

Effect of three different maxillary expansion appliances on root resorption

Refika Topal¹, Seher Gündüz Arslan²

¹ Sakarya University, Faculty of Dentistry, Department of Orthodontics, Sakarya, Turkey

² Dicle University, Faculty of Dentistry, Department of Orthodontics, Diyarbakır, Turkey

Received: 14 March 2022

Accepted: 17 December 2022

Correspondence:

Dr. Refika TOPAL

Sakarya University, Faculty of Dentistry,
Department of Orthodontics, Sakarya,
Turkey.

E-mail: refikatopal@hotmail.com



How to cite this article:

Topal R, Gündüz Arslan S. Effect of three different maxillary expansion appliances on root resorption. Int Dent Res 2023; 13(1):19-26.

<https://doi.org/10.5577/idr.2023.vol13.no1.4>

Abstract

Aim: The study was to examine rapid maxillary expansion (RME), semi-rapid maxillary expansion (SRME), and slow maxillary expansion (SME) compare the root resorptions occurring in the supporting upper first premolar teeth during treatment by using micro-computed tomography (micro-CT).

Methodology: Thirty individuals that required maxillary expansion and upper first premolar tooth extraction were divided into three groups consisting of 10 individuals for RME, SRME, and SME. RME group, first premolar and first molar teeth with hyrax screw were activated ¼ tour twice daily with the banded hyrax appliances. SRME group, acrylic bonded hyrax appliances were activated ¼ tour per every morning and night until the opening of the suture. Upon the opening of the suture, it was activated ¼ tour per every two days until sufficient maxillary expansion was gained. SEM group, quad helix appliances were activated per every 20 days. After 12 weeks of the retention period, the upper first premolar teeth were extracted. The teeth were scanned with Micro-CT (SkyScan 1172, Kontich, Belgium), and images were analyzed Dell Precision T5500 to determine the resorption crater volumes.

Results: In all samples, the resorption craters were concentrated on the buccal surfaces of the tooth roots. The highest resorption craters volume, the total resorption volume, was observed in the RME group, followed by the SRME group, and the least resorption crater volume was detected in the SME group.

Conclusion: Since the supporting teeth were exposed to more force on the root surfaces, the most resorption was seen in the RME group.

Keywords: Root resorption, maxillary expansion, expansion speed, palatal expansion, micro-computed tomography

Introduction

The treatment of maxillary deficiency may be classified as rapid maxillary expansion (RME), semi-rapid maxillary expansion (SRME), and slow maxillary expansion (SME) based on the activation frequency, the amount of force applied, the patient's age, and the length of treatment (1, 2). When force is applied to the teeth and to the peripheral alveolar bones supporting the teeth, maxillary expansion occurs. This orthopedic force opens the midpalatal suture connecting the two palatine bones (3). Adverse side effects may include injuries to the temporomandibular joint, cracks in the midpalatal sutures, gingival recession, bone loss, and root resorption during RME widening (2, 3). Treatment-related factors such as direction, duration, and amount of orthodontic force are considered important among the factors that may cause orthodontically-induced inflammatory root resorption (4). Root resorption has also been reported as a result of other maxillary expansion methods and has been expressed not only as RME widening but also as the loss of support to the teeth (5).

Expansion speed is the most discussed element of the quick top RME process, and many different screw-turning programs have been proposed in the literature. The banded RME method, which is the most commonly used method in the clinic, involves the rotation of the screw in the morning and evening for two quarters (6,7). SRME treatment was applied by Kılıç (8) and Iseri and Özsoy (9), who used bonded acrylic splint expansion appliances subjected to two quarter turns a day until the suture opened and three-quarter turns per week (one quarter round every two days) after sutural opening. Many quad helix appliances used in SME treatments are extended to the buccolingual size, or every 20 days with activation (0.20-0.25 mm), to subject the surrounding tissues to light and continuous forces (10, 11).

Root resorption usually arises after maxillary expansion procedures. Maxillary expansion procedures after the teeth, which support expansion appliances and prevent undesirable side effects of the root resorption evaluation method. In previous research, two-dimensional radiographic methods, histological methods, immunological biochemical analysis, scanning electron microscopy (SEM), and cone-beam computerized tomography (CBCT) have been used (12-15). These methods are insufficient to calculate the volume of small areas, such as the root resorption crater. The three-dimensional quantitative root resorption evaluation method is feasible, extremely precise, and repeatable. A new high-resolution technique, micro-computed tomography (micro-CT), is a reliable and up-to-date method that allows practitioners to view resorption craters in three dimensions and to perform volume calculations. In this method, the extraction of teeth is required (16).

