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Dimensional Changes of Upper Airway after Rapid Maxillary Expansion: A Prospective Cone-beam Computed Tomography Study

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Contents

Dimensional changes of upper airway after rapid maxillary expansion: A prospective cone-beam computed tomography study

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Introduction

The aim of this prospective study was to use cone-beam computed tomography to assess the dimensional changes of the upper airway in orthodontic patients with maxillary constriction treated by rapid maxillary expansion.

Methods

Fourteen orthodontic patients (mean age, 12.9 years; range, 9.7-16 years) were recruited. The patients with posterior crossbite and constricted maxilla were treated with rapid maxillary expansion as the initial part of their comprehensive orthodontic treatments. Before and after rapid maxillary expansion cone-beam computed tomography scans were taken to measure the retropalatal and retroglossal airway changes in terms of volume, and sagittal and cross-sectional areas. The transverse expansions by rapid maxillary expansion were assessed between the midlingual alveolar bone plates at the maxillary first molar and first premolar levels. The measurements of the before and after rapid maxillary expansion scans were compared by using paired *t* tests with the Bonferroni adjustment for multiple comparisons.

Results

After rapid maxillary expansion, significant and equal amounts of 4.8 mm of expansion were observed at the first molar ($P = 0.0000$) and the first premolar ($P = 0.0000$) levels. The width increase at the first premolar level (20.0%) was significantly greater than that at the first molar level (15.0%) ($P = 0.035$). As the primary outcome variable, the cross-sectional airway measured from the posterior nasal spine to basion level was the only parameter showing a significant increase of 99.4 mm^2 (59.6%) after rapid maxillary expansion ($P = 0.0004$).

Conclusions

These results confirm the findings of previous studies of the effect of rapid maxillary expansion on the maxilla. Additionally, we found that only the cross-sectional area of the upper airway at the posterior nasal spine to basion level significantly gains a moderate increase after rapid maxillary expansion.

Rapid maxillary expansion (RME) is a nonsurgical maxillary expansion technique[1] commonly used for the correction of maxillary width deficiency and posterior crossbite by increasing the width of the dental arch.[2] Angell[3] described the first clinical use of RME in 1860. Over a century, later Haas[2] reintroduced the concept of RME in a series of case reports with long-term orthopedic stability in both the anteroposterior and vertical dimensions. The RME appliances, fixed to the teeth by either bands or chemical bonding, can produce heavy forces of 15 to 50 N[4] that separate the midpalatal suture, providing orthopedic movement of the maxillary bones with minimal orthodontic tooth movement.[5]Orthopedic expansion through RME is achieved not only by opening the midpalatal suture, but also through additional buccal rotational force on the maxillary alveolar shelves.[6, 7]

Anatomically, the airway can be divided into several segments along its path (Fig 1). Evaluation of the upper airway has become an important diagnostic test in several subspecialties of dentistry,[8] in part because of the controversial[9, 10] but potential impact of high-resistance airways contributing to abnormal growth of the nasomaxillary complex, resulting in an increased vertical facial dimension in young patients.[11, 12, 13] Additionally, constricted airways are thought to play a potential role in the pathophysiology of obstructive sleep apnea.[14] Traditionally, studies on the changes of the upper airway dimensions have consisted of analyzing the posttreatment effects with 2-dimensional

(2D) cephalometric radiographs.[15] Lateral and posteroanterior cephalometric radiographs have been used to compare the dimensional changes in the maxilla and the upper airway.[16] However, the complexity of the 3-dimensional (3D) airway anatomy added to the superimposition of the bilateral structures, as well as magnification differences and difficulties in landmark identification, might have overlooked important anatomic features relevant to the airway analysis, thus questioning the accuracy of 2D representations.[8], [17] Major et al[13] found that there was at best a moderate correlation (r = 0.68) between linear measurements of the upper airway in a 2D cephalometric film and the diagnosis of upper airway blockage, suggesting that 2D cephalograms should be used only as a screening tool for airway obstruction. The available 3D techniques, including magnetic resonance imaging[18] and computed tomography(CT),[19] might depict the true morphology of the airway, but their use is limited by high radiation, high cost, and restricted accessibility.[8] Among the 3D imaging techniques, cone-beam CT (CBCT) has become an alternative technique to CT scanning for comprehensive head and neck evaluation because of its significantly lower overall effective radiation dose, greater spatial resolution than medical CT, high contrast between the hard and soft tissues, lower cost, and accessibility to dentists.[5], [8], [19]Although CBCT is not a soft-tissue imaging modality, it is possible to determine the boundaries between soft tissues and air spaces, making it a potential diagnostic method to analyze airway dimensions.[10]

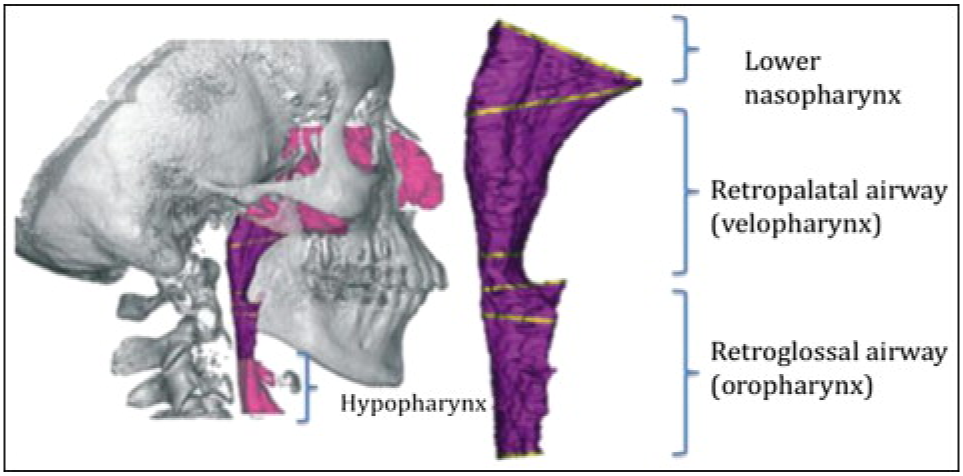


Fig 1. Schematic diagram of airway.

