Original Article

Root resorption during maxillary molar intrusion with clear aligners: a randomized controlled trial

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ABSTRACT

Objectives: To compare changes in maxillary molar root resorption, intrusion amount, dentoskeletal measures, and maximum bite force (MBF) between clear aligners (CA) and fixed appliances with miniscrew (FM) during molar intrusion.

Materials and Methods: Forty adults with anterior open bite were randomized into either CA or FM groups. Lateral cephalograms, cone-beam computed tomography (CBCT), and MBF were collected at pretreatment (T0) and 6 months of treatment (T1). Maxillary molar intrusion in FM were intruded by nickel-titanium (NiTi) closed-coil spring delivered force (150 grams/side) while clear aligners combined with squeezing exercise were performed in CA. Parametric tests were used for statistical analysis.

Results: After 6 months of treatment, significant root resorption of 0.21–0.24 mm in CA and 0.38–0.47 mm in FM were found while maxillary molars were intruded 0.68 and 1.49 mm in CA and FM, respectively. CA showed significant less root resorption and intrusion than FM. Overbite, bite closing, and MBF increased significantly. CA showed significantly less overbite and SN-MP changes but more MBF increase than FM. MBF in CA was correlated with the amount of maxillary molar intrusion ($r = 0.736$, $P < .05$).

Conclusions: Maxillary molar intrusion and root resorption in CA were half the amount in FM in 6 months. The amount of maxillary molar root resorption was one-third of the intrusion distance. CA displayed less overbite increase and bite closing but more MBF increase than FM. MBF in CA was positively correlated with the molar intrusion amount. (*Angle Orthod.* 2023;93:629–637.)

KEY WORDS: Anterior open bite treatment; Maximum bite force; Molar intrusion; Root resorption

INTRODUCTION

The key to success in anterior open bite (AOB) correction is good vertical control during treatment. Molar intrusion is an effective treatment modality for AOB correction and increased post-treatment stability.[1] Autorotation of the mandible can generate the closure of the bite following molar intrusion.[2,3]

Maxillary molar intrusion by fixed appliances with miniscrew (FM) may be used in AOB treatment and is effective in segmented posterior dental intrusion.[3,4] Recently, clear aligners (CA) have become popular as a comfortable and noninvasive esthetic appliance. Previous case reports claimed that occlusal thermoplastic can create posterior tooth intrusion;[5,6] however, the subjects and appliance design were variable and the outcomes inconclusive.[5–7] Although molar intrusion is an effective way to correct AOB, apical root resorption after treatment would be a concern.

The etiology of apical root resorption includes: amount of molar intrusion, intrusive force magnitude,

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type and duration, and point of force application.[8,9] Miniscrew treatment for molar intrusion has been shown to cause apical root resorption;[3] however, no study stated evaluated apical root resorption after AOB correction with clear aligners.

The action of clear aligners in AOB treatment is based upon a previous hypothesis that biting on the thermoplastic creates intrusive force on the molar teeth.[5,6] Some studies indicated that after the appliance was delivered, the occlusal bite force decreased[10] or increased[11] and affected dental movement.[12,13] Previous literature suggested a squeezing exercise to control the vertical dimension and increased treatment stability;[14] however, more evidence supporting this protocol is needed to prove the effects.

The objectives of the study were to compare maxillary molar root resorption and intrusion, changes of dentoskeletal variables and maximum bite force between clear aligners and fixed appliances with miniscrew after molar intrusion in AOB treatment. The null hypothesis was that there would be no differences in root resorption, dentoskeletal, and maximum bite force changes between the two appliances after molar intrusion.

MATERIALS AND METHODS

Trial Design

This prospective study was a single-center, two-arm parallel randomized controlled trial and registered at the Thai Clinical Trials Registry (TCTR) ID: TCTR20201218004.

Participants, Eligibility Criteria, and Setting

The trial was conducted at the orthodontic clinic, Faculty of Dentistry, Prince of Songkla University. The study protocol was approved by the institutional review board committee (protocol EC 6308-030) of Prince of Songkla University and the study was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from all subjects.

The inclusion criteria for subjects were: (1) adult males or females, age 18–35 years; (2) AOB of 0–4 mm (vertical gap between the incisal edge of upper and lower incisors); (3) Angle Class I or II; (4) Skeletal Class I (ANB = 0–5°); (5) normo- to hyperdivergent pattern (MPA = 23–39°); and (6) healthy periodontal status. The exclusion criteria were: (1) moderate to severe crowding; (2) loss of posterior teeth; (3) history of trauma to the molars; (4) history of endodontic treatment to the maxillary first molar; (5) systemic disease related to bone metabolism; (6) taking immunosuppressive drugs or drugs inhibiting or accelerating tooth movement; and (7) neuromuscular deficiencies.

The sample size was calculated by G-power (version 3.1). The level of significance was set at 95% ($\alpha = 0.05$), calculated effect size of 0.96 and the power of test (1-β) was set at 80% based on a study by Al-Falahi et al.[15] Eighteen subjects were needed per group. The estimated dropout rate was about 20%. Therefore, the study required 21 subjects per group.

