) completion permanent dentition (except third molars); and (5) no history of any trauma or agenesis.

The exclusion criteria were: (1) The existence of craniofacial syndromes, cleft lip, and/or cleft palate (soft and/or hard); (2) Skeletal or dental crossbite; (3) patients with missing teeth or periodontal diseases; and (4) Previous orthodontic treatment.

Randomization, allocation concealment, and blinding

Randomization was performed using a computer-generated random list of random numbers was exported by Minitab™ (version 21; Minitab Inc., State College, PA, USA) with an allocation ratio of 1:1. It performed by one academic staff not involved in this research project. Using sealed, sequentially numbered envelopes, the patients were divided into the two groups at random. Blinding was limited to the outcome assessor because it was not possible to blind personnel or participants.

Experimental group: lingual fixed orthodontic group

The individuals within this group received treatment with lingual brackets with 0.018-inch slots (DTC® IN-Tendo JK-SL, DTC Medical Apparatus Co., Hangzhou, China) were applied with the aid of a special indirect bonding technique "Modified HIRO® Technique" [26]. The lingual brackets were positioned on both arches during the same visit (*figure 1*). The lingual archwires

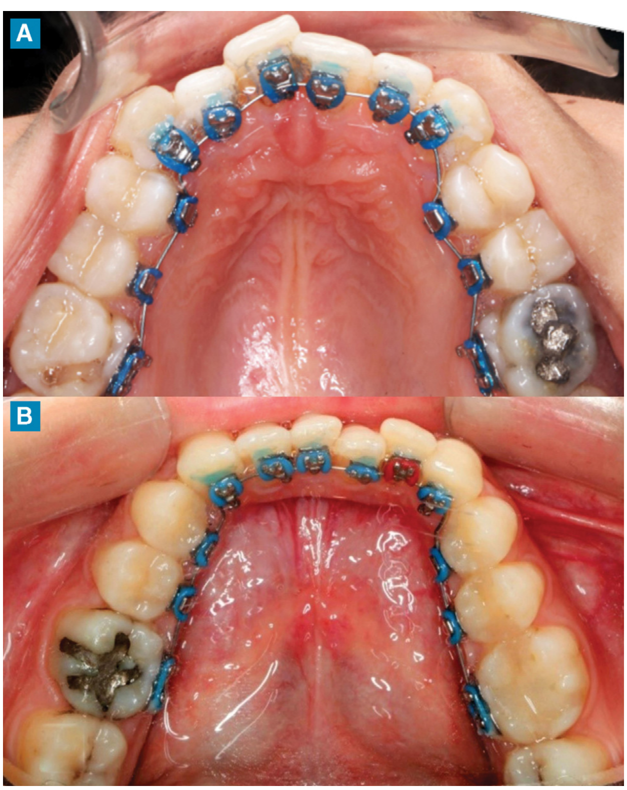

FIGURE 1

The lingual appliance used in the current study. A. An occlusal view of the upper jaw's lingual appliance. B. An occlusal view of the lower jaw's lingual appliance

(Forestadent®, Germany) were custom-made on the initial dental cast using an Arch Forming Turret (Dentaurum Inc. Langhorne, USA) with a prominence premolar offset only. The sequence of archwires used was 0.012″, 0.014″, 0.016″ nickel-titanium, 0.016″ × 0.022″ TMA, 0.016″ × 0.022″ stainless steel, and 0.017″ × 0.025″ stainless steel.

Control group: labial fixed orthodontic group

Patients in this group received treatment with labial appliances with 0.018-inch slots (AO Mini Master® – MBT System, metal brackets, Sheboygan, WI, USA) were used and directly bonded on both arches (*figure 2*). The following sequence of prefabricated archwires (American Orthodontics®, Sheboygan, WI, USA) was used: 0.012″-0.014″-0.016″ nickel-titanium, 0.016″ × 0.022″ nickel-titanium, 0.016″ × 0.022″, and 0.017″ × 0.025″ stainless steel.

Following the application of the appliances, the first archwire was placed in both groups, and patients were followed up. Archwires were only replaced when there was an improvement in the alignment of the teeth and the subsequent archwire could be inserted with little to no bending and without applying undue strain to the teeth [27]. To generate the necessary space for correcting crowded teeth, a mild interproximal reduction (IPR) was performed in both groups on nine contact areas, ranging from the second premolar to the second premolar. The amount of IPR was determined by the treating orthodontist based on the specific needs of each case, considering factors such as the degree of crowding, tooth anatomy, and overall treatment objectives. The tool used for the IPR was 45-micron, single-sided, hand-held metal abrasion strips (Galaxy™, Ortho Technology®, Florida, USA). These strips are designed to provide precise and controlled enamel reduction. This procedure was repeated every one to two visits to gradually create the necessary space for tooth alignment. The total amount of enamel reduction in each case was limited to a maximum of 0.25 mm from each surface, in accordance with the established protocol to minimize any potential risks associated with excessive enamel removal, as measured using an IPR gauge. This limit was established to ensure that the integrity of the teeth was

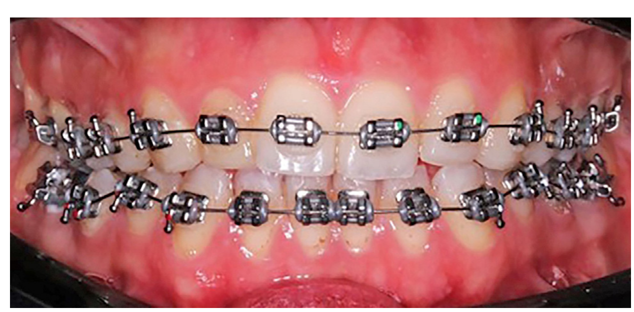

FIGURE 2

The labial appliance used in the current study

maintained while still achieving the required space. For occlusal stability and further detail where needed, 0.014″ stainless steel archwire was used to complete the treatment.

