Original Article

Mandibular incisor root length and root volume changes using removable anterior bite planes in two mealtime protocols in growing deep bite patients: a randomized clinical trial

Thanapat Sangwattanarat[a]; Udom Thongudomporn[b]

ABSTRACT

Objectives: To compare mandibular incisor root length (RL) and root volume (RV) changes after 6 months of wearing either a removable anterior bite plane (RABP) during meals (F + M) or not during meals (F − M). Additionally, changes in incisal maximum bite force (IMBF) and their correlation with RL and RV changes were assessed.

Materials and Methods: Thirty-six children with deep bite using RABPs full time were randomly assigned in equal numbers to either the F + M group or F − M group. Cone-beam computed tomographic radiographs and IMBF were recorded at baseline (CT0) and after 6 months (CT1). Within and between group comparisons of RL and RV were performed ($P = .05$) with Bonferroni correction applied for segmental RV differences ($P = .008$). Relationships between IMBF changes and RL and RV changes were analyzed ($P = .05$).

Results: Both groups showed significant reductions in RL and RV. RL decrease in the F + M group (0.25 ± 0.14 mm) was significantly greater than in the F − M group (0.21 ± 0.14 mm). Reduction in RV was not significantly different between the groups, but IMBF significantly increased in both groups. Significant correlations were observed between IMBF changes and RL ($r = 0.56$) and RV ($r = 0.86$) changes.

Conclusions: Deep bite correction using RABPs for 6 months with F + M protocol resulted in a greater decrease in mandibular incisor RL compared to the F − M protocol. However, RV changes were comparable between protocols. IMBF may influence the degree of RL and RV changes. (*Angle Orthod*. 2025;00:000–000.)

KEY WORDS: Anterior bite plane; Bite force; Deep bite; CBCT; Root resorption; Three-dimensional reconstruction; Wearing protocol

INTRODUCTION

Removable anterior bite planes (RABPs) are appliances frequently used for deep bite correction in growing patients. They feature a flat biting surface for mandibular incisor contact, allowing eruption of mandibular posterior teeth and proclination of mandibular incisors.[1,2]

RABPs typically require full-time wear, except during tooth brushing. However, opinions on the optimal protocol differ. Some suggest wearing them during meals to maintain posterior tooth separation, reduce chewing forces, and enhance vertical eruption.[3,4] Others recommend removing them during meals, arguing that, despite the intensity of chewing forces, limited daily chewing time may not significantly influence tooth movement.[1,5] A randomized clinical trial compared two RABP protocols: full-time wear except during tooth brushing (F + M) and full-time wear except during meals and tooth brushing (F − M).[2] Both resulted in similar cephalometric changes in deep bite growing patients, but the F + M group wore the appliance longer and achieved faster deep bite correction.

The effectiveness and side effects of different protocols must be carefully considered. Root resorption, a side effect of orthodontic tooth movement, can be assessed by root length (RL) and root volume (RV). RL refers to

[a] Dentist, Faculty of Dentistry, Chiang Mai University, Mueang, Chiang Mai, Thailand.

[b] Associate Professor, Orthodontic Section, Department of Preventive Dentistry, Faculty of Dentistry, Prince of Songkla University, Hat Yai, Songkhla, Thailand.

Corresponding author: Dr Udom Thongudomporn, Department of Preventive Dentistry, Faculty of Dentistry, Prince of Songkla University, Hat Yai, Songkhla 90110, Thailand (e-mail: udom.t@psu.ac.th)

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root length along the tooth axis, whereas RV represents its three-dimensional quantity. Force magnitude and duration are linked to root resorption.[6] A cone beam computed tomography (CBCT) study in deep bite children showed a reduction in mandibular incisor RV after 6 months of using an acrylic RABP with the F − M protocol.[1] Differences in contact force duration and magnitude between F + M and F − M protocols may result in varying RL and RV changes.

