Original Article

Mandibular incisor root volume changes between anterior bite planes fabricated from acrylic resin and thermoplastic materials: a prospective randomized clinical trial

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ABSTRACT

Objectives: To compare mandibular incisor root volume change (RVC) after 6 months between an anterior bite plane fabricated from acrylic resin (ABP) and thermoplastic materials (TBP) in a group of growing patients.

Materials and Methods: Thirty-four deep bite patients (age: 11.57 $\pm$ 1.30 years) were randomized into the ABP or TBP group. The RVC from before treatment (T_0) to 6 months after treatment (T_{ct}) at the labio-coronal (La1), labio-middle (La2), labio-apical (La3), linguo-coronal (Li1), linguo-middle (Li2), and linguo-apical (Li3) segments were investigated from cone beam computed tomography (CBCT) images. Cephalometric changes between T_0 and the visit that normal overbite was achieved (T_{cep}) were also assessed ($\alpha = 0.05$).

Results: Thirty-four patients completed the trial. Treatment duration was 5.0 $\pm$ 2.9 months. Significant decrease in root volume (RV) was found at the La2, La3, and Li3 segments of the ABP group ($P < .05$). No significant RVC was found in any segment of the TBP group ($P \geq .05$). Comparing between groups, the RVC at La3 and Li3 of the ABP group was significantly greater than that of the TBP group ($P < .05$). However, total RVC between groups was not significantly different ($P \geq .05$).

Conclusions: Growing patients undergoing deep bite correction for 6 months with ABP displayed more apical RVC of mandibular incisors than those who used TBP. However, total RVC between appliances was not significantly different. (*Angle Orthod.* 2022;92:755–763.)

KEY WORDS: Deep bite; Root resorption; CBCT; Three-dimensional reconstruction

INTRODUCTION

Deep bite malocclusion is commonly seen in orthodontic patients, with a prevalence of 18.4%–34.5% in growing patients.[1,2] A removable anterior bite plane is an appliance commonly used to treat deep bite in children, allowing extrusion of mandibular posterior teeth and forward positioning of the mandibular incisors.[3,4]

Conventionally, an anterior bite plane is fabricated from acrylic resin material because of its high elastic modulus and hardness, thus providing excellent strength and fracture resistance.[5] The general design of an anterior bite plane incorporates only four mandibular incisors to have contact with the bite plane. During oral function, the occlusal force directed on these teeth may create a high stress distribution to the root apices which may, subsequently, induce changes in root volume. However, this assumption has never been evaluated.

Cone beam computed tomography (CBCT) is a three-dimensional method used to measure root volume change (RVC)[6–8] and orthodontically induced inflammatory root resorption (OIIRR). CBCT overcomes the limitations of methods based on two-

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dimensional radiographic images. Two studies have used this three-dimensional quantitative method, which has been shown to be precise, detailed, reproducible, and efficient in assessing even minimal root resorption.[6–8]

Recently, clear thermoplastic appliances have become increasingly popular because of their esthetic appearance and transparency. These appliances are claimed to be more comfortable than conventional fixed or removable appliances.[9] The appliances are custom made from various types of plastic materials, such as, polyethylene, polyurethane, and polycarbonate.[10] Bilaminate thermoplastic materials have been introduced recently by combining the advantageous properties of two materials. An inner polyurethane layer is resilient, aiding in absorbing force while providing patient comfort. The outer harder polyethylene layer has good formability and dimensional stability, helping to maintain the arch form.[11] A "bite ramp," similar to the bite plane of a conventional appliance, can be added and has been showed to be effective.[12] Due to a large difference in elastic modulus properties of the acrylic resin and thermoplastic materials (3.5–3.7 GPa vs 1.9–2.2 GPa),[5,13] the force of the mandibular incisors when contacting the material surface during oral function may be different, which may, subsequently, lead to a difference in RVC occurrence.

This purpose of this study was to compare the RVC in mandibular incisors between 6 months' use of an acrylic resin bite plane (ABP) and a clear thermoplastic bite plane (TBP) in a group of growing patients. The null hypothesis was that there would be no significant difference in the mandibular root volume change between ABP and TBP.