Outcome measures

An assessment of root resorption and alveolar bone height was conducted by the principal researcher (J.M.K.) under the supervision of one of the co-authors (A.S.B.), who teaches radiological diagnosis in the Orthodontic Department at the University of Damascus.

CBCT image acquisition

The CBCT images were taken before the commencement of treatment (T0) and one day following the end of treatment (T1). All of these images were taken using the same CBCT imaging system (Pax-i3D®, Vatech, Yongin, Korea), with 85 kV, 15 mA, 0.23-mm voxel size, 9-second exposure time, and a 150- × 150-mm field of view (FOV). The patients were instructed to sit upright and close their teeth closed in maximum intercuspation. The midsagittal plane was perpendicular to the floor, and the Frankfort horizontal plane was parallel to it. [28]. The collected CBCT data was transferred into a Digital Imaging and Communication in Medicine (DICOM) file format and then processed by Ondemand3D™ software (version 1.0.9.1451; CyberMed, Seoul, Korea) to perform the 3D analysis.

Assessment of apical root resorption

The CBCT volume's axial, coronal, and sagittal planes were reoriented so that they were perpendicular to the long axis of each tooth under evaluated [29]. The tooth axis of the incisors was determined by drawing a line from the incisal midpoint to the apex of the root. As for the long axis of the canines, it was determined by the line connecting the cusp tip and the apex of the root. The long axis of the posterior teeth was determined by the line connecting the middle of the mesiodistal and labiolingual distance for the tip of the cusps and the apex of the root for the single-rooted teeth and the centre of the bifurcation or trifurcation of a double-rooted or triple-rooted tooth (*figure 3*) [30].

The teeth lengths were measured as follows: central and lateral incisors, from incisal edge to apex (sagittal section); canines, from cusp tip to apex (sagittal section); single-rooted premolar, from vestibular cusp tip to apex (sagittal section); two-rooted premolar, from vestibular cusp tip to apex (sagittal section) and from lingual cusp tip to apex (coronal section); upper molars, from the mesiolingual cusp tip to apex of the lingual root of molar (coronal section), from mesiobuccal cusp tip to apex of mesiobuccal root of molar (sagittal section), from distobuccal cusp tip to the apex of distobuccal root of molar (sagittal section); lower molars, from mesiolingual cusp tip to apex of mesiolingual root of molar (coronal section), from mesiobuccal cusp tip to apex of mesiobuccal root of molar (sagittal section); and from distobuccal cusp tip to apex of distobuccal root of molar (sagittal section; *figure 3*) [31].