The purpose of this study was to use 3D images from CBCT to prospectively evaluate the changes of the upper airway dimensions and the transverse width in orthodontic patients after RME therapy.

Material and methods

Fourteen children (5 boys, 9 girls) with a mean age of 12.9 years (range, 9.7-16 years) were recruited from the Department of Developmental Sciences/Orthodontics at the School of Dentistry, Marquette University, in Milwaukee, Wis. This research was approved by the university's institutional review board. Informed consents from the patients and parents were obtained before the study. The inclusion criteria comprised young orthodontic patients (<16 years old) with unilateral or bilateral posterior crossbites, scheduled to receive RME as an initial part of their comprehensive orthodontic treatment. Exclusion criteria included craniofacial anomalies, previous orthodontic treatments, and systemic diseases. All patients were treated with a hyrax type of maxillary expander banded to the maxillary first premolars and first molars. The activation protocol consisted of 1 activation (90° turn) of the jackscrew per day for 28 consecutive days or until resolution of the posterior crossbite. Clinical observation of 2 to 3 mm of overexpansion marked the termination of expansion; the beginning of the retention phase consisted of tying off the jackscrew with a ligature wire and placing composite material over it. No additional orthodontic treatment was initiated in both jaws until after the retention phase started. The initial CBCT scan was taken 0 to 14 days before cementation of the maxillary expander, and the progress CBCT scan was taken 3 to 4 months after completion of active maxillary expansion to allow new bone to fill in the space at the midpalatal suture and the skeletal expansion to become stable.[20]

All CBCT scans were taken by a certified radiologist (L.J.K.) at the radiology department at Marquette University, using a Scanora 3D device (Soredex, Tuusula, Finland) under an extended field of view mode (14.5 × 13.0 cm). The overall effective radiation dose was 125 µSv, with a 0.35-mm voxel size, a total scanning time of 20 seconds, and an effective radiation time of 4.5 seconds. The patients sat upright with the chin supported on an adjustable platform and the Frankfort horizontal plane parallel to the floor while the rotating source detector captured a volumetric image of the patient's head. Immediately before scanning, all patients were instructed to keep their teeth in contact throughout the scanning process. These images were reconstructed and imported as digital imaging and communications in medicine (DICOM) data files into Dolphin imaging software (version 11.0; Dolphin Imaging & Management Solutions, Chatsworth, Calif) for observation and analysis.

All CBCT images were oriented so that in the frontal view the skeletal midline (nasion to anterior nasal spine) was perpendicular to the floor, and in the axial view the midsagittal line (middle point between the maxillary incisors to posterior nasal spine) was perpendicular to the floor (Fig 2). In patients with asymmetry, the orientation was made as close as possible to these guidelines. Once the image was properly oriented, the software was able to create a 2D simulated lateral cephalometric image at the midsagittal plane. From this view, the airway analysis tool was used to define the airway of interest. Because the nasal cavity contains multiple connecting air cavities, turbinates, and rarefactions, a clear segmentation was not possible, and it was excluded from our measurements.

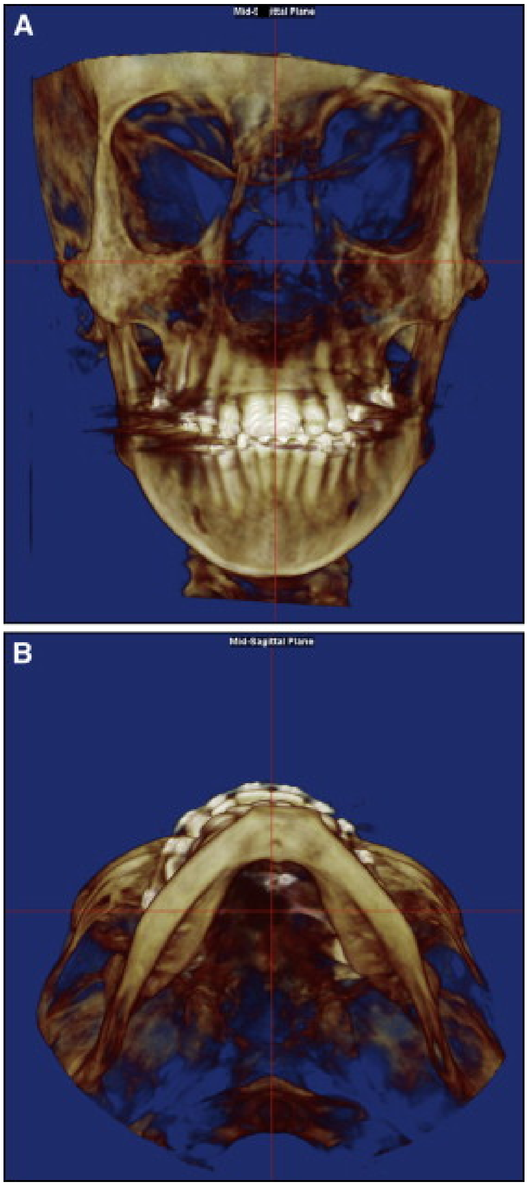


Fig 2. **A,** Skeletal midline orientation from front view; **B,** midsagittal line orientation from axial view.

