

## Long-term effects of mini-screw–assisted rapid palatal expansion on airway:

### *A three-dimensional cone-beam computed tomography study*

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#### ABSTRACT

**Objectives:** To evaluate the long-term effects on airway in patients with mini-screw–assisted rapid palatal expansion (MARPE), rapid palatal expansion (RPE), and controls with three-dimensional cone-beam computed tomography (CBCT) analysis.

**Materials and Methods:** A total of 180 CBCTs of 60 patients were analyzed at different time points, such as pretreatment, postexpansion, and posttreatment. Patients were divided into three groups: mini-screw assisted rapid palatal expansion (MARPE), rapid palatal expansion (RPE), and controls. The nasal cavity, nasopharyngeal, oropharyngeal, and laryngopharyngeal airway volume and area were measured. Changes in total airway volume, total airway area, minimal cross-sectional area, maxillary intermolar width, external maxillary width, and palatal width were also evaluated.

**Results:** Both MARPE and RPE caused a statistically significant increase in the airway after expansion as compared with the control group, but there was no statistically significant difference in the change in airway between MARPE, RPE, and the control group at posttreatment, except for nasopharyngeal volume, which was significantly increased in the MARPE group. There was no correlation between the amount of expansion and increase in total airway volume.

**Conclusions:** There was a significant increase in total airway volume, total airway area, and minimal cross-sectional area with MARPE and RPE immediately after expansion, but at posttreatment, the changes in the MARPE and RPE groups were similar to the change in the control group. However, MARPE led to a significant long-term increase in nasopharyngeal volume. The amount of expansion did not correlate with the increase in pharyngeal airway volume. (*Angle Orthod.* 2021;91:195–205.)

**KEY WORDS:** Mini-screw–assisted rapid palatal expansion; MARPE; Rapid palatal expansion; Nasal cavity; Minimal cross-sectional area; Pharyngeal airway

#### INTRODUCTION

Posterior crossbite is a common clinical finding in patients with transverse maxillomandibular discrep-

ancies. The prevalence of posterior crossbite is estimated to be 8% to 23% of the population.<sup>1,2</sup> Thus, these patients need maxillary expansion to correct the

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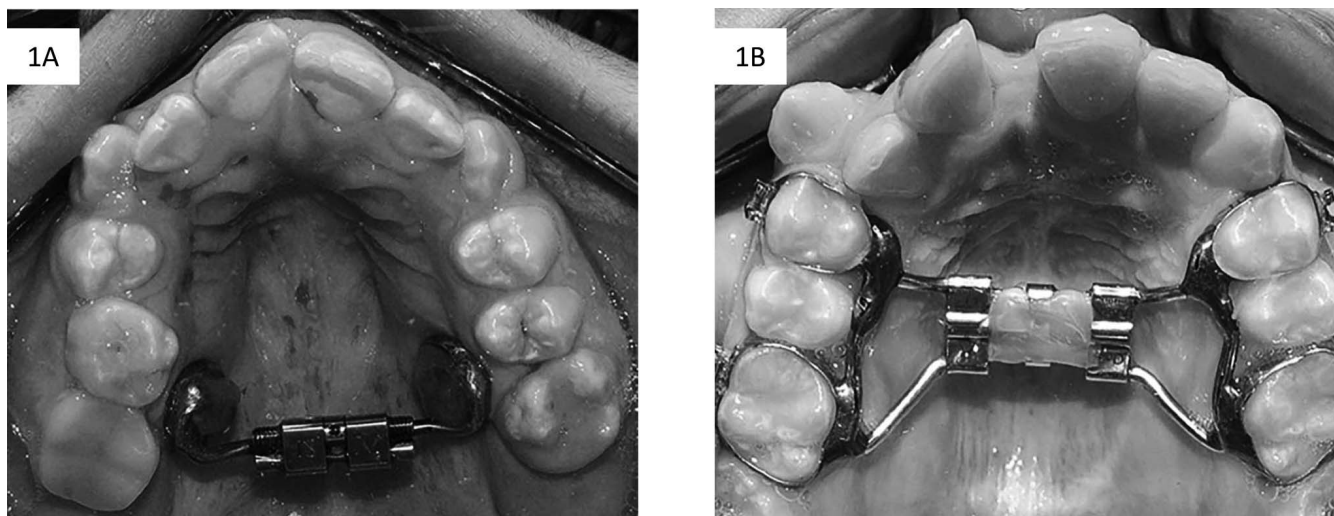
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**Figure 1.** Design of the expansion appliances. (A) MARPE appliance. (B) RPE appliance.

posterior crossbite. To resolve the transverse discrepancy, rapid palatal expansion (RPE) is often used as a treatment option.<sup>3</sup> Another approach for expansion of the maxilla is mini-screw–assisted rapid palatal expansion (MARPE).<sup>4</sup> The main difference between conventional RME and the MARPE appliance is that the MARPE appliance is anchored to the bone with temporary anchorage devices (TADs), which results in greater orthopedic expansion of the maxillary arch.<sup>5</sup>

As the expansion appliance is activated, the maxillary arch expands, which results in opening of the mid-palatal suture. The opening of the suture and expansion of the nasal floor lead to decreased nasal resistance and beneficial effects on the airway.<sup>6</sup> With both RPE and MARPE, there is a positive change in the airway immediately after expansion.<sup>7,8</sup> However, often the criticism of these studies is that the changes are observed over a short period and that long-term changes are not documented.<sup>7,9</sup> Furthermore, in many of these studies, airway changes with the expansion appliances are not compared with controls.<sup>8,9</sup> To conclusively analyze the effects of expansion appliances on airway, it is necessary to compare the effects of expansion with that of controls over a longer period of time.

Thus, the objective of this study was to compare the immediate and long-term effects on the airway in patients undergoing MARPE and RPE with a matched control group. In addition, the correlation between the airway parameters and the amount of expansion was analyzed to determine whether the amount of expansion can cause a significant change in airway area and volume.