This study aimed to compare RL and RV changes in mandibular incisors over 6 months while wearing an RABP in either the F + M or F − M protocol. The second objective was to examine the association between incisal maximum bite force (IMBF) changes and RL and RV changes, since IMBF is considered a reliable representative of muscle strength during masticatory function.[7]

MATERIALS AND METHODS

Trial Design

This was a secondary study from the main research that compared treatment outcomes in deep bite growing patients using RABPs with F + M and F − M protocols.[2] The two-arm, parallel (1:1 allocation ratio), single-center randomized clinical trial was approved by the Human Research Ethics Committee of the Faculty of Dentistry, Prince of Songkla University (EC6601-001) and registered at the Thai Clinical Trial Registry (TCTR20230305001).

Sample Size Calculation

The sample size was calculated using G*Power software (Heinrich Heine University Düsseldorf, Düsseldorf, Germany) based on a study investigating mandibular incisor RV changes with functional appliances.[8] With a mean RV change of 6.13 mm^3, standard deviation of 6.28 mm^3, effect size of 0.98, $P = .05$, and $\beta = 0.95$, 16 subjects per group were required. However, all 36 subjects from the main study were included in this analysis.

Participants, Eligibility Criteria, and Settings

Participants were recruited at the Orthodontic Clinic of the Dental Hospital, Faculty of Dentistry, Prince of Songkla University, Thailand. The inclusion criteria were: (1) deep bite (overbite $>$ 40%), (2) Angle Class I/II molar relationship, (3) skeletal Class I or mild Class II (ANB = 1° to 9°), (4) growing patient (CVM stage $\leq$ CS5), (5) normal or hypodivergent growth pattern (SN-MP $<$ 35°), (6) no temporomandibular disorders, and (7) no history of orthodontic treatment. The exclusion criteria were: (1) noncooperation, (2) incomplete mandibular incisor root formation, (3) clinical absence of maxillary or mandibular first molar or incisor, or (4) long-term use of anti-inflammatory or immunosuppressive medications. Written informed consent was obtained from all participants and their parents.

Randomization and Blinding

Subjects were randomly assigned to the F + M or F − M group (n = 18 each) using computer-generated numbers in sealed envelopes, opened individually in order. A single orthodontist provided treatment, while a researcher collected data and performed measurements. Blinding was not feasible for subjects and the orthodontist due to the protocols, but the researcher remained blinded during measurement and analysis.

Appliance Design and Intervention

The RABP design, detailed and illustrated in a previous study,[2] included Adams clasps on the first molars, a labial wire, and a baseplate with an anterior bite plane, ensuring consistent lower incisor contact and 2-mm disclusion of the first molars. Participants in the F + M group were instructed to wear the RABP full time except during tooth brushing, while the F − M group was instructed to wear the RABP full time except during meals and tooth brushing. Measurement of the overbite with a 1-mm-scale probe was conducted monthly. Acrylic resin was added as needed to maintain consistent incisor contact and molar disclusion. The RABP was maintained for 6 months even if normal overbite was achieved earlier.

CBCT Evaluation

CBCT scans (Veraviewepocs 3D R100, J. Morita, Kyoto, Japan) of the mandibular incisors were taken at 80 kV, 5 mA, 7.5-second exposure time, 0.125-mm voxel resolution, and 80 × 40 mm field of view. Scans were constructed before (CT0) and 6 months into treatment (CT1). All CBCT files were exported as DICOM files and converted to 3D models (STL format) using Mimics inPrint 3.0 (Materialise, Belgium). The same threshold values were applied to all images, and a single researcher manually identified tooth boundaries.

The STL files were imported into Geomagic Control X 2020 software (Geomagic, USA). The CT0 and CT1 models were aligned using the best-fit method with an iterative closest-point algorithm. For each tooth, reference plane 1 was constructed between the highest point of the labial and lingual cementoenamel junction (CEJ) to separate the roots from the crowns. The roots were segmented into labial and lingual aspects using a midpoint of reference plane 1 as reference plane