Randomization and Blinding

A randomization sequence was generated using randomization software (sealed envelope) with a 1:1 allocation using block randomization. The allocation sequence was concealed from the investigator with sequentially numbered, opaque, and sealed envelopes. Operator and subject blinding were not possible due to the nature of intervention. The data were coded and presented to the blinded evaluator.

All subjects were randomized into CA and FM groups. All data were collected at two timepoints: pretreatment (T0) and at 6 months of treatment (T1). The dental and skeletal changes were recorded by lateral cephalograms. Maxillary first molar intrusion and root resorption were recorded by cone-beam computed tomography (CBCT) and maximum bite force (MBF) was recorded by bite force recorder.

Clear Aligner Treatment

An intraoral scanner (TRIOS 3, 3Shape, Copenhagen, Denmark) was used to render an STL file, which was imported to the 3Shape OrthoAnalyzer, and models were printed with a 3D printer (Pro 4K, Asiga, Michigan, USA). The attachment design is shown in Figure 1. The maxillary anterior teeth were set for extrusion of 0.2 mm/aligner with a 3-week change interval. The clear aligners were fabricated using 1-mm Duran thermoplastic sheets (Figure 2a).

The squeezing protocol was modified from a previous study.[14] Subjects were instructed to clench on a clear aligner for a minute. Each 1-minute session included 5 seconds of isometric clenching (80% of MBF), followed by 5 seconds of rest, repeated six times. The exercise was repeated at least 5 times/day. Wear time was at least 22 hours/day, full time except when brushing and eating.

Fixed Appliance with Miniscrew

The fixed-appliance intrusion protocol was modified from a previous study.[16] A miniscrew, 2.0-mm in diameter and 6.0-mm in length (AbsoAnchor, Dentos, Daegu, Korea), was placed in the midpalatal area, corresponding to the maxillary first molar position. The

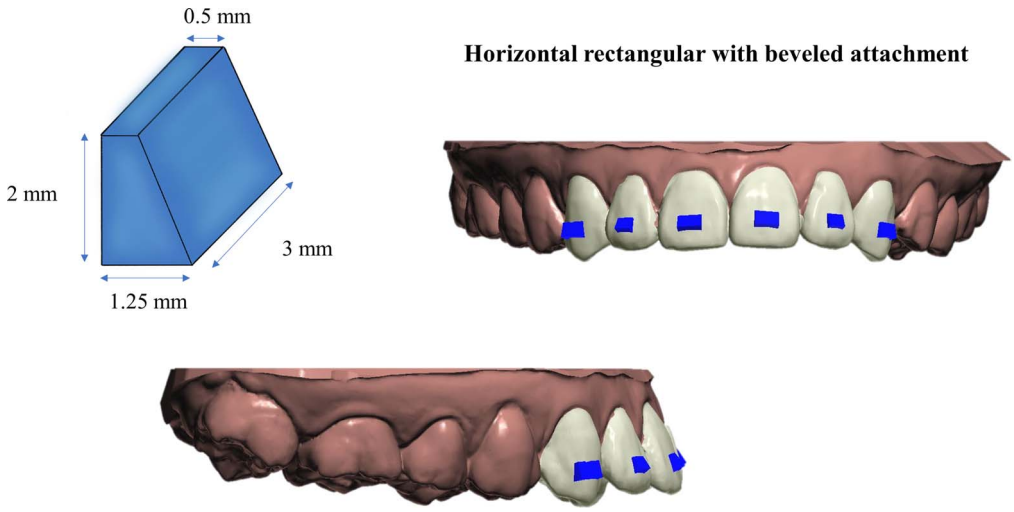

Figure 1. Clear aligner attachment design.

transpalatal arch (TPA) was fabricated with soldered hooks on the molar bands and placed 3.0 mm away from the palatal tissue. Segmental 0.018 × 0.025-inch stainless steel wire was passive in Roth 0.022 × 0.028-inch posterior slots. Two NiTi-closed coil springs were stretched from the miniscrew to the TPA hooks (Figure 2b). A force gauge was used to calibrate 150 grams/side of intrusive force every 3 weeks.

Lateral Cephalometric Analysis

The same cephalostat and cephalometric machine were used for all lateral cephalograms. Cephalometric radiographs were traced using Dolphin Imaging software (Dolphin Imaging and Management Solutions, Chatsworth, Calif.). Cephalometric landmarks, linear, and angular cephalometric measurements are shown in Figure 3.

Cone-beam Computed Tomography

All subjects had CBCT (80 kV, 5 mA, 9.2 s exposure time, 0.125 mm voxel resolution, 80 × 80-mm field of view; Veraviewepocs J Morita MPG, Fushimi, Kyoto, Japan). CBCT images were reconstructed every 0.125 mm. One Volume Viewer Software (Version 11.0, J Morita, Chatsworth, CA, USA) was used to magnify the image to 200×.