MATERIALS AND METHODS

Trial Design

This two-arm, parallel study was a single-center randomized control trial with a 1:1 allocation ratio. The trial was approved by the Ethics Committee on Human Research of the Faculty of Dentistry, Prince of Songkla University (ethical approval No. EC6305-014-P-HR). The trial was registered at Thai Clinical Trial Registry, under the identifier TCTR20201230001.

Participants, Eligibility Criteria, and Settings

Subjects were consecutively recruited at the Orthodontic Clinic of the Faculty of Dentistry, Prince of Songkla University according to the following inclusion criteria: dental deep bite (overbite $>$ 40%), overjet: 1–5 mm, skeletal Class I or mild Class II (ANB $=$ 1°–9°), Class I or II malocclusion, late mixed dentition (9–13 years) and hypo/normodivergent pattern (SN–MP $<$ 35°). Exclusion criteria were: noncooperative patients; signs or symptoms of temporomandibular disorders; incomplete root formation/previous endodontic treatment/history of trauma to mandibular incisors; clinical absence of first molars or mandibular incisors; and use of long-term anti-inflammatory, immunosuppressive drugs or other root-altering medications.

Interventions and Outcomes

Subjects in the ABP group were treated with a maxillary ABP appliance comprising a labial bow with U-loops, two Adam's clasps, and an acrylic resin baseplate with an anterior bite plane (Figure 1A). Four mandibular incisors occluded on the flat and smooth bite plane in centric relation position causing 2 mm disocclusion of the posterior teeth.[14] The subjects in the TBP group were treated with a maxillary TBP appliance fabricated from a thermoplastic bilaminate polyethylene/polyurethane material (Durasoft pd; Scheu Dental, Iserlohn, Germany), which was 1.8 mm thick. The appliance covered the clinical crowns of all teeth and extended 2 mm from the gingival margin. Prior to the heated vacuum forming procedure,[15] plaster was added onto the dental cast at the palatal surface of the maxillary anterior teeth and trimmed to resemble the shape of the anterior bite plane of the ABP appliance (Figure 1B). Subjects were advised to wear their appliances continuously except during meals and tooth brushing. All subjects were followed every 4 weeks until normal overbite (2 mm) was obtained. If the posterior teeth were occluding, yet normal overbite had not been achieved, a new appliance with further bite raising was provided. Subjects were instructed to continue wearing the appliance for 6 months.

Cephalometric Evaluation

Lateral cephalograms were taken with the same cephalometric machine before treatment (T_0) and after achieving normal overbite (T_{cep}) with natural head position. Cephalometric measurements were performed with Dolphin Imaging (version 11.9, Dolphin Imaging, Chatsworth, CA, USA). All landmarks in all images, including overbite, mandibular anterior/posterior dental height, lower facial height, and the inclination of mandibular incisor were measured by the same researcher (Figure 2).

CBCT Evaluation

CBCT of the mandibular incisors in both groups were taken (Veraviewepocs, J Morita Co, Kyoto, Japan) at 80 kV, 5 mA, 7.5-second exposure time, 0.125 mm

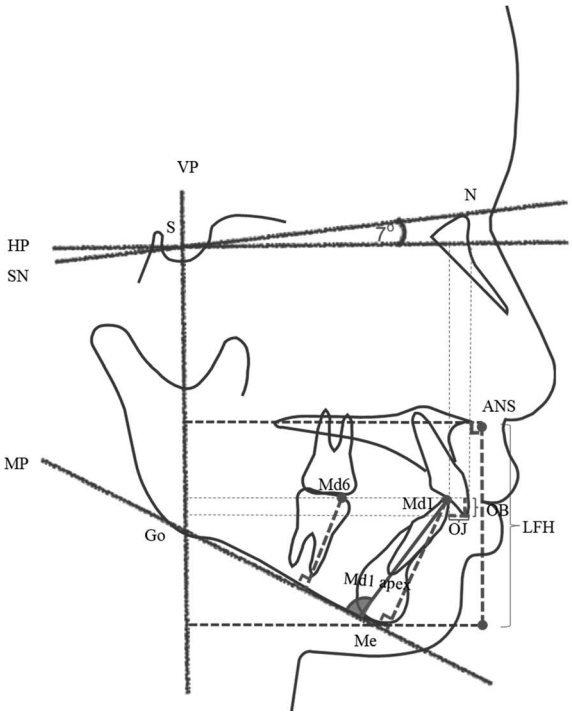
Figure 1. Occlusal (left) and lateral (right) views of the ABP (A) and TBP (B).