## MATERIALS AND METHODS

This institutional review board (IRB) at the University of Connecticut granted approval for the secondary use of cone-beam computed tomography (CBCT) scans obtained from a randomized controlled trial for a retrospective analysis of the airway (project number assigned by IRB: SM 1168). All subjects in the retrospective study were treated orthodontically in the clinical setting at the University of Alberta, Edmonton, Canada. However, the patients were part of a randomized controlled trial and were randomly assigned to three groups: (1) MARPE, (2) RPE, and (3) controls. The inclusion criteria comprised patients aged 11 to 15 years with no history of prior orthodontics, temporomandibular joint disorder, adenoidectomy or tonsillectomy, and presence of a bilateral maxillary crossbite. Because of the randomization of the patients in the assigned groups, there were no significant differences in initial conditions between the three groups (Supplemental Table 1). The MARPE group had two mini-screws in the palatal region (length: 12 mm; diameter: 1.5 mm; Straumann GBR System, Andover, Mass; Figure 1A). The RPE group received a tooth-borne expansion appliance attached to the molars and premolars (Figure 1B). The expander screw was activated with two turns per day. Three time points were used to obtain the CBCT records with the same machine (iCAT Imaging Sciences International, Hartfield, Penn) and protocol (0.3 voxels, 8.9 seconds, 120 kV, and 20 mA). The first time point was the pretreatment (T1) CBCT for all three groups, and the second CBCT was recorded postexpansion (T2) for the RPE and MARPE groups. The control group had no treatment for the first 6 months, at which time the

**Table 1.** Boundaries of the Airway Measurements and Description of the Parameters

Parameter	Description
Nasal cavity boundary	Anteriorly, nasion (N), tip of nasal bone and anterior nasal spine (ANS); posteriorly, sella (S) to posterior nasal spine (PNS); superiorly, sella to nasion; inferiorly, ANS to PNS
Nasopharynx boundary	Anteriorly, PNS; posteriorly, tip of odontoid process; superiorly, sella; inferiorly, the line connecting the PNS to tip of odontoid process
Oropharynx boundary	Posteriorly, tip of odontoid process and cervical vertebrae 2 (cv2); anteriorly, PNS to the point parallel to CV2; inferiorly, the line connecting the CV2 parallel to HRF to the anterior boundary; superiorly, PNS to tip of odontoid process
Laryngopharynx boundary	Posteriorly, anteroinferior point of CV2 and cervical vertebrae 4 (CV4); anteriorly, PNS to point parallel to CV4; superiorly, the inferior border of oropharynx; inferiorly, the line joining CV4 to anterior boundary parallel to HRF
Nasal cavity volume (NCV), mm <sup>3</sup>	Volume of the airway space within the nasal cavity boundary
Nasal cavity area (NCA), mm <sup>2</sup>	Area of the airway space within the nasal cavity boundary
Nasopharyngeal volume (NPV), mm <sup>3</sup>	Volume of the airway space within the nasopharynx boundary
Nasopharyngeal area (NPA), mm <sup>2</sup>	Area of the airway space within the nasopharyngeal boundary
Oropharyngeal volume (OPV), mm <sup>3</sup>	Volume of the airway space within the oropharynx boundary
Oropharyngeal area (OPA), mm <sup>2</sup>	Area of the airway space within the oropharyngeal boundary
Laryngopharyngeal volume (LPV), mm <sup>3</sup>	Volume of the airway space within the laryngopharynx boundary
Laryngopharyngeal area (LPA), mm <sup>2</sup>	Area of the airway space within the laryngopharyngeal boundary
Total airway volume (TAV), mm <sup>3</sup>	Airway volume is the sum of nasopharyngeal volume and oropharyngeal volume
Total airway area (TAA), mm <sup>2</sup>	Sum of the nasopharyngeal area and oropharyngeal area
Minimal cross-sectional area (MCA), mm <sup>2</sup>	Dimension of the least axial cross-sectional area found in the airway of the patient
Maxillary intermolar width, mm	Width between the maxillary first molars measured at the central fossa on the coronal slice passing through the furcation of maxillary right first molar
External maxillary width, mm	Width of the line connecting the depths of concavity of the lateral wall of maxillary sinuses on the coronal slice passing through the furcation of maxillary right first molar
Palatal width, mm	Width of the line connecting the junction of the hard palate and lingual alveolar bone on the coronal slice through the furcation of maxillary right first molar

second CBCT was recorded (T2). After T2, all three groups underwent orthodontic treatment with fixed preadjusted edgewise appliances, and the third CBCT was recorded posttreatment (T3) for all three groups, which was an average of 2 years and 8 months after T1 (2 years 8 months for MARPE, 2 years 9 months for RPE, and 2 years 7 months for control). A total of 180 CBCTs were analyzed for 60 patients at three time points. Of the 180 CBCTs, 5 CBCTs were discarded due to motion artifacts. The mean age of patients in the MARPE group was  $13.69 \pm 1.74$  years (20 patients), the RPE group was  $13.9 \pm 1.14$  years (21 patients), and the control group was  $13.3 \pm 1.49$  years (19 patients).

Digital imaging and communication in medicine (DICOM) data were used to reconstruct the three-dimensional CBCT volumes with Dolphin Software (version 11.9; Dolphin Imaging and Management Solutions, Chatsworth, Calif). The orientation of the CBCTs was accomplished in a standardized manner in the Frankfort horizontal plane, the skeletal midline, and the line through the deepest part of the lateral aspect of the zygomatic bone. The airway boundaries and parameters used in the study are described in Table 1 and Figures 2, 3, and 4. All measurements were recorded by a single investigator (Dr Mehta). Twenty random CBCTs were reevaluated by the same

investigator for intraobserver reliability and another investigator (Dr Wang) for interobserver reliability.