The amount of molar intrusion was measured following these steps (Figure 4): (1) Palatal plane (PP) was set, (2) The deepest point of the central pit (C-pit) was located in the coronal and sagittal view, and (3) The vertical distance from C-pit to PP (U6-PP) was measured. The difference between T0 and T1 was the intrusion amount, and right and left sides were averaged.

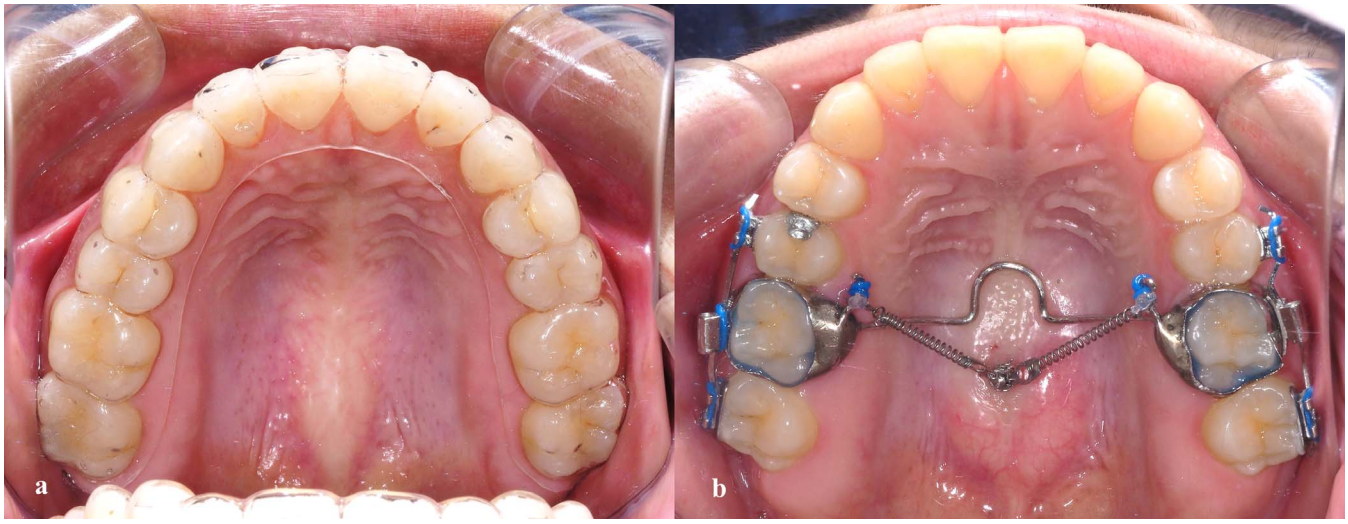

Figure 2. Treatment protocol. (a) Clear aligner (b) Fixed appliance with miniscrew.

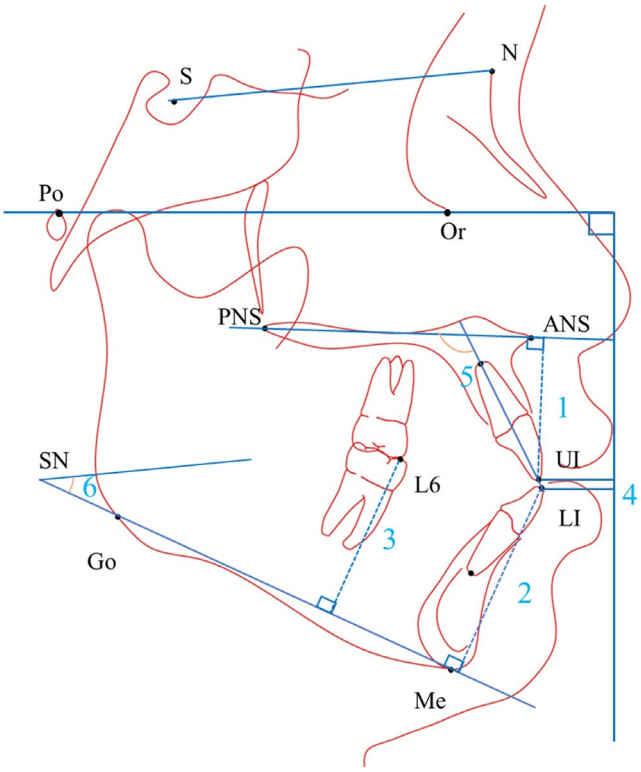

Figure 3. Cephalometric measurements. (a) Maxillary incisal edge to palatal plane (UI-PP; mm), (b) mandibular incisal edge to mandibular plane (LI-MP; mm), (c) mesiobuccal cusp of mandibular molar to mandibular plane (L6-MP; mm), (d) overbite, (e) maxillary incisor axis-palatal plane angle (UI-PP; °), (f) mandibular plane angle (MPA; °).