In the literature, there are no studies comparing the micro-CT examination of root resorption in upper first premolars treated with RME, SRME, and SME protocols. Therefore, in our study, we evaluated the root resorption

of the maxillary first molar using the micro-CT method in cases of RME, SRME, and SME. The null hypothesis of the study was that there would be no significant differences in the volume of root resorption between treatment groups.

Materials and Methods

Ethics

This study was approved by the Ethics Committee of the Dicle University Faculty of Dentistry (approval number 2015/3-8).

Study design and patient selection

Our study group comprised 30 patients. These patients had maxillary deficiency due to unilateral or bilateral posterior crossbite and required maxillary expansion with the extraction of the upper first maxillary premolar. Patients were divided into three groups based on their need for RME, SRME, or SME treatment. In the beginning of the study, 15 patients were in the RME group, 14 patients were in the SRME group, and 13 patients were in the SME group. Over the course of the study, there were five dropouts in the RME group and three dropouts each in the SRME and SME groups. To maintain the equivalence of the sample size of the groups, 10 patients were evaluated in each group. In the RME group, there were three males and seven females (mean age 13.9 ± 1.4 years). In the SRME group, there were four males and six females (mean age 13.6 ± 1.7 years), and in the SME group, there were two males and eight females (mean age 13.4 ± 1.2 years). The results of post-hoc power analysis using G*Power (Version 3.1.9.4, Heinrich Heine, Universität Düsseldorf, Germany) showed that the presence of 10 patients in each group was sufficient for a power of 80%. Inter-examiner reliability was evaluated, and intraclass correlation coefficients (ICCs) were 0.90.

Patient Selection Criteria

1. The presence of bilateral or unilateral posterior crossbite due to maxillary deficiency
2. The presence of maxillary deficiency
3. Age between 11 and 15 years.
4. Patients had not received previous orthodontic treatment
5. Patients did not have any local or systemic diseases
6. Patients had good oral hygiene
7. The root apicals of the upper first premolar teeth were closed
8. The presence of a severe discrepancy (12 mm) in the maxillary arch (17)
9. After maxillary expansion, there was enough crowding to require the extraction of the first upper premolars.

RME treatment was carried out using banded Hyrax expansion appliances (Fig. 1). In the RME group, the first premolar and the first molar teeth were banded. During a routine clinical procedure, the expansion screw was activated by two turns per day. Bonded Hyrax expansion appliances were used for SRME. In this group, acrylic bonded Hyrax appliances were activated by two turns per day until the suture opened, and once the suture opened, Hyrax appliances were activated twice a week (Fig. 2). Quad helix slow expansion appliances were used to expand the maxilla (Fig. 3). In the SME group, the quad helix unit was activated once every 20 days. In this group, active expansion continued until the palatal cusps of the maxillary molars were in contact with the buccal cusps of the first mandibular molars. Occlusal radiographs were taken after the clinical observation of the maxillary median diastema, which was the result of expansion treatment. The same amount of expansion was reached in all patients. Stainless steel wire transpalatal arch (1.1 mm) was placed for a 12-week retention period.