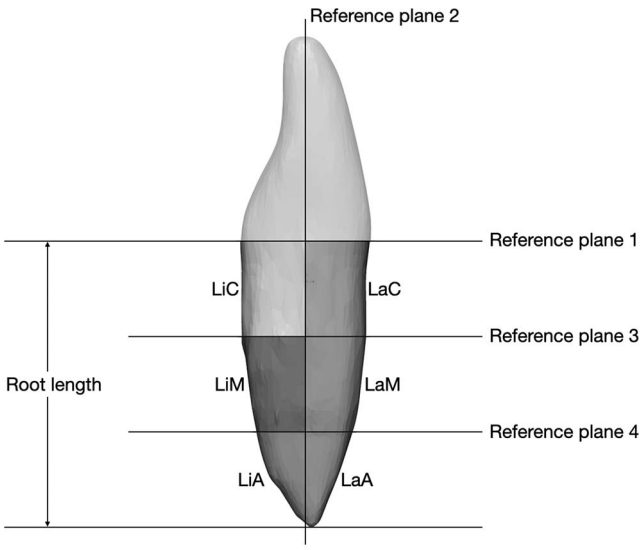

Figure 1. Evaluation of root segmentation into six segments.

2. RL was measured along reference plane 2 from the CEJ to the root apex. RV measurement followed the protocol of a previous study.[1] Both labial and lingual portions of the roots were divided vertically into cervical, middle, and apical thirds from the CEJ to the root apex along reference plane 2 as reference planes 3 and 4, respectively, that resulted in six segments: labio-coronal (LaC), labio-middle (LaM), labio-apical (LaA), linguo-coronal (LiC), linguo-middle (LiM), and linguo-apical (LiA) (Figure 1). The RV for each segment at CT0 and CT1 was measured, and volumetric change was calculated as the difference between CT0 and CT1. The statistical analysis revealed no significant differences in the RL or RV among the four mandibular incisors within a subject ($P > .05$). Therefore, RL and RV of the four incisors were averaged to represent RL and RV for each subject.

IMBF Measurement

IMBF was measured using a custom-made device with a FlexiForce sensor (TekScan, USA) (Figure 2). The forces were displayed in newtons (N). The sensor was calibrated using a universal testing machine (LRX-Plus, Lloyd Instruments, Ametek Inc, UK) that was incrementally adjusted from 0 to 800 N in 50 N steps.

Baseline IMBF at CT0 was measured without the appliance in both groups. The force exerted on the mandibular incisors during chewing was mimicked at CT1 by measuring IMBF without the appliance in the F − M group but with the appliance in the F + M group. Participants were seated upright with unsupported heads and were asked to relax for 5 minutes before measurement. The sanitized device, shielded with a disposable latex sheet, was placed on the

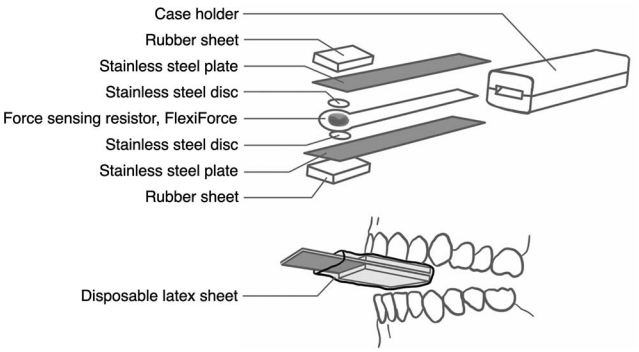

Figure 2. Custom-made incisal maximum bite force measurement device.

palatal side of the maxillary central incisors. Participants bit with maximum force for 3 seconds, repeated three times with 30-second intervals to prevent fatigue. IMBF value was averaged from the three measurements.

Measurement Accuracy and Reliability

Ten CBCT images were randomly selected for remeasurement by the same researcher after a 4-week interval. Dahlberg's error was calculated and found to be under 0.1 mm for linear measurements and 0.1 mm^3 for volumetric measurements, which were within acceptable levels. The intraclass correlation coefficient ranged from 0.98 to 0.99, which indicated excellent reliability.

Statistical Analysis

Statistical analysis was performed using SPSS v29 (IBM, USA). The Shapiro-Wilk test was used to assess data normality, which guided the use of paired *t*-tests or Wilcoxon signed-rank tests for within-group comparisons. For between-group comparisons, the Chi-square test, independent *t*-test, Mann-Whitney *U*-test, or one-way analysis of variance were used. Pearson correlation analysis was used to evaluate relationships between IMBF changes and RL/RV changes. Significance was set at 0.05, except for segmental RV comparisons, for which the Bonferroni adjustment was set at 0.008.