voxel resolution, and 80 × 40 mm field of view. Measurements were taken before (T_0) and 6 months after treatment (T_{ct}). All images were exported as DICOM files. Mimics inPrint 3.0 software (Materialise NV, Leuven, Belgium) was used to reconstruct the DICOM files into stereolithography (STL) files of all four mandibular incisors at each time point by the same researcher. To reconstruct the tooth morphology, the same threshold values were set appropriately for subjects in T_0 and T_{ct} images. In each slice, the outer boundaries of the tooth were identified manually (Figure 3).[8]

All STL images at T_0 and T_{ct} of each subject were imported into Geomagic Control X 2020 (Geomagic, Cary, NC, USA). This software was used to superimpose images using the best fit alignment of T_0 to T_{ct} images.[6,7] Reference plane 1 was constructed between the labial and lingual CEJ to separate the roots from the crowns. The root portions were segmented into labial and lingual aspects using a line perpendicular to reference plane 1 at the midpoint between the labial and lingual as reference plane 2. Reference planes 3 and 4 were constructed below reference plane 1 to separate the root into cervical, middle, and apical thirds.[6] Therefore, the T_0 roots and T_{ct} roots were segmented into six segments: labio-coronal (La1), labio-middle (La2), labio-apical (La3), linguo-coronal (Li1), linguo-middle (Li2), and linguo-apical (Li3) for each root. The root volume (RV) in each segment of roots at T_0 and T_{ct} were measured (Figure 4). RVC was analyzed as the difference between T_0 and T_{ct} in each segment. The measurements obtained from the RV and RVC of the four mandibular incisors were averaged and used for statistical analysis.

Method Errors

Ten patients were randomly selected and had their cephalometric and CBCT data remeasured after an interval of 4 weeks by the same investigator. Dahl-