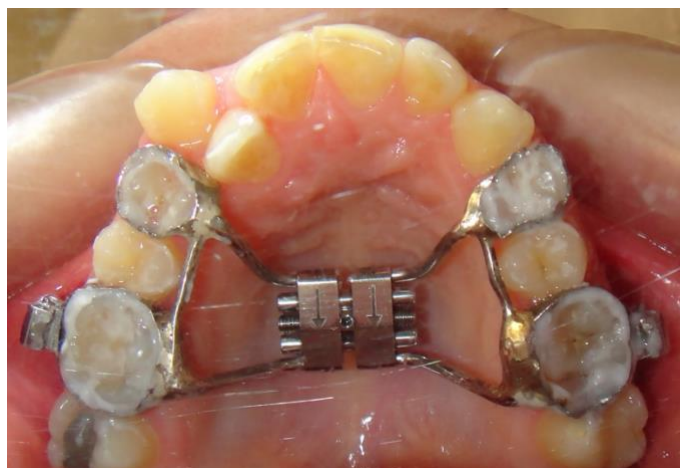


Figure 1. Rapid maxillary expansion appliance



Figure 2. Semi-rapid maxillary expansion



Figure 3. Slow maxillary expansion

To achieve skeletal expansion, the maxillary first premolars were extracted at the end of the retention phase of expansion treatment. (18) There was no need for any mandibular extraction in the study groups. At the end of 12 weeks, the upper first premolars were extracted without fixed orthodontic treatment. After the extraction, tissue and blood residue was removed with saline solution without the use of pressure. Extracted teeth were placed in 5 ml sterile tubes containing distilled water (SARSTEDT AG & Co. KG, Nümbrecht, Germany). The distilled water was renewed every two weeks.

Micro-CT analyses

Sample teeth were scanned using micro-CT (SkyScan 1172, Bruker Micro-CT, Kontich, Belgium), and a high-capacity workstation (Dell Precision T5500, Dell, Round Rock, TX, USA) was used to determine resorption crater volumes for image analysis. NRecon v. 1.6.9.4 software (SkyScan, Kontich, Belgium) was used to eliminate image impurities and radiological artifacts and to prepare for mathematical analysis. Radiological images were processed using a SkyScan DataViewer v. 1.5.2.4 (SkyScan, Kontich, Belgium) 64-bit program, and sagittal, transversal, and vertical positional errors were eliminated in all three planes of space. The resorption crater was determined using the new data series from CTAn v. 1.13.5.1 (SkyScan, Kontich, Belgium), and volume calculations of the lesion were conducted (19) (Figs. 4, 5, 6).

To check for the presence or absence of root resorption, ortopantomographs of each patient were taken before treatment. Due to ethical considerations and the “as low-as-reasonably-achievable” principle, no cone-beam CT images were taken at the beginning of the study, and no control group was used (20). In the three groups in which we performed maxillary expansion, root surfaces were classified to examine root resorption crater volumes. Different surfaces of the root were

divided into eight subgroups as follows: total buccal volume, total palatal volume, total distal volume, total mesial volume, total cervical volume, total middle volume, and total apical volume.