The upper airway (Fig 3, *A*) was defined as the airway volume between the 2 planes as follows: the superior plane, arbitrarily called the “P plane,” was defined on the midsagittal image as the horizontal line connecting the posterior nasal spine to basion (because these anatomic points were closest to the upper airway and clearly shown on the sagittal plane of the CBCT image), and the inferior plane, arbitrarily called the “EP plane,” was defined as the horizontal line passing through the most superior point of the epiglottis. The upper airway was divided into 2 segments to further evaluate the specific effects of RME. The upper segment or retropalatal airway (Fig 3, *B*) was limited superiorly by the P plane and inferiorly by a horizontal plane crossing the most posteroinferior point of the soft palate, arbitrarily called the “SP plane.”[10], [21] To increase the accuracy of the airway measurements, once the posterior nasal spine and basion points were selected in the midsagittal view, the P plane was reoriented so that it became parallel to the floor, and subsequent planes (SP and EP) were traced parallel to the P plane. The inferior segment or the retroglossal airway (Fig 3, *C*) was limited superiorly by the SP plane and inferiorly by the EP plane.[21] Once each airway had been demarcated, the Dolphin software allowed the selection of the airway by defining a threshold range of CT units that characterized all air spaces of the head and neck regions. We arbitrarily standardized the threshold range to 60 units (0-200 units were available) after observing consecutively that this unit provided the most comprehensive airway selection without adding or leaving out upper airway space, with the exception of 2 patients whose threshold range was decreased to 50 units. Because the air space has a lower CT value than the more dense surrounding soft tissue, it was possible to produce a clean segmentation of the airway.[16] By using the sinus/airway analysis option, boundary position, seed point, and update volume option, airway volumes for the upper, retropalatal, retroglossal, and minimal cross-sectional airways (Fig 3, *D*), and cross-sectional area for the P plane (Fig 4, *A*), SP plane, and EP plane (Fig 4, *B*) were obtained.

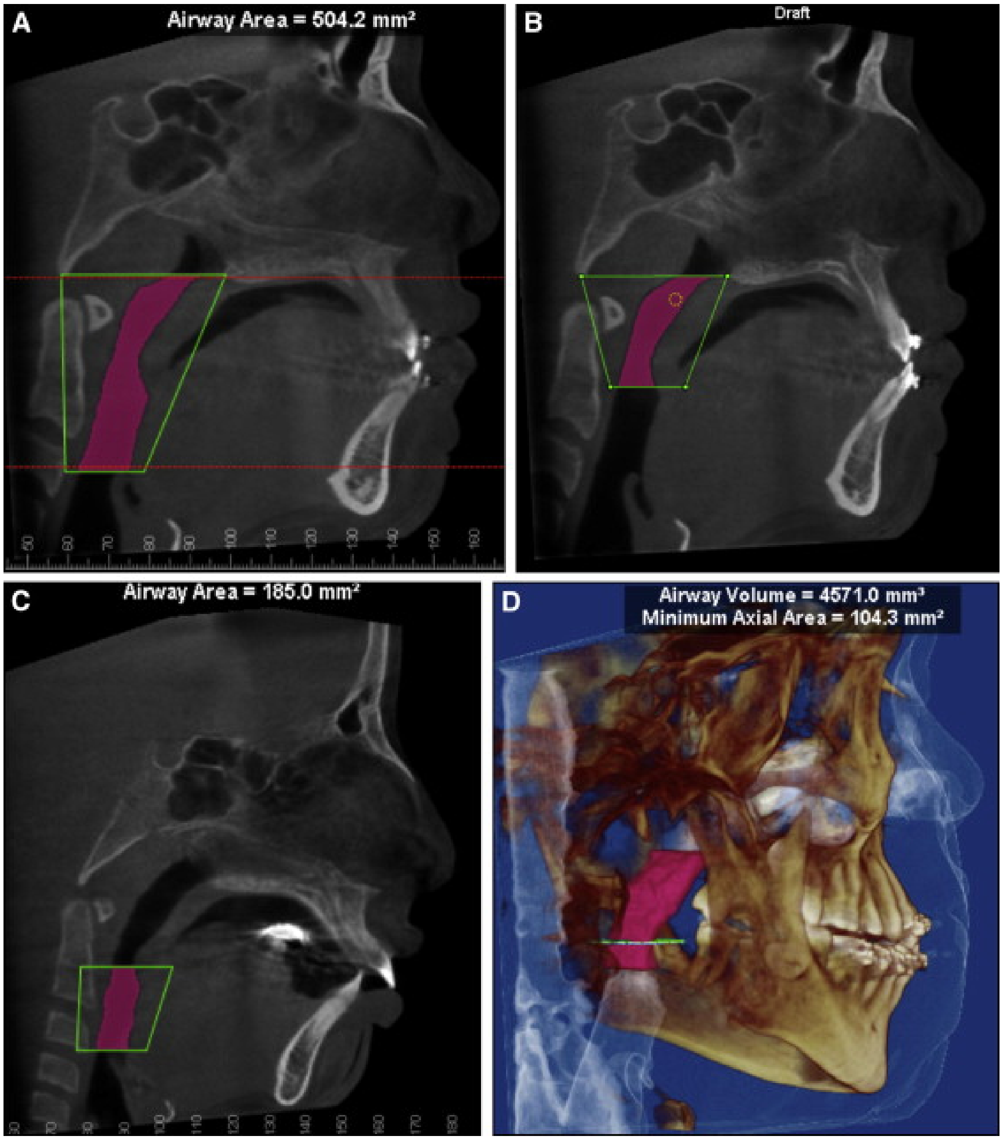


Fig 3. Segmentations of the airway: **A,** total upper airway; **B,** retropalatal airway; **C,** retroglossal airway; **D,** minimal cross sectional airway.

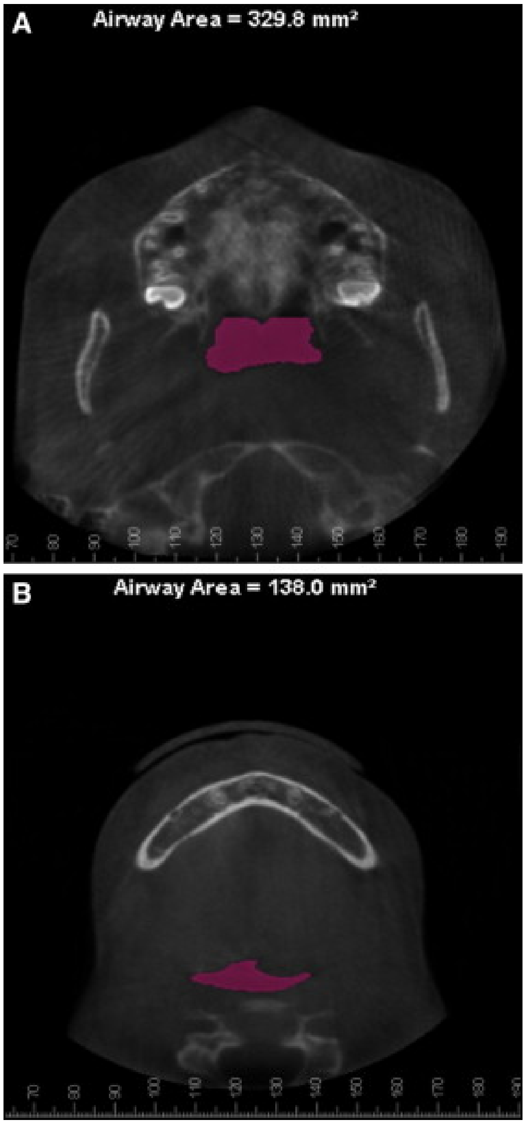


Fig 4. **A,** P plane cross-sectional airway; **B,** EP plane cross-sectional airway.