RESULTS

Forty patients were initially recruited; however, three were ineligible and one declined participation. Thirty-six participants (16 males, 20 females; mean age 10.94 ± 2.04 years) were randomly assigned to F + M and F − M groups with no dropouts (Figure 3). Baseline characteristics were comparable between the groups (Table 1).

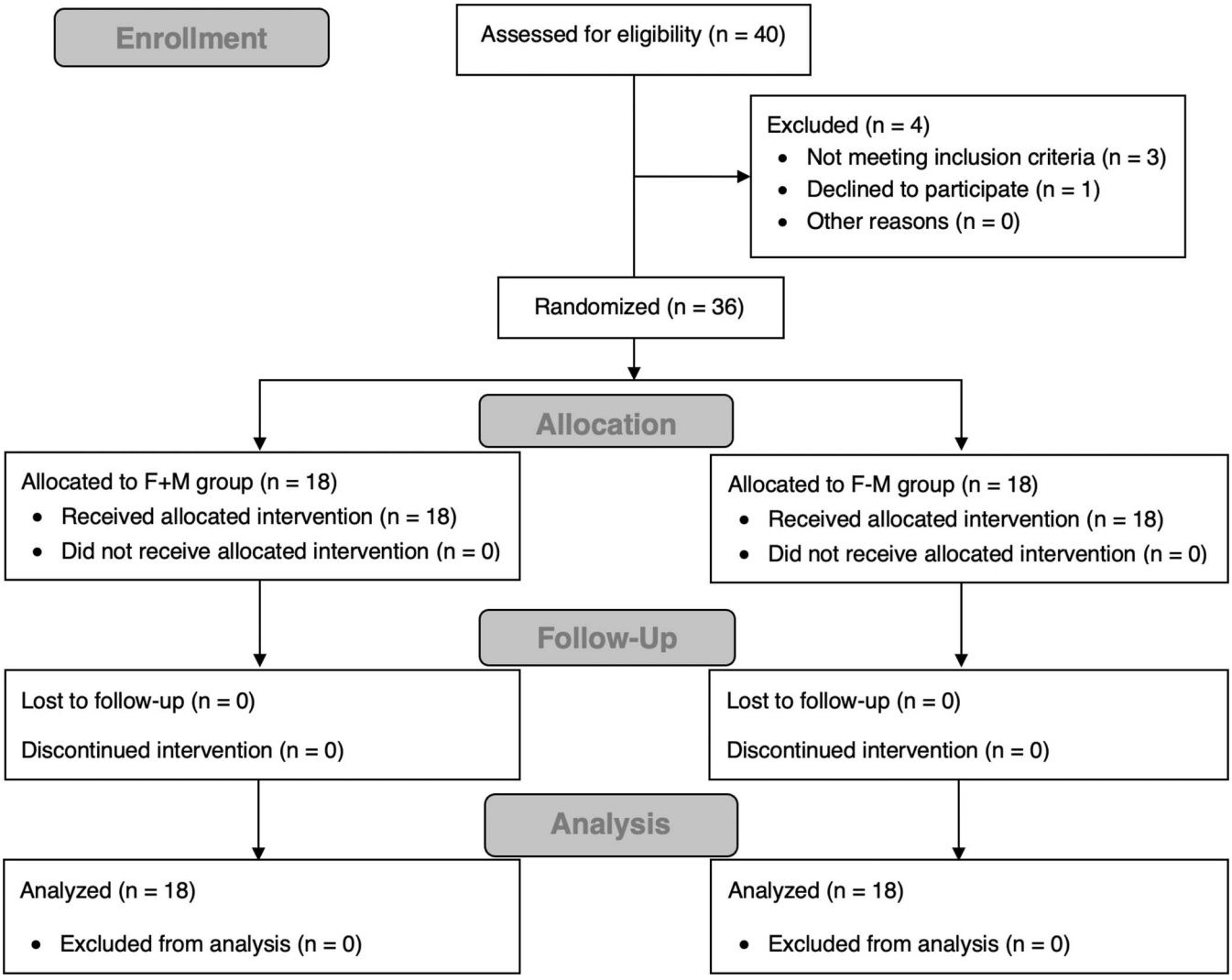

Figure 3. CONSORT flow diagram of the study.