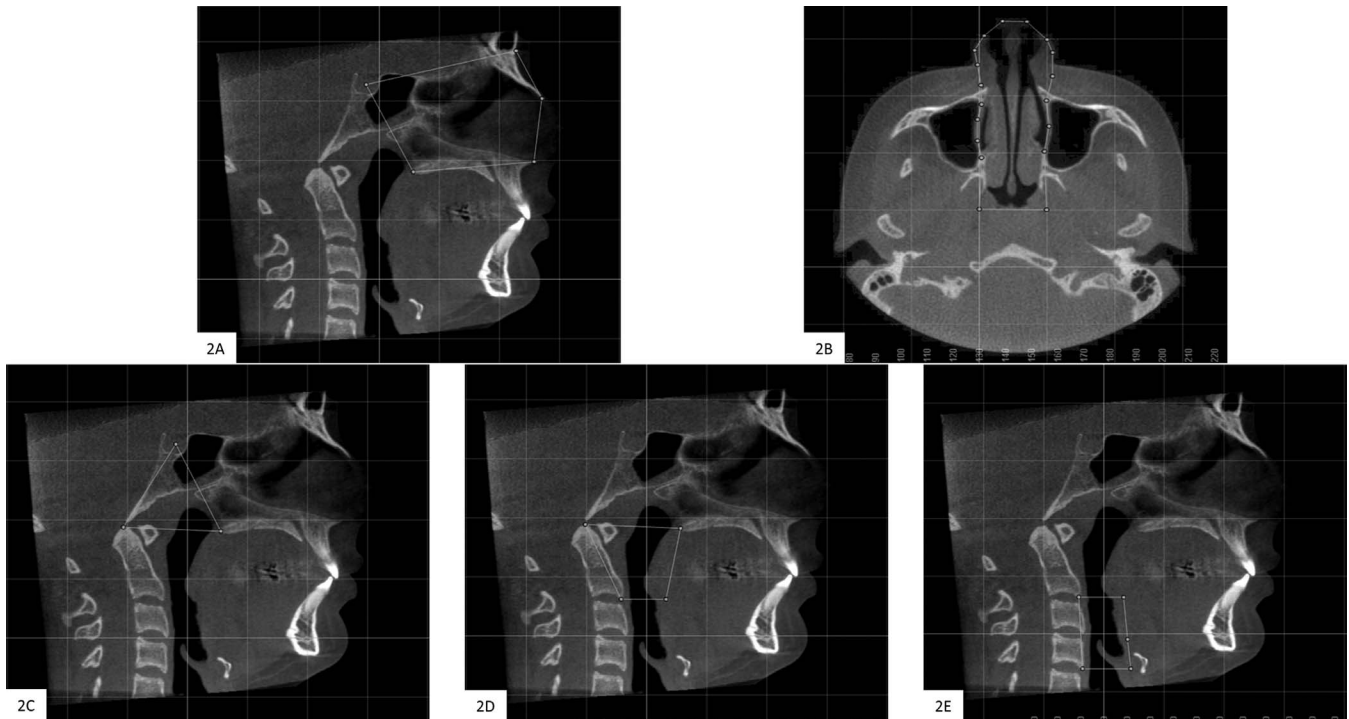
### Statistical Analysis

Analysis of variance (ANOVA) *F*-test determined that 19 samples per group would allow detection of a 0.9 standard deviation mean difference between groups in change from T1 to T3, for 80% power at the 5% significance level. The mean change from T1 to T2 or from T1 to T3 was tested against no change within groups by paired *t*-test, and the mean changes were compared among the three groups by ANOVA *F*-test. In addition, three between-group comparisons were conducted, and the *P* values were adjusted for multiple testing using the Tukey honest significant difference method. Pearson correlation coefficients, 95% confidence intervals, and *P* values were calculated for correlations between changes from T1 to T2 or from T1 to T3. All statistical analyses were performed using R version 3.5.2. *P* values less than 5% were considered statistically significant.

### RESULTS

The results of the interobserver and intraobserver reliability indicated good reliability for all parameters, with an intraclass coefficient greater than .8 (Supplemental Table 2).





**Figure 2.** Boundaries for the airway measurements. (A) Nasal cavity boundary, sagittal view. (B) Nasal cavity boundary, axial view. (C) Nasopharyngeal boundary. (D) Oropharyngeal boundary. (E) Laryngopharyngeal boundary.

### Immediate Changes From Pretreatment (T1) to Postexpansion (T2) Within the Three Groups

In the MARPE and RPE groups, a significant increase ( $P < .05$ ) was found in the nasal cavity volume (NCV; percentage of change 14.4% and 11.5% for MARPE and RPE, respectively), nasopharyngeal volume (NPV; 21.8%, 24.1%), nasopharyngeal area (NPA; 22.7%, 29.8%), oropharyngeal volume (OPV; 19.2%, 26.4%), total airway volume (TAV; 20.5%, 25.5%), total airway area (TAA; 8.1%, 16.9%), minimal cross-sectional area (MCA; 20.3%, 21.7%), maxillary intermolar width (MIW; 10.7%, 14.3%), external maxillary width (EMW; 2.8%, 3.3%), and palatal width (PW; 10.4%, 6.4%). The control group demonstrated no significant change in the parameters from T1 to T2 (Tables 2, 3, and 4).

### Long-term Changes From Pretreatment (T1) to Posttreatment (T3) Within the Three Groups

The airway parameters that experienced significant increases at T2 also had a significant increase at T3 when compared with T1 in the MARPE and RPE groups (Tables 2 and 3). In the control group, there was a significant increase at T3 when compared with T1 in the NCV (29.4%), nasal cavity area (NCA; 39.5%), NPV (35.6%), OPV (40.7%), TAV (39%), MCA (59.3%), MIW (8.6%), and PW (3.7%; Table 4).

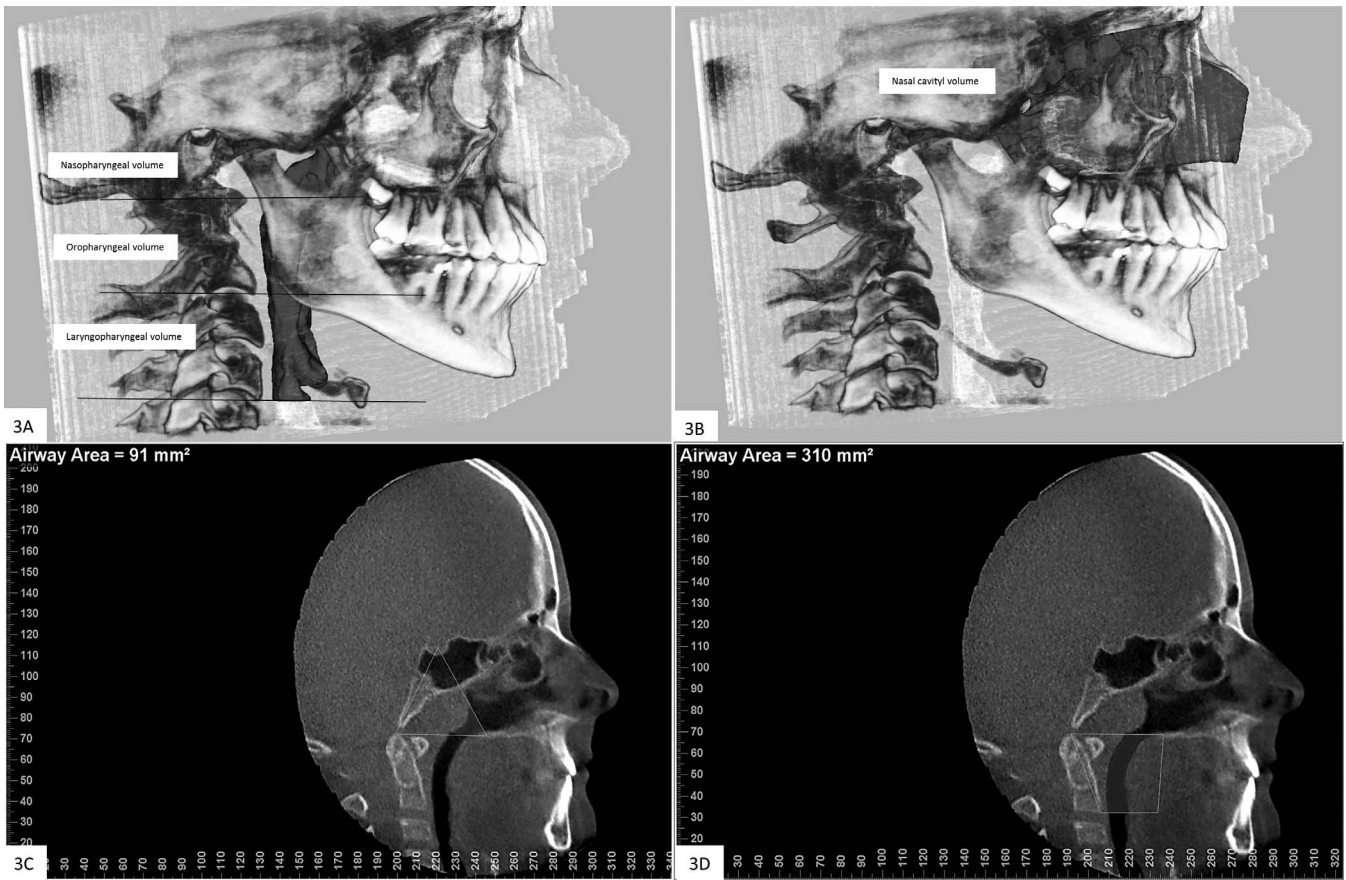
### Comparison of the Changes Between MARPE, RPE, and Control Groups

