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Original article

Dental root development associated with treatments by rapid maxillary expansion/ reverse headgear and slow maxillary expansion

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Summary

Objectives: To assess dental root development in two groups of paediatric patients who received treatments with reverse headgear and rapid maxillary expansion and slow maxillary dental arch expansion.

Materials and methods: The 20 subjects (13 girls, 7 boys; mean age: 8.9 ± 1.3 years) in the first group were treated with a Petit-type reverse headgear attached to a full-coverage bonded rapid maxillary expander *via* elastics (RME&RHg group). The 20 subjects included in the second group (9 girls, 11 boys; mean age: 9.1 ± 2.2 years) were selected among patients who were treated with Hawley appliances for slow maxillary expansion (SME group). Digitized panoramic radiographs were used. A total of 960 permanent teeth (maxillary–mandibular incisors, canines, premolars, and first molars) were measured quantitatively for pre-treatment and post-treatment.

Results: No significant increase was found except for the right and left maxillary and mandibular second premolars and left mandibular and first premolar in the RME&RHg group ($P < 0.05$). Teeth length values increased significantly in all maxillary and mandibular teeth except maxillary first molars and mandibular incisors in the SME group ($P < 0.05$). Inter-group comparisons showed that statistically significant differences were observed in maxillary and mandibular incisors, left maxillary first premolar, and molar teeth ($P > 0.05$).

Limitation: A limitation of this study is the use of two-dimensional radiographic images for root length measurement. However, ethical obligations limit the dental cone beam computed tomography imaging application for protection of paediatric patients from harm.

Conclusions: RME&RHg therapy inhibits root development of maxillary and mandibular teeth in the early period. However, further studies should be performed to determine whether this effect on root development is reversible or irreversible.

Introduction

Skeletal Class III malocclusions are associated with maxillary retrognathism, mandibular prognathism, or combinations of these (1). Skeletal Class III malocclusion is usually a three-dimensional disorder, and maxillary narrowness is frequently diagnosed in patients with Class III malocclusion (2). The combined use of reverse headgear (RHg) and rapid maxillary expansion (RME) techniques is typically a treatment option in growing patients with Class III malocclusion in mixed or early permanent dentition, and it may be used to skeletally advance the maxilla (3, 4).

It was reported that RME appliances produce between 3 and 10 pounds of force with one-turn activation on the anchor teeth (5).

Heavy forces which are generated by RME may lead to resorption of the roots of teeth (6, 7). Moreover, orthopaedic heavy forces are transmitted by the reverse headgear to the support teeth and maxilla (8). Heavy forces that are generated by the combination of RME and RHg may induce resorption in the apical area or negatively influence root development in teeth that have incomplete root formation (9). In spite of this possibility, studies on evaluation of root-growth inhibition or apical root resorption associated with the combination of RME and RHg treatments were not found in the reviewed literature. Although this treatment appears to be the best option in correction of Class III malocclusion in the early period, we also believe that evaluation of the effects of the treatment on tooth root structures is necessary to understand all this process.

Conventional radiography may be used in the assessment of root resorption or development after orthodontic therapy (10). Several routine radiographic procedures can be used to assess root resorption or development, including panoramic, cephalometric and periapical radiography or a combination of these (11, 12). Panoramic films have several advantages especially in paediatric dental practice such as lower rate of exposure to radiation and simplicity of use (13, 14).

The aim of this study was to assess whether root development is disrupted during the combination of RME and RHg treatments in the paediatric population with Class III malocclusion. The null hypothesis of this study was that there is no significant difference in the dental root development following treatment with reverse headgear and rapid maxillary expansion and slow maxillary dental arch expansion.

Material and methods

The patients were selected from the archive of the orthodontic department at the University of Erciyes, Kayseri, Turkey. Forty patients were included in this study and half of them were in the Petit-type reverse headgear attached to a full-coverage bonded rapid maxillary expander *via* elastics (RME&RHg) group, while the other half were in the slow maxillary expansion (SME) group. The experimental protocol of the study was approved by the Erciyes University Local Ethics Committee (2016–623).

The patients had the following inclusion characteristics: 1. treatment with a Petit-type reverse headgear with a full-coverage bonded rapid maxillary expander or Hawley appliances for slow maxillary expansion, 2. mixed dentition, 3. non-extraction, 4. no congenitally missing or impacted teeth and 5. pre- and post-treatment radiographic and progress records present. Exclusion criteria were any systemic disease or craniofacial syndrome, previous orthodontic treatment, and poor quality radiographs.

