Original Article

An evaluation of root resorption associated with the use of photobiomodulation during orthodontic treatment with clear aligners: a retrospective cohort pilot study

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ABSTRACT

Objectives: To evaluate the change in tooth root volume using cone-beam computed tomography (CBCT) in a group of patients treated concurrently with clear aligners and an adjunctive photobiomodulation (PBM) device.

Materials and Methods: This retrospective cohort pilot study included the records of 32 consecutively treated clear aligner patients (23 female, 9 male) from the private practice of one orthodontist. The PBM group (n = 16) used the device once per day for 5 minutes per arch and was compared with a matched control group (n = 16). A semiautomated segmentation technique was used to obtain tooth volume of anterior teeth from CBCT imaging prior to (T0) and during or immediately following (T1) orthodontic treatment with clear aligners. The change in root volume between time points was assessed.

Results: There was no statistically significant difference between the pre- and posttreatment root volumes of maxillary and mandibular anterior teeth, regardless of which intervention group the patient belonged to ($P > .05$). There was also no difference in the mean percentage change in root volume between clear aligner patients in this study who were treated with the PBM device compared with a matched control group ($P > .05$).

Conclusions: Clear aligner patients in this study who changed their aligners every 3 to 5 days and used adjunctive photobiomodulation therapy did not experience clinically relevant orthodontically induced external root resorption. Due to the small sample size and measurement error in the root segmentation process, the results should be interpreted with caution. (*Angle Orthod*. 2024;94:294–302.)

KEY WORDS: Photobiomodulation; Orthodontics; Tooth movement; Techniques; Root resorption

INTRODUCTION

Orthodontically induced external root resorption (OIERR) is a common undesirable side effect of orthodontic treatment. Some degree of OIERR occurs on all teeth but is generally not clinically significant.[1] Severe OIERR (greater than 6 mm) is observed in approximately 1.5% of patients.[2,3] This root shortening may affect the long-term prognosis of a tooth, leading to possible loss of the tooth. The risk of developing external root resorption during orthodontic treatment may be influenced by both orthodontic and patient-related factors.[1]

Longer treatment times have been shown to increase the risk of tooth root resorption, enamel decalcification, caries, and periodontal disease.[4,5] Photobiomodulation (PBM) is among the nonsurgical adjunctive interventions intended for accelerating tooth movement (Figure 1). Also known as low-level light therapy (LLLT), PBM uses light in the red-to-near infrared range (600–950 nm) generated by low-energy laser or light-emitting diode (LED) arrays.[6,7] PBM devices produce light using LEDs with a near infrared wavelength of 850 nm and an intensity of 60 mW/cm^2 continuous wave.[8] Studies have shown that mitochondrial cytochrome c oxidase,

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Figure 1. Photobiomodulation device.

the terminal enzyme in the mitochondrial oxidative respiration chain, becomes activated when it absorbs photons in this PBM wavelength range, which in turn leads to an increase in adenosine triphosphate production and cell metabolism.[9,10] LLLT has been shown to significantly increase periodontal ligament (PDL) cell proliferation, decrease PDL cell inflammation, and increase PDL osteoclastic activity in vitro.[11] While the increase in PDL osteoclastic activity by LLLT may enhance orthodontic tooth movement, it may also contribute to root resorption in orthodontic patients treated with this adjunctive therapy.

Recently, cone-beam computed tomography (CBCT) has become widely used in orthodontics, and it has been shown to be an acceptable and precise way of quantifying OIERR.[12–14] In addition, the in vivo volumetric assessment of changes in root morphology using CBCT has been studied.[15–17]

It was reported that clear aligners and light orthodontic forces with fixed appliances had similar effects on OIERR.[18,19] A recent study found that the prevalence and severity of OIERR in patients with clear aligners may be less than those in patients with fixed appliances.[20] A previous study investigated the effect of PBM therapy on tooth root morphology following orthodontic treatment but focused only on patients treated with fixed orthodontic appliances.[21]

The aim of this study was to evaluate volumetric changes in root morphology using CBCT in patients treated with clear aligners and PBM therapy.