There was a significant increase in the NCV, NPV, NPA, OPV, and TAV ( $P < .05$ ) with both MARPE and RPE as compared with the control group at T2. MIW, EMW, and PW significantly increased in both the MARPE and RPE groups compared with the control group, but MIW was significantly greater in RPE than the MARPE group, and PW was significantly greater in the MARPE group compared with the RPE group ( $P < .05$ ; Table 5). The comparison of the MARPE, RPE, and control groups from T2 to T3 showed that the NCV, MIW, EMW, and PW increased significantly in controls compared with the MARPE and RPE groups (Table 6).

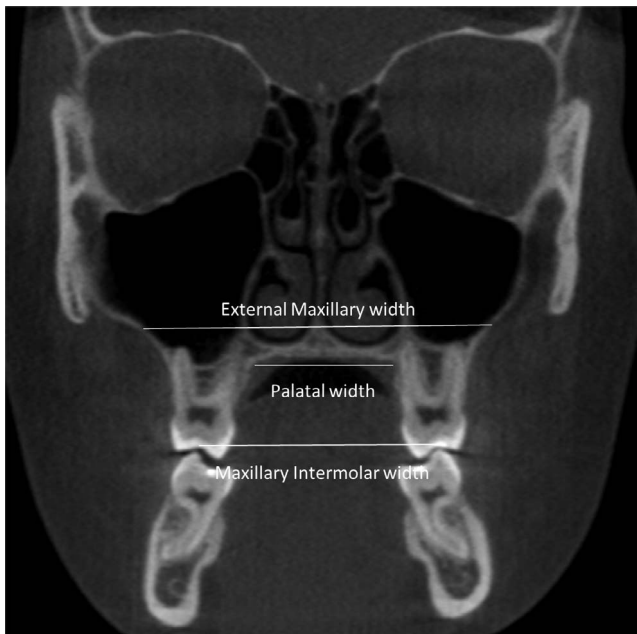
The long-term comparison from T1 to T3 of the MARPE, RPE, and control groups revealed that the NPV and PW were significantly increased in the MARPE group when compared with the RPE and control groups ( $P < .05$ ), and EMW was significantly increased in the MARPE group compared with the control group. There was no significant difference in the other parameters among the three groups at posttreatment (Table 7).

### Correlation Analysis

OPV and OPA, LPV, and LPA showed moderate to strong correlation in the MARPE and RPE groups at T2 and T3 (Supplemental Tables 3 and 4). PW showed a



**Figure 3.** Airway volume measurements. (A) Nasopharyngeal, oropharyngeal, and laryngopharyngeal volume. (B) Nasal cavity volume. (C) Nasopharyngeal area. (D) Oropharyngeal area.



**Figure 4.** Measurement of maxillary intermolar width, palatal width, and external maxillary width.

moderately strong correlation ( $r = .7$ ) with NCV at T2 for the MARPE group and NCA at T3 for the MARPE ( $r = .48$ ) and RPE groups ( $r = .51$ ). The amount of expansion of EMW and PW did not show correlations with MCA or TAV (Supplemental Table 4).

**DISCUSSION**

In this retrospective study, we assessed the long-term effects on the airway by evaluating the changes in a random sample group that was assigned RPE and MARPE for expansion and compared with the control group. Previous literature on the effects of expansion on airway focused on the immediate effects on airway after expansion but not much information is available for the long-term effects of expansion on airway.<sup>7,9</sup> To definitely ascertain whether there is any beneficial long-term effect, an additional time point for measuring the airway changes, a few years after expansion, becomes essential. Thus, the findings of this study are significant, because it was the first to directly address this subject, describing the long-term effects of RPE and MARPE on the airway in comparison with controls.