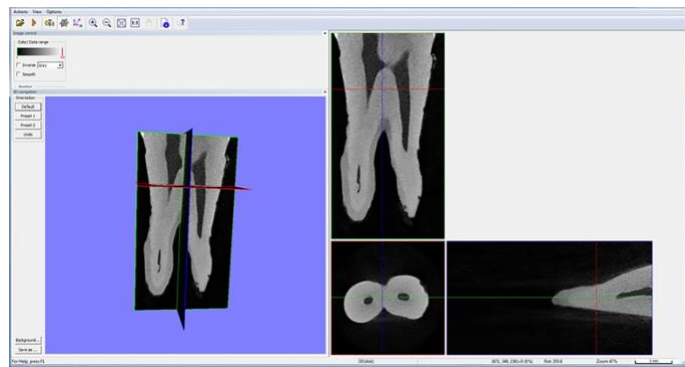


Figure 4. Micro-CT image

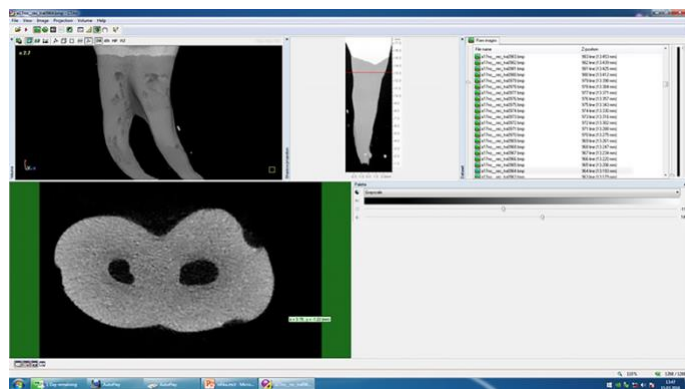


Figure 5. Root resorption image

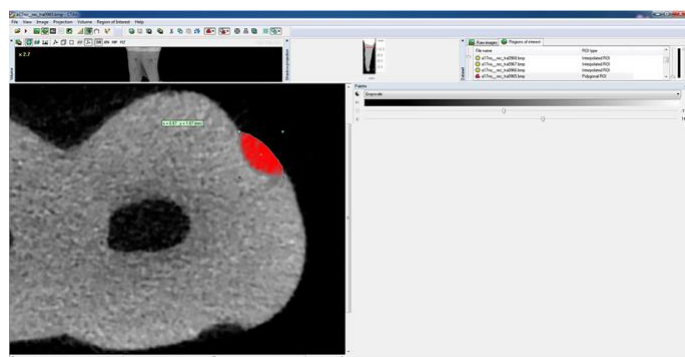


Figure 6. Root resorption crater

Statistical analysis

Analyses were performed by using SPSS software (IBM SPSS Statistics version 21, IBM Inc., Armonk, NY, USA).

In this study, the Kolmogorov-Smirnov test was used to test for normality, and the homogeneity of variables was calculated using Levene's test. A one-way analysis of variance (ANOVA) test was used to evaluate differences between the averages of independent groups, and Tukey's honestly significant difference (HSD) test was used for multiple comparisons.

Results

Mean activation in the RME group was 20 ± 5 days. The minimum expansion duration was 15 days, and the maximum was 25 days for all patients. Descriptive statistics for crater volumes in the RME group have been shown in Table 1. There was a statistically significant difference between different parts of the root ($p < 0.05$). Total buccal volume was higher than total palatal, total distal, and total mesial volumes (Table 1). In addition, measured root resorption values were mostly observed in the cervical triad of the root, the middle triad of the root, and the apical triad of the root. Total cervical and total middle triples had more resorption volume than the apical triad ($p = 0.029$; Table 2).

Descriptive statistics for crater volumes in the SRME group have been shown in Table 4. Total resorption volumes measured on root surfaces were highest on the total buccal surface. Minimum average crater volumes were observed on the total palatal surface, total mesial surface, and total distal surface (Table 1). Resorption volume on the buccal surface of the root was higher than it was on the palatal, distal, and mesial surfaces, and this difference was statistically significant ($p < 0.001$; Table 1).

In the SRME group, the resorption volume of the root was highest in the middle triad, followed by the cervical triad and the apical triad. Additionally, the total middle triad had a greater resorption volume than the apical triad ($p = 0.003$; Table 2). Descriptive statistics for crater volumes in the SME group have been shown in Table 5. The highest resorption was observed in the cervical triad of the root followed by the middle triad of the root. The least resorption was observed in the apical triad. Total volume resorption of the root in the cervical triad was higher than it was in the apical triad ($p = 0.045$; Table 2).

Root Resorption among RME, SRME, and SME groups

According to one-way ANOVA test results, there were significant between-group differences in total resorption volume (Table 3). Significance levels were $p = 0.004$ for total mesial volume and $p = 0.000$ for all other surfaces. Tukey's HSD test results have been shown in Tables 4 and 5. Total resorption crater volume in the RME group was higher than it was in the SRME group ($p = 0.031$). Total resorption volume was also higher in the RME group than that of the SRME and SME groups ($p = 0.000$).

Table 1. Findings on the comparison of the resorption volumes (mm³) measured in the RME, SRME and SME groups on the different surfaces of the root (n = 20) (Multiple Comparisons Tukey HSD)

	RME								SRME										
			P								P								
	Mean	SD	Total palatalinal volume (mm³)		Total distal volume (mm³)		Total mesial volume (mm³)		Mean	SD	Total palatalinal volume (mm³)		Total distal volume (mm³)		Total mesial volume (mm³)		Mean		
Total buccal volume(mm³)	2.2943	1.2800	0.008	**	0.001	***	0.000	***	1.6961	1.0027	0.001	***	0.000	***	0.000	***	0.3810		
Total palatalinal volume(mm³)	1.3180	0.8452				0.850	-	0.216	-	0.8614	0.5625				0.376	-	0.385	-	0.3092
Total distal volume(mm³)	1.0777	0.8416						0.665	-	0.5276	0.3266						1.000	-	0.2832
Total mesial volume(mm³)	0.7445	0.6904								0.5346	0.5282								0.1858

*: p≤0.05 **: p.0,01 ***: p≤0.001 -: p>0.05 non significant Mean: Mean SD: Standard Deviation

Table 2. Findings on the comparison of the resorption volumes (mm³) measured in different regions of the RME, SRME and SME groups in their own region (n = 20) (Multiple Comparisons Tukey HSD)