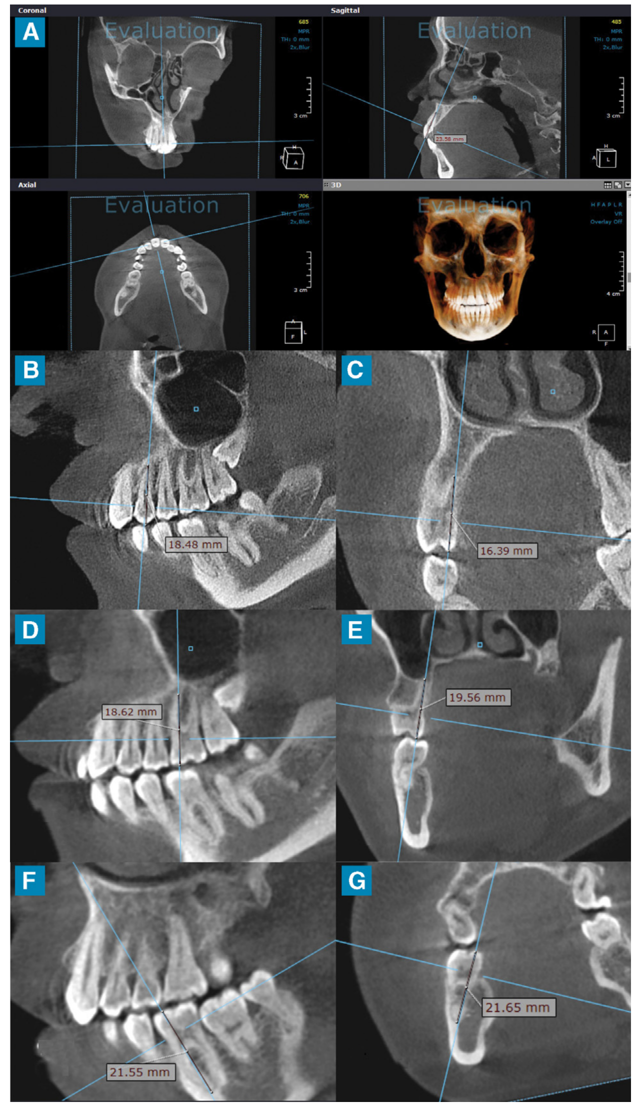

FIGURE 3

Measurement of teeth lengths

A. Measurement of the length of the central incisor in the sagittal view. B. Measurement of the length of the buccal root of the maxillary premolar in the sagittal view. C. Measurement of the length of lingual root of the upper premolar in the coronal view. D. Measurement of the length of mesiobuccal root of the upper molar in the sagittal view. E. Measurement of the length of lingual root of the upper molar in the coronal view. F. Measurement of the length of mesiobuccal root of the lower molar in the sagittal view. G. Measurement of the length of mesiolingual root of the lower molar in the coronal view.

The extent of resorption was determined by subtracting the pre-treatment tooth length from the post-treatment tooth length [32].

Assessment of alveolar bone height

The CBCT images were redirected then the long axis of each tooth was determined as previously described. The distance

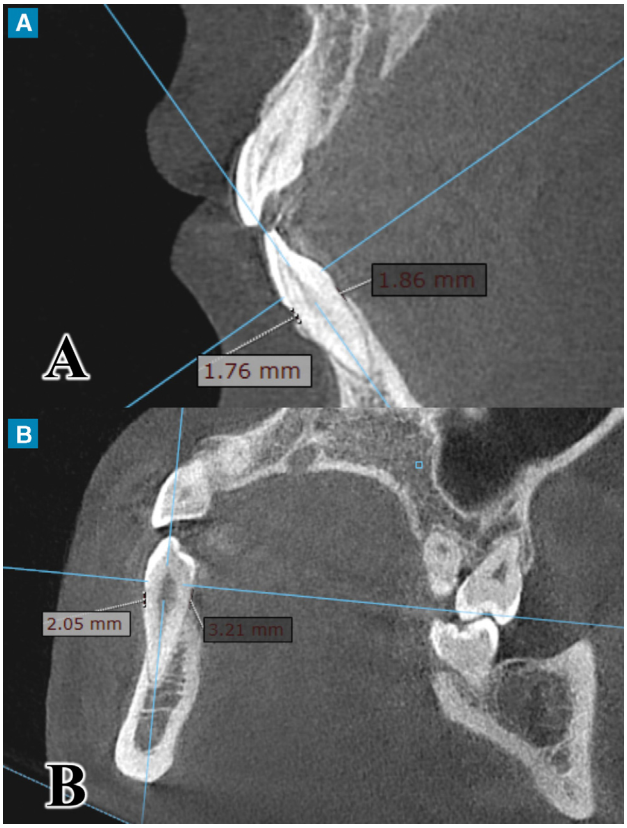

FIGURE 4

Measurement of the vestibular and lingual alveolar bone height

A. Measurement of the vestibular and lingual alveolar bone height of the central incisor in the sagittal view. B. Measurement of the vestibular and lingual alveolar bone height of premolar in coronal view.

between the alveolar bone's crest from the cementoenamel junction was measured parallel to this axis using a method outlined by Castro et al., which involved drawing a vertical line between the vestibular and lingual cementoenamel junction and the vestibular and lingual alveolar bone crest. For central and lateral incisors, this line was measured in the sagittal plane, while for canines, first and second premolars, and first molars, it was measured in the coronal plane (*figure 4*) [14].

The error of the method

After a month, the principal researcher re-measured twenty CBCT images (ten from each group) that were chosen at random. These images were obtained both before and after treatment. Interclass correlation coefficients were utilized to assess the intra-examiner reliability (random error), and paired-sample *t*-tests were employed to identify systematic errors.

Statistical analysis

SPSS® Version 22 (SPSS Inc., 444 Michigan Avenue, Chicago, USA) was employed for data analysis. The distributions were checked for normality using Kolmogorov-Smirnov tests. For assessing intragroup changes, two-sample *t*-tests (or Mann-Whitney U-tests) were used, while for assessing intergroup differences, paired-sample *t*-tests or Wilcoxon matched-pairs signed-rank tests (the nonparametric equivalent) were employed. The results were evaluated with a 95% confidence interval, and the statistical significance was set at $P < 0.004$ after adjusting it using Bonferroni's correction. Data were analysed using a per-protocol (PP) analysis.

Results

Baseline sample characteristics

The CONSORT flow diagram for participant recruiting, follow-up, and data analysis entry is displayed in *figure 5*. Forty patients (24 females, 16 males; mean age: 21.3 years) patients were randomly distributed into two groups: 20 patients (11 females, 9 males; mean age: 21.7 years) in the lingual group and 20 patients (13 females, 7 males; mean age: 20.8 years) in the labial group, but 2 patients (one patient in each group) were lost to follow-up due to personal reasons. Therefore, only 38 patients were enrolled in the statistical analysis. *Table I* shows the study sample's baseline characteristics.