The amount of molar root resorption was measured following these steps (Figure 5): (1) PP was set, (2) the mesiobuccal (MB) cusp tip was located in the coronal and sagittal view, (3) the MB horizontal plane was created parallel to PP, (4) the MB root apex was located in the coronal and sagittal view, and (5) the vertical root length from the MB cusp tip to the apex (U6-MB) was measured. The difference between T0 and T1 was the amount of root resorption, and right and left sides were averaged. The distobuccal (DB) and palatal (Pa) roots were measured following the same steps as for the MB root.

Maximum Bite Force Measurement

All subjects were in an upright position and relaxed for 5 minutes in a strictly environmentally controlled room before measurements were made. A bite force recorder was constructed by the FlexiForce ELF system and sensors (Tekscan, Boston, USA) with custom-made holders were used for bite force recording. The recorder was placed on the maxillary first molar on the right and left sides. Forces were displayed in Newton (N). MBF was measured in CA and FM at T0 and T1. All subjects were instructed to bite with and without the appliance as hard as possible without pain to produce MBF for 3 seconds and rest for 20 seconds with 1-minute intervals between sessions to prevent muscle fatigue.[17] The average of three replications was recorded.

Statistical Analysis

All parameters were evaluated by one examiner. Ten samples of lateral cephalograms, CBCT, and MBF were randomly remeasured after a 4-week interval to assess measurement error and reliability. The intraclass correlation coefficient of 0.92 showed excellent reliability. Random errors were estimated by the Dahlberg formula: 0.06 to 0.08 mm for linear cephalometric measurements, 0.07° to 0.09° for angular cephalometric measurements, 0.02 to 0.03 mm for linear CBCT measurements. These random errors were considered acceptable.

All data tested by the Shapiro-Wilk test were normally distributed. To determine the changes within each group and between groups, paired *t*-test and independent *t*-test were used, respectively. Correlation analysis between the change of MBF and the amount of maxillary molar intrusion were tested by Pearson's

Table 1. Pretreatment Dentoskeletal Variables Between CA and FM at Pretreatment (T0)

Measurements (mean ± SD)	Clear Aligner (CA)	Fixed Appliance With Miniscrew (FM)	Differences	*P* Value
Overbite (mm)	−1.08 ± 0.48	−1.05 ± 0.51	0.03	.827
Divergent pattern				
SN-MP (°)	35.53 ± 1.81	35.80 ± 1.38	0.27	.751
Dental variables				
Vertical distances				
UI-PP (mm)	26.65 ± 0.78	26.90 ± 0.82	0.25	.232
L6-MP (mm)	30.18 ± 0.88	29.89 ± 0.94	0.29	.211
LI-MP (mm)	40.21 ± 1.07	40.07 ± 1.04	0.14	.715
Upper incisal inclination				
UI-PP (°)	127.98 ± 2.90	128.10 ± 2.09	0.12	.987

* $P < .05$, ** $P < .01$, *** $P < .001$, The differences were tested by independent *t*-test.

