Original Article

Effects of symmetric and asymmetric rapid maxillary expansion treatments on pharyngeal airway and sinus volume: *A cone-beam computed tomography study*

Emire Aybuke Erdur[a]; Mucahid Yıldırım[a]; Rabia Merve Celik Karatas[b]; Mehmet Akin[c]

ABSTRACT

Objective: To evaluate pharyngeal airway and maxillary sinus volumes following symmetric rapid maxillary expansion (RME) and asymmetric rapid maxillary expansion (ARME) treatment using cone-beam computed tomography (CBCT).

Materials and Methods: The study consisted of 60 patients presenting to the orthodontics clinic with an indication that they required symmetric or asymmetric rapid maxillary expansion treatment. Individuals were included if they were aged 12–15 years and had symmetric (RME group; 14 girls, 16 boys) or asymmetric (ARME group; 16 girls, 14 boys) maxillary deficiency. Maxillary sinus volume (mm^3) and pharyngeal airway volume (upper, lower, and total; mm^3) were evaluated using CBCT records. The parameters were compared before treatment (T1) and after 3 months in retention (T2).

Results: All measurements at T2 were increased significantly compared with T1 in the RME group ($P < .05$). In the ARME group, changes in the lower pharyngeal airway and the nonaffected maxillary sinus volumes (non-affected side of maxillary sinus volumes) were not significant; however, the other measurements increased significantly from T1 to T2 ($P < .05$). Intergroup comparisons revealed that total pharyngeal airway volume and total maxillary sinus volume changes were significantly greater in the RME group.

Conclusions: Pharyngeal airway and maxillary sinus volumes increased with both RME and ARME treatment. Both were found to be effective for treating transverse maxillary deficiency. (*Angle Orthod.* 2020;90:425–431.)

KEY WORDS: Airway volume; Asymmetric rapid maxillary expansion; Cone-beam computed tomography; Rapid maxillary expansion

INTRODUCTION

Posterior crossbite is a commonly occurring malocclusion observed in the primary and early mixed dentition as unilateral or bilateral.[1] It is defined as any abnormal transverse relation between the upper and lower posterior teeth in centric occlusion.[1] Posterior crossbite could be due to dental, skeletal, and neuromuscular functional components, but the most common cause is transverse maxillary deficiency. Such a deficiency can be induced by sucking habits, certain swallowing habits, or upper airway obstruction caused by nasal allergies or adenoid tissues.[2–5]

In the treatment of bilateral posterior crossbite, symmetric rapid maxillary expansion (RME) has been commonly used to correct maxillary constriction. In the treatment of unilateral posterior crossbite, RME or asymmetric rapid maxillary expansion (ARME) have been frequently used, depending on whether the crossbite was functional or not. To distinguish between a true unilateral posterior crossbite and a functional posterior crossbite, the mandible can be observed along the closing path. In a true unilateral posterior crossbite, the unilateral crossbite relationship is seen

[a] Assistant Professor, Department of Orthodontics, Faculty of Dentistry, Necmettin Erbakan University, Konya, Turkey.

[b] Assistant Professor, Department of Orthodontics, Faculty of Dentistry, Afyonkarahisar Saglık Bilimleri University, Afyon, Turkey.

[c] Associate Professor, Department of Orthodontics, Faculty of Dentistry, Alanya Alaaddin Keykubat University, Alanya, Turkey.

Corresponding author: Dr Emire Aybuke Erdur, Department of Orthodontics, Faculty of Dentistry, Necmettin Erbakan University 42050, Konya, Turkey
(e-mail: dtaybuke@gmail.com)

Accepted: November 2019. Submitted: May 2019.
Published Online: January 14, 2020

both in centric relation and centric occlusion without a functional shift of the mandible. In the functional posterior crossbite, bilateral constriction of the maxillary arch causes occlusal interferences, leading to a functional shift of the mandible toward the crossbite side along the closing path. While functional posterior crossbite patients should be treated with RME, true unilateral posterior crossbite patients should be treated with ARME.[5–7] If true unilateral posterior crossbite is treated with RME, undesirable expansion and buccal crossbite malocclusion can occur on the nonaffected side.[6,7] The skeletal changes with RME and ARME appliances include maxillary sutural expansion, widening of the nasal cavity, and changes in the upper airway and maxillary sinus.[8–11]