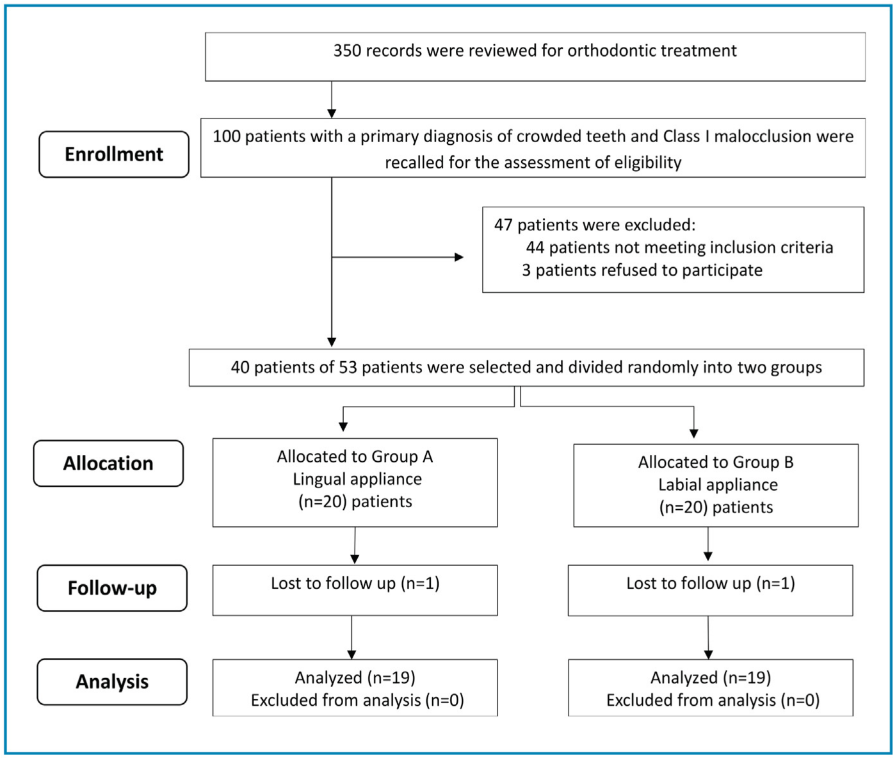

FIGURE 5

The CONSORT flow diagram of patient recruitment, follow-up, and entry into data analysis

TABLE I

Basic sample characteristics in terms of gender distribution, age, treatment time, crowding, and inclination of incisor

Variable	Lingual group	Labial group	*P*-value
Gender (females/males)[1]	11/9	13/7	0.194
Mean age (SD) (years)[2]	21.7 (3)	20.8 (2.8)	0.389
Mean treatment time (SD) (months)[2]	13.7 (1.9)	14.5 (2.3)	0.881
Mean crowding (SD) (mm)[2]	4.9 (0.8)	4.8 (0.7)	0.825
Mean U1-SN (SD) (°)[2]	108.8 (7.2)	110.3 (5.7)	0.469
Mean L1-MP (SD) (°)[2]	90.6 (4.5)	92.0 (5.7)	0.581

SD: standard deviation.
[1]Chi^2 test for comparison gender between the two groups.
[2]Two sample *t*-test for comparison age, treatment time, crowding, and inclination of incisor between the two groups.

Sample homogeneity

There were no statistically significant differences between the two groups in tooth lengths and the height of the lingual and vestibular alveolar bone across all teeth prior to treatment ($P > 0.05$; *supplementary table I*).

The error of the method

For error of the method, paired-sample *t*-test for the two sets of measurement showed that there were no significant differences ($P > 0.05$). Therefore, systematic errors were found to be small and could be negligible. The interclass correlations coefficients (ICCs) for the measures manifested strong intra-examiner reliability, ranging from 0.985 to 0.999, indicating high intra-examiner reliability.

Apical root resorption

In both groups, there was a significant decrease in the lengths of all studied teeth at T1 ($P < 0.004$; *table II*). When analysing the resorption in lingual appliance group, the lower central incisors showed the greatest mean change in tooth length (−1.34 mm; *table II*), followed by the lower lateral incisors, upper lateral incisors, and upper central incisors (−1.15, −1.14, and −0.7 mm; respectively). Whereas, the changes were minimal for the canines and posterior teeth. The upper first molars showed the least mean change in tooth length (−0.25 mm), and this decrease was statistically significant compared with T0 ($P < 0.001$; *table II*).

For the labial appliance group, the lower central incisors showed the greatest mean change in tooth length (−0.7 mm; *table II*) followed by the upper central incisors and lower canines

Table II

Changes in tooth lengths (in millimetres) between the two groups as well as *P*-values for significance tests