To evaluate the effect of the RME appliance on the transverse dimension, midlingual alveolar bone points were first located from the axial view for each of the maxillary first premolars and first molars, and their interbony widths were measured from the coronal view to enhance visibility and accuracy (Fig 5). This step was performed with the digitize/measure option. All measurements were made by an author (Y.C.) who was trained and calibrated to identify 3D landmarks on the axial, sagittal, and coronal planes by the certified radiologist (L.J.K.).

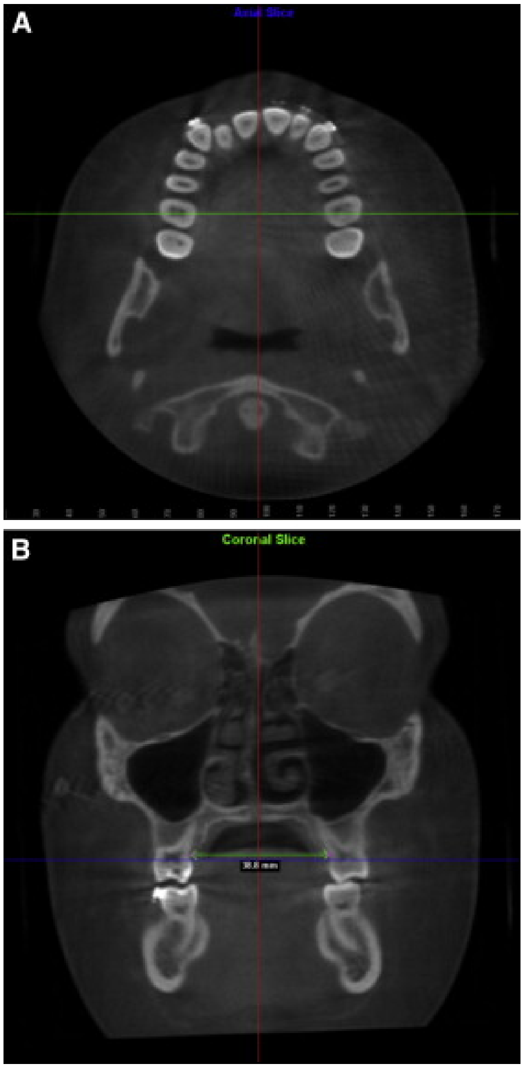


Fig 5. **A,** Location of the midlingual alveolar plates at the maxillary first molars from the axial view; **B,** location of the midlingual plates at the maxillary first molar level from the coronal view.

Statistical analysis

Since the data were normally distributed, before and after RME dimensions (volumetric, sagittal, and cross-sectional) were compared by using the paired *t* test. Bonferroni adjustments were used to adjust for multiple comparisons. To improve accuracy, all measurements were repeated 3 times, 1 week apart, and the means were used for the comparisons. Intraexaminer reliability coefficients were calculated for 3 randomly selected parameters by using the Shrout-Fleiss reliability statistic. All analyses were based on a significance level of 0.05.

Results

The intraexaminer reliability coefficients for the randomly selected parameters were 0.995 for the sagittal area, 0.853 for the P plane cross-sectional area, and 0.982 for the first intermolar linear measurement. All measurements were considered to be reliable, since the reliability statistics were close to 1, which indicates perfect reliability. The CBCT scans after RME were taken an average of 105 days (range, 90-133 days) after the retention phase started. There was an average of 158 days (range, 119-211 days) between the first and second scans.

Table I shows the measurements of all variables in the 14 patients.

Table I. Measurements of all variables in the patients in this study

Patient	**Time**	**6-6 (mm)**	**4-4 (mm)**	**Retropalatal airway**					**Retroglossal airway**			**Total airway**	
				P plane (mm^2)	**SP plane (mm^2)**	**Volume (mm^3)**	**Sagittal area (mm^2)**	**MCA (mm^2)**	**EP plane (mm^2)**	**Volume (mm^3)**	**Sagittal area (mm^2)**	**Volume (mm^3)**	**Sagittal area (mm^2)**
1	T1	27.37	22.13	286.70	138.00	6006.10	247.63	138.37	128.37	5705.87	247.50	11711.97	495.13
	T2	33.10	26.67	449.000	286.33	13069.47	386.23	360.67	552.57	13988.80	434.67	27058.27	820.90
2	T1	36.17	27.40	119.27	153.93	5539.33	303.83	119.63	337.70	7405.97	316.87	12945.30	620.70
	T2	41.90	34.50	206.97	124.37	4717.17	263.80	104.30	293.13	5303.80	244.50	10020.97	508.30
3	T1	33.20	25.23	158.90	74.93	3531.13	179.33	71.50	65.80	2027.87	147.70	5559.00	327.03
	T2	36.60	29.00	313.47	78.47	4453.40	215.40	71.00	293.13	5567.57	292.90	10020.97	508.30
4	T1	30.63	25.23	281.40	100.10	9497.43	365.27	134.83	144.67	4372.63	252.53	13870.07	617.80
	T2	34.27	27.47	444.60	237.80	11089.90	367.80	293.33	367.77	9554.07	375.83	20643.97	743.63
5	T1	29.50	23.33	241.00	145.10	9461.07	402.57	224.70	316.60	6757.57	290.20	16218.63	692.77
	T2	34.97	28.97	273.90	142.97	10015.73	402.90	86.30	207.10	4023.80	206.43	14039.53	609.33
6	T1	30.83	22.60	161.80	98.63	3549.90	260.23	85.07	216.37	3526.70	205.27	7076.60	465.50
	T2	37.50	29.57	166.07	109.20	4181.33	258.07	101.93	239.00	4209.23	236.80	8390.57	494.87
7	T1	32.30	23.60	258.80	309.97	9911.33	425.40	262.67	261.70	5092.73	233.90	15004.07	659.30
	T2	35.40	26.47	367.27	96.40	5671.50	318.33	127.70	119.33	2775.27	192.07	8446.77	510.40