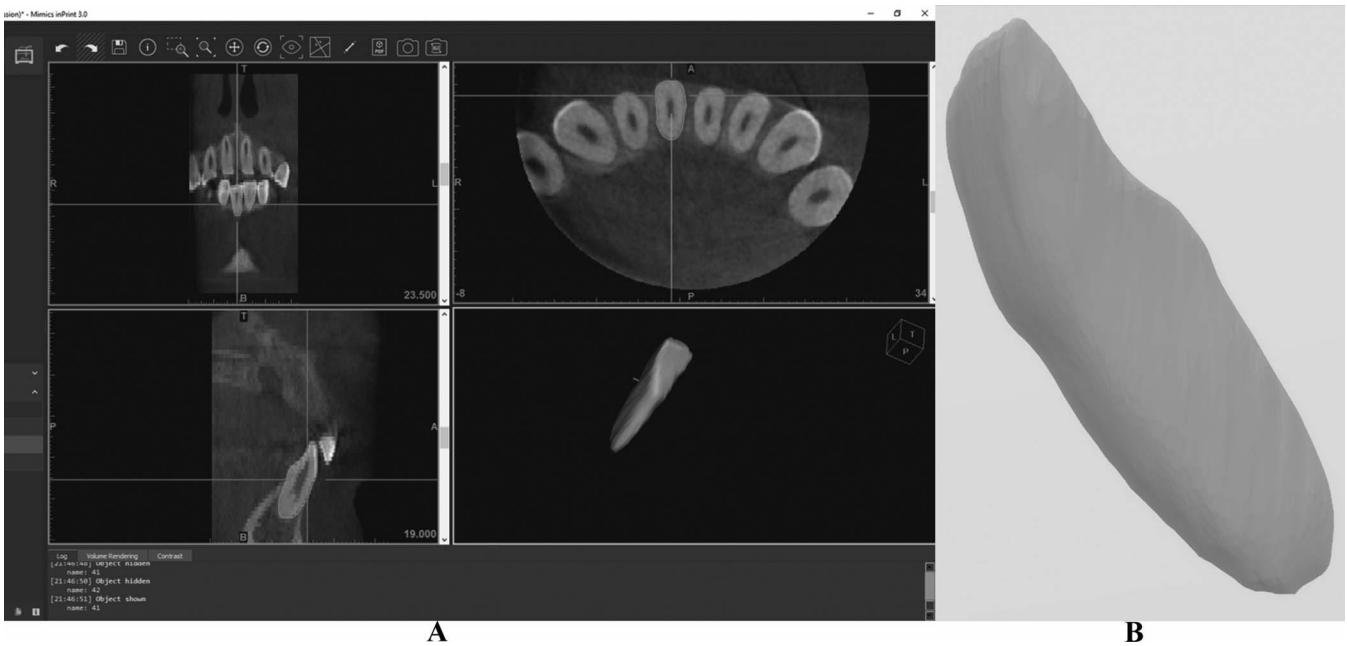
Landmarks	Definitions
HP	Horizontal reference plane (7° downward from S-N plane)
VP	Vertical reference plane (perpendicular to HP at sella)
MP	Mandibular plane (Go-Me)
Md6	The mesial cusp tip of the mandibular first molar
Md1	The incisal tip of maxillary incisor
OB	Overbite, the distance between maxillary and mandibular incisal edge (Mx1-Md1) parallel to VP
Md6-perpMP	The measured distance perpendicular to mandibular plane (Go-Me) to mesiobuccal cusp of mandibular first molar
Md1-perpMP	The measured distance perpendicular to mandibular plane to mandibular incisal edge
Md1-MP inclination	The angle formed from the long axis of mandibular incisor (Md1-Md1apex) and mandibular plane
LFH	Lower facial height, the distance between ANS and Me parallel to VP

Figure 2. Cephalometric measurements used in this study.

berg's error for each variable was less than 0.1 mm^3 for volumetric variables, 0.5 mm for linear variables, and 0.5° for angular variables and within acceptable levels. The intraclass correlation coefficient ranged from 0.93 to 0.97, indicating acceptable reliability for all measurements.

Sample Size Calculation

The sample size was calculated by G*Power (Version 3.1) using parameters from a study on the RVC of mandibular incisors.[8] A mean difference of 6.13 mm^3 with a standard deviation of 6.28, significance level of 0.05, and power to detect this difference of 0.90



A B

Figure 3. (A) Identification of incisor morphology in each slice. (B) STL image of the mandibular incisor.

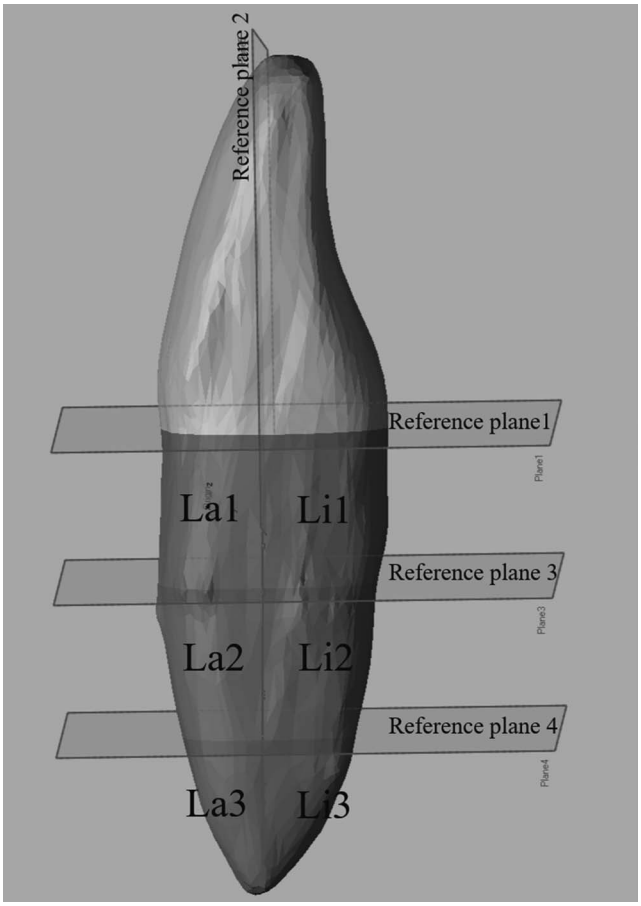


Figure 4. Analysis of root segmented into six segments.