**Table 2.** Parameters for the MARPE Group, Pretreatment (T1), Postexpansion (T2), and Posttreatment (T3)<sup>a</sup>

	Mean (SD) T1	Mean (SD) T2	Mean (SD) T3	Mean (95% CI) T2–T1
Nasal cavity volume, mm <sup>3</sup>	16,204.1 (3100.53)	18,475.95 (3329.13)	20,855.37 (3083.89)	2335.74 (2026.42, 2645.05)
Nasal cavity area, mm <sup>2</sup>	958.8 (306.2)	1172.11 (309.94)	1358.42 (295.28)	207.53 (144.35, 270.71)
Nasopharyngeal volume, mm <sup>3</sup>	3412.89 (1425.84)	4158.32 (1459.81)	4771.17 (1135.28)	745.42 (673.47, 817.37)
Nasopharyngeal area, mm <sup>2</sup>	124.32 (79.6)	152.47 (77.59)	165.53 (67.67)	28.16 (23.16, 33.15)
Oropharyngeal volume, mm <sup>3</sup>	6270.35 (2617.56)	7675.74 (3047.01)	8460.37 (3541.67)	1204.89 (484.84, 1924.95)
Oropharyngeal area, mm <sup>2</sup>	378.1 (102.27)	401.63 (95.89)	394.26 (90.35)	11.79 (–10.51, 34.09)
Laryngopharyngeal volume, mm <sup>3</sup>	6662.93 (3459.65)	8361.92 (3321.25)	6923.83 (3852.16)	291.6 (–242.66, 825.86)
Laryngopharyngeal area, mm <sup>2</sup>	362.21 (120.69)	412.31 (109.81)	318 (111.58)	3.8 (–41.18, 48.78)
Total airway volume, mm <sup>3</sup>	9512.6 (3806.74)	11,834.05 (3896.53)	12,980.42 (4529.72)	1950.32 (1244.64, 2655.99)
Total airway area, mm <sup>2</sup>	496.2 (147.47)	554.11 (126.87)	570.74 (129.95)	39.95 (16.91, 62.98)
Minimal cross-sectional area, mm <sup>2</sup>	91.3 (58.47)	112.95 (71.76)	145.63 (75.23)	18.53 (1.1, 35.95)
Maxillary intermolar width, mm	42.12 (3.46)	46.55 (4.44)	47.06 (2.23)	4.51 (3.46, 5.55)
External maxillary width	62.12 (3.32)	63.93 (3.64)	63.5 (3.53)	1.73 (1.5, 1.96)
Palatal width	22.21 (2.68)	24.47 (2.76)	24.13 (2.79)	2.3 (2.01, 2.59)

<sup>a</sup> MARPE indicates mini-screw–assisted rapid palatal expansion.\* Significant at  $P < .05$ .**Table 3.** Parameters for the RPE Group, Pretreatment (T1), Postexpansion (T2), and Posttreatment (T3)<sup>a</sup>

	Mean (SD) T1	Mean (SD) T2	Mean (SD) T3	Mean (95% CI) T2–T1
Nasal cavity volume, mm <sup>3</sup>	16,803.14 (2299.46)	18,739.9 (2278.25)	21,141.05 (1935.09)	1936.76 (1705.32, 2168.21)
Nasal cavity area, mm <sup>2</sup>	998.71 (322.99)	1105.76 (333.46)	1355.32 (319.6)	107.05 (–69.6, 283.69)
Nasopharyngeal volume, mm <sup>3</sup>	3432.57 (1317.59)	4259.95 (1313.48)	4288.68 (1257.72)	827.38 (737.56, 917.21)
Nasopharyngeal area, mm <sup>2</sup>	123.19 (66.06)	159.95 (69.23)	157.42 (74.83)	36.76 (25.58, 47.94)
Oropharyngeal volume, mm <sup>3</sup>	5628.48 (1726.06)	7114.05 (2350.36)	7922.26 (3477.49)	1485.57 (800.67, 2170.47)
Oropharyngeal area, mm <sup>2</sup>	337.14 (73.28)	378 (85.71)	377.95 (113.93)	40.86 (16.72, 64.99)
Laryngopharyngeal volume, mm <sup>3</sup>	7135.92 (2356.81)	7701.43 (2925.87)	6256.89 (1937.39)	268.73 (–250.14, 787.6)
Laryngopharyngeal area, mm <sup>2</sup>	366.62 (79.61)	372.21 (104.33)	332.44 (110.7)	5.36 (–43.28, 54.01)
Total airway volume, mm <sup>3</sup>	9061.05 (2536.29)	11,374 (2813.49)	12,210.95 (3411.57)	2312.95 (1620.1, 3005.81)
Total airway area, mm <sup>2</sup>	460.33 (111.97)	537.95 (120.6)	535.37 (137)	77.62 (47.2, 108.04)
Minimal cross-sectional area, mm <sup>2</sup>	90.62 (35.99)	110.29 (37.88)	138.95 (73.9)	19.67 (2.95, 36.38)
Maxillary intermolar width, mm	42.38 (3.04)	48.45 (3.58)	46.72 (2.9)	6.07 (5.09, 7.05)
External maxillary width	63.25 (3.47)	65.32 (3.35)	64.26 (3.3)	2.07 (1.84, 2.3)
Palatal width	22.82 (2.77)	24.29 (2.78)	23.86 (2.81)	1.47 (1.1, 1.85)

<sup>a</sup> RPE indicates rapid palatal expansion.\* Significant at  $P < .05$ .**Table 4.** Parameters for the Control Group, Pretreatment (T1), Postexpansion (T2), and Posttreatment (T3)

	Mean (SD) T1	Mean (SD) T2	Mean (SD) T3	Mean (95% CI) T2–T1
Nasal cavity volume, mm <sup>3</sup>	16,559 (5348.13)	16,492.94 (5505.35)	20,990.17 (5597.5)	109.94 (–91.77, 311.66)
Nasal cavity area, mm <sup>2</sup>	925.16 (304.55)	931.28 (326.91)	1263.22 (285)	20.33 (–24.07, 64.74)
Nasopharyngeal volume, mm <sup>3</sup>	3091.84 (863.44)	3208.06 (881.35)	4191.89 (956.09)	71.94 (–79.36, 223.25)
Nasopharyngeal area, mm <sup>2</sup>	148.32 (132.42)	157.83 (141.04)	194.68 (211.42)	3.06 (–16.53, 22.64)
Oropharyngeal volume, mm <sup>3</sup>	6291.89 (2466.99)	6511.83 (2760.69)	8853.63 (2610.55)	134.28 (–112.56, 381.11)
Oropharyngeal area, mm <sup>2</sup>	385.37 (112.33)	386.28 (107.07)	433.79 (140.42)	0.61 (–26.24, 27.46)
Laryngopharyngeal volume, mm <sup>3</sup>	6800.59 (2668.65)	7367.69 (2580.19)	8197.6 (3563.1)	141.23 (–388.05, 670.51)
Laryngopharyngeal area, mm <sup>2</sup>	333.76 (91.65)	347.15 (106.85)	424.8 (150.35)	4.23 (–49.39, 57.85)
Total airway volume, mm <sup>3</sup>	9383.74 (3104.25)	9719.89 (3409.77)	13,045.53 (3294.99)	206.22 (–137.26, 549.7)
Total airway area, mm <sup>2</sup>	533.68 (185.73)	544.11 (193.37)	628.47 (324.96)	3.67 (–31.22, 38.55)
Minimal cross-sectional area, mm <sup>2</sup>	97.37 (48.96)	103.06 (54.96)	153.61 (94.11)	4.67 (–9.15, 18.48)
Maxillary intermolar width, mm	42.33 (3.34)	42.63 (3.15)	45.96 (4)	0.02 (–0.16, 0.21)
External maxillary width	62.23 (3.01)	62.25 (3.07)	62.62 (2.92)	0.12 (–0.13, 0.36)
Palatal width	22.32 (1.87)	22.34 (2.09)	23.13 (2.03)	0.1 (–0.1, 0.3)

\* Significant at  $P < .05$ .