Within-group analysis showed significant decreases in RL, total RV, and RV of all six segments in both the F + M and F − M groups ($P < .001$) (Table 2). Between-group comparisons revealed a significantly greater RL decrease in the F + M group (0.25 ± 0.14 mm) compared to the F − M group (0.21 ± 0.14 mm) ($P < .01$) (Table 3). However, changes in total RV and segmental RV were not significantly different between the groups ($P \geq .05$ for total RV and $P \geq .008$ for segmental RV) (Table 3).

Both groups showed significant within-group IMBF increases after 6 months of RABP use ($P < .001$) with no significant difference between the groups ($P \geq .05$) (Table 4). Correlation analysis revealed strong relationships between IMBF changes and RL changes ($r = 0.86$ for F + M and $r = 0.81$ for F − M ($P < .001$)) and moderate-to-strong relationships between IMBF changes and total RV changes ($r = 0.56$ for F + M ($P < .01$) and $r = 0.74$ for F − M ($P < .001$)) (Figure 4).

DISCUSSION

Both RABP protocols showed that 6 months of RABP use reduced mandibular incisor RL and RV, which was in agreement with a prior study on RV changes using anterior bite planes fabricated from different materials under the F − M protocol.[1] Continuous disocclusion of posterior teeth during the day directed intermittent forces, such as those from swallowing[9] or speaking,[10] to the mandibular incisors contacting the bite plane. These forces, though intermittent, likely contributed to the reduction in RL and RV, although to a lesser extent than continuous forces.[11]

Total RV and segmental RV changes in the F − M group exceeded the changes reported in a prior study of full-time acrylic anterior bite plane use with the F − M

Table 1. Baseline (CT0) Characteristics of Measurements Between the Groups[a]

Variables	F + M Mean	F + M SD	F − M Mean	F − M SD	*P* Value
N (male : female)	8:10		8:10		.985[b]
Age (y)	11.00	1.97	10.88	2.18	.897[c]
Overbite (mm)	5.88	1.52	5.35	1.06	.211[c]
Root length (mm)	12.60	1.10	12.94	1.33	.092[d]
Total root volume (mm^3)	136.84	33.79	141.24	32.90	.481[c]
Root volume of each segment (mm^3)					
LaC	37.94	9.31	38.71	8.33	.603[d]
LaM	24.97	6.29	25.81	6.14	.374[c]
LaA	7.60	3.02	8.44	3.41	.115[c]
LiC	32.86	8.89	33.56	7.81	.589[c]
LiM	23.44	6.22	24.23	6.29	.509[c]
LiA	10.03	3.58	10.50	4.60	.770[c]

[a] F + M indicates full-time appliance wearing except for tooth brushing; F − M, full-time appliance wearing except for meals and tooth brushing.
[b] Pearson Chi-square test.
[c] Mann-Whitney *U*-test.
[d] Independent-sample *t*-tests.

Table 3. Comparison of Root Length and Volume Changes (CT1-CT0) Between Groups[a]

Variables	F + M Mean	F + M SD	F − M Mean	F − M SD	*P* Value
Root length (mm)	−0.25	0.14	−0.21	0.14	.003**
Total root volume (mm^3)	−5.17	2.78	−4.50	2.59	.117
Root volume of each segment (mm^3)					
LaC	−1.10	0.77	−1.03	0.80	.267[b]
LaM	−1.42	0.74	−1.30	0.70	.355[b]
LaA	−0.52	0.29	−0.55	0.27	.378[b]
LiC	−1.43	0.91	−1.15	0.73	.021[b]
LiM	−1.34	0.89	−1.16	0.64	.614[b]
LiA	−0.86	0.55	−0.81	0.43	.654[b]

[a] F + M indicates full-time appliance wearing except for tooth brushing and F − M, full-time appliance wearing except for meals and tooth brushing. Negative values indicate a decrease. Mann-Whitney *U*-tests.
[b] Mann-Whitney *U*-tests with Bonferroni adjustment.
* $P < .05$; ** $P < .01$; *** $P < .001$.

protocol in children of similar age over a 6-month period.[1] Differences in skeletal divergence and mandibular incisor inclination and vertical position changes likely explain the variation. Subjects in the previous study exhibited a more hypodivergent tendency that potentially altered the angle between the mandibular incisor axis and the bite plane compared to the present study. Additionally, unlike the previous study, in which the mandibular incisors showed no inclination or vertical position changes post-treatment, subjects in the current study experienced significant proclination and intrusion. These factors may have increased stress on the root areas that resulted in greater RV changes.