	RME						SRME						SME			
			P						P						P	
	Mean	SD	Total middle volume (mm ³)		Total apical volume (mm ³)		Mean	SD	Total middle volume (mm ³)		Total apical volume (mm ³)		Mean	SD	Total middle volume (mm ³)	
Total cervical volume(mm ³)	1.4722	1.0336	1.000	-	0.029	*	0.9640	0.6053	0.410	-	0.085	-	0.3004	0.2977	0.373	-
Total middle volume(mm ³)	1.4711	1.0000			0.029	*	1.2716	1.0776	1.0776		0.003	**	0.2058	0.1649		
Total apical volume(mm ³)	0.7288	0.5644					0.4446	0.4397	0.4397				0.1290	0.1765		

*: p≤0.05 **: p.0,01 ***: p≤0.001 -: p>0.05 non significant Mean: Mean SD: Standard Deviation

Table 3. Findings on the comparison of total crater volumes (mm³) measured on the root surfaces of RME, SRME and SME groups (ANOVA)

	RME		SRME		SME		p	
	Mean	SD	Mean	SD	Mean	SD		
Total volume (mm ³)	3.8776	1.9794	2.6765	1.5021	0.6573	0.1047	0.000	***
Total buccal volume (mm ³)	2.2943	1.2800	1.6961	1.0027	0.3810	0.3356	0.000	***
Total palatal volume (mm ³)	1.3180	0.8452	0.8614	0.5625	0.3092	0.5740	0.000	***
Total distal volume (mm ³)	1.0777	0.8416	0.5276	0.3266	0.2832	0.3131	0.000	***
Total mesial volume (mm ³)	0.7445	0.6904	0.5346	0.5282	0.1858	0.1734	0.004	**
Total cervical volume (mm ³)	1.4722	1.0336	0.9640	0.6053	0.3004	0.2977	0.000	***
Total middle volume (mm ³)	1.4711	1.0002	1.2716	1.0776	0.2058	0.3688	0.000	***
Total apical volume (mm ³)	0.7288	0.5644	0.4446	0.4397	0.1290	0.1765	0.000	***

*: $p \leq 0.05$ **: $p \leq 0.01$ ***: $p \leq 0.001$ -: $p > 0.05$ non-significant Mean: Mean SD: Standard deviation

Table 4. Findings related to the comparison of total crater volume (mm³) differences measured on the root surfaces of RME, SRME and SME groups (Multiple comparison Tukey HSD results)

	Difference between groups						Tukey HSD					
	RME-SRME		RME-SME		SRME-SME		RME-SRME		RME-SME		SRME-SME	
	Mean	SD	Mean	SD	Mean	SD	p		p		p	
Total volume (mm ³)	1.2011	0.4616	3.2203	0.4616	2.0192	0.4616	0.031	*	0.000	***	0.000	
Total buccal volume (mm ³)	0.5981	0.3031	1.9132	0.3031	1.3151	0.3031	0.128	-	0.000	***	0.000	
Total palatal volume (mm ³)	0.4566	0.1912	1.0088	0.1912	0.5522	0.1912	0.052	-	0.000	***	0.015	
Total distal volume (mm ³)	0.5501	0.1744	0.7945	0.1744	0.2444	0.1744	0.007	**	0.000	***	0.347	
Total mesial volume (mm ³)	0.1099	0.1620	0.5587	0.1620	0.3484	0.1620	0.411	-	0.003	**	0.090	

*: $p \leq 0.05$ **: $p \leq 0.01$ ***: $p \leq 0.001$ -: $p > 0.05$ non-significant Mean: Mean SD: Standard deviation

Table 5. Findings on the comparison of total crater volume (mm³) differences measured on the root surfaces of RME, SRME and SME groups (Multiple comparison Tukey HSD results)

	Difference between groups						Tukey HSD					
	RME-SRME		RME-SME		SRME-SME		RME-SRME		RME-SME		SRME-SME	
	Mean	SD	Mean	SD	Mean	SD	p		p		p	
Total cervical volume (mm ³)	0.5082	0.2253	1.1718	0.2253	0.6635	0.2253	0.071	-	0.000	***	0.013	*
Total middle volume (mm ³)	0.1995	0.2701	1.2653	0.2701	1.0658	0.2701	0.742	-	0.000	***	0.001	**
Total apical volume (mm ³)	0.2842	0.1345	0.5998	0.1345	0.3156	0.1345	0.096	-	0.000	***	0.058	-