Measurements, mm		Lingual fixed orthodontic group (*n* = 19)					Labial fixed orthodontic group (*n* = 19)					95% confidence interval of the difference	*P*-value[3] Lingual group vs. Labial group
Jaw	Tooth	T0	T1	T1-T0	95% confidence interval of the difference	*P*-value[2]	T0	T1	T1-T0	95% confidence interval of the difference	*P*-value[2]		
		Mean (SD)	Mean (SD)				Mean (SD)	Mean (SD)					
Maxillary	Central incisor	24.08 (1.51)	23.34 (1.63)	−0.74	−1.06, −0.41	< 0.001[1]	23.55 (1.42)	22.99 (1.32)	−0.56	−0.8, −0.32	< 0.001[1]	−0.57, 0.21	0.359
	Lateral incisor	22.70 (1.29)	21.56 (1.36)	−1.14	−1.68, −0.6	< 0.001[1]	22.47 (1.20)	22.04 (1.19)	−0.43	−0.67, −0.19	0.001[1]	−1.29, −0.13	0.016
	Canine	26.58 (1.48)	26.25 (1.45)	−0.33	−0.5, −0.16	0.001[1]	26.64 (1.50)	26.42 (1.51)	−0.22	−0.28, −0.16	< 0.001[1]	−0.29, 0.07	0.207
	First premolar	20.81 (1.69)	20.47 (1.72)	−0.33	−0.54, −0.12	0.003[1]	20.44 (1.51)	19.97 (1.57)	−0.47	−0.72, −0.23	0.001[1]	−0.17, 0.45	0.359
	Second premolar	20.77 (1.53)	20.35 (1.59)	−0.42	−0.63, −0.21	0.001[1]	20.97 (1.24)	20.49 (1.08)	−0.48	−0.65, −0.31	< 0.001[1]	−0.2, 0.32	0.655
	First molar	19.56 (1.35)	19.31 (1.46)	−0.25	−0.38, −0.13	< 0.001[1]	19.17 (1.22)	18.86 (1.21)	−0.31	−0.41, −0.21	< 0.001[1]	−0.1, 0.21	0.448
Mandibular	Central incisor	20.85 (1.14)	19.51 (1.26)	−1.34	−1.54, −1.14	< 0.001[1]	21.16 (1.39)	20.46 (1.13)	−0.70	−1.01, −0.39	< 0.001[1]	−0.99, −0.28	0.001[1]
	Lateral incisor	22.44 (1.34)	21.29 (1.33)	−1.15	−1.39, −0.9	< 0.001[1]	22.67 (0.62)	22.22 (0.74)	−0.45	−0.65, −0.24	< 0.001[1]	−1.01, −0.39	< 0.001[1]
	Canine	25.29 (1.40)	24.72 (1.49)	−0.57	−0.76, −0.37	< 0.001[1]	25.46 (1.25)	24.89 (1.29)	−0.56	−0.81, −0.34	< 0.001[1]	−0.28, 0.3	0.942
	First premolar	22.14 (1.22)	21.63 (1.27)	−0.51	−0.79, −0.23	0.001[1]	21.91 (1.17)	21.67 (1.12)	−0.24	−0.36, −0.11	0.001[1]	−0.57, 0.02	0.066
	Second premolar	22.41 (1.74)	21.82 (1.78)	−0.59	−0.86, −0.32	< 0.001[1]	22.11 (1.19)	21.54 (1.27)	−0.57	−0.75, −0.39	< 0.001[1]	−0.34, 0.3	0.893
	First molar	20.52 (1.67)	19.96 (1.79)	−0.55	−0.81, −0.3	< 0.001[1]	19.96 (0.94)	19.64 (0.90)	−0.32	−0.41, −0.24	< 0.001[1]	−0.5, 0.03	0.077

n: number of patients; T0: before the commencement of treatment; T1: one day following the end of treatment.
[1]Bonferroni correction was used to adjust the level of significance to 0.004.
[2]Paired *t*-tests were used for intragroup comparisons.
[3]Two sample *t*-tests were conducted for the comparisons between the two groups.

(−0.56 mm). The upper canines showed the least mean change in tooth length (−0.22 mm), and this decrease was statistically significant compared with T0 ($P < 0.001$; *table II*).

Regarding the differences between the two groups, the mean amount resorption was significantly greater in the lingual appliance group for lower central and lateral incisors in comparison to the labial appliance group ($P = 0.001$, $P < 0.001$, respectively; *table II*). However, there were no statistically significant differences between the two groups for the other studied teeth ($P > 0.004$; *table II*).

Alveolar bone height

The greatest mean decrease in the alveolar bone height in labial appliance group was found in the vestibular surfaces of upper canines, lower central and lateral incisors (0.4 mm and 0.6 mm, respectively) with a statistically significant difference when compared with T0 ($P = 0.001$, $P = 0.002$, and $P < 0.001$; respectively; *table III*). On the other hand, in the lingual appliance group, the greatest mean decrease in the alveolar bone height was found in the lingual surfaces of lower central and lateral incisors (0.7 mm and 0.5 mm, respectively) with a statistically significant difference when compared with T0 ($P < 0.001$ and $P = 0.001$, respectively; *table IV*). However, there were no statistically significant intragroup differences for the other studied teeth ($P > 0.004$; *tables III and IV*).

When the changes in alveolar bone height was compared between the two groups, the mean lingual bone loss in the lingual appliances was greater than that in the labial appliances for lower central incisors (0.53 mm), with a statistically significant differences ($P = 0.002$; *table IV*). The mean labial bone loss in the labial appliance group was greater than that in the lingual appliance group for the lower lateral incisors (0.52 mm), with a statistically significant differences ($P < 0.001$; *table III*). However, there were no statistically significant differences between the two groups for the other studied teeth ($P > 0.004$; *tables III and IV*).