Two-dimensional imaging (cephalometric radiographs), three-dimensional imaging (magnetic resonance, computed tomography [CT], cone-beam computed tomography [CBCT]), and rhinomanometry have been used in the evaluation of RME treatment and its effects on facial structures.[8–13] Because of structural superimposition and the presence of complex bony structures, it is difficult to obtain definitive, accurate results with two-dimensional imaging techniques.[8] Three-dimensional evaluation with CBCT allows quantitative airway volume measurement with many advantages compared with conventional CT, such as lower cost and lower radiation dose with minimal distortion.[5,12–17]

Some previous studies evaluated changes in the pharyngeal airway and maxillary sinus volumes (MSVs) with RME treatment, but there was no consensus among those studies.[11,17,18] No studies were found that evaluated airway changes and sinus volumes with ARME. The aim of this study was to evaluate the changes in pharyngeal airway and MSVs after RME and ARME treatment in growing patients using three-dimensional images obtained from CBCT.

MATERIALS AND METHODS

This was a retrospective study, and the images used were prescribed diagnostic records collected due to dental treatment needs. The patients had signed an informed consent form allowing the use of their data for any scientific purposes. The study was approved by the Regional Ethical Committee of Necmettin Erbakan University, Faculty of Dentistry. The sample size for the groups was calculated based on a significance level of .05 and a power of 90% to detect a clinically meaningful difference of between 833 and 1719 mm^3 ($\pm$1032 mm^3) for the difference in the nasoalveolar airway volume between the two groups. The power analysis showed that 29 patients in each group were required. The clinical meaningful value was determined according to a study by El and Palomo.[18]

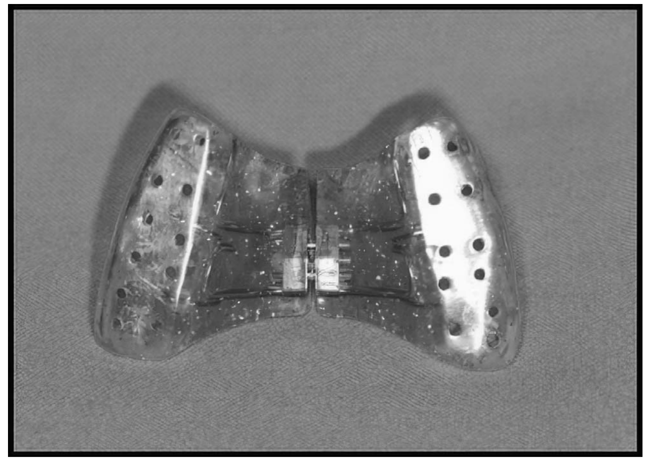

Figure 1. Rapid maxillary expansion.

Individuals, aged 12–15 years, previously treated with symmetric expansion (RME group; 14 girls, 16 boys; mean age, 14.04 years) or asymmetric expansion (ARME group; 16 girls, 14 boys; mean age, 13.75 years) were included in the study. The inclusion criteria were posterior crossbite; no previous orthodontic or orthopedic treatment; all permanent teeth up to the first molars present; no carious lesions, gingival lesions, or periodontal lesions; no previous tonsillar, nasal, adenoid, or head or neck surgery; no history of facial trauma; no systemic diseases; no craniofacial anomalies or temporomandibular joint disorders; beginning and progress CBCT scans of the treatment; and no major variation in the head or craniocervical orientation ($>5°$) between the pretreatment (T1) and postexpansion or posttreatment (T2) CBCT scans. CBCT images at pretreatment and after 3 months of retention (Kodak Model CS 9300, Carestream Health Inc, Rochester, NY) of the 60 patients were compared.