Patient	Time	6-6 (mm)	4-4 (mm)	Retropalatal airway					Retroglossal airway			Total airway	
				P plane (mm^2)	SP plane (mm^2)	Volume (mm^3)	Sagittal area (mm^2)	MCA (mm^2)	EP plane (mm^2)	Volume (mm^3)	Sagittal area (mm^2)	Volume (mm^3)	Sagittal area (mm^2)
8	T1	31.32	21.83	77.23	77.20	3559.60	184.57	80.87	188.27	3526.47	190.63	7086.07	375.20
	T2	32.27	24.70	299.03	101.20	5100.23	213.17	103.47	259.20	4069.63	198.43	9169.87	411.60
9	T1	32.23	26.33	123.73	209.67	3983.60	184.00	113.93	230.13	8831.33	334.00	12814.93	518.00
	T2	38.93	32.50	142.33	201.50	3261.93	119.10	111.67	169.73	4816.10	186.53	8078.03	305.63
10	T1	30.77	22.50	422.23	260.63	12143.63	457.90	461.57	367.20	6707.60	274.93	18851.23	732.83
	T2	35.37	26.77	374.47	270.27	11003.70	445.37	303.47	196.43	4911.60	215.83	15915.30	661.20
11	T1	34.00	25.20	290.90	69.70	4869.73	216.17	102.93	103.97	3125.30	179.90	7995.03	396.07
	T2	39.40	29.57	325.70	36.27	4194.73	160.23	53.03	121.47	2747.80	129.73	6942.53	289.97
12	T1	27.47	18.53	364.00	219.17	8797.27	329.60	234.93	356.40	4246.33	223.30	13043.60	552.90
	T2	33.07	23.37	507.10	148.73	9984.70	314.13	195.17	246.93	3409.10	163.17	13393.80	477.30
13	T1	37.10	25.70	183.83	142.20	3872.03	239.83	137.07	204.03	3524.97	206.47	7397.00	446.30
	T2	40.57	30.50	321.70	256.87	8936.63	309.83	255.80	351.43	7470.87	209.20	16407.50	519.03
14	T1	33.83	26.43	233.03	130.40	3756.57	295.43	121.23	117.00	3383.10	286.43	7139.67	581.87
	T2	39.97	33.00	403.37	201.17	9615.63	497.97	179.80	196.93	2860.50	197.30	12476.13	695.27

6-6, Maxillary first molar level; *4-4*, maxillary first premolar level; *T1*, initial CBCT scan; *T2*, progress CBCT scan; *MCA*, minimal cross-sectional airway.

As shown in Table II, the transverse expansions (after RME − before RME) measured between the midlingual aspects of the maxillary first molars and first premolars were equal at 4.8 mm. The average increase ([after/before RME] −1) × 100% at the first premolar level (20.0%) was greater than that at the first molar level (15.0%) (*P* = 0.035).

Table II. Comparison of the changes of the distances between bilateral maxillary first premolars and between first molars before (*T1*) and after (*T2*) RME (n = 14)

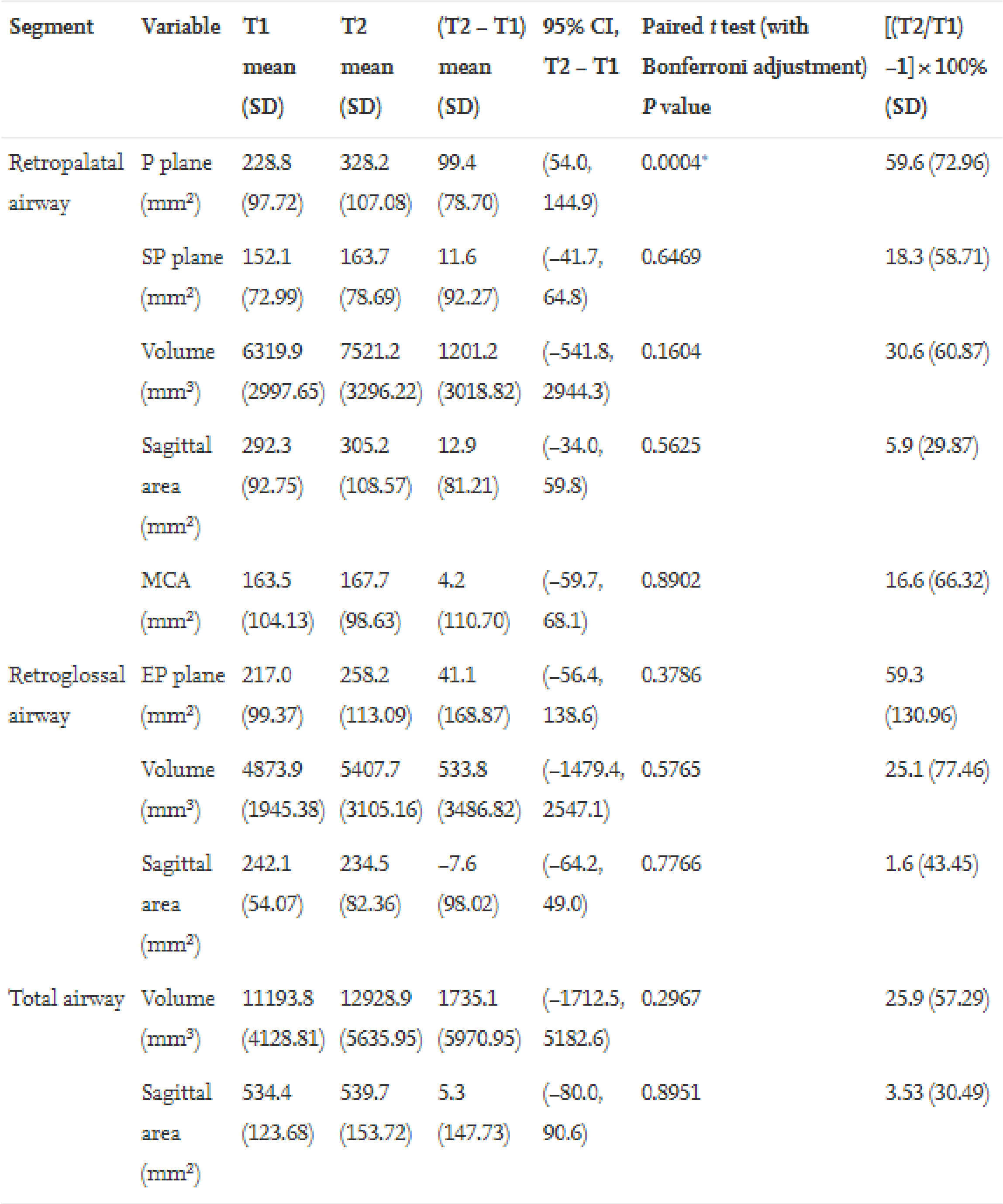
Measurement (mm)	**T1 mean (SD)**	**T2 mean (SD)**	**(T2 − T1) mean (SD)**	**95% CI, T2 − T1**	**Paired *t* test *P* value**	**[(T2/T1) −1] × 100%* (SD)**
Transverse width						
Between first molars	31.9 (2.75)	36.7 (3.09)	4.8 (1.64)	(3.8, 5.7)	0.0000	15.0 (5.56)
Between first premolars	24.0 (2.37)	28.8 (3.16)	4.8 (1.55)	(3.9, 5.7)	0.0000	20.0 (6.27)