Power analysis revealed that a sample size of 20 patients in each group was calculated to give >80% power to identify significant differences with an effect size of 0.9 at a significance level of $\alpha = 0.05$.

The 20 subjects (13 girls and 7 boys; mean age, 8.9 ± 1.3 years) in the study group were treated with a RME&RHg from 2012 to 2015. According to the treatment records of the patients, only transverse maxillary expansion was performed for the first week and the screw was activated two times a day (0.25 mm per turn, 0.5 mm daily). After opening the midpalatal suture, protraction was performed simultaneously with maxillary expansion. The active expansion protocol was continued until posterior dental crossbite overcorrection was provided. All patients were advised to wear the RHg appliance for at least 16 hours per day. RME&RHg treatment was discontinued when a positive overjet was obtained. The mean time of treatment was 8.15 ± 2.4 months. Pre-treatment ($T0$) and post-treatment ($T1$—when the rapid maxillary expander were removed) radiographic records of these patients were used in this retrospective analysis.

The 20 subjects included in the SME group were selected among patients who were treated with Hawley appliances for slow maxillary expansion from 2013 to 2015. The subjects of SME group consisted of 9 girls and 11 boys. Their mean age was 9.1 ± 2.2 years for $T0$ in the SME group. The post-treatment panoramic radiographs ($T1$) of the patients in the SME group were obtained on average 7.3 ± 1.4 months after the first records. The radiographs of all included patients had been taken with the same panoramic machine (OP200, Instrumentarium, Tuusula, Finland). The demographic characteristics of the included patients are shown in Table 1.

Radiographic analysis

Digitized panoramic films were analysed with image processing and analysis software (ImageJ software, version 1.37, National Institutes of Health, Bethesda, Maryland, USA) to determine whether RME&RHg treatment affected apical root development. The scale setting was performed after importing the radiographic image based on the change of known distance in pixels to a known distance as a millimetre unit (16.4 pixels/ mm).

Lengths of a total of 960 permanent teeth including upper and lower incisors, canines, premolars, and first molars were measured quantitatively for the two time points ($T0$ and $T1$). The mesio-buccal root of the maxillary first molar and the mesial root of the mandibular first molar were included in the measurement. The linear tooth length measurement was performed from the centre of the incisal edge or the cusp tip to the most apical border of the root apex (15) (Figure 1).

To eliminate false positive or negative results due to vertical magnification differences between the panoramic radiographs at $T0$ and $T1$, the magnification factor was calculated using the following equation (16, 17):

$$\text{Change of root length value } (T1 - T0) = \frac{C0}{C1} \times R1 - R0$$

where $C0$ is radiographic incisor crown length at $T0$; $C1$, radiographic incisor crown length at $T1$; $R0$, radiographic root length at $T0$; and $R1$ is radiographic root length at $T1$. The radiographic analysis was blind and was performed by the same examiner.

Statistical analysis

Measurements were performed blind by the same operator (EDS). Ten panoramic radiographs (5 from each group) were randomly selected and premeasured after 1 month in order to assess measurement reliability. The method error results were found to be clinically insignificant ($P > 0.05$). The mean method error for the RME&RHg

Table 1. Demographic characteristics of patients

	RME+RHg	SME	Total
Boys (*n* %)	7 (35%)	11 (55%)	18
Girls (*n* %)	13 (65%)	9 (45%)	22
Mean age (year) ± SD	8.9 ± 1.3	9.1 ± 2.2	40

SD, standard deviation.