*: $p \leq 0.05$ **: $p \leq 0.01$ ***: $p \leq 0.001$ -: $p > 0.05$ non-significant Mean: Mean SD: Standard deviation

Discussion

Previous research has compared skeletal and dentoalveolar changes arising from SME and RME conducted with a tooth support and/or tooth tissue appliances (21, 22). However, no research has investigated differences in root resorption in three dimensions among RME, SRME, and SME protocols, which are the most commonly used protocols for upper maxillary expansion. We evaluated the root resorption of support teeth using the micro-CT method, which has various benefits, including the ability to evaluate specimens in three dimensions before and after experimental treatments as well as a noninvasive three-dimensional assessment. In our study, three different appliances and procedures were preferred for maxillary expansion.

In cadaveric studies, no relationships were found between midpalatal suture maturation level and chronological age. Therefore, chronological age was not taken into account in the present study (23, 24).

In our study, resorption craters were more often observed on the buccal surfaces in the RME group compared to the other surfaces. Baysal et al. banded first premolar and first molar teeth in maxillary expansion and activated the screw by two turns per day (25). According to their cone-beam CT results, the root resorption of the first premolar and first molar teeth was higher in buccal surfaces. In our study, buccal surface resorption was statistically higher in the RME group than in the SRME and SME groups. In our opinion, the reason for this was that the residual load accumulation was higher in the RME group because the screw was activated two turns per day in the RME treatment protocol. Yildirim and Akin observed the teeth on tissue-borne RME side and more resorption on the buccal surface than on the lingual surface (16). In another study, Gönüldaş evaluated SRME and RME procedures with bonded acrylic splint appliances and researched the buccal root surface changes of supporting teeth with SEM (22). Her study found no statistically significant difference in the amount of resorption between the two groups.

In our study, the highest rate of total resorption was found in the RME group, followed by the SRME group. The lowest rate of total resorption was found in the SME group. Colak examined individuals treated with rapid and slow maxillary expansion using bonded acrylic splint appliances and researched the resorption of the first premolar teeth using micro-CT (26). Root resorption craters were concentrated on the total buccal surface of support teeth, and the amount of resorption did not differ between groups. In our opinion, the differences between our study and Colak's study derive from individual differences between participants. Dindaroğlu and Doğan used cone-beam CT to compare volumetric root resorption after RME using tooth-borne and tissue-borne appliances (27). They observed more resorption in the Hyrax expander group, but the difference was not statistically significant between the groups.

In our study, cervical, middle, and apical triad resorption volumes were higher in the RME group than in the SME group. Additionally, cervical and middle triad resorption volumes were higher in the SRME group than in the SME group. Barber and Sims applied the RME procedure with and without first premolar tooth support and evaluated the root surface using SEM analysis (12). They observed resorption areas on the cervical and middle triads of the buccal surface of supporting premolar teeth, but there were no resorption areas in non-supported teeth. Yildirim and Akin treated maxillary transverse deficiency with the use of tooth tissue-borne RME and found that more root resorption occurred in the cervical, middle, and apical thirds and on the buccal and lingual sides than with the use of bone-borne RME (16).

According to the results of our study, total resorption volume differences were the greatest between RME and SME groups, followed by differences between the SRME and SME groups. The smallest differences were between the RME and SRME groups. In our opinion, the higher rates of total resorption volume in the RME group were caused by the application of greater residual load and heavy force in that group. We believe that the total resorption volume difference between the SRME and SME groups was caused by using different appliances, expansion procedures, and expansion times. İseri et al. stated that high forces occur in different regions of the craniofacial complex with RME, and these structures vary in their resistance to stresses depending on the direction and center of the force (28). Therefore, there would be less resistance with a slower expansion procedure, and a decreased residual force would result from decreasing stress intensity. In all groups, we observed significantly high buccal surface resorption volume on the lingual surface. These findings were similar to those of previous studies (14, 29, 30).

Conclusion

The volume of root resorption craters was significantly greater in the RME group than in the SRME and SME groups. Therefore, the null hypothesis of the study was rejected. The minimum root resorption was found in the SME group. If the individual's age is suitable according to the need for maxillary expansion, we recommend using a quad helix for maxillary expansion due to the fact that it may cause minimal root resorption.