MATERIALS AND METHODS

This retrospective nonrandomized cohort study was approved by the University of Alberta research ethics committee (Pro00078048). CBCT imaging from 32 subjects who received comprehensive orthodontic treatment with clear aligners (16 consecutively treated PBM [Biolux Research, Fremont, Calif] patients who met the inclusion/exclusion criteria and 16 matched control patients) were retrospectively compared for this study (Table 1). The number of patients in both groups was dependent on the availability of records. Written informed consent was obtained from each participant. All patients began treatment between January 1, 2015, and July 1, 2019. Both treatment and control groups were treated by one orthodontist in a private practice setting. All new patients in this orthodontic office also received a full field-of-view CBCT prior to the start of active aligner therapy (T0) and at the end

Table 1. Baseline Characteristics of Participants in the Two Groups (Nominal Variables)

	OrthoPulse + Clear Aligners (n = 16)	Clear Aligners (n = 16)
Gender, n (%)		
Male	11 (69)	12 (75)
Female	5 (31)	4 (25)
Type of malocclusion, n (%)		
Class I	7 (44)	7 (44)
Class II	7 (44)	7 (44)
Class III	2 (12)	2 (12)

of treatment (T1). Subjects were excluded if they possessed any risk factors for root resorption.[1,22]

The PBM group (n = 16) received treatment with clear aligners (Invisalign, Align Technology, San Jose, Calif) and changed their aligners every 3 to 5 days. They were instructed to use their PBM device for 10 minutes once per day (5 minutes to each dental arch per day) at any time during the day.[8] Compliance was monitored using an application on the patient's mobile phone that was synced to the PBM device. The control (clear aligner) group (n = 16) received treatment with Invisalign clear aligners. They were instructed to change their aligners every 7 to 10 days.

To ensure that both groups were similar, patients in the control group were matched to those in the PBM group based on the following: type of malocclusion based on the Angle molar classification, total number of aligners used between the two time points, case difficulty as determined by the irregularity index of both arches, age, and gender.

The baseline characteristics (age, total number of aligners used in treatment, total treatment time, pretreatment incisor irregularity index, pretreatment inclination of incisors, and pretreatment root volumes) were evaluated between the two groups since those variables were identified as possible confounding variables in previous studies. Using univariate analysis of variance, the baseline characteristics of the participants in the two groups were similar for all continuous variables except total treatment time ($P < .0005$; Table 2).

All CBCT images were acquired with the patient in centric occlusion using the i-CAT FLX (Imaging Sciences International, Hatfield, Penn) with the following exposure parameters: scanning time 3.7 seconds, 5 mA, 120 kVp, field of view 16 cm × 13 cm, voxel size 0.3 mm. Images were converted to Digital Imaging and Communications in Medicine (DICOM) format using InVivo software (Anatomage, San Jose, Calif). CBCT data were imported into ITK-Snap software (version 3.8, http://www.itksnap.org) in DICOM format. A semiautomatic segmentation technique was used to generate volumes for all 12 teeth (Figure 2).[17,23] Measurements were performed by the same blinded investigator. The volume data sets for T0 and T1 were exported as the Visualization Toolkit (VTK) file format and imported into 3DSlicer software (version 4.10.2, https://www.slicer.org/.). T0 to T1 images were superimposed by the best fit alignment using an iterative closest point algorithm (Figure 3A). A reference plane was constructed using the highest point of the labial and palatal cementoenamel junction and a perpendicular line drawn through the long axis of the tooth (Figure 3B). The superimposed teeth were cut immediately below the reference plane, the crowns of the teeth were removed, and only the volume of the root portion was computed (Figure 3C). The root volume change was calculated from pre- and posttreatment root volumes for each tooth using the following formula:

$$\%\Delta \text{ root volume} = \frac{\text{root volume}_{\text{post-treatment}} - \text{root volume}_{\text{pre-treatment}}}{\text{root volume}_{\text{pre-treatment}}} \times 100.$$

Statistical analyses were performed using IBM SPSS Statistics for Mac, version 23 (IBM Corp, Armonk, NY). A significance level of $\alpha = .05$ was chosen for all statistical analyses.

RESULTS

Complete descriptive statistics are shown in Table 3. Data are expressed as mean ± standard deviation. When considering both groups combined, the greatest mean decrease in root volume was found to be 1.54% ± 10.66% on tooth 11 followed by 1.41% ± 10.55% on tooth 21. For the PBM group, the greatest mean decrease in root volume was found to be 4.14% ± 13.21% on tooth 13 followed by 2.87% ± 12.42% for tooth 11. For the control group, the greatest mean decrease in root volume was found to be 0.68% ± 10.22% on tooth 21 followed by 0.22% ± 8.76% for tooth 11. Overall, the PBM group showed a mean decrease in root volume of 1.05% ± 2.14% when all teeth were considered, whereas the control group showed a mean increase in root volume of 2.07% ± 2.14%. Mean compliance for the PBM group was 88.1% ± 16.3%. No adverse events were reported by any of the patients in either group.