All patients in the RME group were treated with acrylic bonded appliances (Figure 1). In the ARME group, patients were treated with modified acrylic bonded appliances, which were built by adding an occlusal-lock mechanism on the nonaffected side (Figure 2). The occlusal-lock mechanism on the nonaffected side was designed so that the vestibular surface of the appliance extended to the middle third of the mandibular teeth, and the inner surface of the appliance extended along the lingual surface of the mandibular teeth vertically.[7] In both appliances, a hyrax screw (Dentaurum, Pforzheim, Germany) was placed in the acrylic plate parallel to the first molars and as close to the palate as possible. After occlusal adjustments were made, the appliances were bonded. The expansion protocol consisted of turning the screw twice every day for the first week and then turning once

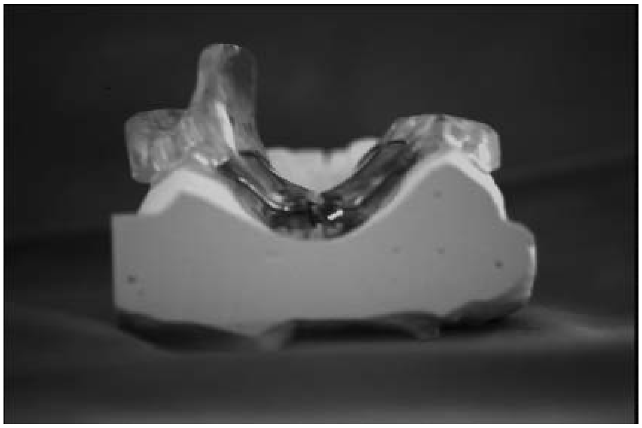

Figure 2. Asymmetric rapid maxillary expansion appliance.

a day until a slight overcorrection of the crossbite was achieved. The screw was stabilized in both groups, and the occlusal lock was removed in the ARME group during the retention period. The appliances were left in place passively for 3 months.

The CBCT scans were made at 70 kV and 8.0 mA with the following protocol: 25-cm field of view, 0.18-mm voxel size, and 6.15 seconds per section. The scans were taken with the patients in a supine position and the palatal plane perpendicular to the floor. The data obtained from CBCT images were transferred to a network computer workstation, where volumetric changes of the pharyngeal airway and maxillary sinus were measured using MIMICS Software (14.01 version, Materialise, Leuven, Belgium). All measurements were made by the same orthodontist with 10 years of experience (M.A.).

Quantitative measurement of the upper and lower pharyngeal airway volumes was determined according to the following defined borders: anterior border, the vertical plane passing through the posterior nasal spine (PNS); superior border, the roof of the pharynx; posterior border, posterior pharyngeal wall; and inferior border, horizontal plane passing from the most anterior and inferior point of the third vertebra (Figure 3). Then, the connection with the outer air was cropped slice by slice. The structures that failed to connect with the outer airway were separated, and the three-dimensional image of the pharyngeal airway was constructed and calculated in mm^3. The three-dimensional image of the pharyngeal airway was divided into upper and lower parts by a plane drawn from the PNS to the most anterior and inferior point of the first vertebra.

The MSVs of the affected and nonaffected sides for ARME and the right and left side MSVs for RME were determined. For the assessment of MSV, the coronal image was selected. The same thresholding limits were applied as in the pharyngeal airway assessment, and the sinus was cropped in the slice in which the

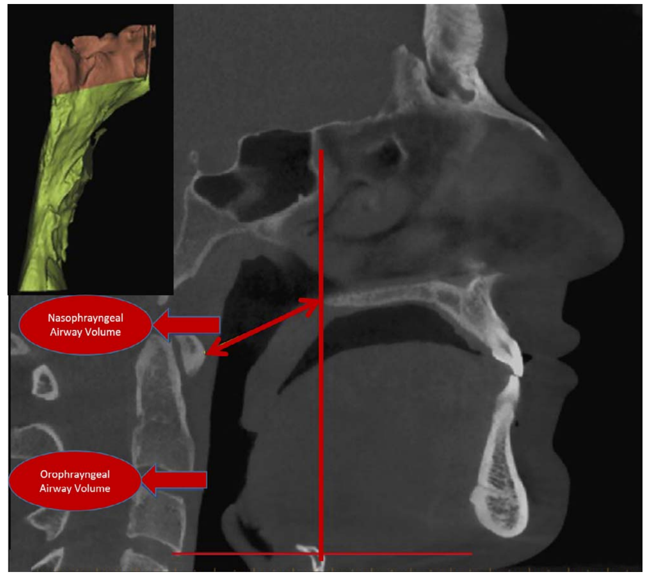

Figure 3. Pharyngeal airway volume measurement.