was used to calculate the sample size. After setting the dropout rate at 20%, the sample size was set at 17 patients per group.

Randomization

All 34 subjects were randomly allocated to either the ABP group or the TBP group by using a number-generated list provided by www.random.org.

Blinding

Operator and subject blinding were not possible due to awareness of the appliance type. However, single blinding was accomplished while the researcher measured the CBCT and lateral cephalogram data. All datasets were identified with the individual number of each subject to conceal the subject's group. The numbers were exposed after completing cephalometric and RV measurements.

Statistical Analysis

Statistical analysis was performed using SPSS (version 25). Shapiro-Wilk tests showed some outcome variables were not normally distributed. Thus, nonparametric statistics were applied where appropriate. Mann-Whitney *U*-tests and Chi-square tests were used to compare baseline characteristics between groups. Wilcoxon signed rank tests were used to compare the cephalometric data between time points. Mann-Whitney *U*-tests were used to compare the difference between groups. Because RV data were normally distributed, paired *t*-tests were used to compare RV at two time points within groups. Independent *t*-tests were used to compare the initial RV and RVC between groups. Data were analyzed following the intention-to-treat principle.

RESULTS

A total of 46 children were assessed for eligibility; 10 were excluded because they did not meet the inclusion criteria and two refused to participate. Thus, 34 patients were randomized in a 1:1 ratio to the ABP or TBP groups (Figure 5). Comparison of baseline characteristics are presented in Table 1. There were no statistically significant differences in any parameter between the two groups. The deep bite in all subjects in the ABP and TBP groups were successfully corrected with an average treatment duration of 5.00 $\pm$ 2.90 months (range: 3–11 months).

Cephalometrically, there was a significant decrease in overbite within both groups ($P < .001$). Mandibular molars were significantly moved upward ($P < .05$), and lower facial height was significantly increased (Table 2). Comparing between groups, there were no significant differences in any cephalometric variables, treatment duration, or overbite correction rate ($P \geq .05$) (Table 3).

The average RV in each segment of the same tooth at T_0 and average RV of four mandibular incisors in each segment at T_0 were not significantly different between groups ($P \geq .05$). Table 4 demonstrates the within group RVC. In the ABP group, RV at La2, La3, Li3 segments, and total RV significantly decreased ($P < .05$), whereas there were no significant changes in any segments or total RV in the TBP group ($P \geq .05$). Comparing between groups, there were significantly greater changes in RVC at La3 and Li3 in the ABP group compared to the TBP group ($P < .05$). However, there were no significant differences in total RVC between the two groups ($P \geq .05$) (Table 5).

DISCUSSION

Nonsignificant differences in treatment duration, overbite correction rate, and cephalometric changes between the two groups indicated the comparable effectiveness of ABP and TBP. In agreement with previous studies,[4,12] deep bite was mainly corrected by