Disclosures

Ethical Approval: Ethics committee approval was received for this study from Dicle University, Faculty of Dentistry, Research Ethics Committee, Research Ethics Committee, in accordance with the World Medical Association Declaration of Helsinki, with the approval number: 2015/3-8).

Peer-review: Externally peer-reviewed.

Author Contributions: Conception - R.T.; Design - R.T., S.G.A.; Supervision - S.G.A.; Materials - R.T., S.G.A.; Data Collection and/or Processing - R.T., S.G.A.; Analysis and/or Interpretation - R.T.; Literature Review - R.T., S.G.A.; Writer -R.T.; Critical Review - R.T.

Conflict of Interest: No conflict of interest was declared by the authors.

Funding: This study was funded by the Scientific Research Projects Coordination Unit of Dicle University. Project number: DİŞ.15-018.

References

- Haas AJ. The treatment of maxillary deficiency by opening the midpalatal suture. *Angle Orthodontist* 1965;35:200-17.
- Graber TM, Vanarsdall RL, Vig KWL. *Orthodontics Current Principles and Techniques*. Fourth Edition. Mosby Elsevier 2005; 547.
- Isaacson RJ, Ingram AH. Forces produced by rapid maxillary expansion. II. Forces present during treatment, *Angle Orthodontist* 1964; 34: 261-70
- Aras B, Cheng LL, Turk T, Elekdag-Turk S, Jones AS, Darendeliler MA. Physical Properties Of Root Cementum: Part 23. Effects of 2 or 3 Weekly Reactivated Continuous Or Intermittent Orthodontic Forces On Root Resorption And Tooth Movement: A Microcomputed Tomography Study. *Am J Orthod Dentofacial Orthop* 2012;(141), e29-e37. <https://doi.org/10.1016/j.ajodo.2011.07.018>
- Lilja E, Odenrick L. Root resorption following slow maxillary expansion. *Swed Dent J Suppl* 1982;15: 123-9.
- Haas AJ. Rapid expansion of the maxillary dental arch and nasal cavity by opening the mid-palatal suture. *Angle Orthodontist* 1961; 31: 73-89.
- Ciambotti C., Ngan P., Durkee M., Kohli K., Kim H. A comparison of dental and dentoalveolar changes between rapid palatal expansion and nickel-titanium palatal expansion appliances. *Am J Orthod Dentofac Orthop* 2001; 119:11-20. <https://doi.org/10.1067/mod.2001.110167>
- Kılıç N. Study of the changes of dentofacial structures and chewing muscles in the tonocytes of semi-rapid and rapid maxillary expansion, Master Thesis, Ataturk University Health Sciences Institute (2005).
- Işeri H, Özsoy S. Semirapid maxillary expansion a study of long-term transverse effects in older adolescents and adults. *Angle Orthodontist* 2004; 74: 71-8.
- Hicks EP. Slow maxillary expansion: A clinical study of the skeletal versus dental response to low-magnitude force. *American Journal of Orthodontics* 1978; 73:121. [https://doi.org/10.1016/0002-9416\(78\)90183-5](https://doi.org/10.1016/0002-9416(78)90183-5)
- Chan E, Darendeliler MA. Physical properties of root cementum: Part 5. Volumetric analysis of root resorption craters after application of light and heavy orthodontic forces. *Am J Orthod Dentofacial Orthop* 2005; 127(2): 186-95. <https://doi.org/10.1016/j.ajodo.2003.11.026>
- Barber AF, Sims MR. Rapid maxillary expansion and external root resorption inman: a scanning electron microscope study. *American Journal of Orthodontics* 1981; 79(6); 630-52. [https://doi.org/10.1016/0002-9416\(81\)90356-0](https://doi.org/10.1016/0002-9416(81)90356-0)
- Baumrind S, Korn EL, Boyd RL. Apical root resorption in orthodontically treated adults. *Am J Orthod Dentofacial Orthop* 1996; 110:311-20. [https://doi.org/10.1016/S0889-5406\(96\)80016-3](https://doi.org/10.1016/S0889-5406(96)80016-3)