greatest area was apparent. Cropping was also done in the axial and sagittal views. Any connection with the outer air was eliminated, three-dimensional images of the left and right sinus were constructed, and their volumes were calculated (Figure 4).

Statistical Analysis

All statistical analyses were performed by using the Statistical Package for Social Sciences, 21.0 (SPSS for Windows, SPSS Inc, Chicago, Ill) at $P < .05$. To assess intraobserver method error, 15 randomly selected CBCT records were remeasured 3 weeks after the first measurement by the same evaluator. The intraclass correlation coefficient for the entire group of measurements was 0.996, with a 0.990 to 0.999 confidence interval, confirming the reliability and reproducibility of the measurements. In addition, measurements made in the two examinations were compared by a paired-samples *t*-test, and no significant difference was found ($P > .05$).

To compare the mean values between the affected and nonaffected sides at T1 and T2 and the treatment effect, an independent-sample *t* test and a paired-sample *t* test were used.

RESULTS

Descriptive statistics and comparisons of MSVs between the RME and ARME groups before treatment are presented in Table 1. Pretreatment, there were significant differences between the affected and nonaffected sides in MSV in the ARME group ($P < .05$). However, there was no difference between the right- and left-side MSVs in the RME group ($P > .05$).

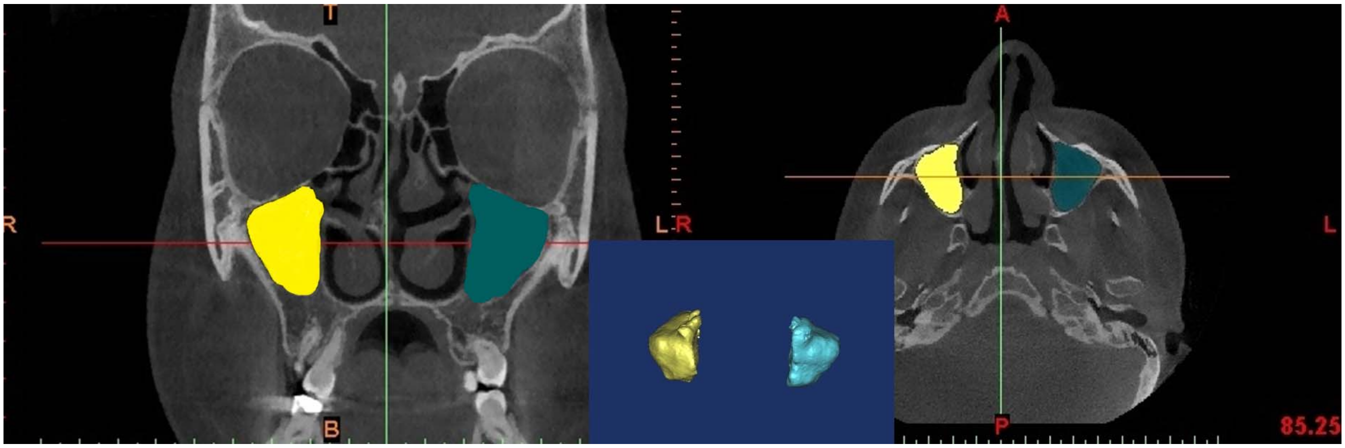

Figure 4. Maxillary sinus volume measurement.

