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Tongue posture improvement and pharyngeal airway enlargement as secondary effects of rapid maxillary expansion: A cone-beam computed tomography study

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Introduction: Rapid maxillary expansion (RME) is known to improve nasal airway ventilation. Recent evidence suggests that RME is an effective treatment for obstructive sleep apnea in children with maxillary constriction. However, the effect of RME on tongue posture and pharyngeal airway volume in children with nasal airway obstruction is not clear. In this study, we evaluated these effects using cone-beam computed tomography. **Methods:** Twenty-eight treatment subjects (mean age 9.96 $\pm$ 1.21 years) who required RME treatment had cone-beam computed tomography images taken before and after RME. Twenty control subjects (mean age 9.68 $\pm$ 1.02 years) received regular orthodontic treatment. Nasal airway ventilation was analyzed by using computational fluid dynamics, and intraoral airway (the low tongue space between tongue and palate) and pharyngeal airway volumes were measured. **Results:** Intraoral airway volume decreased significantly in the RME group from 1212.9 $\pm$ 1370.9 mm^3 before RME to 279.7 $\pm$ 472.0 mm^3 after RME. Nasal airway ventilation was significantly correlated with intraoral airway volume. The increase of pharyngeal airway volume in the control group (1226.3 $\pm$ 1782.5 mm^3) was only 41% that of the RME group (3015.4 $\pm$ 1297.6 mm^3). **Conclusions:** In children with nasal obstruction, RME not only reduces nasal obstruction but also raises tongue posture and enlarges the pharyngeal airway. (Am J Orthod Dentofacial Orthop 2013;143:235-45)

Nasal breathing allows proper growth and development of the craniofacial complex. In contrast, nasal obstruction that leads to mouth breathing results in lower tongue posture (with greater intraoral airway volume) and a constricted and V-shaped maxillary dental arch.[1]

Rapid maxillary expansion (RME) has been widely used by orthodontists to increase the maxillary transverse dimensions of young patients. Recent studies have suggested that RME also increases nasal width and volume.[2-6] Therefore, RME is generally thought to diminish the resistance to nasal airflow.[6,7] Gray[8] investigated the medical results of RME in 310 patients and found that over 80% of them changed their breathing pattern from mouth breathing to nasal breathing. Furthermore, the efficacy of RME to treat obstructive sleep apnea syndrome (OSAS) in children has been reported.[9-11] However, the mechanism behind the RME effect is not clear. OSAS in children has various causes.[12] Our purpose was to clarify a mechanism by which RME improves the symptoms.

Upper airway obstruction has also been associated with low tongue posture; among its other effects, RME

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is thought to change tongue posture.[13] Previously, cephalograms were used to evaluate tongue posture, but precise measurements of tongue posture with these methods are difficult because tongue forms differ among patients.[13,14] Ozbek et al[13] reported that RME in children with maxillary constriction, posterior crossbite, and no signs of respiratory disturbance resulted in higher tongue posture. This result indicates that low tongue posture, without respiratory disturbance, changes when intermolar width is expanded.

Zhao et al[15] compared absolute and percentage changes in the retropalatal and retroglossal airways after RME treatment and found no significant difference between the treated and control groups. However, they did not control tongue position when the cone-beam computed tomography (CBCT) images were taken, and the nasal ventilation condition, which is thought to influence tongue posture, was not considered. Because tongue posture is an important anatomic factor that affects the shape and size of the oropharyngeal airway volume, the absence of control over tongue position when the CBCT images were taken limits the conclusions from their study.

Therefore, further detailed studies are necessary to determine how RME changes tongue posture or pharyngeal airway volume in children with nasal airway obstruction. Thus, we comprehensively evaluated the secondary effects of RME by analyzing nasal airway ventilation, tongue posture, and pharyngeal airway volume from the same CBCT data. The purpose of this study was to clarify the effect of RME on tongue posture and pharyngeal airway volume in children with nasal airway obstruction.

MATERIAL AND METHODS

Records from 85 patients who visited a private orthodontic office in Himeji, Japan, to receive orthodontic treatment were screened for this longitudinal retrospective study. Because airway volume is influenced by head posture, craniocervical inclinations of all subjects were examined to ensure that their inclinations were between 90° and 105°.[16-19] The criteria for selection included (1) Class II skeletal relationship, (2) no previous orthodontic treatment, (3) no craniofacial or growth abnormalities, and (4) no enlarged adenoids or tonsils. Forty-eight patients met these selection criteria.