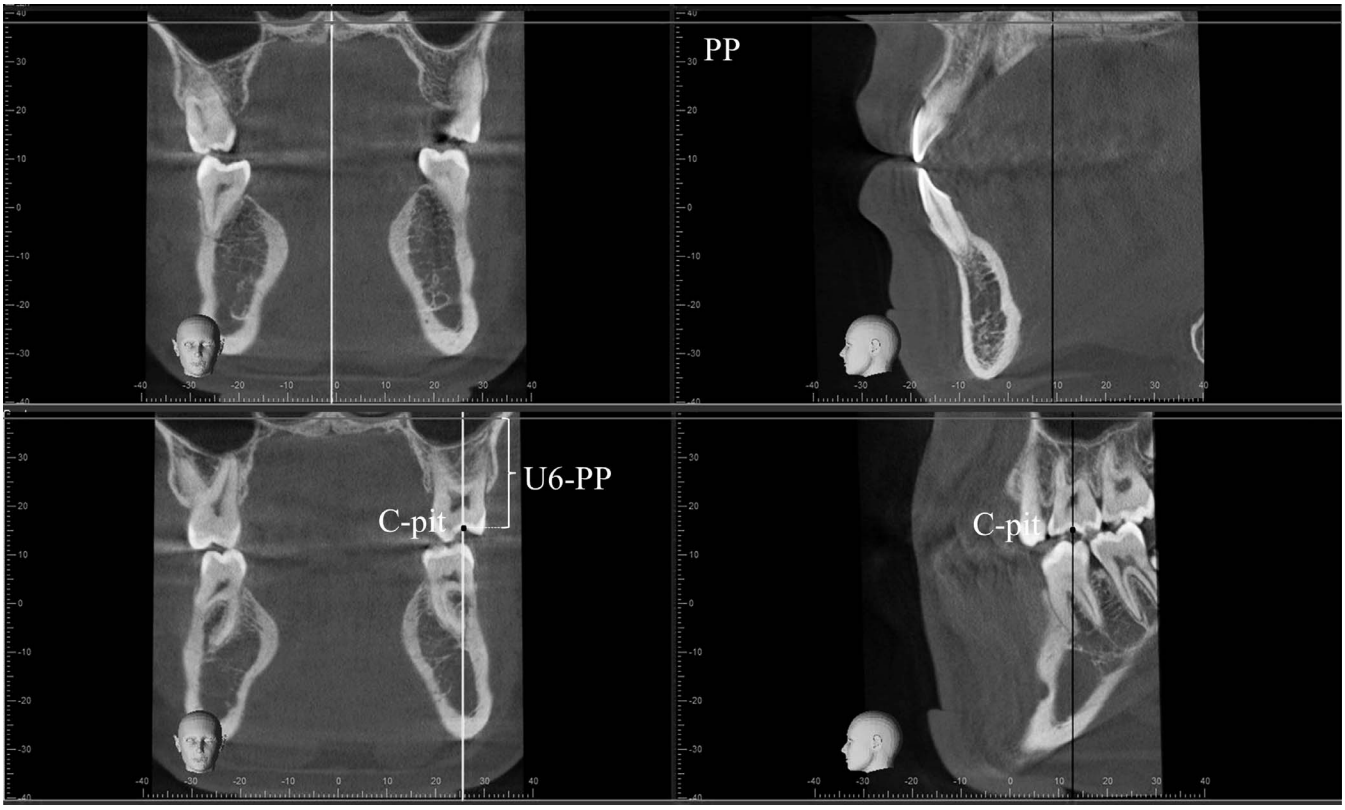

Figure 4. Maxillary first molar intrusion measurement. C-pit indicates central pit of maxillary first molar; PP, palatal plane; U6-PP, vertical distance from C-pit to PP.

correlations. All statistical analysis was done using SPSS version 26 (SPSS, Chicago, IL, USA). The level of significance of all tests was 0.05.

RESULTS

Forty-two subjects were randomized to either the CA or FM group. The CONSORT flow diagram is shown in Figure 6. One subject of each group refused to participate and discontinued the intervention. Finally, twenty subjects in the CA group (eight males and 12 females) with a mean age of 21.69 ± 2.67 years, and twenty subjects in the FM group (seven male, 13 females) with a mean age of 21.85 ± 2.71 years were analyzed.

Dentoskeletal Changes

There was no significant difference in pretreatment overbite, divergent pattern and dental vertical distance, and upper incisor inclination between CA and FM at T0 (Table 1).

Table 2. Change in Dentoskeletal Variables Between Pretreatment (T0) and 6 Months (T1) in CA and FM

	Clear Aligner (CA)				Fixed Appliance With Miniscrew (FM)			
Measurement (mean ± SD)	Pretreatment (T0)	6 months (T1)	T1-T0	*P* Value	Pretreatment (T0)	6 months (T1)	T1-T0	*P* Value
Overbite (mm)	−1.08 ± 0.48	0.17 ± 0.11	1.25	<.001***	−1.05 ± 0.51	0.71 ± 0.47	1.76	<.001***
Divergent pattern								
SN-MP (°)	35.53 ± 1.81	34.96 ± 1.77	−0.57	<.001***	35.80 ± 1.38	34.91 ± 1.35	−0.89	<.001***
Dental variables								
Vertical distances								
UI-PP (mm)	26.65 ± 0.78	27.10 ± 0.83	0.45	<.001***	26.90 ± 0.82	26.96 ± 0.86	0.06	.714
L6-MP (mm)	30.18 ± 0.88	30.08 ± 0.82	−0.10	.271	29.89 ± 0.94	29.93 ± 0.88	0.04	.871
LI-MP (mm)	40.21 ± 1.07	40.25 ± 1.02	0.04	.316	40.07 ± 1.04	40.13 ± 1.09	0.06	.668
Upper incisal inclination								
UI-PP (°)	127.98 ± 2.90	127.66 ± 2.85	−0.32	.001**	128.10 ± 2.09	128.14 ± 2.16	0.04	.897

* $P < .05$, ** $P < .01$, *** $P < .001$. The differences were tested by paired *t*-test, and independent *t*-test.