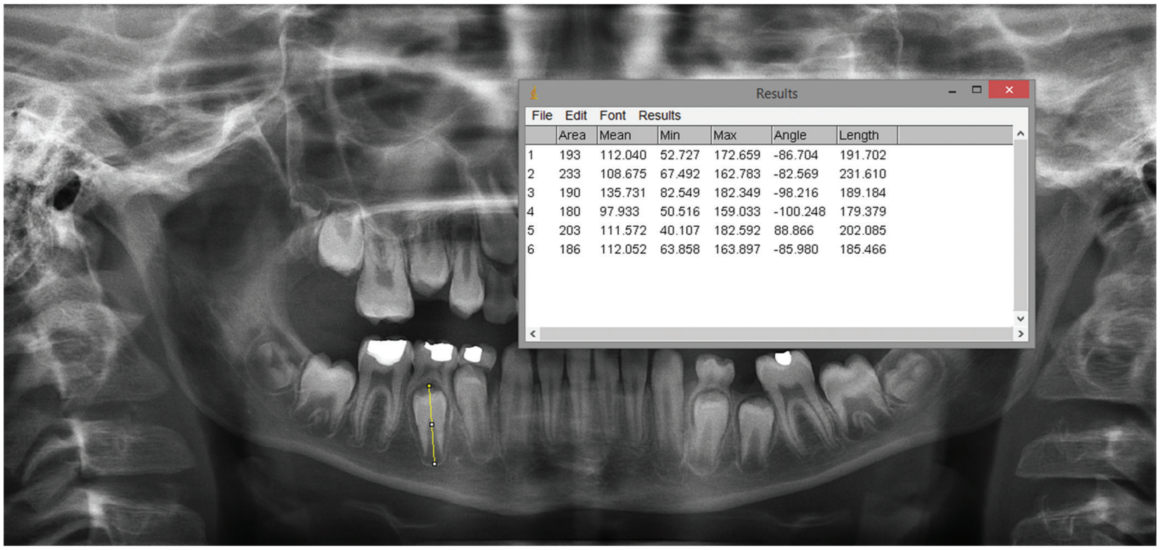

Figure 1. Measurement of the lower second premolar root length (the perpendicular distance from centre of incisal edge to root apex) and analysis of root dimension on the digitized panoramic film with ImageJ software.

group was 0.091 and the mean method error for the SME group was 0.076.

SPSS (version 15.0; SPSS, Chicago, III) was used for the statistical analyses at a significance level of 5%. Paired-samples *t*-test was used to compare the parameters at *T*0 and *T*1 for each tooth in both groups. Differences in the length values between *T*0 and *T*1 were calculated for both the RME&RHg and SME groups, and the comparison of these differences between the groups was performed with Mann–Whitney *U*-test.

Results

From the 40 patients in the RME&RHg and SME groups, the lengths of a total of 480 maxillary and 480 mandibular permanent teeth were measured for *T*0 and *T*1 with ImageJ software. ImageJ software that is based on pixel-wise calculation is frequently used for digitized biological data analysis. In this study, quantitative root length measurement was based on the number of pixels, and it was performed using standard scale settings for panoramic radiographs.

Comparison of *T*0 and *T*1 in the RME&RHg group

Table 2 shows the comparison of the mean tooth length values at *T*0 and *T*1 in the RME&RHg group. A significant increase was observed only in the right and left maxillary and mandibular second premolars and the left mandibular first premolar ($P < 0.05$). Other teeth measurements did not show any significant changes.

Comparison of *T*0 and *T*1 in the SME group

Table 3 demonstrates the comparison of the mean tooth length values at *T*0 and *T*1 in the SME group. Teeth lengths values increased significantly in all maxillary and mandibular teeth except the maxillary first molars and mandibular incisors ($P < 0.05$).

Comparison of the RME&RHg and SME groups for differences from *T*0 to *T*1

Statistically significant differences were found in the maxillary and mandibular incisors, left maxillary first premolar, and molar teeth between the RME&RHg and SME groups ($P > 0.05$). Table 4 provides the descriptive statistics for the differences from *T*0 to *T*1 between groups. The root lengths of these teeth from *T*0 to *T*1 increased more in the SME group in comparison to the RME&RHg group.

Discussion

Early orthopaedic treatment of Class III malocclusion without surgical procedures involves numerous difficulties in clinical orthodontics (18). RHg is the most effective treatment for growing patients with Class III malocclusions, and this appliance is used with a rapid palatal expander for the treatment of maxillary retrognathism and/or mandibular prognathism (19). In this treatment, an RME screw produces between 3 and 10 pounds of force in the transversal direction, while RHg appliance delivers the heavy orthopaedic traction forces to the maxilla. (5, 20, 21). Orthopaedic forces may induce root resorption formation, which is a common iatrogenic problem in orthodontics. These heavy forces may also negatively affect root development in teeth that have incomplete root formation. Although most studies provide a lot of evidence on short- and long-term effects of RME&RHg treatment (18, 19, 22, 23), studies on the effects of RME&RHg treatment on root development in younger school-age children were not found in the reviewed literature. No previous studies have investigated the effects of RME&RHg treatment on root development. This retrospective study investigated the effects of RME&RHg treatment on root development in a paediatric population. To our knowledge, this is the first study that examined the root development of the maxillary and mandibular teeth after RME&RHg treatment.