CBCT data were taken before and after RME treatment (RME group) or at corresponding times but without RME treatment (control group). The RME group consisted of serial CBCT images of 28 subjects (13 boys, 15 girls) with mean ages before and after RME of 9.96 $\pm$ 1.21 and 11.23 $\pm$ 1.12 years, respectively. They required approximately 5 mm of maxillary expansion as part of their orthodontic treatment. No passive retention appliance was used before full orthodontic treatment. The mean treatment time with the RME appliance was 5.5 $\pm$ 1.0 months. The control group consisted of serial CBCT images of 20 subjects (8 boys, 12 girls) with no history of RME appliance treatment. Control CBCT images were taken at age 9.68 $\pm$ 1.02 years (corresponding to before RME) and at age 11.13 $\pm$ 1.31 years (corresponding to after RME). The control subjects were approximately matched by sex, age, and dentition with the RME subjects.

This study was reviewed and approved by the ethics committee of the Graduate School of Medical and Dental Sciences, Kagoshima University, Kagoshima, Japan.

Each subject was seated in a chair with his or her Frankfort horizontal plane parallel to the floor. Each subject was asked to hold his or her breath after the end of expiration, without swallowing, because the pharyngeal airway caliber when awake is smallest at this time. Breath holding at this moment provides a static pharyngeal airway size that can be recorded consistently in all CBCT scans, thereby reducing variations caused by changes in pharyngeal airway caliber during the respiratory cycle.[20] This position is stable and has high reproducibility for measurement. A CBCT device (CB MercuRay; Hitachi Medical, Tokyo, Japan) was set to maximum 120 kV, maximum 15 mA, and exposure time of 9.6 seconds. Data were sent directly to a personal computer and stored in digital imaging and communications in medicine (DICOM) format.

We made morphologic evaluations of the airways (nasal, intraoral, and pharyngeal) (Figs 1 and 2). Volume rendering software (INTAGE Volume Editor; CYBERNET, Tokyo, Japan) was used to create the 3-dimensional (3D) volume data of the airways. Because the airway is a void surrounded by hard and soft tissues, inversion of the 3D rendered image is required: ie, converting a negative value to a positive value and vice versa. Threshold segmentation was used to select the computed tomography units in the airway. The inverted air space has a significantly greater positive computed tomography unit than do the denser surrounding soft tissues. The distinct high-contrast border produces a clean segmentation of the airway. By modifying the threshold limits, an appropriate range defined the tissues of interest in the volume of interest for a particular scan. By using this concept, a threshold of computed tomography units was selected to isolate all empty spaces in the airway region.[21] Subsequently, by using an appropriate smoothing algorithm with a moving average, the 3D model was converted to a smoothed model without losing the patient-specific character of the airway shape.[22] The rendered volume data was in a 512 $\times$ 512 matrix with a voxel size of 0.377 mm.