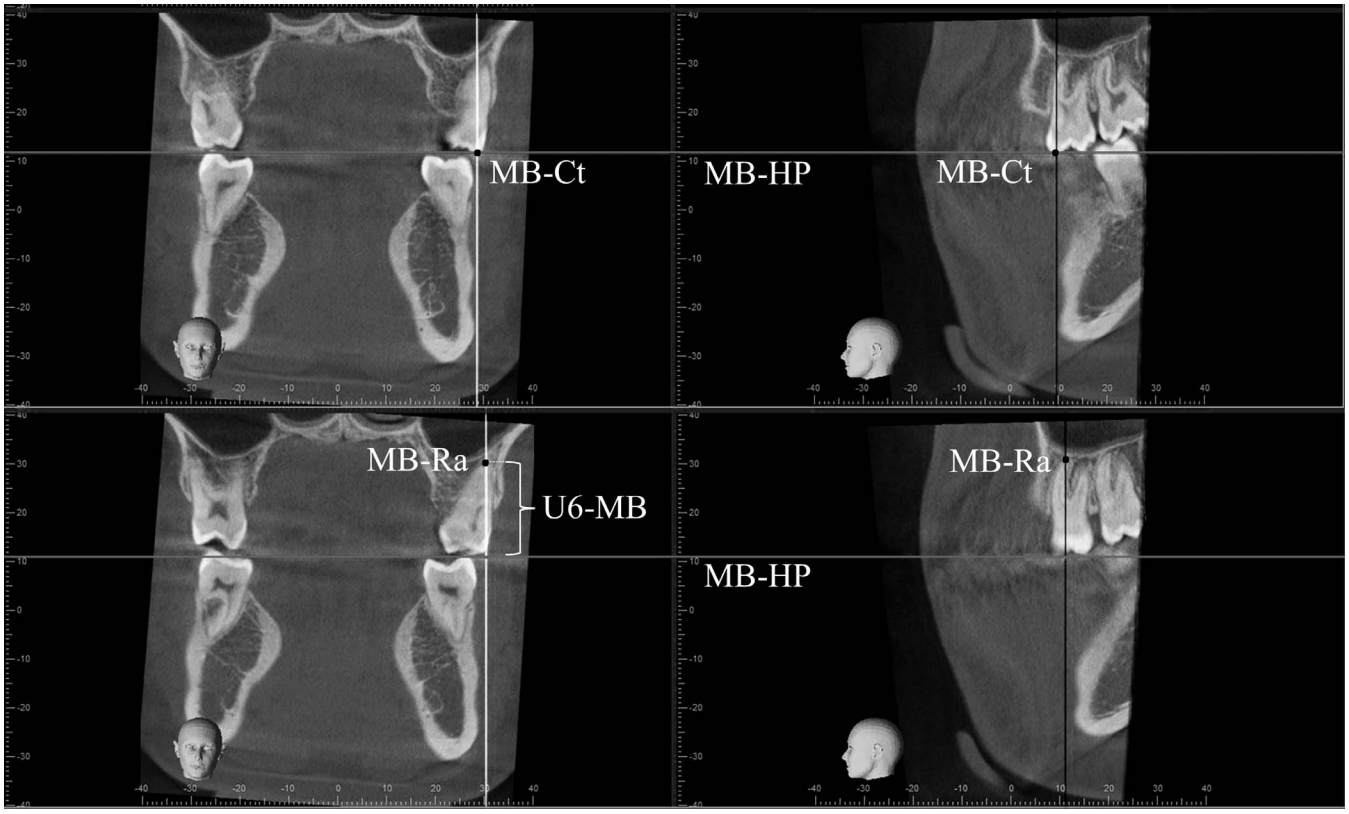

Figure 5. Maxillary first molar root resorption measurement. MB-Ct indicates mesiobuccal cusp tip; MB-HP, mesiobuccal horizontal plane; MB-Ra, mesiobuccal root apex; U6-MB, mesiobuccal root length.

The overbite increased significantly in both groups at T1. Overbite in FM increased significantly more than in CA ($P < .001$). CA showed significantly less bite closing (SN-MP changes) than FM ($P < .001$). Additionally, the maxillary incisor in the CA group showed significant extrusion of 0.45 mm (UI-PP, mm) ($P < .001$) and retroclination of 0.32° (UI-PP°) ($P = .001$) (Table 2).

Table 2. Extended

Changes (T1-T0) Comparison Between FM and CA			
CA	FM	Differences	*P* Value
1.25 ± 0.78	1.76 ± 0.59	0.51	<.001***
−0.57 ± 0.09	−0.89 ± 0.11	0.32	<.001***
0.45 ± 0.17	0.06 ± 0.04	0.39	<.001***
−0.10 ± 0.02	0.04 ± 0.02	0.14	<.001***
0.04 ± 0.02	0.06 ± 0.03	0.02	.171
−0.32 ± 0.08	0.04 ± 0.07	0.36	<.001***

Maxillary First Molar Intrusion and Root Resorption

The maxillary first molar position (U6-PP) was significantly intruded in both groups ($P < .001$), CA showed significantly less molar intrusion than FM ($P < .001$). All maxillary first molar roots were significantly shortened after treatment in both groups ($P < .001$). The CA group showed similar shortening of the mesiobuccal (U6-MB), distobuccal (U6-DB), and palatal (U6-Pa) roots of 0.21 to 0.24 mm, whereas the FM group showed more shortening of the palatal root (0.47 mm) (U6-Pa), followed by the other roots (0.38–0.39 mm) (Table 3).

Maximum Bite Force

There was no significant difference in the MBF between CA and FM at T0. MBF increased significantly in both groups at T1 (CA, $P < .001$) (FM, $P = .043$). CA exhibited a significantly greater increase in MBF than FM ($P = .009$) (Table 4).

Pearson correlation analysis showed that the MBF in CA was moderately and positively correlated with the amount of molar intrusion ($r = 0.736$, $P = .015$) whereas the MBF in FM was not significantly correlated with the amount of molar intrusion ($r = 0.207$, $P = .565$).