Table III

Changes in labial alveolar bone height (in millimetres) between the two groups as well as *P*-values for significance tests

Measurements, mm		Lingual fixed orthodontic group (n = 19)					Labial fixed orthodontic group (n = 19)					95% confidence interval of the difference	*P*-value[3] Lingual group vs. Labial group
Jaw	Tooth	T0	T1	T1-T0	95% confidence interval of the difference	*P*-value[2]	T0	T1	T1-T0	95% confidence interval of the difference	*P*-value[2]		
		Mean (SD)	Mean (SD)				Mean (SD)	Mean (SD)					
Maxillary	Central incisor	1.17 (0.39)	1.27 (0.36)	0.10	−0.01, 0.21	0.067	1.17 (0.47)	1.25 (0.43)	0.08	−0.02, 0.18	0.127	−0.12, 0.17	0.769
	Lateral incisor	1.39 (0.77)	1.57 (0.61)	0.18	−0.03, 0.38	0.084	1.57 (0.62)	1.62 (0.59)	0.05	−0.06, 0.15	0.348	−0.09, 0.35	0.237
	Canine	1.77 (0.35)	1.86 (0.26)	0.09	−0.05, 0.23	0.199	1.92 (1.23)	2.35 (1.22)	0.43	0.21, 0.64	0.001[1]	−0.58, −0.09	0.009
	First premolar	1.56 (0.70)	1.66 (0.61)	0.10	−0.06, 0.26	0.201	1.47 (0.63)	1.61 (0.67)	0.14	−0.03, 0.3	0.097	−0.26, 0.18	0.736
	Second premolar	0.94 (0.58)	1.07 (0.56)	0.13	−0.08, 0.33	0.205	1.05 (0.48)	1.09 (0.64)	0.04	−0.21, 0.12	0.595	−0.08, 0.42	0.181
	First molar	0.93 (0.69)	0.98 (0.76)	0.05	−0.08, 0.18	0.413	0.73 (0.46)	0.82 (0.39)	0.09	−0.03, 0.22	0.117	−0.21, 0.13	0.624
Mandibular	Central incisor	1.20 (0.89)	1.34 (0.75)	0.14	−0.01, 0.29	0.064	1.48 (0.71)	2.12 (1.26)	0.64	0.27, 1.01	0.002[1]	−0.88, −0.11	0.013
	Lateral incisor	1.33 (0.60)	1.45 (0.70)	0.12	−0.01, 0.25	0.063	1.35 (0.54)	1.99 (0.54)	0.64	0.49, 0.8	< 0.001[1]	−0.72, −0.33	< 0.001[1]
	Canine	1.62 (0.50)	1.71 (0.45)	0.08	−0.04, 0.21	0.166	1.83 (0.98)	2.40 (1.14)	0.57	0.13, 1.01	0.013	−0.93, −0.05	0.030
	First premolar	1.44 (0.97)	1.50 (0.79)	0.06	−0.23, 0.36	0.661	1.54 (0.69)	1.62 (0.83)	0.07	−0.1, 0.25	0.392	−0.34, 0.32	0.949
	Second premolar	0.75 (0.56)	0.85 (0.49)	0.11	−0.11, 0.32	0.320	0.88 (0.72)	0.93 (0.44)	0.05	−0.29, 0.38	0.769	−0.33, 0.44	0.762
	First molar	0.53 (0.54)	0.65 (0.62)	0.12	−0.06, 0.29	0.172	0.55 (0.44)	0.59 (0.49)	0.05	−0.06, 0.16	0.380	−0.13, 0.26	0.485

n: number of patients; T0: before the commencement of treatment; T1: one day following the end of treatment.
[1]Bonferroni correction was used to adjust the level of significance to 0.004.
[2]Paired t-tests were used for intragroup comparisons.
[3]Two sample t-tests were conducted for the comparisons between the two groups.

TABLE IV
Changes in lingual alveolar bone height (in millimeters) between the two groups as well as *P*-values for significance tests