As shown in Table 4, the main effect of the intervention showed that there was no statistically significant difference in mean percentage change in root volume between groups ($P = .310$). Therefore, there was no difference in mean percentage change in root volume between PBM and control patients. While not significant, it was noted that the PBM group showed a greater reduction in root volume compared with the control group for almost all teeth studied (Table 3).

There was no statistically significant interaction between the intervention and tooth number on change in root volume ($P = .588$; Table 5). Therefore, the differences in mean percentage change in root volume between the intervention groups were independent of the tooth being analyzed.

DISCUSSION

The results showed that the teeth that experienced the most OIERR were the maxillary central incisors (Table 3). This is contrary to what has been found in previous studies, which showed that the most resorbed teeth were the maxillary lateral incisors.[24,25] This was

Table 2. Baseline Characteristics of Participants in the Two Groups (Continuous Variables)

	Intervention	Mean	SD	Significance
Age, y	Control	27.38	8.28	.371
	OrthoPulse	29.94	7.67	
	Total	28.66	7.96	
Total number of aligners	Control	81.50	29.08	.973
	OrthoPulse	81.13	32.12	
	Total	81.31	30.14	
Total treatment time, d	Control	767.25	243.81	<.0005*
	OrthoPulse	377.31	125.86	
	Total	572.28	275.08	
Maxillary Irregularity Index, mm	Control	7.04	3.68	.802
	OrthoPulse	6.70	3.84	
	Total	6.87	3.70	
Mandibular Irregularity Index, mm	Control	5.59	3.38	.932
	OrthoPulse	5.49	3.07	
	Total	5.54	3.17	
Pretreatment inclination of maxillary incisors U1-PP, °	Control	114.55	9.34	.554
	OrthoPulse	112.42	10.77	
	Total	113.48	9.98	
Pretreatment inclination of mandibular incisors IMPA, °	Control	91.75	8.23	.211
	OrthoPulse	88.18	7.57	
	Total	89.96	7.99	
Pretreatment volume tooth No. 1.3, mm^3	Control	491.24	194.19	.249
	OrthoPulse	566.78	168.67	
	Total	529.01	182.99	
Pretreatment volume tooth No. 1.2, mm^3	Control	318.59	104.05	.597
	OrthoPulse	337.35	94.19	
	Total	327.97	98.09	
Pretreatment volume tooth No. 1.1, mm^3	Control	499.31	106.63	.621
	OrthoPulse	517.22	96.06	
	Total	508.26	100.25	
Pretreatment volume tooth No. 2.1, mm^3	Control	493.89	100.57	.733
	OrthoPulse	505.71	93.61	
	Total	499.80	95.76	
Pretreatment volume tooth No. 2.2, mm^3	Control	310.61	100.27	.665
	OrthoPulse	325.92	97.82	
	Total	318.27	97.75	
Pretreatment volume tooth No. 2.3, mm^3	Control	504.59	138.21	.378
	OrthoPulse	549.30	144.60	
	Total	526.94	140.98	
Pretreatment volume tooth No. 3.3, mm^3	Control	448.56	127.06	.616
	OrthoPulse	471.97	134.36	
	Total	460.26	129.18	
Pretreatment volume tooth No. 3.2, mm^3	Control	257.61	64.42	.688
	OrthoPulse	265.90	50.28	
	Total	261.75	57.00	
Pretreatment volume tooth No. 3.1, mm^3	Control	210.05	51.96	.679
	OrthoPulse	216.52	33.93	
	Total	213.28	43.29	
Pretreatment volume tooth No. 4.1, mm^3	Control	211.78	50.33	.778
	OrthoPulse	216.19	36.49	
	Total	213.99	43.30	
Pretreatment volume tooth No. 4.2, mm^3	Control	257.38	59.38	.239
	OrthoPulse	280.42	48.66	
	Total	268.90	54.67	
Pretreatment volume tooth No. 4.3, mm^3	Control	472.14	133.20	.749
	OrthoPulse	487.40	134.48	
	Total	479.77	131.89	

* Statistical significance.