The *P* values of the paired *t* test gave the significance of the expansion between T1 and T2, at the first molar level (*P* = 0.0000) and the first premolar level (*P* = 0.0000).

∗ Statistically significant difference of the expansions between the first molars and the first premolars (*P* = 0.035).

The dimensions of the various designated segments of airway before and after RME are listed in Table III. Since 10 paired *t* tests were reported in this table, the Bonferroni adjustment was used to control the type I error rate. No significant changes were found for the midsagittal areas and volumes for the oropharyngeal airway and its segments before and after RME. The P plane cross-sectional area (measured from posterior nasal spine to basion) increased by 99.4 mm^2 (59.6%) on average, and it was the only airway parameter that showed a statistical significance (*P* = 0.0004). The minimal cross-sectional airway was mostly found in the retropalatal airway and increased on average by 4.2 mm^2 (16.6%).

Table III. Comparison of the dimensional changes of various designated segments of the airway before (*T1*) and after (*T2*) RME (n = 14)



Segment	Variable	T1 mean (SD)	T2 mean (SD)	(T2 – T1) mean (SD)	95% CI, T2 – T1	Paired *t* test (with Bonferroni adjustment) *P* value	[(T2/T1) –1] × 100% (SD)
Retropalatal airway	P plane (mm^2)	228.8 (97.72)	328.2 (107.08)	99.4 (78.70)	(54.0, 144.9)	0.0004*	59.6 (72.96)
	SP plane (mm^2)	152.1 (72.99)	163.7 (78.69)	11.6 (92.27)	(–41.7, 64.8)	0.6469	18.3 (58.71)
	Volume (mm^3)	6319.9 (2997.65)	7521.2 (3296.22)	1201.2 (3018.82)	(–541.8, 2944.3)	0.1604	30.6 (60.87)
	Sagittal area (mm^2)	292.3 (92.75)	305.2 (108.57)	12.9 (81.21)	(–34.0, 59.8)	0.5625	5.9 (29.87)
	MCA (mm^2)	163.5 (104.13)	167.7 (98.63)	4.2 (110.70)	(–59.7, 68.1)	0.8902	16.6 (66.32)
Retroglossal airway	EP plane (mm^2)	217.0 (99.37)	258.2 (113.09)	41.1 (168.87)	(–56.4, 138.6)	0.3786	59.3 (130.96)
	Volume (mm^3)	4873.9 (1945.38)	5407.7 (3105.16)	533.8 (3486.82)	(–1479.4, 2547.1)	0.5765	25.1 (77.46)
	Sagittal area (mm^2)	242.1 (54.07)	234.5 (82.36)	–7.6 (98.02)	(–64.2, 49.0)	0.7766	1.6 (43.45)
Total airway	Volume (mm^3)	11193.8 (4128.81)	12928.9 (5635.95)	1735.1 (5970.95)	(–1712.5, 5182.6)	0.2967	25.9 (57.29)
	Sagittal area (mm^2)	534.4 (123.68)	539.7 (153.72)	5.3 (147.73)	(–80.0, 90.6)	0.8951	3.53 (30.49)

MCA, Minimal cross-sectional airway.

*

Only the cross-sectional area of the retropalatal airway at the level of the posterior nasal spine to basion showed a statistically significant difference between T1 and T2 (*P* = 0.0004).