Measurements, mm		Lingual fixed orthodontic group (n = 19)					Labial fixed orthodontic group (n = 19)					95% confidence interval of the difference	*P*-value[3] Lingual group vs. Labial group
Jaw	Tooth	T0	T1	T1-T0	95% confidence interval of the difference	*P*-value[2]	T0	T1	T1-T0	95% confidence interval of the difference	*P*-value[2]		
		Mean (SD)	Mean (SD)				Mean (SD)	Mean (SD)					
Maxillary	Central incisor	0.89 (0.58)	1.34 (0.82)	0.44	0.13, 0.76	0.008	0.99 (0.53)	1.23 (0.55)	0.24	−0.05, 0.52	0.098	−0.2, 0.61	0.316
	Lateral incisor	0.87 (0.57)	1.22 (0.80)	0.35	0.09, 0.62	0.013	0.99 (0.48)	1.03 (0.43)	0.04	−0.17, 0.25	0.715	−0.01, 0.64	0.058
	Canine	1.01 (0.68)	1.23 (0.85)	0.23	−0.03, 0.48	0.075	1.18 (0.65)	1.63 (0.82)	0.45	−0.04, 0.94	0.071	−1.16, −0.01	0.405
	First premolar	1.14 (0.75)	1.23 (0.81)	0.09	−0.31, 0.13	0.401	1.26 (0.54)	1.42 (0.68)	0.16	−0.04, 0.36	0.117	−0.53, 0.04	0.089
	Second premolar	1.08 (0.71)	1.23 (0.78)	0.15	−0.09, 0.39	0.200	1.08 (0.33)	1.17 (0.43)	0.09	−0.12, 0.31	0.367	−0.25, 0.37	0.709
	First molar	1.19 (0.98)	1.29 (0.63)	0.11	−0.17, 0.39	0.440	1.33 (0.55)	1.45 (0.36)	0.12	−0.04, 0.27	0.142	−0.32, 0.3	0.946
Mandibular	Central incisor	1.59 (0.76)	2.29 (0.75)	0.70	0.43, 0.97	< 0.001[1]	1.52 (0.97)	1.69 (0.93)	0.17	−0.01, 0.35	0.066	0.21, 0.85	0.002[1]
	Lateral incisor	1.18 (0.81)	1.71 (0.71)	0.52	0.25, 0.79	0.001[1]	1.04 (0.56)	1.23 (0.43)	0.19	−0.08, 0.47	0.150	−0.04, 0.7	0.042
	Canine	0.96 (0.81)	1.32 (0.64)	0.35	0.13, 0.57	0.004	1.18 (0.53)	1.38 (0.42)	0.19	−0.05, 0.44	0.116	−0.16, 0.48	0.324
	First premolar	1.27 (0.70)	1.42 (0.84)	0.15	−0.04, 0.34	0.121	1.26 (0.83)	1.41 (0.74)	0.15	−0.03, 0.32	0.097	−0.25, 0.25	1.000
	Second premolar	1.17 (1.00)	1.26 (1.07)	0.09	−0.13, 0.31	0.396	1.16 (0.46)	1.20 (0.49)	0.04	−0.14, 0.22	0.625	−0.22, 0.32	0.724
	First molar	0.68 (0.63)	0.82 (0.63)	0.14	−0.03, 0.3	0.098	0.75 (0.52)	0.91 (0.47)	0.15	−0.03, 0.34	0.105	−0.26, 0.23	0.895

n: number of patients; T0: before the commencement of treatment; T1: one day following the end of treatment.
[1]Bonferroni correction was used to adjust the level of significance to 0.004.
[2]Paired *t*-tests were used for intragroup comparisons.
[3]Two sample *t*-tests were conducted for the comparisons between the two groups.

Discussion

The present study seems to be the first randomized controlled trial comparing root resorption and alveolar bone height between lingual and labial orthodontic treatment after the complete orthodontic treatment course for both anterior and posterior teeth using CBCT imaging.

Studying root resorption and alveolar bone levels through CBCT investigations offers the advantage of high-resolution, three-dimensional analysis of anatomical structures in multiple planes, thereby facilitating a comprehensive evaluation of each case. Additionally, measurements obtained from CBCT are regarded as reliable and reproducible across different phases of orthodontic treatment [33]. However, the performance characteristics of CBCT images were used to determine the lowest possible radiation dose associated with the diagnostic task, in accordance with the As Low As Reasonably Achievable (ALARA) principle, while following relevant guidelines and regulatory protocols.

The labial and lingual appliances were extended from the right first molar to the left first molar in both the upper and lower jaws because the first molars serve as effective anchorage points for tooth movement, and research has demonstrated that anchoring treatment mechanics primarily to first molars and anterior teeth can be sufficient for achieving alignment goals. This approach helps to avoid the complications and risks of unwanted movements associated with second molars.

Our null hypothesis was rejected, as we observed that lingual appliances cause greater resorption of lower incisors compared to labial appliances. Additionally, we found that bone loss in the lingual region is more pronounced when using lingual orthodontic appliances, whereas vestibular bone loss is greater with labial orthodontic appliances, particularly in the incisor region.

This trial showed a significant decrease in the lengths of all teeth after treatment in both groups. The rate of resorption ranged from 0.25 to 1.34 mm in the lingual appliances group and from 0.22 to 0.70 mm in the labial appliances group. The current study did not record resorption more than 1.34 mm regardless of the technique used, and this amount of resorption can be considered clinically acceptable, it is classified as mild to moderate and is not associated with any noticeable clinical symptoms and does not affect long-term stability [6,7,22,33]. Therefore, orthodontic treatment for moderate crowding can be considered safe for both the labial and lingual appliances, but other factors such as Individual readiness, applied force, treatment duration and the amount of tooth movement still need more research to determine the extent of their effect on increasing the amount of root resorption.

The results of this study agreed with the results of previous studies, which have found notable mild to moderate root resorption after orthodontic treatment with lingual and labial appliances, similar to the resorption recorded in this study [5,6,21,22].

The results of the current study showed that the amount of resorption in the lingual group was significantly greater than in the labial group for the lower central (0.64 mm) and lateral (0.7 mm) incisors, while there were no significant differences between the two groups for the remaining teeth studied. This difference in the amount of resorption can be explained by mechanical differences. The decreased inter-bracket distance in lingual appliances leads to a reduction in the springiness of the wires. This makes them apply a greater force than the labial brackets, especially in the mandibular arch [34]. In addition, the force applied by lingual brackets is closer to the centre of resistance causing a greater force to be applied. The occlusal contact between the lower incisors and the upper lingual brackets causing additional occlusal trauma [21]. Therefore, all of the above reasons are risk factors for increased root resorption in lingual orthodontics.