**Table 2.** Extended

% Change (T2–T1)	Mean (95% CI) T3–T1	% Change (T3–T1)	<i>P</i> Values (T2 vs T1)	<i>P</i> Values (T3 vs T1)
14.4	4797.26 (4171.89, 5422.64)	29.6	<.001*	<.001*
21.6	409.32 (370.67, 447.96)	42.7	<.001*	<.001*
21.8	1512.33 (1385.71, 1638.96)	44.3	<.001*	<.001*
22.7	52.11 (44.09, 60.13)	41.9	<.001*	<.001*
19.2	2230.21 (656.93, 3803.49)	35.6	.002*	.008*
3.1	19.26 (–20.41, 58.93)	5.1	.281	.321
4.4	400.5 (–559.28, 1360.28)	6	.248	.276
1	–1 (–99.42, 97.42)	–0.3	.853	.976
20.5	3662.95 (2077.24, 5248.65)	38.5	<.001*	<.001*
8.1	86.53 (42.66, 130.4)	17.4	.002*	.001*
20.3	52.89 (16.88, 88.91)	57.9	.038*	.006*
10.7	5.24 (3.98, 6.5)	12.4	<.001*	<.001*
2.8	1.47 (1.15, 1.8)	2.4	<.001*	<.001*
10.4	2.07 (1.83, 2.32)	9.3	<.001*	<.001*

**Table 3.** Extended

% Change (T2–T1)	Mean (95% CI) T3–T1	% Change (T3–T1)	<i>P</i> Values (T2 vs T1)	<i>P</i> Values (T3 vs T1)
11.5	4695.53 (4308.79, 5082.27)	27.9	<.001*	<.001*
10.7	363.32 (117.85, 608.78)	36.4	.221	.006*
24.1	994 (895.11, 1092.89)	29	<.001*	<.001*
29.8	37.47 (13.75, 61.2)	30.4	<.001*	.004*
26.4	2538.42 (931.41, 4145.43)	45.1	<.001*	.004*
12.1	49.21 (6.61, 91.82)	14.6	.002*	.026*
3.8	443 (–28.24, 914.24)	6.2	.275	.06
1.5	–9.83 (–147.41, 127.75)	–2.7	.811	.861
25.5	3532.42 (1940.45, 5124.39)	39	<.001*	<.001*
16.9	86.68 (34.34, 139.03)	18.8	<.001*	.003*
21.7	50.68 (18.8, 82.57)	55.9	.023*	.004*
14.3	4.2 (3.13, 5.27)	9.9	<.001*	<.001*
3.3	1.27 (0.93, 1.62)	2	<.001*	<.001*
6.4	1.1 (0.68, 1.52)	4.8	<.001*	<.001*

**Table 4.** Extended

% Change (T2–T1)	Mean (95% CI) T3–T1	% Change (T3–T1)	<i>P</i> Values (T2 vs T1)	<i>P</i> Values (T3 vs T1)
0.7	4872.5 (4316.21, 5428.79)	29.4	.266	<.001*
2.2	365.28 (320.53, 410.03)	39.5	.348	<.001*
2.3	1100.05 (853.28, 1346.83)	35.6	.33	<.001*
2.1	46.37 (–27.91, 120.65)	31.3	.746	.206
2.1	2561.74 (2135.72, 2987.75)	40.7	.267	<.001*
0.2	48.42 (–10.66, 107.51)	12.6	.962	.102
2.1	226.6 (–575.38, 1028.58)	3.3	.572	.477
1.3	55 (–83.95, 193.95)	16.5	.866	.333
2.2	3661.79 (3136.83, 4186.75)	39	.222	<.001*
0.7	94.79 (–16.71, 206.28)	17.8	.827	.091
4.8	57.72 (21.04, 94.41)	59.3	.486	.004*
0	3.64 (2.52, 4.75)	8.6	.805	<.001*
0.2	0.39 (–0.13, 0.92)	0.6	.334	.13
0.4	0.82 (0.47, 1.16)	3.7	.317	<.001*



**Table 5.** Comparison of the Parameters Among MARPE, RPE, and Control Groups at Postexpansion (T2–T1)<sup>a</sup>

	MARPE Mean (95% CI)	RPE Mean (95% CI)	Control Mean (95% CI)
Nasal cavity volume, mm <sup>3</sup>	2335.74 (2026.42, 2645.05)	1936.76 (1705.32, 2168.21)	109.94 (–91.77, 311.66)
Nasal cavity area, mm <sup>2</sup>	207.53 (144.35, 270.71)	107.05 (–69.6, 283.69)	20.33 (–24.07, 64.74)
Nasopharyngeal volume, mm <sup>3</sup>	745.42 (673.47, 817.37)	827.38 (737.56, 917.21)	71.94 (–79.36, 223.25)
Nasopharyngeal area, mm <sup>2</sup>	28.16 (23.16, 33.15)	36.76 (25.58, 47.94)	3.06 (–16.53, 22.64)
Oropharyngeal volume, mm <sup>3</sup>	1204.89 (484.84, 1924.95)	1485.57 (800.67, 2170.47)	134.28 (–112.56, 381.11)
Oropharyngeal area, mm <sup>2</sup>	11.79 (–10.51, 34.09)	40.86 (16.72, 64.99)	0.61 (–26.24, 27.46)
Laryngopharyngeal volume, mm <sup>3</sup>	291.6 (–242.66, 825.86)	268.73 (–250.14, 787.6)	141.23 (–388.05, 670.51)
Laryngopharyngeal area, mm <sup>2</sup>	3.8 (–41.18, 48.78)	5.36 (–43.28, 54.01)	4.23 (–49.39, 57.85)
Total airway volume, mm <sup>3</sup>	1950.32 (1244.64, 2655.99)	2312.95 (1620.1, 3005.81)	206.22 (–37.26, 549.7)
Total airway area, mm <sup>2</sup>	39.95 (16.91, 62.98)	77.62 (47.2, 108.04)	3.67 (–31.22, 38.55)
Minimal cross-sectional area, mm <sup>2</sup>	18.53 (1.1, 35.95)	19.67 (2.95, 36.38)	4.67 (–9.15, 18.48)
Maxillary intermolar width, mm	4.51 (3.46, 5.55)	6.07 (5.09, 7.05)	0.02 (–0.16, 0.21)
External maxillary width	1.73 (1.5, 1.96)	2.07 (1.84, 2.3)	0.12 (–0.13, 0.36)
Palatal width	2.3 (2.01, 2.59)	1.47 (1.1, 1.85)	0.1 (–0.1, 0.3)

<sup>a</sup> MARPE indicates mini-screw–assisted rapid palatal expansion; RPE, rapid palatal expansion.