Greater RL loss in the F + M group compared to the F − M group possibly resulted from factors such as force magnitude and duration. Increased force magnitude has previously been shown to be strongly associated with root resorption.[12] In the F + M protocol, subjects chewed exclusively on the bite plane with four mandibular incisors during meals, which generated substantial force that was potentially up to 369 newtons.[13] This additional load likely contributed to the greater RL loss observed in the F + M group.

Duration differences in wearing the RABP appliance may also have played a role. Data from the main study[2] showed that the F + M group had longer durations of wearing the appliances (22.69 hr/d vs 19.41 hr/d). Despite this, cephalometric changes in the mandibular incisors were comparable between the F + M and F − M groups. With the amount and type of tooth movement controlled, prolonged force duration in the F + M group likely contributed to the greater RL loss.

Table 2. Within-Group Comparison of Root Length and Volume Measurements Between the Two Time Points (CT0 and CT1)[a]

Variables	F + M CT0 Mean	F + M CT0 SD	F + M CT1 Mean	F + M CT1 SD	F + M *P* Value	F − M CT0 Mean	F − M CT0 SD	F − M CT1 Mean	F − M CT1 SD	F − M *P* Value
Root length (mm)	12.60	1.10	12.35	1.10	<.001***[b]	12.94	1.33	12.73	1.31	<.001***[b]
Total root volume (mm^3)	136.84	33.79	131.67	33.54	<.001***[c]	141.24	32.90	136.74	32.37	<.001***[c]
Root volume of each segment (mm^3)										
LaC	37.94	9.31	36.84	9.10	<.001***[b]	38.71	8.33	37.69	8.13	<.001***[b]
LaM	24.97	6.29	23.55	6.31	<.001***[c]	25.81	6.14	24.51	6.00	<.001***[b]
LaA	7.60	3.02	7.07	2.97	<.001***[c]	8.44	3.41	7.89	3.35	<.001***[b]
LiC	32.86	8.89	31.43	8.76	<.001***[c]	33.56	7.81	32.40	7.71	<.001***[c]
LiM	23.44	6.22	22.10	6.11	<.001***[c]	24.23	6.29	23.06	6.33	<.001***[c]
LiA	10.03	3.58	9.17	3.50	<.001***[c]	10.50	4.60	9.69	4.44	<.001***[c]

[a] F + M indicates full-time appliance wearing except for tooth brushing; F − M, full-time appliance wearing except for meals and tooth brushing.
[b] Paired sample *t*-tests.
[c] Wilcoxon signed rank tests.
* $P < .05$; ** $P < .01$; *** $P < .001$.

Table 4. Comparison of Incisal Maximum Bite Force Between the Two Time Points (CT0 and CT1)[a]

	F + M		F − M		
Variables	Mean	SD	Mean	SD	*P* Value
IMBF at CT0 (N)	132.63[b]	61.60	123.43[b]	49.92	.626[d]
IMBF at CT1 (N)	165.70[c]	68.18	145.16[b]	49.90	.310[d]
P-value	< .001***[e]		< .001***[e]		

[a] F + M indicates full-time appliance wearing except for tooth brushing and F − M, full-time appliance wearing except for meals and tooth brushing; IMBF indicates incisal maximum bite force.
[b] IMBF was measured without wearing the appliance.
[c] IMBF was measured with wearing the appliance.
[d] Independent sample *t*-tests.
[e] Paired sample *t*-tests.
* $P < .05$; ** $P < .01$; *** $P < .001$.

Since RL measures root length linearly, whereas RV reflects the three-dimensional root quantity, changes in one may not always align with changes in the other. In the between-group analysis, the RL change was significantly different between the F + M and F − M groups, but the RV change was not. This discrepancy may have been because RL loss primarily occurs in the conical apical area, which has a small volume. Thus, significant RL loss in this region may have a minimal impact on the RV measurement.