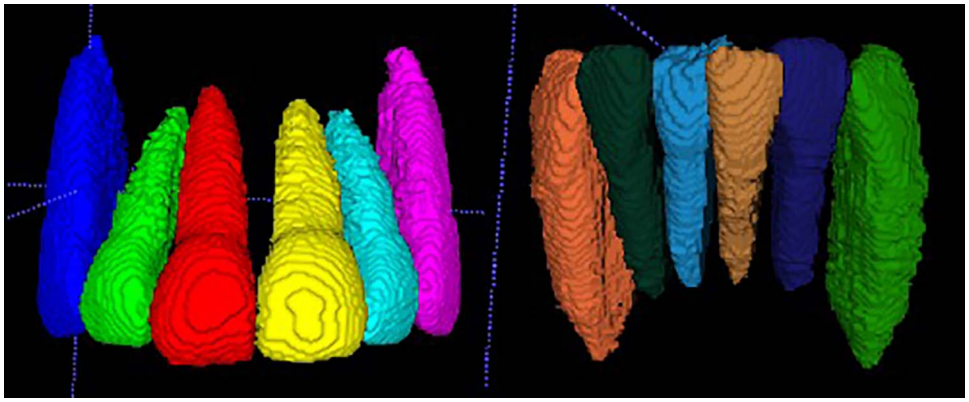

Figure 2. Completed segmentation of all maxillary and mandibular teeth in ITK-SNAP.

likely an incidental finding in this group of patients. The results of this study were also supported by a recent systematic review that concluded that nonsurgical adjunctive interventions did not affect the amount of OIERR when compared with conventional orthodontic treatment alone.[26]

It was also interesting to note that approximately 41.6% of all teeth in the PBM group and 57.9% of all teeth in the control group in this study demonstrated mean increases in root volume, which were not statistically significant (Table 2). This can first be explained by observer error as well as measurement error due to the partial volume effect in low-resolution CBCT imaging, which was the main limitation of this study.[27] Some increase in root volume may be attributable to repair of the root by new cementum, which is formed shortly after the application of