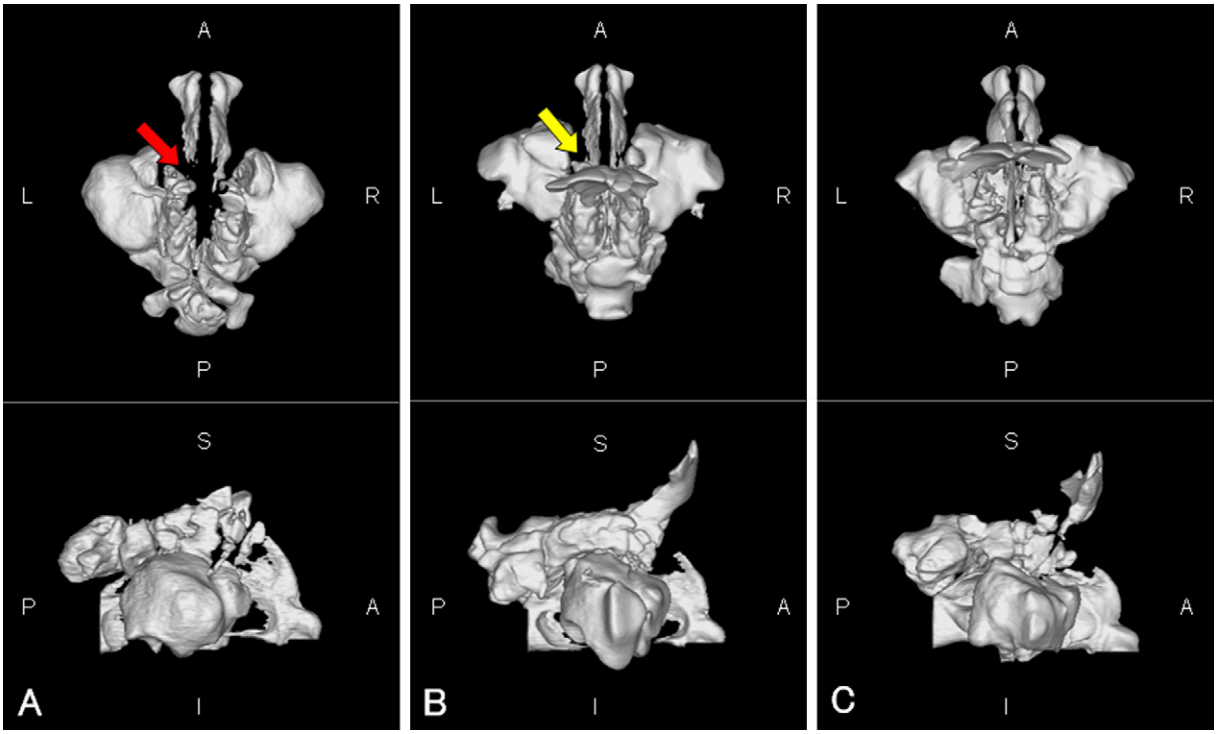

Fig 1. Evaluation of nasal airway obstruction from 3D nasal airway forms in 3 subjects (top image, superior view; bottom image, lateral view): **A,** obvious complete obstruction (*red arrow*); **B,** rhinostenosis, but the presence or absence of complete obstruction cannot be determined (*yellow arrow*); **C,** no rhinostenosis or obstruction.[6]

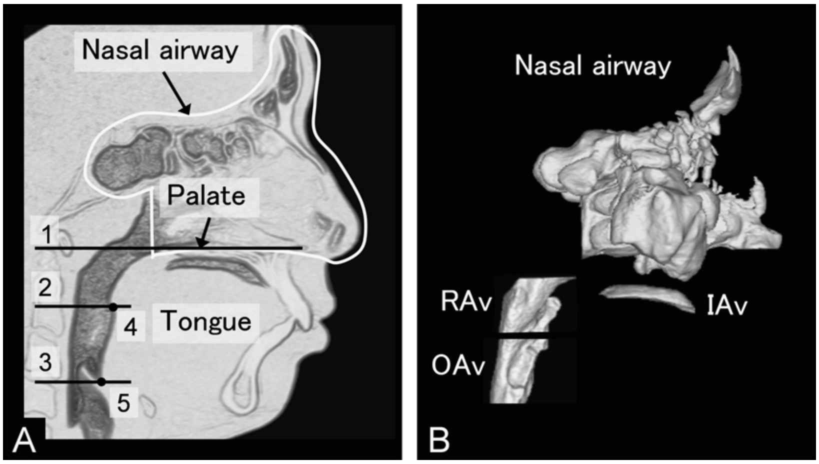

Fig 2. Measurement of airway volumes. **A,** Landmarks and planes for the axial section of the airway: *1*, Palatal plane; *2*, soft palatal plane (parallel to the palatal plane passing through the soft palatal plane); *3*, epiglottis plane (parallel to the palatal plane passing through the base of the epiglottis); *4*, soft palatal plane (inferior-most point on the uvula); *5*, base of the epiglottis. **B,** Parts of the airway: nasal airway; *RAv*, Retropalatal airway volume, between the palatal and soft palatal planes; *OAv*, oropharyngeal airway volume, between the soft palatal and epiglottis planes; *IAv*, intraoral airway volume, between the palate and the tongue.

The nasal airway (from the external nares to the choanae, including the paranasal sinuses) is shown in Figure 1. When the continuity of the bilateral nasal meatus was broken, a 3D obstruction was assumed (Fig 1, *A*).[6]

The intraoral and pharyngeal airways are shown in Figure 2. Intraoral airway volume between the tongue and palate was measured as an indication of vertical tongue position.[23] Pharyngeal airway volumes were also measured.