Baseline IMBF at CT0 in the subjects was comparable to a previous study of masticatory muscle responses to RABP use.[14] However, that study reported no change in IMBF after 6 months, while the current study observed an increase. This difference may be attributed to variations in age,[15] developmental stages,[16] gender,[17] and stress level[18] among the study samples. The significant positive correlations between IMBF increment and decreases in RL and RV support the hypothesis that bite force exerted on mandibular incisors contributes to RL and RV loss.

The F + M group exhibited significantly greater RL shortening than the F − M group; however, the difference was minimal in clinical terms (0.25 ± 0.14 mm vs 0.21 ± 0.14 mm), and no significant difference in RV loss was observed. This suggests that both protocols were comparable in terms of treatment outcomes and clinical side effects. Choosing the appropriate protocol should consider factors such as the patient's developmental stage, severity of deep bite, and susceptibility of the root anatomy to resorption. For faster deep bite resolution, the F + M protocol may be preferred, whereas the F − M protocol could be a safer option for patients with a higher risk for root resorption.

Limitations

This study had limitations. A negative control group for RL and RV changes was omitted due to ethical concerns about radiation. Overjet, which may influence mandibular incisor inclination, was not included in the criteria, though initial inclinations were similar between the groups[2]. CBCT, although requiring a higher dose of radiation than 2D radiographs, was an essential tool to assess RL and RV changes in three dimensions. However, small RV changes, particularly at the apex, may have been below the resolution threshold and that could potentially have underestimated root changes.[19] Though micro-CT offers higher precision, it requires tooth extraction, making it unsuitable for in vivo studies. Static bite force measurements may not fully reflect functional forces, suggesting that future research should assess dynamic mastication forces. The 6-month RABP treatment duration may limit generalizability, warranting longer studies to evaluate combined effects of incisor inclination and heavy intermittent forces. Future research should also examine changes in alveolar bone thickness and height, as well as the long-term impact of RABP on stability, bone, and root quality.

CONCLUSIONS

- The F + M protocol resulted in greater mandibular incisor RL reduction than the F − M protocol, though the difference was minimal clinically.

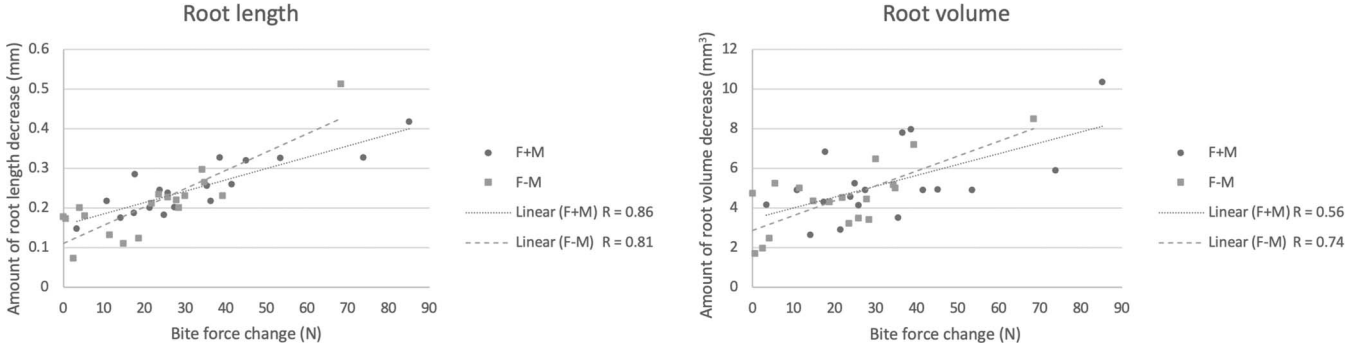

Figure 4. (Left) Relationship between changes in incisal maximum bite force (N) and root length (mm) in the F + M and F − M groups. (Right) Relationship between changes in incisal maximum bite force (N) and root volume (mm^3) in the F + M and F − M groups.

- Total RV and segmental RV changes were comparable between the two protocols.
- Increased IMBF was associated with reduced mandibular incisor RL and RV.

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DISCLOSURE

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