The results of the current study is in agreement with Nassif et al. [6] who found no significant differences in resorption of the roots of the upper incisors between labial and lingual orthodontic appliances. While this result differs from the results of Deguchi et al. [5] who did not find differences between labial and lingual appliances in the amount of root resorption of the upper and lower incisors in class II cases. This difference can be explained by the fact that the resorption in Deguchi's study was evaluated after premolar extraction and retraction of incisors, and the overjet resulting from Class II cases prevents the contact of the upper brackets with the lower incisors and this may relieve pressure on the incisors. In addition, resorption was evaluated based on two-dimensional periapical images. This result also differs from the results of Pamukçu et al. [21] who did not find statistical differences between labial and lingual orthodontic appliances in the degree of root resorption in upper and lower incisors and canines after treatment. This difference can be explained by the different methods used to assess root resorption. In the study by Pamukçu et al., panoramic images were used to determine the cementoenamel junction with a root-crown ratio calculation, whereas in our study the total length of the tooth was measured from the incisal edge to the apex using CBCT images.

Most previous studies have focused on studying root resorption of incisors, because they are the most teeth affected by root resorption during orthodontic treatment [35]. This may be due to their single cone-shaped roots, and de-crowding or retracting teeth requires more movements at this tooth. However, aligning and levelling the teeth requires a degree of movement of the molars and posterior teeth, so they had to be evaluated, as the results of this study showed that the incisors showed a greater rate of resorption than the canines and posterior teeth in both groups. This finding has been confirmed by many researchers [36,37].

The relationship between orthodontic treatment and changes in alveolar bone height has been widely discussed in the medical literature, but differences in orthodontic treatment techniques and the different radiographic and diagnostic methods used in different studies may limit comparison of results.

In this study, the crest of the alveolar bone and the cementoenamel junction were used to study alveolar bone height because the bone follows the movement of the teeth in the presence of healthy gingival tissue [38]. In the present study, both groups recorded a decrease in alveolar bone height on the vestibular and lingual sides of all the study teeth after treatment, but neither group recorded a decrease in vestibular or lingual bone height of more than 0.7 mm. This is considered clinically acceptable as shown in a systematic review published by Bollen et al. [39] who found that routine orthodontic treatment results in a small loss in alveolar bone.

In this study, the lower central and lateral incisors recorded the greatest values of loss in vestibular bone height in the labial group and the greatest values of loss in lingual bone height in the lingual group. This may be due to the shape and structure of the alveolar bone in these regions, as these surfaces contain thin cortical bone and a small amount of bone marrow [40]. This result is consistent with the results of several studies that showed that the most frequent surfaces in which bone loss occurs are the vestibular surfaces of the lower incisors after treatment with labial orthodontic appliances [14,41].

Comparing the two groups, the current study showed that the vestibular bone loss was greater in the labial appliances group, while the lingual bone loss was greater in the lingual appliances. The force during tooth movement is concentrated at the cervical of the tooth, leading to bone loss, and at the peak, leading to root resorption. Also, tooth movement towards the vestibular or lingual direction results in a loss of alveolar bone height [41]. Thus, in lingual appliances the force is closer to the lingual bone plate, while the force is closer to the vestibular bone plate in the labial appliances. This could explain the increased lingual bone loss in the lingual appliance group and the increased vestibular bone loss in the labial appliance group. To our knowledge, we did not find a published study that evaluated bone loss in patients with lingual appliances to compare with the current study.

Limitations

The limitations of this study encompass various aspects, including the use of the traditional lingual appliance system, which may yield different outcomes compared to other systems such as Incognito™ or Orapix™ in terms of root resorption and alveolar bone height. Additionally, the study sample consisted of patients with moderate crowding treated without extraction; more comprehensive studies should be conducted to evaluate the root resorption and alveolar bone height for lingual orthodontics with severe crowding or skeletal problems. Moreover, gender differences were not assessed in this study, which would have needed a bigger sample size.

Conclusions

Based on this study, the following points can be concluded:

- the use of DTC® lingual or AO Mini Master® labial brackets with arcwire sequences is associated with both mild to moderate root resorption which is clinically acceptable, and clinically insignificant alveolar bone loss when treating moderate crowding cases;
- the lingual appliances cause greater resorption of incisors than labial appliances. Additionally, lingual bone loss is greater when using lingual orthodontic appliances for lower central incisors, while vestibular bone loss is greater when using labial orthodontic appliances for the lower later al incisors.

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Registration: This trial was retrospectively registered at Clinical Trials.gov (NCT06401369) on May 2nd, 2024. URL: https://clinicaltrials.gov/study/NCT06401369.

Ethics approval and consent to participate: The Local Research Ethics Committee of the University of Damascus approved this research project (Approval No.: UDDS-1978-12122021/SRC-3499). In order to participate in this trial, each participant had to complete an informed consent form.

Consent for publication: Not applicable.

Availability of data and materials: The datasets used during the current investigation are available from the corresponding author on reasonable request.

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Authors' contributions: JMK treated all patients in this trial, collected data from CBCT images, analysed the collected data, and wrote the first drafts of the manuscript. ASB supervised the research project, helped in data interpretation and manuscript writing. MYH co-supervised the work, helped in data analysis and manuscript editing. FRN and STJ contributed to the data analysis, results interpretation, and in revising the manuscript. The final manuscript was read and approved by all authors.

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Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ortho.2025.100968.

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