Discussion

Several craniofacial abnormalities, including retrognathic mandible, shorter anteroposterior face length, reduced distance from the posterior nasal spine to the posterior pharyngeal wall, lower position of the hyoid bone, larger soft palate, smaller pharynx, larger tongue, obesity, and combinations of these have been recognized as part of the pathophysiology of obstructive sleep apnea.[22] It is hypothesized that these abnormalities predispose a person to obstructive sleep apnea by the constricting effect on the upper airway dimensions. Maxillary constriction in particular has been postulated to play a role in the pathophysiology of obstructive sleep apnea because of its association with low tongue posture that might contribute to narrowing of the oropharynx airway.11, 12 Pirelli et al[23] grouped 31 children with obstructive sleep apnea and followed them up to 4 months after RME treatment. All children had their apnea-hypoapnea index values decreased while their mean maxillary cross-sectional widths expanded to about 4.5 mm. Although no breathing test was performed in our study, a modest numeric increase of the minimal cross-sectional airway was observed that could explain the breathing improvement in the previous study.[23]Enoki et al[24] evaluated the effect of RME on the nasal cavity in 29 children and compared acoustic rhinometric and computed rhinomanometric values before, immediately after, and 90 days after RME. Their results showed no significant difference for the minimal cross-sectional airway at the levels of the nasal valve and the inferior turbinate with the acoustic rhinometric evaluation. Nevertheless, despite the absence of minimal cross-sectional airway changes, the computed rhinomanometry found a progressive decrease in the inspiration and expiration resistances, reaching statistical difference from before and 90 days after RME, indicating that the benefits of RME might be a modest functional improvement based on bony expansion rather than a mucosal dimensional change. Our findings indicated not only bony expansion after RME, but also a significant cross-sectional area increase immediately posterior to the hard palate. We believe that the effect of RME on the upper airway is local and diminishes farther down the airway, possibly as a result of soft-tissue adaptation. In other words, the farther from the maxillary suture, the less the effect on the upper airway.

Studies in airway imaging have emphasized that airway dimensions can change with the phase of respiration.[25] Studies with functional 3D CT techniques have shown the variability of the airway dimension behind the tongue at the 10-second scan interval and also demonstrated the changes after a mandibular advancementdevice is placed in the mouth. Interestingly, the effect of the mandibular advancement device on the airway occurred more laterally than anteroposteriorly, increasing the cross-sectional area.[26] One limitation of our study was that the subjects were not given special instructions for breathing other than to keep their teeth in contact during the 20-second scan. During this time, both inspiration and expiration would have taken place and might have contributed differently to airway size and shape. Unfortunately, a special breathing instruction might have introduced an artificial mechanism differing from the airway observed during quiet breathing with the possibility of producing an erroneous depiction of the 3D structure. This lateral effect on the airway was also perceived in our study by the lack of change in the sagittal area measurements, suggesting that the anteroposterior effect of RME on the upper airway is not significant. To test the effect of swallowing, 1 investigator (D.L.) volunteered to have 2 consecutive CBCT scans, 1 during quiet breathing and 1 during active swallowing. Both volumetric and cross-sectional measurements were considerably different in these scans because of the blurred tongue position and the unequal soft palate position. No CBCT image in this study showed any blurriness of the tongue or soft palate; this ruled out the introduction of errors caused by tongue movement.

In our study, the amounts of transverse expansion gained between the bilateral midlingual alveolar bones at the maxillary first molar and first premolar levels were identical at 4.8 mm, reflecting high and reliable efficacy of the hyrax appliance. This finding was similar to a recent study in which an average transverse expansion of 5.09 mm between the lingual alveolar crests of the bilateral maxillary first molars was reported after rapid palatal expansion.[27]However, the percentile increase ([after/before RME] −1) × 100% at the first premolar level (average, 20.0%) was greater than that at the first molar level (average, 15.0%). This phenomenon can be explained by the fact that, although the net gains were the same (after − before RME), the smaller initial transverse dimension between the first premolars will have a greater percentage change. This agrees with previous studies in which maxillary expansion was evaluated by using axial CT[23] and CBCT.[5]

A retrospective analysis of 10 airways of adults by using CBCT images scanned while the patients were sitting upright demonstrated that the position of the minimal cross-sectional area varied but was more often located in the oropharyngeal region.[8] In a magnetic resonance imaging study in which the subjects were evaluated during both waking and sleeping, it was concluded that the smallest cross-sectional area was located in the retropalatal area in 13 of 15 subjects.[28] In our study, the minimal cross-sectional airway was almost always found in the retropalatal airway, with the exception of 3 patients who had the minimal cross-sectional airway located in the retroglossal airway. According to Tso et al,[8] the range of the minimal cross-sectional airway in healthy adults varies from 90 to 360 mm^2. In another airway study evaluating subjects with obstructive sleep apnea by using spiral CT, it was found that the average minimal cross-sectional airway for these patients was 67.1 mm^2, whereas the control subjects had a mean value of 177.8 mm^2.[29] In our study, the mean minimal cross-sectional airway before RME was 163.5 mm^2, with a range of 71.5 to 461.6 mm^2. These numbers compare favorably with the healthy population previously mentioned. Whether airway dimensions scanned during quiet breathing correlate with apneic events during sleep is still controversial. However, there is evidence that subjects with obstructive sleep apnea have smaller cross-sectional areas of the airway, implying a range in airway sizes in normal subjects, and that the cross-sectional areas of subjects with obstructive sleep apnea can be below this range.[8]

Because of the 3D nature of the scans, small tracing variations might cause significant differences in the airway measurements. The P plane orientation parallel to the floor was aimed to minimize the inherent tracing variations by ensuring that subsequent posterior nasal spine and basion point selections produced a line parallel to the floor, and its cross-sectional area could be reliably measured from the axial view. Second, the posterior nasal spine and basion points were clearly visible in the midsagittal view, and it became evident after a few trial tracings that they provided the most reliable and easily detectable points to define the superior boundary according to the method of Lenza et al.[10] The retropalatal airway inferior limit (retroglossal airway superior limit) was defined as a line parallel to the P plane contacting the most inferior aspect of the uvula or soft palate (SP plane) in reference to a previous study.[21]

Conclusions

The results of our study confirm the findings of previous studies that RME produces a significant expansion of the maxilla. Additionally, we found that only the cross-sectional area of the upper airway at the posterior nasal spine to basion level significantly gains a moderate increase after RME.