Comparisons of the airway and MSVs before and after ARME treatment are presented in Table 2. The ARME treatment affected the upper and total pharyngeal airway volumes and the affected side and total MSVs ($P < .05$). Comparisons of the airway and MSV before and after RME treatment are presented in Table 3. All parameters except lower pharyngeal airway volume were significantly increased by RME treatment ($P < .05$).

Treatment comparisons between the ARME and RME groups of the airway and MSVs are presented in Table 4. There was a significantly greater change in upper pharyngeal airway volume and all parameters of MSV for the RME group ($P < .05$).

DISCUSSION

The aim of the study was to evaluate the changes in pharyngeal airway (upper, lower, and total; mm^3) and MSVs quantitatively via CBCT that occur with RME and ARME treatment. RME is a treatment method used to correct transverse deficiency in the maxillary arch. RME treatment also affects other structures such as the nasal cavity, maxillary sinus, and pharyngeal airways.[5,19–21] Although the effects of RME on the nasal cavity, maxillary sinus, or pharyngeal airways have been investigated in previous studies[22–24] two-dimensionally with cephalometric radiographs[25] and three-dimensionally with CBCT,[21,26,27] no previous study was found that evaluated the effects of ARME on these structures.

In the current study, a significant increase in upper and total pharyngeal airway volume after ARME and RME treatment was found, but the observed increase in the lower pharyngeal airway volume was insignificant. When ARME and RME treatment were compared, there was a significantly greater increase in upper pharyngeal airway volume in the RME group. Although many studies have been done, the effect of RME on pharyngeal airway volume is still under debate. Smith et al.[11] evaluated the pharyngeal airway volume of adolescent RME patients with CBCT. Similar to the current study, they found significant increases in nasopharyngeal airway volume after RME treatment. Conversely, Ribeiro et al.[28] used CBCT to evaluate the effect of RME treatment on nasopharyngeal dimensions. They reported that the oropharyngeal airway experienced increased volume, while the nasopharyngeal airway did not have the same effect. Zhao et al.[17] analyzed the same area with CBCT before and 15 months after RME and found no significant differences in the volume of the oropharynx and nasopharynx. Chang et al.[29] analyzed the oropharyngeal airway volume via CBCT and reported that there was no significant change in total airway volume after RME treatment. The differences between the studies might be due to the lack of standardized positioning of the

Table 1. Results of the Independent-Sample *t*-Test Used to Compare the Right and the Left Side of Maxillary Sinus Volume Before Expansion (T1)

	Asymmetric Rapid Maxillary Expansion Group					Rapid Maxillary Expansion Group				
	Affected Side		Nonaffected Side			Right Side		Left Side		
	Mean	SD	Mean	SD	*P*	Mean	SD	Mean	SD	*P*
Maxillary sinus volume, mm^3	12,425.52	3218.03	14,376.81	3891.55	.023*	13,168.73	5032.83	12,985.92	4728.92	.141

* $P < .05$ was considered to indicate statistical significance.

Table 2. Results of the Paired-Sample *t*-Test Used to Compare Expansion Volumes Before (T1) and After (T2) Asymmetric Rapid Maxillary Expansion Treatment

	T1		T2		T2–T1		
	Mean	SD	Mean	SD	Mean Difference	SD	*P*
Airway volume, mm³							
Upper pharyngeal airway	7632.67	2054.36	9362.59	2190.51	1729.92	681.72	.024*
Lower pharyngeal airway	17,635.41	5108.52	18,126.07	4894.73	490.66	274.63	.062
Total pharyngeal airway	25,268.08	6753.78	27,488.66	6836.57	2220.58	864.70	.041*
Maxillary sinus volume, mm³							
Affected maxillary sinus	12,425.52	3218.03	14,603.46	3973.58	2677.94	2082.04	.037*
Nonaffected maxillary sinus	14,376.81	3891.55	15,024.63	4079.49	647.82	312.68	.073
Total maxillary sinus	26,802.33	6081.47	29,628.09	6427.07	3325.76	2319.57	.043*

* $P < .05$ was considered to indicate statistical significance.

head and tongue, different reference points for the pharynx, and different imaging techniques.[17,29]