- Erverdi N, Okar I, Küçükkeles N, Arbak S. A comparison of two different rapid palatal ex-pansion techniques from the point of root resorption. *Am J Orthod Dentofacial Orthop* 1994; 106: 47-51. [https://doi.org/10.1016/S0889-5406\(94\)70020-6](https://doi.org/10.1016/S0889-5406(94)70020-6)
- Acar A, Canyurek U, Kocaaga M, Erverdi N. Continuous vs discontinuous force application and root resorption. *Angle Orthod* 1999;69:159-63.
- Yıldırım M, Akin M. Comparison of root resorption after bone-borne and tooth-borne rapid maxillary expansion evaluated with the use of microtomography. *Am J Orthod Dentofacial Orthop* 2019; 155:182-90. <https://doi.org/10.1016/j.ajodo.2018.03.021>
- Junqueira-Mendes CHZ, Mendes LM, Valerio MV, Garib D, Janson G. Treatment time of Class I malocclusion four-premolar extraction protocol, with and without crowding: A retrospective study. *Journal of the World Federation of Orthodontists* 2019;8: 159-64. <https://doi.org/10.1016/j.ejwof.2019.10.001>
- Lin L, Ahn HW, Kim SJ, Moon SC, Kim SH, Nelson G. Tooth-borne vs bone-borne rapid maxillary expanders in late adolescence. *Angle Orthod* 2015; 85:253-62. <https://doi.org/10.2319/030514-156.1>
- Küçük EB. Evaluation of Recovery of Initial Caries Lesions Treated with Different Methods by Micro-CT Analysis, Master Thesis, İnönü ve Selçuk University Health Sciences Institute (2014).
- Brooks SL. CBCT Dosimetry: Orthodontic Considerations. *Semin Orthod* 2009; 15: 14-8. <https://doi.org/10.1053/j.sodo.2008.09.002>
- Oliveira N.L, Da Silveria A.C, Kusnoto B, Viana G. Three-dimensional assessment of morphologic changes of the maxilla: a comparison of 2 kinds of palatal expanders. *Am J Orthod Dentofacial Orthop* 2004; 126: 354-62. <https://doi.org/10.1016/j.ajodo.2003.07.008>
- Gönüldas SR. Comparison of dentofacial and periodontal effects of rapid and semirapid maxillary expansion, Master Thesis, Baskent University Health Sciences Institute (2012).
- Korbmacher H, Schilling A, Püschel K, Amling M, Kahl-Nicke B. Age-dependent three-dimensional micro-computed tomography analysis of the human midpalatal suture. *J Orofac Orthop* 2007; 68:364-76. <https://doi.org/10.1007/s00056-007-0729-7>
- Knaup B, Yildizhan F, Wehrbein H. Age-related changes in the midpalatal suture. *J Orofac Orthop* 2004;65(6):467-74. <https://doi.org/10.1007/s00056-004-0415-y>
- Baysal A, Karadede Mİ, Hekimoğlu S, Ucar F, Özer T, Veli İ, Uysal T. Evaluation of root resorption following rapid maxillary expansion using cone-beam computed tomography. *Angle Orthodontist* 2012; 82: 488-94. <https://doi.org/10.2319/060411-367.1>
- Çolak C. The evaluation of root resorption after rapid and slow maxillary expansion: A Micro-CT Study. Master Thesis, Ondokuz Mayıs University Health Sciences Institute (2012).
- Dindaroğlu F, Doğan S. Evaluation and comparison of root resorption between tooth-borne and tooth-tissue borne rapid maxillary expansion appliances: a CBCT study. *Angle Orthod* 2015;86:46-52. <https://doi.org/10.2319/010515-007.1>
- Işeri H, Tekkaya AE, Öztan Ö, Bilgiç S. Biomechanical effects of rapid maxillary expansion on the craniofacial skeleton, studied by the finite element method, *European Journal of Orthodontics* 1998; 20(4): 347-56. <https://doi.org/10.1093/ejo/20.4.347>
- Weiland F. Constant versus dissipating forces in orthodontics: the effect on initial tooth movement and root resorption. *Eur J Orthod* 2003;25:338-42. <https://doi.org/10.1093/ejo/25.4.335>
- Odenrick L, Karlander EL, Pierce A, Kretschmar U. Surface resorption following two forms of rapid maxillary expansion. *Eur J Orthod* 1991;13:264-70. <https://doi.org/10.1093/ejo/13.4.264>