Radiographic techniques such as periapical radiographs, panoramic radiographs, and cone beam computed tomography (CBCT) are used to measure the root lengths of teeth (13, 24, 25). Recent studies have reported that CBCT provides many advantages to detect external root resorption that is induced with orthodontic treatment. On the other hand, CBCT imaging has several limitations such as relatively high radiation doses and costs (24–26). Computed tomography imaging exposes patients to significantly more ionizing radiation than conventional radiographic techniques (27). However,

Table 2. Comparison of root length values between pre- and post-treatment in the RME&RHg group.

	*T*0		*T*1		
	Mean	SD	Mean	SD	*P*-value
16	246.59	19.37	254.82	27.67	0.08
15	230.31	40.88	251.13	35.89	0.01
14	246.81	29.38	259.14	32.43	0.12
13	301.1	38.08	322.34	39.86	0.05
12	281.55	28.87	282.87	29.78	0.84
11	299	28.73	292.42	35.16	0.3
21	295.59	29.21	294.19	30.94	0.82
22	286.65	25.2	283.16	32.22	0.51
23	312.04	46.19	324.61	34.79	0.12
24	252.48	35.79	257.66	37.47	0.3
25	234.91	34.47	250.46	33.52	0.04
26	248.13	19.38	248.36	24.59	0.95
36	275.09	22.63	276.34	22.07	0.84
35	233.70	44.34	253.04	45.18	0.01
34	244.46	33.01	260.33	27.81	0.01
33	293.08	31.73	302.39	42.89	0.18
32	253.43	27.6	256.34	34.21	0.67
31	242.84	26.6	254.14	35.11	0.12
41	243.18	30.64	247.68	35.6	0.23
42	257.1	28.4	262	31.77	0.46
43	287.11	34.07	304.51	45.95	0.06
44	243.09	35.18	255.46	35.26	0.19
45	233.57	43.45	259.47	34.23	0.007
46	274.63	23.21	274.6	20.65	0.99

Mean value is the length in pixels converted to length in millimetres using the pixel size of 16.4 mm. SD, standard deviation; *T*0, pre-treatment; *T*1, post-treatment.

Table 3. Comparison of root length values between pre- and post-treatment in the SME group.

	*T*0		*T*1		
	Mean	SD	Mean	SD	*P*-value
16	247.58	15.88	255.2	24.11	0.07
15	176.29	20.39	192.98	25.48	<0.001
14	186.66	32.02	212.04	30.93	<0.001
13	237.01	30.05	257.68	32.86	<0.001
12	245.68	35.93	251.52	31.13	<0.001
11	303.71	25.95	318.39	29.	0.003
21	299.35	27.01	315.3	24.95	0.003
22	253.87	35.37	275.48	34.75	<0.001
23	238.32	33.92	258.53	34.64	<0.001
24	197.06	29.66	222.91	28.42	<0.001
25	176.48	27.97	194.22	32.29	<0.001
26	251.36	24.41	258.08	24.08	0.18
36	259.47	14.85	269.14	12.7	<0.001
35	158.89	22.79	176.63	29.17	<0.001
34	187.26	27.82	225.56	54.85	<0.001
33	230.86	28.97	253.17	30.98	<0.001
32	242.31	18.79	249.98	21.32	0.53
31	246.85	23.18	251.93	21.77	0.22
41	244.48	20.27	249.96	32.32	0.14
42	255.08	18.16	258.27	23.88	0.11
43	232.71	26.83	256.23	27.66	<0.001
44	187.39	25.51	203.46	29.48	<0.001
45	167.46	27.99	185.54	36.95	<0.001
46	261.81	15.98	276.86	16.46	<0.001

Mean value is the length in pixels converted to length in millimetres using the pixel size of 16.4 mm. SD, standard deviation; *T*0, pre-treatment; *T*1, post-treatment.

the risks associated with radiographic imaging should be considered well. The concept of 'as low as reasonably achievable' (ALARA) should be adopted in dental imaging both for the patient and the clinician (28). This is because very low doses of ionizing radiation may also produce biological harm such as cancer. However, the paediatric population has a higher sensitivity to radiation due to the greater number of cell divisions occurring in children in comparison to adults (29, 30). Additionally, it was reported that especially head CT examinations induce brain malignancies because children are more radiosensitive (31). Therefore, CBCT should not be taken routinely to investigate the effects of orthodontic treatment in younger patients.