Table 3. Change in Maxillary First Molar Intrusion and Root Length Between Pretreatment (T0) and 6 Months (T1) in CA and FM

Maxillary First-Molar Variables (mean ± SD)	Clear Aligner (CA)				Fixed Appliance With Miniscrew (FM)			
	Pretreatment (T0)	6 months (T1)	T1–T0	*P* Value	Pretreatment (T0)	6 months (T1)	T1–T0	*P* Value
Maxillary molar intrusion								
U6-PP (mm)	21.54 ± 0.84	20.86 ± 0.76	−0.68 ± 0.05	<.001***	21.83 ± 0.95	20.34 ± 0.91	−1.49 ± 0.04	<.001***
Maxillary molar root length								
U6-MB (mm)	19.43 ± 0.63	19.21 ± 0.63	−0.21 ± 0.02	<.001***	19.31 ± 0.89	18.92 ± 0.93	−0.39 ± 0.06	<.001***
U6-DB (mm)	18.42 ± 0.51	18.20 ± 0.55	−0.23 ± 0.04	<.001***	18.44 ± 0.65	18.06 ± 0.62	−0.38 ± 0.06	<.001***
U6-Pa (mm)	20.60 ± 0.87	20.36 ± 0.90	−0.24 ± 0.03	<.001***	20.70 ± 0.51	20.22 ± 0.53	−0.47 ± 0.16	<.001***

* $P < .05$, ** $P < .01$, *** $P < .001$. The differences were tested by paired *t*-test, and independent *t*-test.

DISCUSSION

The study outcome was the amount of external apical root resorption related to the applied force. CA required active bite force to generate the bite block effect whereas FM required NiTi coil spring activation to apply a constant force of intrusion. FM exhibited more molar intrusion than CA. FM produced continuous force with longer duration whereas CA produced intermittent force with a shorter duration. Additionally, the bite closing and forward rotation of the mandible after treatment of FM were greater than CA. The degree of bite closing was correlated to the amount of molar intrusion, consistent with a previous study.[2]

Maxillary incisor extrusion and retroclination in CA may have resulted due to the intrusive force on the posterior teeth from the squeezing bite force generating a reactive extrusive force. This extrusive force,