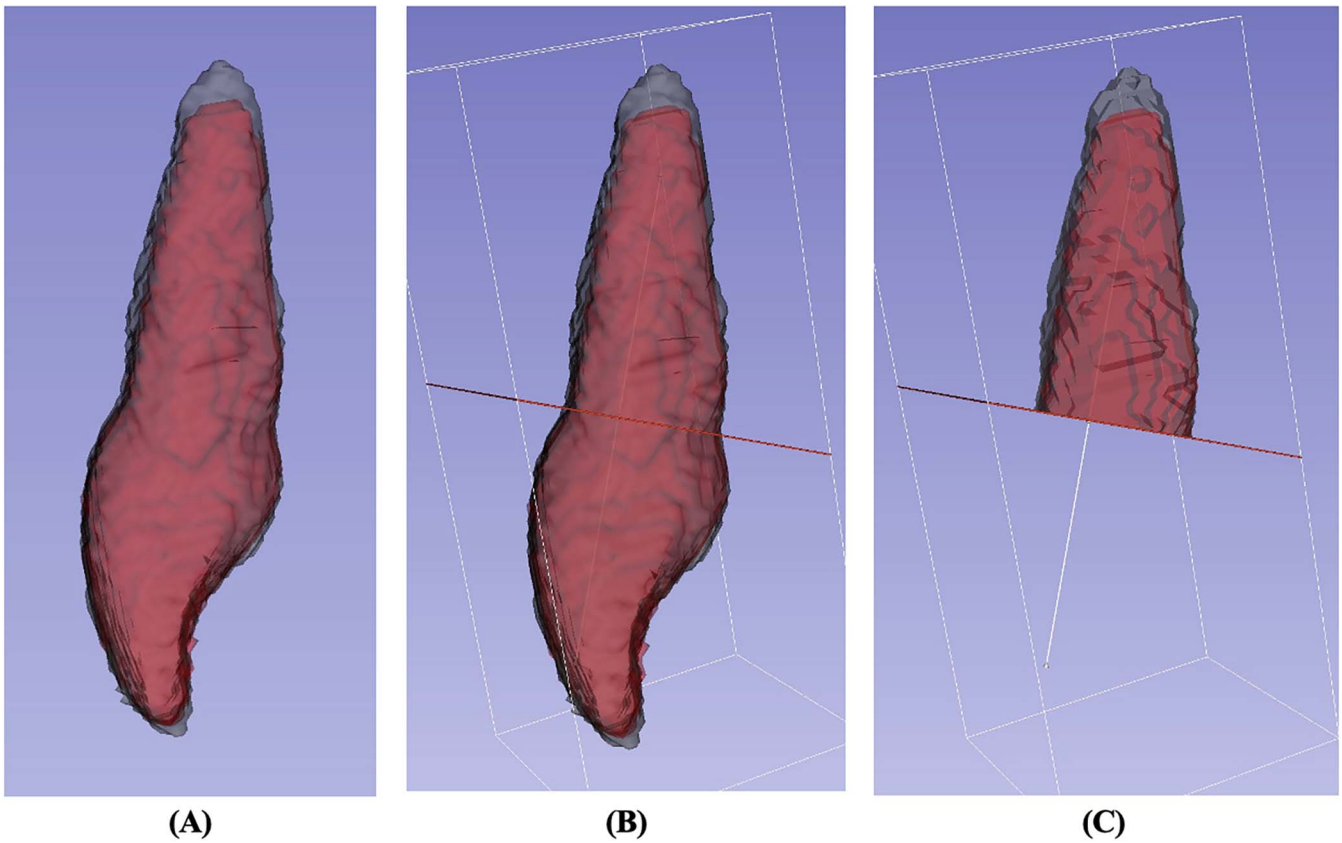

Figure 3. (A) Superimposition of tooth volumes at T0 (gray) and T1 (red). (B) Reference plane (red line). (C) Superimposed root volumes at T0 and T1, mesial palatal color map view.

Table 3. Descriptive Statistics of Change in Root Volume Data in PBM Patients, Control Patients, and Combined for All Teeth

Tooth No.	Intervention	Mean Change in Root Volume, mm^3	SD	Mean Change in Root Volume, %	SD
1.3	Control	2.94	22.74	2.42	9.96
	PBM	−18.49	38.83	−4.14	13.21
	Combined	−7.78	33.14	−0.86	11.98
1.2	Control	−1.84	19.53	1.64	14.75
	PBM	−6.89	22.84	−1.96	16.04
	Combined	−4.36	21.06	−0.16	15.27
1.1	Control	−1.43	15.41	−0.22	8.76
	PBM	−9.64	27.61	−2.87	12.42
	Combined	−5.53	22.39	−1.54	10.66
2.1	Control	−2.11	16.95	−0.68	10.22
	PBM	−7.19	26.44	−2.13	11.16
	Combined	−4.65	22.00	−1.41	10.55
2.2	Control	−2.03	18.93	1.30	16.38
	PBM	−3.88	23.90	−0.26	16.13
	Combined	−2.95	21.23	0.52	16.01
2.3	Control	7.23	21.84	2.63	9.94
	PBM	−14.96	39.43	−3.28	14.25
	Combined	−3.87	33.32	−0.33	12.45
3.3	Control	9.36	23.36	4.88	9.80
	PBM	−12.06	42.69	−0.93	14.32
	Combined	−1.35	35.55	1.98	12.43
3.2	Control	3.42	14.45	3.85	10.37
	PBM	−0.23	19.53	2.38	17.53
	Combined	1.60	17.00	3.12	14.19
3.1	Control	1.16	10.23	2.21	12.57
	PBM	2.64	17.99	3.51	16.92
	Combined	1.90	14.42	2.86	14.68
4.1	Control	0.28	11.08	1.26	11.88
	PBM	0.13	15.06	1.47	14.51
	Combined	0.20	13.00	1.36	13.05
4.2	Control	4.91	15.24	5.33	13.34
	PBM	−7.41	25.29	−2.75	18.71
	Combined	−1.25	21.47	1.29	16.50
4.3	Control	−0.45	33.21	0.19	11.84
	PBM	−9.00	30.79	−1.64	13.34
	Combined	−4.73	31.80	−0.72	12.44

orthodontic force.[28] The similarity in gray values on a CBCT between a tooth and surrounding tissue makes the segmentation procedure quite challenging, especially in the mandibular incisor and maxillary canine regions, where the roots of these teeth are in close proximity to the cortical plate of bone. The interproximal region between teeth was equally challenging due to similarities in gray values between the adjacent enamel. The presence of normal anatomical variation in root morphology also influenced the segmentation of the apical region. The level of mineralization of the tooth and the presence of metallic restorations also needs to be considered.[29] There are a variety of CBCT-related factors, such as scanning parameters and machine calibration, which affect volume measurements.[30] However, these factors may not have