In the present study, the changes in MSV as the affected side for ARME, right side for RME, non-affected side for ARME, and left side for RME were also evaluated. Since there was no difference between the right and left sides in the MSV in the RME group before treatment, it was logical to believe that there would be no difference between choosing the right or left sides to compare the affected and nonaffected sides in MSV in the ARME group. In the pretreatment comparison, there were significant differences in MSV between the affected and nonaffected sides in the ARME group. The volume of the affected side was found to be significantly less than the nonaffected side. This may mean that, in the ARME group, maxillary sinus development might be decreased on the affected side. In the ARME results, MSV significantly increased only on the affected side after treatment. In the RME results, MSV significantly increased after treatment on both sides. When the ARME and RME treatment effects were compared, there were significant differences on both sides. The increase in MSV was higher on the affected side of the ARME group than the right side of the RME group, and the other parameters showed greater increases in the RME group than the ARME group. These results showed that the ARME treatment provided successful skeletal expansion on the affected side.

Darsey et al.[21] examined the MSV of RME patients via CBCT and found that MSV did not change after RME treatment. Smith et al.[11] showed that MSV was not affected by RME treatment. On the other hand, Garrett et al.[5] observed that maxillary sinus width decreased with RME treatment, which was a possible cause of decreased MSV. Pangrazio-Kulbersh et al.[30] evaluated the changes in nasopharyngeal airway and MSV after RME treatment with CBCT. Similar to the current study, they reported that MSV increased after treatment. Adkins et al.[31] stated that alveolar bending in the molar and premolar regions could cause changes in the inferior border of the sinus; in the current study, increased MSV might have been related to changes in the inferior border of the sinus.

In patients treated with ARME in this study, an occlusal-lock mechanism was used with anchorage from the mandible formed on the nonaffected side. Therefore, no significant expansion occurred on the nonaffected side. It could be assumed that the occlusal-lock mechanism caused displacement of the condyles or impaired occlusal stability. In the patients treated with ARME, the occlusal lock was removed from the appliance during the retention period. There were no temporomandibular joint complaints after treatment from the patients treated with ARME. Further

Table 3. Results of the Paired-Sample *t*-Test Used to Compare Expansion Volumes Before (T1) and After (T2) Rapid Maxillary Expansion Treatment

	T1		T2		T2–T1		
	Mean	SD	Mean	SD	Mean Difference	SD	*P*
Airway volume, mm³							
Upper pharyngeal airway	7237.16	1835.39	9580.39	2730.73	2340.23	813.06	.013*
Lower pharyngeal airway	17,453.28	4304.47	18,014.26	5284.35	565.98	186.23	.118
Total pharyngeal airway	24,690.44	6108.04	27,594.65	6891.52	2705.21	1095.40	.038*
Maxillary sinus volume, mm³							
Right maxillary sinus	13,168.73	3032.83	15,392.51	4047.62	2225.78	1562.15	.037*
Left maxillary sinus	12,985.92	4728.92	14,978.72	4115.59	1994.38	1483.47	.041*
Total maxillary sinus	26,154.65	6089.57	30,371.23	6581.73	4217.78	2568.92	.032*

* $P < .05$ was considered to indicate statistical significance.

Table 4. Results of the Paired-Sample *t*-Test Used to Compare Expansion Volumes Before (T1) and After (T2) Rapid Maxillary Expansion (RME) and Asymmetric Rapid Maxillary Expansion (ARME) Treatment

	ARME Group (T2–T1)		RME Group (T2–T1)		
	Mean Difference	SD	Mean Difference	SD	*P*
Airway volume, mm^3					
Upper pharyngeal airway	1729.92	681.72	2340.23	813.06	.032*
Lower pharyngeal airway	490.66	274.63	565.98	186.23	.212
Total pharyngeal airway	2220.58	864.70	2705.21	1095.40	.178
Maxillary sinus volume, mm^3					
Affected/right maxillary sinus	2677.94	2082.04	2225.78	1562.15	.047*
Nonaffected/left maxillary sinus	647.82	312.68	1994.38	1483.47	.008**
Total maxillary sinus	3325.76	2319.57	4217.78	2568.92	.032*

* $P < .05$ and ** $P < .01$ were considered to indicate statistical significance.

studies of the ARME appliance are needed to confirm this finding. Unfortunately, there were no previously published data evaluating pharyngeal airway and MSV in patients with true unilateral posterior crossbite. Future studies are needed to determine the effect of RME and ARME appliances on the pharyngeal airway and MSV.