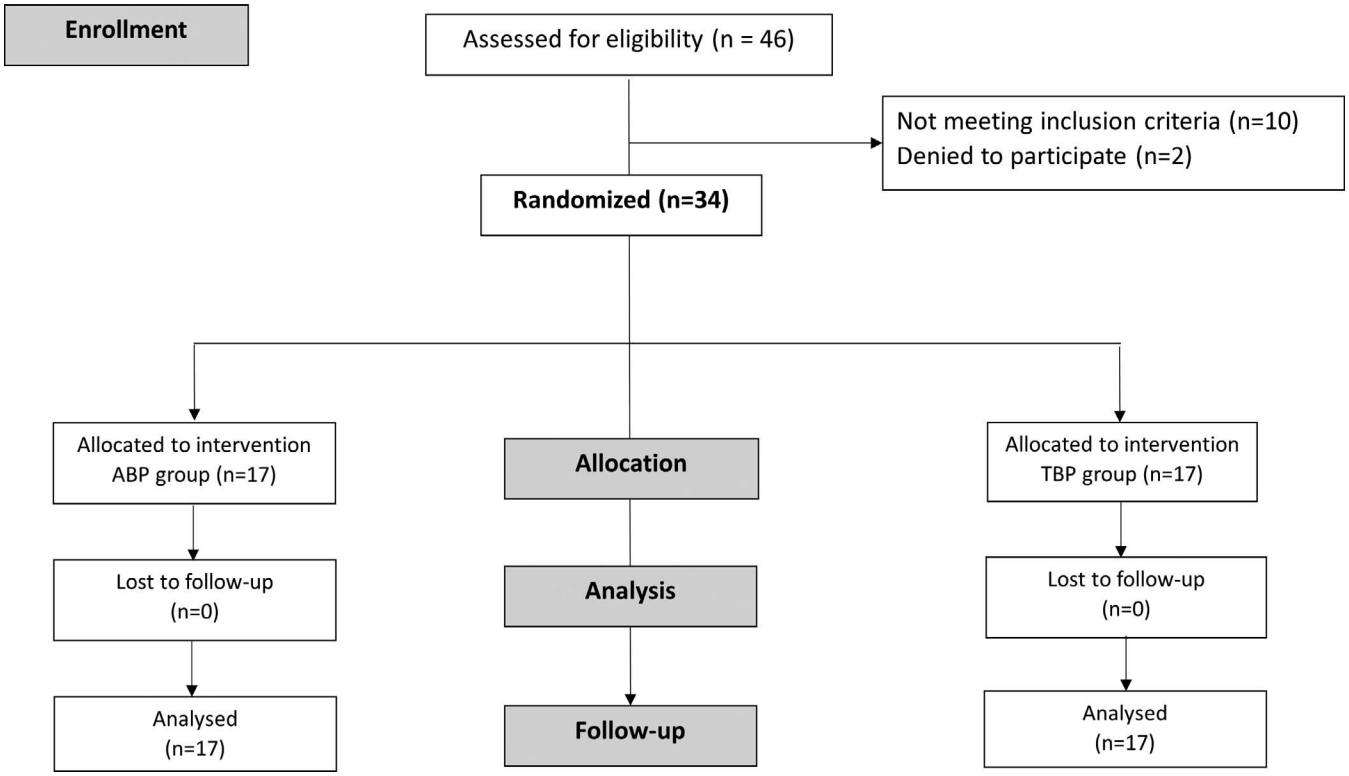


Figure 5. CONSORT flow diagram of the study.

the extrusion of mandibular molars leading to an increase in lower facial height. Since the subjects were children, molar extrusion was a combination of vertical dentoalveolar growth and the effect of continuous disocclusion of posterior teeth. In this study, the nonsignificant change in mandibular incisor position in the vertical plane, despite the natural vertical dentoalveolar growth of approximately 1.5 mm/y,[16] indicated the slight intrusive effect of the bite plane.

The force that affected the mandibular incisors during wear of an anterior bite plane is considered heavy.[17] A microcomputed tomography (micro-CT) study that compared root resorption crater volume in premolars following light (25 g) vs heavy (225 g) continuous intrusive force demonstrated mean resorption crater volumes that were two and four times greater, respectively, than the control group.[18] In addition, a tendency of greater resorption volume loss in the apical third area compared with the middle and cervical third areas in light and heavy force groups was observed. Yet, these results may not be directly comparable to the results in this study because of different teeth observed, different types of forces, and variations in measurement methods.

However, although heavy, the force occurring on the mandibular incisors during functioning with a bite plane is intermittent, which may cause less root resorption than continuous forces[19] because, when the force is periodically paused, it allows time for the cementum to initiate the reparative process itself.[20] Subjects were informed not to wear the appliance during meals, therefore reducing the frequency of heavy impingement of the mandibular incisors onto the bite plane, yet the deep bite was successfully alleviated.