\* Significant at  $P < .05$ .

**Table 6.** Comparison of the Parameters Among MARPE, RPE, and Control Groups at Posttreatment (T3–T2)<sup>a</sup>

	MARPE Mean (95% CI)	RPE Mean (95% CI)	Control Mean (95% CI)
Nasal cavity volume, mm <sup>3</sup>	2376.33 (1538.71, 3213.96)	2741.89 (2332.36, 3151.43)	4803.29 (4200.86, 5405.72)
Nasal cavity area, mm <sup>2</sup>	191.28 (137.72, 244.84)	265.32 (25.76, 504.87)	350.65 (281.24, 420.05)
Nasopharyngeal volume, mm <sup>3</sup>	772.33 (635.23, 909.44)	179.53 (99.2, 259.86)	1059.44 (719.12, 1399.77)
Nasopharyngeal area, mm <sup>2</sup>	23.72 (13.23, 34.21)	–0.32 (–21.76, 21.13)	47.56 (–27.6, 122.71)
Oropharyngeal volume, mm <sup>3</sup>	892.39 (–937.36, 2722.14)	1147.63 (–528.21, 2823.48)	2486.78 (2033.19, 2940.37)
Oropharyngeal area, mm <sup>2</sup>	2 (–45.81, 49.81)	12.05 (–33.03, 57.14)	57.44 (11.19, 103.7)
Laryngopharyngeal volume, mm <sup>3</sup>	179.67 (–1265.63, 1624.96)	70.17 (–742.24, 882.57)	–13 (–832.81, 806.81)
Laryngopharyngeal area, mm <sup>2</sup>	–21.67 (–196.34, 153.01)	–8.5 (–153.75, 136.75)	7.25 (–39.15, 53.65)
Total airway volume, mm <sup>3</sup>	1664.72 (–147.72, 3477.16)	1327.16 (–353.89, 3008.21)	3546.22 (2942.5, 4149.94)
Total airway area, mm <sup>2</sup>	44.61 (–7.86, 97.08)	11.74 (–43.49, 66.97)	105 (0.22, 209.78)
Minimal cross-sectional area, mm <sup>2</sup>	31.5 (–9.8, 72.8)	31.47 (0.08, 62.87)	59.41 (25.09, 93.73)
Maxillary intermolar width, mm	1.1 (–0.41, 2.61)	–1.73 (–3.03, –0.42)	3.57 (2.41, 4.72)
External maxillary width	–0.19 (–0.49, 0.1)	–0.76 (–0.96, –0.56)	0.36 (–0.08, 0.79)
Palatal width	–0.17 (–0.48, 0.14)	–0.31 (–0.45, –0.16)	0.74 (0.35, 1.12)

<sup>a</sup> MARPE indicates mini-screw–assisted rapid palatal expansion; RPE, rapid palatal expansion.

\* Significant at  $P < .05$ .

**Table 7.** Comparison of the Parameters Among MARPE, RPE, and Control Groups at Posttreatment (T3–T1)<sup>a</sup>

	MARPE Mean (95% CI)	RPE Mean (95% CI)	Control Mean (95% CI)
Nasal cavity volume, mm <sup>3</sup>	4797.26 (4171.89, 5422.64)	4695.53 (4308.79, 5082.27)	4872.5 (4316.21, 5428.79)
Nasal cavity area, mm <sup>2</sup>	409.32 (370.67, 447.96)	363.32 (117.85, 608.78)	365.28 (320.53, 410.03)
Nasopharyngeal volume, mm <sup>3</sup>	1512.33 (1385.71, 1638.96)	994 (895.11, 1092.89)	1100.05 (853.28, 1346.83)
Nasopharyngeal area, mm <sup>2</sup>	52.11 (44.09, 60.13)	37.47 (13.75, 61.2)	46.37 (–27.91, 120.65)
Oropharyngeal volume, mm <sup>3</sup>	2230.21 (656.93, 3803.49)	2538.42 (931.41, 4145.43)	2561.74 (2135.72, 2987.75)
Oropharyngeal area, mm <sup>2</sup>	19.26 (–20.41, 58.93)	49.21 (6.61, 91.82)	48.42 (–10.66, 107.51)
Laryngopharyngeal volume, mm <sup>3</sup>	400.5 (–559.28, 1360.28)	443 (–28.24, 914.24)	226.6 (–575.38, 1028.58)
Laryngopharyngeal area, mm <sup>2</sup>	–1 (–99.42, 97.42)	–9.83 (–147.41, 127.75)	55 (–83.95, 193.95)
Total airway volume, mm <sup>3</sup>	3662.95 (2077.24, 5248.65)	3532.42 (1940.45, 5124.39)	3661.79 (3136.83, 4186.75)
Total airway area, mm <sup>2</sup>	86.53 (42.66, 130.4)	86.68 (34.34, 139.03)	94.79 (–16.71, 206.28)
Minimal cross-sectional area, mm <sup>2</sup>	52.89 (16.88, 88.91)	50.68 (18.8, 82.57)	57.72 (21.04, 94.41)
Maxillary intermolar width, mm	5.24 (3.98, 6.5)	4.2 (3.13, 5.27)	3.64 (2.52, 4.75)
External maxillary width	1.47 (1.15, 1.8)	1.27 (0.93, 1.62)	0.39 (–0.13, 0.92)
Palatal width	2.07 (1.83, 2.32)	1.1 (0.68, 1.52)	0.82 (0.47, 1.16)

<sup>a</sup> MARPE indicates mini-screw–assisted rapid palatal expansion; RPE, rapid palatal expansion.

\* Significant at  $P < .05$ .