CONCLUSIONS

- RME treatment was found to be effective in increasing pharyngeal airway and MSV in patients with bilateral maxillary deficiency.
- ARME treatment was found to be effective for treating true unilateral posterior crossbite and also for increasing pharyngeal airway and MSV.

REFERENCES

1. Kutin G, Hawes RR. Posterior cross-bites in the deciduous and mixed dentitions. *Am J Orthod*. 1969;56:491–504.
2. Linder-Aronson S. Adenoids. Their effect on mode of breathing and nasal airflow and their relationship to characteristics of the facial skeleton and the dentition. *Acta Otolaryngol*. 1970;265:1–132.
3. Melsen B, Steengard K, Pedersen J. Sucking habits and their influence on swallowing pattern and prevalence of malocclusion. *Eur J Orthod*. 1979;1:271–280.
4. Bresolin D, Shapiro PA, Shapiro GG, Chapko MK, Dassel S. Mouth breathing in allergic children: its relationship to dentofacial development. *Am J Orthod*. 1983;83:334–340.
5. Garrett BJ, Caruso JM, Rungcharassaeng K, Farrage JR, Kim JS, Taylor GD. Skeletal effects to the maxilla after rapid maxillary expansion assessed with cone-beam computed tomography. *Am J Orthod Dentofacial Orthop*. 2008;134:8–9.
6. Toroglu MS, Uzel E, Kayalioglu M, Uzel I. Asymmetric maxillary expansion (AMEX) appliance for treatment of true unilateral posterior crossbite. *Am J Orthod Dentofacial Orthop*. 2002;122:164–173.
7. Akin M, Baka ZM, Ileri Z, Basciftci FA. Alveolar bone changes after asymmetric rapid maxillary expansion. *Angle Orthod*. 2015;85:799–805.
8. Chung CH, Font B. Skeletal and dental changes in the sagittal, vertical, and transverse dimensions after rapid palatal expansion. *Am J Orthod Dentofacial Orthop*. 2004;126:569–575.
9. Haas AJ. Rapid expansion of the maxillary dental arch and nasal cavity by opening the mid palatal suture. *Angle Orthod*. 1961;31:73–89.
10. Starnbach H, Bayne D, Cleall J, Subtelny JD. Facioskeletal and dental changes resulting from rapid maxillary expansion. *Angle Orthod*. 1966;36:152–164.
11. Smith T, Ghoneima A, Stewart K, et al. Three-dimensional computed tomography analysis of airway volume changes after rapid maxillary expansion. *Am J Orthod Dentofacial Orthop*. 2012;141:618–626.
12. Sun Z, Smith T, Kortam S, Kim DG, Tee BC, Fields H. Effect of bone thickness on alveolar bone height measurements from cone-beam computed tomography images. *AmJ Orthod Dentofacial Orthop*. 2011;139:e117–e127.
13. Jun BC, Song SW, Park CS, Lee DH, Cho KJ, Cho JH. The analysis of maxillary sinus aeration according to aging process; volume assessment by 3-dimensional reconstruction by high resolutional CT scanning. *Otolaryngol Head Neck Surg*. 2005;132:429–434.
14. Oliveria NL, Da Silveira AC, Kusnoto B, Viana G. Three dimensional assessment of morphologic changes in the maxilla: a comparison of 2 kinds of palatal expanders. *Am J Orthod Dentofacial Orthop*. 2004;126:354–362.
15. Kau CH, Richmond S, Palomo JM, Hans MG. Three dimensional cone beam computerized tomography in orthodontics. *J Orthod*. 2005;32:282–293.
16. Kim HY, Kim MB, Dhong HJ, et al. Changes of maxillary sinus volume and bony thickness of the paranasal sinuses in longstanding pediatric chronic rhinosinusitis. *Int J Pediatr Otorhinolaryngol*. 2008;72:103–108.
17. Zhao Y, Nguyen M, Gohl E, Mah JK, Sameshima G, Enciso R. Oropharyngeal airway changes after rapid palatal expansion evaluated with cone-beam computed tomography. *Am J Orthod Dentofacial Orthop*. 2010;137:S71–S78.
18. El H, Palomo JM. Three-dimensional evaluation of upper airway following rapid maxillary expansion: a CBCT study. *Angle Orthod*. 2014;84:265–273.
19. Haralambidis A, Ari-Demirkaya A, Acar A, Küçükkeleş N, Ateş M, Ozkaya S. Morphologic changes of the nasal cavity induced by rapid maxillary expansion: a study on 3-dimensional computed tomography models. *Am J Orthod Dentofacial Orthop*. 2009;136:815–821.
20. Wertz RA. Skeletal and dental changes accompanying rapid midpalatal suture opening. *Am J Orthod*. 1970;58:41–66.