Another radiographic imaging method, periapical radiographs are effective in the evaluation of root resorption or development (32). However, it was reported that ionizing radiation dose exposure to the patients was 82% lower with panoramic scan than with full-mouth periapical radiographs (33). In summary, the amount of ionizing radiation delivered to the patient should be taken into account while considering CBCT or full-mouth periapical imaging as an alternative to an examination with panoramic radiographs.

Panoramic radiographs are one of the routine initial diagnostic records in orthodontics, although they have potential limitations. Panoramic radiography is useful when complete assessment of all the upper and lower teeth is needed in paediatric dentistry (14).

In this study, panoramic radiographs that were taken by the same machine were used to evaluate root development and measurements by the ImageJ software. Stramotas *et al.* (34) reported that measurements of tooth length and crown–root ratio are reliable, and pathological dimensional changes in tooth morphology can be measured on panoramic radiographs. They also reported that when the occlusal plane is retained in an equal position at different times when panoramic radiographs are taken and not inclined by more than 10 degrees, linear root length measurements are reliable on these radiographs (34). Modern panoramic machines provide a standard patient position with a digital monitor and bite forks. These lead to minimization of differences in magnification of the image (34). However, this study used a calculation to predict radiographical magnification differences between pre- and post-treatment panoramic radiographs (16, 17).

A previous study reported that while the length measurements of the upper first molars' buccal roots were reproducible, the measurements of the palatal root of the maxillary first molars were unreliable (10). In this study, the mesio-buccal roots of the maxillary molars were measured because of their direct association with the buccal bone plate. However, the disto-buccal roots of the maxillary molars were not analysed because tracing these from panoramic films was difficult and unreproducible.

In this study, a total of 960 teeth (including the maxillary incisors, canines, buccal roots of first premolars, second premolars, mesio-buccal roots of first molars and mandibular incisors, canines, premolars, distal roots of first molars) were examined for assessment of root development after RME&RHg treatment.

To our knowledge, this was the first study in the literature in which measurements were performed on all maxillary and mandibular teeth for evaluating root development after RME&RHg. Thus, the results of the study are difficult to compare to those

Table 4. Differences between pre- and post-treatment and comparison of the root length between the RME&RHg and SME groups

	RME&RHg (n = 20)			SME (n = 20)			
	$T1 - T0$			$T1 - T0$			
	Mean	SD	Median	Mean	SD	Median	P-value
16	8.23	20.02	8.1	7.62	15.22	5.56	0.10
15	20.82	33.53	16	16.68	13.68	13.97	0.90
14	12.33	34.72	13.55	25.37	16.52	23.87	0.1
13	21.24	43.07	10.1	20.67	11.23	24.05	0.2
12	1.31	30.15	3.85	23.84	15.22	26.22	0.004
11	−6.36	26.77	−1.2	14.68	19.43	15.91	0.014
21	−1.39	28.2	-0.25	15.95	21.26	11.91	0.034
22	−3.49	23.71	−2.55	21.61	18.81	17.78	<0.001
23	12.57	35.07	4.5	20.21	10.5	20.94	0.35
24	5.18	21.91	9.95	25.85	14	24.11	0.001
25	15.55	31.88	14.8	17.74	11.19	18.47	0.4
26	0.22	18.04	−0.75	6.72	8.3	16.13	0.002
36	1.25	27.26	5.8	9.67	9.78	6.83	0.27
35	19.33	35.15	9.55	17.73	12.67	15.88	0.36
34	15.87	24.66	10.25	38.29	37.96	26.38	0.05
33	9.31	30.51	5.9	22.31	16.49	18.21	0.21
32	2.91	30.24	2.65	7.67	15.33	6.71	0.12
31	11.3	31.13	4.85	5.08	15.22	4.47	0.62
41	4.5	27.48	6.3	5.48	32.67	7.15	0.4
42	4.89	29.27	8.5	3.19	14.52	4.807	0.3
43	17.39	39.77	19.4	23.51	11.59	24.1	0.23
44	12.37	41.01	18.55	16.06	11.8	14.5	0.9
45	25.9	38.42	16.75	18.07	14.34	19.26	0.9
46	−0.03	24.71	1.55	15.04	10.5	14.83	0.05

Mean value is the length in pixels converted to length in millimetres using the pixel size of 16.4 mm. SD, standard deviation; $T0$, pre-treatment; $T1$, post-treatment.

obtained by previous studies, because no previous studies evaluated whether root development will be inhibited with RME&RHg treatment. However, there are numerous studies that evaluated the root resorption changes associated with RME in the literature (7, 35, 36). Martins *et al*. (35) reported that root resorption was found in all the first premolars after banded RME. Another study showed statistically significant volume loss on the roots of posterior teeth during RME treatment (36). An interesting result was found in the analysis of mandibular teeth which were not subjected to orthodontic forces in the RME&RHg group. It was found that the mandibular teeth except the mandibular second premolars and left mandibular first premolars did not show significantly increased root lengths.