Segmentation RVC measurement pinpoints the response in different parts of a root to a certain type of orthodontic tooth movement. The significant RVC at La2, La3, and Li3 in the ABP group was similar to the study by Puttaravuttiporn et al.,[6] who reported a reduction of labio- and palato-apical RV of maxillary incisors after use of continuous intrusive force to the

Table 1. Baseline Characteristics Before Treatment (T_0)[a]

	ABP (n = 17)		TBP (n = 17)		
Variable	Mean	SD	Mean	SD	*P* Value
N (boys:girls)	10:7		9:8		.784[b]
Age (y)	11.87	1.37	11.04	1.33	.097[c]
Overbite (mm)	4.27	1.38	4.22	1.37	.871[c]
Overjet (mm)	4.56	1.38	5.07	0.85	.247[c]
ANB (°)	4.37	1.20	3.44	2.47	.871[c]
SNMP (°)	25.87	5.40	27.25	5.65	.158[c]

[a] ABP indicates acrylic bite plane; SD, standard deviation; TBP, clear thermoplastic bite plane.
[b] *P* value of Pearson chi-square.
[c] *P* value of Mann-Whitney *U*-tests.

Table 2. Cephalometric Measurements Before Treatment (T_0) and After Achieving Normal Overbite (T_{cep})[a]

	ABP (n = 17)					TBP (n = 17)				
	T_0		T_{Cep}			T_0		T_{Cep}		
Variable	Mean	SD	Mean	SD	*P* Value	Mean	SD	Mean	SD	*P* Value
Overbite (mm)	4.42	1.56	1.86	0.56	.000***	4.29	1.32	2.05	0.83	.000***
Md1-perpMP (mm)	37.51	1.87	38.08	1.92	.063	37.28	2.52	38.80	2.18	.052
Md6-perpMP (mm)	27.16	1.93	28.75	1.98	.001**	26.82	2.11	27.90	2.05	.007**
Md1-MP inclination (°)	95.93	6.54	97.52	6.70	.266	92.41	7.86	94.11	8.00	.068
ANS-Me (mm)	57.81	3.21	60.50	3.50	.000***	56.80	3.95	59.34	3.44	.000***

[a] ABP indicates acrylic bite plane; SD, standard deviation; TBP, clear thermoplastic bite plane.
** $P < .01$, *** $P < .001$; Wilcoxon signed rank tests.

four maxillary incisors with fixed orthodontic appliances. In contrast, a micro-CT study demonstrated significant RVC at the middle, not the apical region, of the maxillary first premolars that occluded on glass ionomer cement bonded on the occlusal surface of the opposing mandibular first premolars, compared with contralateral untraumatized control teeth.[21] The differences in crown and root anatomy and the direction of forces transmitted to the roots between incisors and premolars may explain the difference in results.

Differences in material hardness may be responsible for the different RVC between groups. The amount of RVC at La3 and Li3 in the ABP group was significantly greater than that in the TBP group. The harder ABP surface may cause a higher compressive force to the occluding teeth than the softer TBP surface. A previous study claimed that a polyurethane soft thermoplastic layer is a ductile elastomer, which aids in absorbing the impact force.[11] However, comparing to studies that used a similar RVC measurement method, the total RVC of 1.75 mm^3 for mandibular incisors in the ABP group in this study was less than the RVC of 3.29 to 6.13 mm^3 for mandibular incisors after 5 months' use of a Forsus appliance.[8] The authors of that study claimed that the amount of root structure loss was minimal and clinically insignificant. Additionally, the RVC in this study was much smaller than the average RVC of 11.48 mm^3 found in maxillary and mandibular incisors after 21.45 months of treatment with clear aligner appliances.[22] Therefore, it may be assumed that the amount of RVC occurring from 6 months' wear of an ABP is slight and not clinically significant.