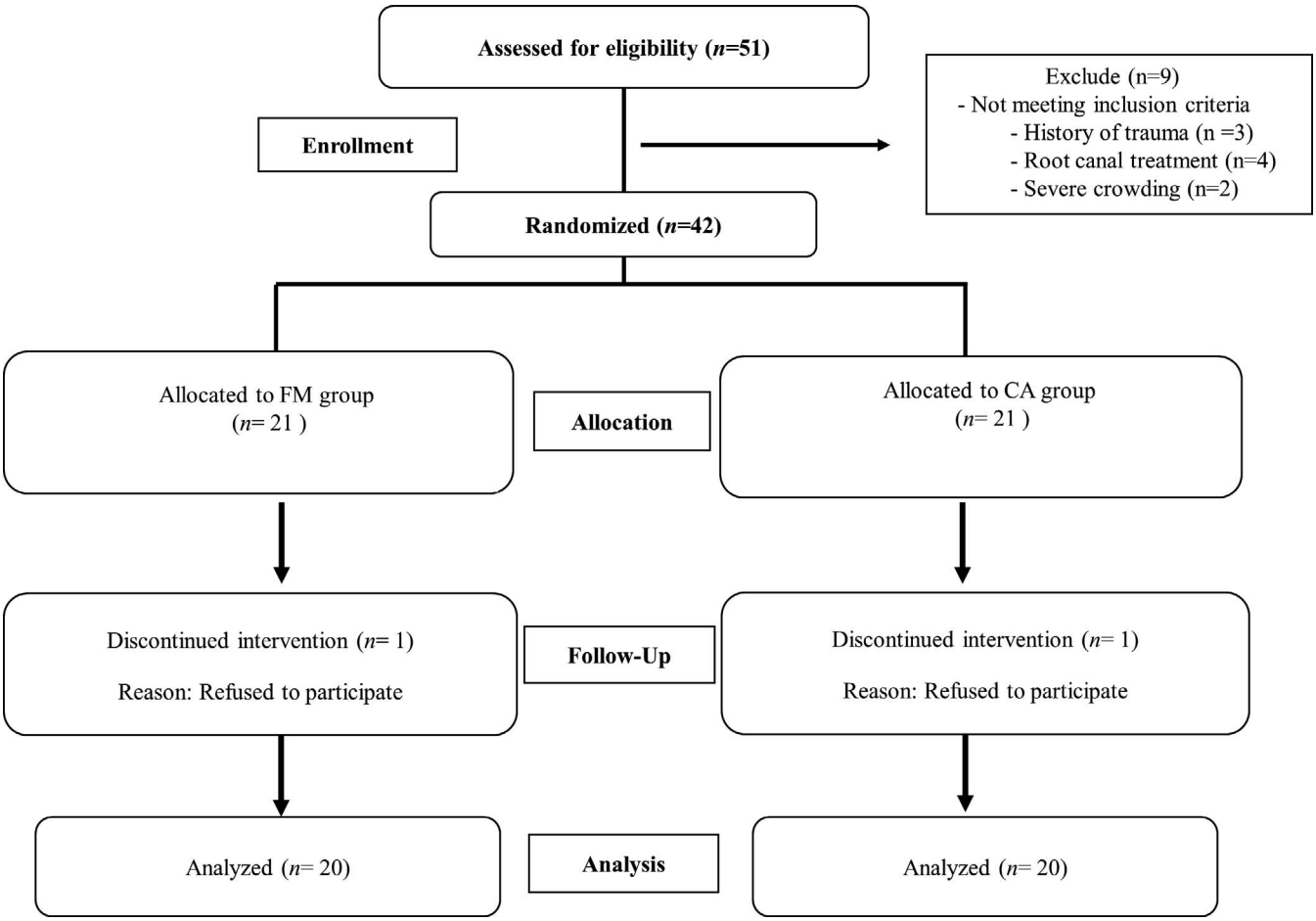

Figure 6. CONSORT (consolidated standards of reporting trials) flow diagram.

Table 3. Extended

Changes (T1–T0) Comparison Between FM and CA			
CA	FM	Differences	*P* Value
−0.68 ± 0.05	−1.49 ± 0.04	0.81	<.001***
−0.21 ± 0.02	−0.39 ± 0.06	0.18	<.001***
−0.23 ± 0.04	−0.38 ± 0.06	0.15	<.001***
−0.24 ± 0.03	−0.47 ± 0.16	0.23	<.001***

applied anterior to the center of resistance of the maxillary incisors at the attachment, could have produced retroclination.

Apical root resorption frequently occurs when heavy intrusive force is applied[18–21] in the narrow, apical area. Although molar intrusion is one way to increase treatment stability in AOB correction,[22] root resorption should be minimized and the orthodontist should be aware of its potential. As observed at T1, CA produced less root resorption than FM. These results were consistent with previous findings that intermittent orthodontic force produced less root resorption than continuous force.[23]

The amount of root resorption in CA was similar among all roots because of an almost equal force distribution. However, FM displayed the greatest severity of root resorption at the maxillary palatal root due to the line of force application of the NiTi coil spring, which was applied from the palatal side. Finite element analysis might be useful to elucidate more details about the force distribution. Maxillary molar root resorption and intrusion amount of CA was half that of FM. Interestingly, root resorption equaled approximately one-third of the intrusion distance in both groups.

Correlation analysis showed that MBF had a moderate correlation with the amount of maxillary first molar intrusion in CA. However, CA displayed a lesser amount of molar intrusion compared to FM but a greater increase in MBF because the squeezing exercise in CA increased muscle strength. Previous studies showed that squeezing or masticatory exercise in AOB patients maintained vertical dimension or caused intrusion of maxillary and mandibular molars.[14,24,25]

This study revealed that CA combined with squeezing exercises could achieve molar intrusion during anterior open bite correction. The squeezing exercise was previously used to increase muscle strength in open bite patients and enhance vertical control of posterior teeth.[14] In addition, this study supported that clear aligners may serve as a bite block appliance to intrude molars. This was in contrast to a previous study[26] but the current study controlled appliance design and the biting exercise protocol. However, the squeezing exercise still depends on patient compliance and requires a suitable monitoring protocol. Therefore, future randomized controlled trials are recommended, with and without squeezing exercises, to confirm these findings. Additionally, patients with bruxism and noncompliant patients need to be excluded since these factors may directly affect recorded outcomes.

Limitations of this study included the short-term observation period, and the inclusion of only adult patients with mild to moderate AOB. This may reduce generalizability of this treatment modality. A longer observation period is recommended to obtain more complete treatment and follow-up data.

CONCLUSIONS

- Maxillary molar intrusion and root resorption in CA were about half the amount observed in FM during the 6 months of treatment in this study.
- The amount of maxillary molar root resorption was one-third of the intrusion amount in both groups.
- CA presented less overbite increase and bite closing compared to FM.
- MBF increased in both groups and CA displayed a greater increase than FM.
- MBF in CA was positively correlated with the amount of maxillary molar intrusion.

ACKNOWLEDGMENT

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Table 4. Change in Maximum Bite Force Between Pretreatment (T0) and 6 Months (T1) in CA and FM

	Maximum Bite Force (N)			
Treatment Group (mean ± SD)	Pretreatment (T0)	6 months (T1)	T1–T0	*P* Value
Clear aligner (CA)	254.94 ± 7.47	456.53 ± 6.48	201.58 ± 6.25	<.001***
Fixed appliance with miniscrew (FM)	253.39 ± 7.49	331.79 ± 5.06	78.40 ± 4.57	.043*
Difference between CA and FM			−123.18	.009**

* $P < .05$, ** $P < .01$, *** $P < .001$. The differences were tested by paired *t*-test, and independent *t*-test.

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