In this study, the root lengths did not significantly increase from $T0$ to $T1$ in the maxillary and mandibular teeth, except for the right and left maxillary and mandibular second premolars, left mandibular, and first premolars in the RME&RHg group ($P < 0.05$, Table 2). On the contrary, the root length increased significantly in all maxillary and mandibular teeth, except the maxillary first molars and mandibular incisors in the SME group ($P < 0.05$, Table 3). The results of the comparison between the groups for differences from $T0$ to $T1$ showed statistically significant differences in the maxillary incisors, left maxillary first premolars, and first molar teeth ($P > 0.05$, Table 4). The root lengths of the maxillary teeth that were treated with heavy orthopaedic loads with RME&RHg appliances were not increased as expected. Such a result was in accordance with previous data. However, similar findings were found in non-orthodontically treated mandibular teeth. A previous study reported that root resorption was observed in nonbonded maxillary teeth after maxillary expansion (36). The thickness of the occlusal acrylic surface of RME restricts the freeway space, and this occlusal acrylic may lead to an increase in the chewing force. In this study, the increased chewing force may have caused restriction of root development of mandibular teeth in the RME&RHg group.

Zilberman *et al*. (37) reported that the disturbances in root development may occur in teeth which were traumatized from initial calcification to formation of two-thirds of dental root. The prevalence of root formation disturbances may be associated with the severity of the trauma. This may affect the further root development of the permanent teeth. The pressure to the deciduous teeth is transmitted to the developing permanent teeth. The severity of the disruption of root development depends on the amount and the direction of transmission of the heavy forces that are applied to deciduous teeth to the Hertwig's epithelial root sheaths of their permanent successors (37). However, orthodontic force can be considered a controlled trauma as the stress is transmitted to the root surface and adjacent bone (38). Trauma can lead to a deviation from the normal eruption path (ectopic eruption) or impaction of teeth (39). However, it can also cause the dilacerations of permanent teeth in the long-term period (40). Moreover long-term effects of inhibition in root formation may lead to a higher sensitivity to root resorption at the cellular level.

In this study, the mean ages of the patients were 8.9 ± 1.3 and 9.1 ± 2.2 years for the RME&RHg and SME groups, respectively. In these children, the root development process was known to continue. Based on these results, it may be stated that RME&RHg therapy inhibits root development of maxillary and mandibular teeth in the early period. The patients may need close periodic radiographic and clinical examination for root resorption because the pathological risks can occur a long time after the heavy force was applied on teeth. However, further studies should be performed to determine whether this effect on root development is reversible or irreversible. In other words, the question of whether early treatment with RME and RHg cause predisposition to root resorption during fixed orthodontic treatment should be investigated.

A potential limitation of this study is the use of two-dimensional radiographic images for root length measurement. On the other hand, ethical obligations limit dental CBCT imaging application for protection of paediatric patients from harm. Another limitation of this retrospective study is the small sample size with 40 patients due to inclusion criteria such as good quality images and a fixed treatment protocol.

Conclusions

In a younger school-age population:

1. No significant increases were observed in root length, with the exception of maxillary and mandibular second premolars and left mandibular first premolars after the RME&RHg therapy.
2. All maxillary and mandibular teeth, except mandibular incisors and maxillary first molars, showed significant root length differences in the SME group.
3. Significant root length differences from $T0$ to $T1$ were found between the groups in maxillary incisor, left maxillary first premolar, and first molar teeth.

Based on these results, we conclude that RME&RHg therapy disrupts root development in the maxillary and mandibular teeth in the early period. Inhibition of the root development in the mixed dentition may cause an increasing tendency for root resorption in the long-term. Keeping in mind previous RME&RHg treatment history of a patient as a possible risk factor for root resorption may help the clinician to prefer the relatively safe technique for the fixed orthodontic treatment and to avoid complications. However, further prospective studies are needed to evaluate whether retardation in continued root growth during RME&RHg therapy will be a part of future orthodontic root resorption in fixed orthodontic treatment.

Conflict of interest

None to declare.

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