Table 3. Changes in Cephalometric Measurements ($T_{cep} - T_0$), Treatment Duration, and Overbite Correction Rate of the ABP and TBP Groups[a]

	ABP (n = 17)		TBP (n = 17)		
Variable	Mean	SD	Mean	SD	*P* Value
Overbite (mm)	−2.56	1.33	−2.24	1.21	.692[b]
Md1-perpMP (mm)	0.57	1.06	0.51	1.13	.945[b]
Md6-perpMP (mm)	1.58	0.97	1.08	1.22	.154[b]
Md1-MP inclination (°)	1.59	4.70	1.70	1.78	.743[b]
ANS-Me (mm)	2.69	1.58	2.54	2.33	.335[b]
Tx duration (months)	4.82	0.65	5.11	3.19	.790[b]
Overbite correction rate (mm/month)	0.53	0.33	0.43	0.42	.756[c]

[a] ABP indicates acrylic bite plane; SD, standard deviation; TBP, clear thermoplastic bite plane.
[b] *P* value of Mann-Whitney *U*-tests.
[c] *P* value of independent sample *t*-tests.

Limitations

Quantification of RVC using CBCT does not determine the true extent of OIIRR. Should the RVC involve only the cemental layers or surface resorption, the repair process may, subsequently, result in full regeneration or remodeling once the etiologic factor has been removed.[20] Although using micro-CT can provide precise information of the depth and specific area of root resorption, the method requires tooth extraction, which is not possible for studies such as the current study. Further studies should be undertaken to measure the forces acting on the anterior bite plane fabricated from different materials. This information may help explain why RVCs differ between use of different materials.

CONCLUSIONS

- Continual use of an anterior bite plane, except during tooth brushing and meals, was effective in alleviating deep bite in growing children.
- Although statistically significant RVC was found in the ABP group, the amount may be acceptable. Hence, either ABP or TBP can be used.
- TBP may be an alternative to ABP for cases in which teeth are judged to be especially vulnerable to root resorption.

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Table 4. Averaged Root Volume Measurements of the Four Mandibular Incisors Before (T_o) and After the 6 Months of Appliance Wear (T_{ct}) in the ABP and TBP Groups[a]

		ABP (n = 17)					TBP (n = 17)				
		T_o		T_{ct}			T_o		T_{ct}		
Variables	Segment	Mean	SD	Mean	SD	*P* Value	Mean	SD	Mean	SD	*P* Value
Root volume (mm^3)	La1	34.43	3.10	34.36	2.93	.900	35.49	4.13	35.37	4.35	.448
	La2	24.57	3.45	24.06	3.43	.002**	23.96	3.56	23.82	3.49	.504
	La3	8.93	1.95	8.72	2.02	.010*	8.48	1.82	8.42	1.46	.194
	Li1	30.56	3.02	30.26	2.81	.155	29.90	3.75	29.49	3.28	.228
	Li2	22.17	2.12	21.81	2.52	.203	21.32	3.10	21.25	2.94	.766
	Li3	9.20	2.07	8.90	2.15	.004**	8.00	1.44	7.94	1.61	.499
Total root volume (mm^3)		129.86	13.15	128.11	13.60	.001**	127.15	20.72	126.29	20.45	.084

[a] ABP indicates acrylic bite plane; SD, standard deviation; TBP, clear thermoplastic bite plane.
* $P < .05$, ** $P < .01$; paired-sample *t*-tests.

Table 5. Averaged Root Volume Change (RVC) of the Four Mandibular Incisors ($T_{ct} - T_o$) of the ABP and TBP Groups[a]

		ABP (n = 17)		TBP (n = 17)		
Variables	Segment	Mean	SD	Mean	SD	*P* Value
RVC (mm^3)	La1	−0.07	0.15	−0.12	0.13	.791
	La2	−0.51	0.50	−0.11	0.09	.100
	La3	−0.21	0.26	−0.06	0.02	.030*
	Li1	−0.29	0.73	−0.41	0.15	.786
	Li2	−0.35	0.16	−0.07	0.12	.219
	Li3	−0.30	0.32	−0.06	0.32	.006**
Total RVC (mm^3)		−1.75	1.39	−0.85	0.54	.612

[a] ABP indicates acrylic bite plane; SD, standard deviation; TBP, clear thermoplastic bite plane.
* $P < .05$, ** $P < .01$; independent sample *t*-tests.

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