**Table 5.** Extended

<i>P</i> Values Overall	<i>P</i> Values MARPE-Control	<i>P</i> Values MARPE-RPE	<i>P</i> Values RPE-Control
<.001*	<.001*	.053	<.001*
.084	.069	.42	.532
<.001*	<.001*	.484	<.001*
.001	.018*	.578	.001*
.005*	.036*	.768	.005*
.046*	.786	.182	.046*
.887	.998	.898	.922
.999	.999	.999	.999
<.001*	<.001*	.655	<.001*
.002*	.19	.146	.001*
.331	.436	.994	.362
<.001*	<.001*	.022*	<.001*
<.001*	<.001*	.083	<.001*
<.001*	<.001*	<.001*	<.001*

**Table 6.** Extended

<i>P</i> Value Overall	<i>P</i> Values MARPE-Control	<i>P</i> Values MARPE-RPE	<i>P</i> Values RPE-Control
<.001*	<.001*	.661	<.001*
.325	.293	.751	.691
<.001*	.125	<.001*	<.001*
.288	.714	.703	.256
.234	.253	.963	.366
.179	.191	.944	.316
.932	.971	.925	.98
.935	.983	.93	.97
.065	.155	.938	.073
.173	.457	.786	.154
.423	.491	.999	.482
<.001*	.023*	.007*	<.001*
<.001*	.038*	.03*	<.001*
<.001*	<.001*	.777	<.001*

**Table 7.** Extended

<i>P</i> Values Overall	<i>P</i> Values MARPE-Control	<i>P</i> Values MARPE-RPE	<i>P</i> Values RPE-Control
.885	.976	.956	.875
.872	.899	.888	.999
<.001*	.002*	<.001*	.625
.894	.981	.886	.955
.917	.926	.936	.999
.574	.64	.624	.999
.807	.89	.992	.803
.609	.738	.992	.611
.986	.999	.988	.989
.983	.986	.999	.986
.955	.977	.995	.952
.122	.108	.382	.75
.001*	.001*	.748	.006*
<.001*	<.001*	<.001*	.444

The amount of change in intermolar width was recorded as the amount of expansion at the molars with RPE and MARPE. There was a significant change in the intermolar width at T2 with both RPE and MARPE. Immediately after expansion, the intermolar width in the RPE group was greater than in the MARPE group. This could have been due to additional dental effects, such as buccal tipping of the molars, with RPE.<sup>10,11</sup> However, in the long term (T3), the intermolar width was higher (not significantly) in the MARPE than in the RPE group. This may have occurred because of dental relapse as a result of uprighting of the buccally tipped molar teeth in the RPE group.<sup>12</sup> At posttreatment, the change in the intermolar width between the three groups was not statistically significant (Table 7).

In both the MARPE and RPE groups, there was a significant increase in the NPV at T2 as compared with the control group (Table 5). The changes in NPV were statistically significant even at T3 in the MARPE group when compared with the control and RPE groups (Table 7). This could be attributed to the greater skeletal expansion with MARPE.<sup>5</sup> MARPE leads to a more parallel opening of the mid-palatal suture than RPE does, which leads to a triangular sutural opening (more anteriorly and less posteriorly).<sup>13,14</sup> In addition, the increase in PW from T1 to T3 in the MARPE group was significantly higher than the RPE and control groups (Table 7). These effects of MARPE on the posterior aspects of the nasal cavity may have contributed to the findings of increased NPV with MARPE at T3.

NCV was significantly increased with MARPE and RPE at T2 as compared with the control group, but there was no difference among the three groups at T3. This was because, during the orthodontic treatment phase from T2 to T3, there was a significant increase in the NCV in the control group compared with the MARPE and RPE groups (Table 6). Thus, this study furnished the missing information from the current literature that, although the NCV increases significantly immediately after expansion with MARPE and RPE, the control group catches up in the long term so that NCV is not significantly different posttreatment among the three groups. This may have been due to archwire expansion, growth, or other biological factors that led to increased NCV in the controls over the long term (Table 7). In contrast to the NPV, OPV, and NCV, LPV was not significantly increased with either MARPE or RPE. This showed that MARPE and RPE caused more effects on the upper airway and did not cause significant changes in the lower airway.

Expansion with both MARPE and RPE caused a significant increase in the TAV postexpansion (Tables 2 and 3). This was in accordance with the findings from previous studies.<sup>7,8</sup> However, the MARPE and RPE

groups had no significant increase in the TAV in comparison with the control group at T3. In a previous study comparing the effects of MARPE on airway volume, the authors concluded that MARPE could significantly increase the airway volume.<sup>8</sup> However, these findings should be interpreted carefully, as they did not compare the findings with controls and did not look at the long-term effects. The Pearson correlation analysis showed that the amount of expansion and EMW did not correlate with TAV. However, PW had a moderate correlation with NCV from T1 to T2 in the MARPE group (Supplemental Tables 3 and 4). This was because of wide individual variability in the effects of expansion on airway.

The prevalence of sleep-disordered breathing in children ranges from 4% to 11%.<sup>15</sup> Children with a constricted maxillary arch and high palate have an increased chance of sleep-disordered breathing.<sup>16</sup> A previous study showed beneficial effects of RPE in such children.<sup>17</sup> The findings of a recent systematic review and meta-analysis described that RPE was a useful treatment for improving the apnea-hypopnea index in children with sleep-disordered breathing.<sup>18</sup> The results of the current study showed a significant increase in the MCA within the MARPE and RPE groups at T2 and T3, whereas the control group had a significant increase in MCA only at T3 when compared with T1. However, dynamic evaluation of the respiratory system with rhinomanometry, nasal, and oral peak flow measurements can help to better understand the effects of such treatment modalities on the respiratory system.<sup>19,20</sup> A limitation of this study was that a true control was not present for comparison because of the delayed treatment in the control group that occurred between T2 and T3, and the patients did not suffer from respiratory disease. Ethically, it would not be justified to record three CBCTs with no treatment at all, and this might significantly change the overall interpretation of the results. Additional studies should be performed to evaluate the effects of MARPE and RPE on the respiratory pattern of children with sleep-disordered breathing.

## CONCLUSIONS

- Both MARPE and RPE significantly increased nasal cavity volume, oropharyngeal volume, nasopharyngeal volume, nasopharyngeal area, total airway volume, maxillary intermolar width, external maxillary width, and palatal width when compared with controls in the short term.
- In the long term, MARPE led to a significant increase in the nasopharyngeal volume and palatal width as compared with the RPE and control groups. Both the MARPE and RPE groups showed greater external

maxillary width compared with controls in the long term.

- There was no significant difference in the airway parameters other than nasopharyngeal volume between the MARPE, RPE, and control groups in the long term. Thus, age and growth of the patient may be overriding factors.
- The amount of expansion, external maxillary width, and palatal width were not correlated with airway volume.

## SUPPLEMENTAL DATA

Supplemental tables available online.

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