References

1 C. Ekstrom, C. Hericsson, R. Jensen

Mineralization in the midpalate suture after orthodontic expansion

Am J Orthod, 71 (1977), pp. 449-455

2 A.J. Haas

Palatal expansion: just the beginning of dentofacial orthopedics

Am J Orthod, 57 (1970), pp. 219-255

3 E.C. Angell

Treatment of irregularity of the permanent or adult teeth

Dent Cosmos, 1 (1860), pp. 540-544

4 M.O. Lagravère, P.W. Major, C. Flores-Mir

Long term skeletal changes with rapid maxillary expansion: a systematic review

Angle Orthod, 75 (2005), pp. 1046-1052

5 B.J. Garrett, J.M. Caruso, K. Rungcharassaeng, J.R. Farrage, J.S. Kim, G.D. Taylor

Skeletal effects to the maxilla after rapid maxillary expansion assessed with cone-beam computed tomography

Am J Orthod Dentofacial Orthop, 134 (2008), pp. 8.e1-8.e11

6 H. Lee, K. Ting, M. Nelson, N. Sun, S. Sung

Maxillary expansion in customized finite element method models

Am J Orthod Dentofacial Orthop, 136 (2009), pp. 367-374

7 P. Gautam, A. Valiathan, R. Adhikari

Stress and displacement patterns in the craniofacial skeleton with rapid maxillary expansion: a finite element method study

Am J Orthod Dentofacial Orthop, 132 (2007), pp. 5.e1-5.e11

8 H.H. Tso, J.S. Lee, J.C. Huang, K. Maki, D. Hatcher, A. Miller

Evaluation of the human airway using cone-beam computerized tomography

Oral Surg Oral Med Oral Pathol Oral Radiol Endod, 108 (2009), pp. 768-776

9 P.S. Vig

Nasal obstruction and facial growth: the strength of evidence for clinical assumptions

Am J Orthod Dentofacial Orthop, 113 (1998), pp. 603-611

10 M.G. Lenza, M.M. De Lenza, M. Dalstra, B. Melsen, P.M. Cattaneo

An analysis of different approaches to the assessment of upper airway morphology: a CBCT study

Orthod Craniofac Res, 13 (2010), pp. 96-105

11 J.D. Subtelny

The significance of adenoid tissue in orthodontia

Angle Orthod, 24 (1954), pp. 59-69

12 S. Linder-Aronson

Adenoids: their effect on mode of breathing and nasal airflow and their relationship to characteristics of the facial skeleton and the dentition

Acta Otolaryngol (Supp 265) (1970), pp. 1-132

13 M.P. Major, C. Flores-Mir, P.W. Major

Assessment of lateral cephalometric diagnosis of adenoid hypertrophy and posterior upper airway obstruction: a systematic review

Am J Orthod Dentofacial Orthop, 130 (2006), pp. 700-708

14 A. Johal, S.I. Patel, J.M. Battagel

The relationship between craniofacial anatomy and obstructive sleep apnea: a case controlled study

J Sleep Res, 16 (2007), pp. 319-326

15 J. Mah, D. Hatcher

Three-dimensional craniofacial imaging

Am J Orthod Dentofacial Orthop, 126 (2004), pp. 308-309

16 J.A. Haskell, J. McCrillis, B.S. Haskell, J.P. Scheetz, W.C. Scarfe, A.G. Farman

Effects of mandibular advancement device (MAD) on airway dimensions assessed with cone-beam computed tomography

Semin Orthod, 15 (2009), pp. 132-158

17 J.B. Ludlow, L.E. Davies-Ludlow, S.L. Brooks

Dosimetry of two extraoral direct digital imaging devices: NewTom cone beam CT and Orthophos plus DS panoramic unit

Dentomaxillofac Radiol, 32 (2003), pp. 229-234

18 L.F. Donnelly, V. Surdulescu, B.A. Chini, K.A. Casper, S.A. Poe, R.S. Amin

Upper airway motion depicted at cine MR imaging performed during sleep: comparison between young patients with and those without obstructive sleep apnea

Radiology, 227 (2003), pp. 239-245

19 J. Ludlow, L. Davies-Ludlow, S. Brooks, W. Howerton

Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G, and i-CAT

Dentomaxillofac Radiol, 35 (2006), pp. 219-226

20 W. Proffit

Contemporary orthodontics

(4th ed.), Mosby, St Louis (2007)

p. 286

21 Y. Zhao, M. Nguyen, E. Gohl, J.K. Mah, G. Sameshima, R. Enciso

Oropharyngeal airway changes after rapid palatal expansion evaluated with cone-beam computed tomography

Am J Orthod Dentofacial Orthop, 137 (Supp) (2010), pp. S71-S78

22 J. McCrillis, J. Haskell, B.S. Haskell, M. Brammer, D. Chenin, W. Scarfe, *et al.*

Obstructive sleep apnea and the use of cone beam computed tomography in airway imaging: a review

Semin Orthod, 15 (2009), pp. 63-69

23 P. Pirelli, M. Saponara, C. Guilleminault

Rapid maxillary expansion in children with obstructive sleep apena syndrome

Sleep, 27 (2004), pp. 761-766

24 C. Enoki, F.C. Valera, F.C. Lessa, A.M. Elias, M.A. Matsumoto, W.T. Anselma-Lima

Effects of rapid maxillary expansion on the dimension of the nasal cavity and on nasal air resistance

Int J Pediatr Otorhinolaryngol, 70 (2006), pp. 1225-1230

25 N. Bhattacharyya, S.P. Blake, M.P. Fried

Assessment of the airway in obstructive sleep apnea syndrome with 3-dimensional airway computed tomography

Otolaryngol Head Neck Surg, 123 (2000), pp. 444-449

26 S.H. Kyung, Y.C. Park, E.K. Pae

Obstructive sleep apnea patients with the oral appliance experience pharyngeal size and shape changes in three dimensions

Angle Orthod, 75 (2005), pp. 15-22

27 A. Kartalian, E. Gohl, M. Adamian, R. Enciso

Cone-beam computerized tomography evaluation of the maxillary dentoskeletal complex after rapid palatal expansion

Am J Orthod Dentofacial Orthop, 138 (2010), pp. 486-492

28 F.J. Trudo, W.B. Gefter, K.C. Welch, K.B. Gupta, G. Maislin, R.J. Schwab

State-related changes in upper airway caliber and surrounding soft tissue structures in normal subjects

Am J Respir Crit Care Med, 158 (1998), pp. 1259-1270

29 J.R. Galvin, S.A. Rooholamini, W. Stanford

Obstructive sleep apnea: diagnosis with ultrafast CT

Radiology, 171 (1989), pp. 775-778