21. Darsey DM, English JD, Kau CH, Ellis RK, Akyalcin S. Does hyrax expansion therapy affect maxillary sinus volume? A cone-beam computed tomography report. *Imaging Sci Dent*. 2012;42:83–88.
22. Matsumoto MA, Itikawa CE, Valera FC, Faria G, Anselmo-Lima WT. Long-term effects of rapid maxillary expansion on nasal area and nasal airway resistance. *Am J Rhinol Allergy*. 2010;24:161–165.
23. Ceroni Compadretti G, Tasca I, Alessandri-Bonetti G, Peri S, D'Addario A. Acoustic rhinometric measurements in children undergoing rapid maxillary expansion. *Int J Pediatr Otorhinolaryngol*. 2006;70:27–34.
24. Enoki C, Valera FC, Lessa FC, Elias AM, Matsumoto MA, Anselmo-Lima WT. Effect of rapid maxillary expansion on the dimension of the nasal cavity and on nasal air resistance. *Int J Pediatr Otorhinolaryngol*. 2006;70:1225–1230.
25. da Silva Filho OG, Boas MC, Capelozza Filho L. Rapid maxillary expansion in the primary and mixed dentitions: a cephalometric evaluation. *Am J Orthod Dentofacial Orthop*. 1991;100:171–179.
26. Langer MR, Itikawa CE, Valera FC, Matsumoto MA, Anselmo-Lima WT. Does rapid maxillary expansion increase nasopharyngeal space and improve nasal airway resistance? *Int J Pediatr Otorhinolaryngol*. 2011;75:122–125.
27. Guijarro-Martínez R, Swennen GR. Cone-beam computerized tomography imaging and analysis of the upper airway: a systematic review of the literature. *Int J Oral Maxillofac Surg*. 2011;40:1227–1237.
28. Ribeiro AN, de Paiva JB, Rino-Neto J, Illipronti-Filho E, Trivino T, Fantini SM. Upper airway expansion after rapid maxillary expansion evaluated with cone beam computed tomography. *Angle Orthod*. 2012;82:458–463.
29. Chang Y, Koenig LJ, Pruszynski JE, Bradley TG, Bosio JA, Liu D. Dimensional changes of upper airway after rapid maxillary expansion: a prospective cone-beam computed tomography study. *Am J Orthod Dentofacial Orthop*. 2013;143:462–470.
30. Pangrazio-Kulbersh V, Wine P, Haughey M, Pajtas B, Kaczynski R. Cone beam computed tomography evaluation of changes in the naso-maxillary complex associated with two types of maxillary expanders. *Angle Orthod*. 2012;82:448–457.
31. Adkins MD, Nanda RS, Currier GF. Arch perimeter changes on rapid palatal expansion. *Am J Orthod Dentofacial Orthop*. 1990;97:194–199.