Table 4. Tests of Between-Subject Effects for Change in Root Volume Data

Tests of Between-Subjects Effects					
Measure: MEASURE_1					
Transformed Variable: Average					
Source	Type III Sum of Squares	*df*	Mean Square	*F*	Significance
Intercept	99.328	1	99.328	0.113	.739
num_intervention	933.442	1	933.442	1.065	.310
Error	26,304.317	30	876.811		

Table 5. Tests of Within-Subject Effects for Change in Root Volume Data[a]

Tests of Within-Subjects Effects					
Measure: MEASURE_1 Source	Type III Sum of Squares	*df*	Mean Square	*F*	Significance
root_volume					
Sphericity assumed	902.543	11	82.049	0.683	.755
Greenhouse-Geisser	902.543	2.153	419.135	0.683	.519
Huynh-Feldt	902.543	2.403	375.637	0.683	.534
Lower bound	902.543	1.000	902.543	0.683	.415
root_volume* num_intervention					
Sphericity assumed	737.367	11	67.033	0.558	.862
Greenhouse-Geisser	737.367	2.153	342.428	0.558	.588
Huynh-Feldt	737.367	2.403	306.891	0.558	.606
Lower bound	737.367	1.000	737.367	0.558	.461
Error (root_volume)					
Sphericity assumed	39,644.092	330	120.134		
Greenhouse-Geisser	39,644.092	64.600	613.682		
Huynh-Feldt	39,644.092	72.081	549.994		
Lower bound	39,644.092	30.000	1321.470		

[a] Variable root_volume, percentage change in root volume; variable num_intervention, intervention.

contributed significantly to the measurement error, since all scans in this study were taken by the same machine using the same scanning parameters. Patient-related factors, such as movement during imaging, also appear to play a role.[12,29] The overall measurement error in root volume measurements was found to be 1.9% $\pm$ 1.2% for the segmentation technique used in this study. Given the results of the pilot study, which indicated that a clinically meaningful amount of root resorption may represent between 0.84% and 9.23% of total root volume depending on the type of tooth, the amount of root volume change due to measurement error may be falsely interpreted as clinically significant root resorption.

Although there was no statistically significant difference in the mean percentage change in root volume between the PBM and control groups, patients in the control group appeared to have less reduction in root volume compared with the PBM group for almost all studied teeth. Patients in the control group in this study were asked to change their aligners every 7 to 10 days, which is considered the standard of care according to the manufacturer's most recent clinical protocols.[31] Patients in the PBM group were instructed to change their aligners every 3 to 5 days, which was almost double the tooth movement rate compared with the control group. Therefore, more frequent aligner changes may lead to more sustained forces on the teeth, which increases the risk of OIERR.[32] The inclusion of another control group with patients who used clear aligners and who changed their aligners every 3 to 5 days would be essential to determining whether the similarity in OIERR between the two groups in this study was due to antiresorptive effects of PBM in the treatment group. An alternative explanation to this finding is that, regardless of how often the aligners are changed, the lighter forces delivered to the teeth by clear aligners may lead to less risk of developing OIERR compared with the use of fixed appliances. One study reported that clear aligners may have similar resorptive effects on root cementum as light orthodontic forces with fixed appliances,[18] whereas another study reported that clear aligners produced less OIERR than fixed appliances did.[20] Therefore, the magnitude of OIERR to be expected during orthodontic treatment with clear aligners compared with fixed appliances remains unclear.

Because this was a retrospective study, the allocation to the PBM group was not randomized, and the patients and the treating orthodontist were not blinded. There may exist a selection bias in the patients who chose to use the PBM device, as it was given only to those who could afford to pay for the device. Given the retrospective nature of the study, it was not possible for the treating orthodontist to know which patients would ultimately be included in this study, especially among those in the control group.

Further randomized studies using higher-resolution CBCT imaging are needed to determine a true cause and effect relationship between OIERR and PBM devices.

CONCLUSIONS

- None of the maxillary and mandibular anterior teeth in this study experienced a statistically significant amount of root resorption during treatment when all teeth were considered jointly.
- When controlling for total treatment time, total number of aligners, change in incisor inclination, and

irregularity index, clear aligner patients in this study who changed their aligners every 3 to 5 days and used PBM did not experience a significantly different amount of OIERR compared with matched control patients.
- Due to the small sample size and the measurement error in root segmentation, the presented results should be interpreted with caution.

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