The cross-sectional planes (Fig 2) included (1) the palatal plane, a plane parallel to the hard palate passing through the posterior nasal spine; (2) the soft palatal plane, a plane parallel to the palatal plane passing through the inferior-most point on the uvula; and (3) the base of the epiglottis plane, a plane parallel to the palatal plane passing through the base of the epiglottis.

The following pharyngeal airway volumes (Fig 2) were measured: (1) total pharyngeal airway volume, the airway between the palatal plane and the epiglottis plane; (2) retropalatal airway volume, the airway between the palatal plane and the soft palatal plane; and (3) oropharyngeal airway volume, the airway between the soft palatal plane and the epiglottis plane.

We then evaluated nasal airway ventilation conditions. Computed fluid dynamics were used to determine the presence of any functional obstruction of the nasal airway (Fig 3).[6,24] This method has been shown to provide a more accurate estimate of any obstruction than CBCT images alone. The constructed 3D images for the nasal airway were exported to fluid-dynamic software (PHOENICS; CHAM-Japan, Tokyo, Japan) in stereolithographic format. This software can simulate and evaluate various kinds of computed fluid dynamics under a set of given conditions. The simulation estimated airflow pressure and velocity.

In our simulation, air flowed from the choana horizontally, and air was exhaled through both nostrils. The flow was assumed to be a newtonian, homogeneous, and incompressible fluid.[25] Elliptic-staggered equations and the continuity equation were used in the study.[26] The computed fluid dynamics of the nasal airway were used under the following conditions with PHOENICS: (1) the volume of airflow with a velocity of 200 m per second, which is the rate of respiration of a subject of this age at rest[27]; (2) the wall surface was nonslip; and (3) the simulation was repeated 1000 times to calculate the mean values. Convergence was judged by monitoring the magnitude of the absolute residual sources of mass and momentum, normalized by the respective inlet fluxes. The iteration was continued until all residuals fell below 0.2%.

When the 3D CBCT reconstructions indicated nasal airway obstruction, computed fluid dynamics was not used. When computed fluid dynamics indicated a maximal pressure of more than 100 Pa (with an inflow rate of 200 mL/sec) and a maximum velocity of more than 10 m per second, an obstruction was assumed.[24]

In 1 analysis, the RME subjects were divided into 2 groups by their nasal airway condition before and after RME: (1) the obstruction group included patients in whom a nasal obstruction was detected with the 3D images or the computed fluid dynamics evaluation, and (2) the nonobstruction group included patients in whom no nasal obstruction was found with either method (Fig 4).

In a separate analysis, the RME subjects were classified into 3 groups by the changing pattern of their nasal airway obstruction after RME: (1) the nonimprovement group, with nasal airway obstructions both before and after RME; (2) the improvement group, with nasal airway obstruction before RME but not after RME; and (3) the ventilation group, with no nasal airway obstruction before or after RME.

Statistical analysis

The significance of treatment changes (before and after RME) of all variables (airway volume, nasal ventilation, pressure, and velocity) was determined with the paired *t* test. When a variable had a nonnormal distribution of data or differing variances, the significance of the treatment changes was determined with the nonparametric Wilcoxon rank test. Comparisons between groups at each time interval were made with the Student *t* test. All variables compared with this test had normal distributions and similar variances. When a variable had a nonnormal distribution of data or differing variances, the group comparison was made with the nonparametric Mann-Whitney U test. Spearman correlation coefficients were calculated to evaluate the relationships among nasal airway ventilation conditions, intraoral airway volumes, and pharyngeal airway volumes. One-way analysis of variance (ANOVA) and the post-hoc Bonferroni test were used to compare the 3 groups (nonimprovement, improvement, and ventilation). Statistical significance was set at $P < 0.05$.

To assess the measurement error of the airway volume, 10 randomly selected computed tomography images from the 96 had the 3D rendering of the airway measured twice with the manual method by the same operator (T.I.) within 1 week. The differences between paired linear measurements were calculated, and Dahlberg's error[28] (double determination method) was computed. The errors for airway volume were 83.72 mm^3 for intraoral airway volume, 103.53 mm^3 for total pharyngeal airway volume, 75.36 mm^3 for retropalatal airway

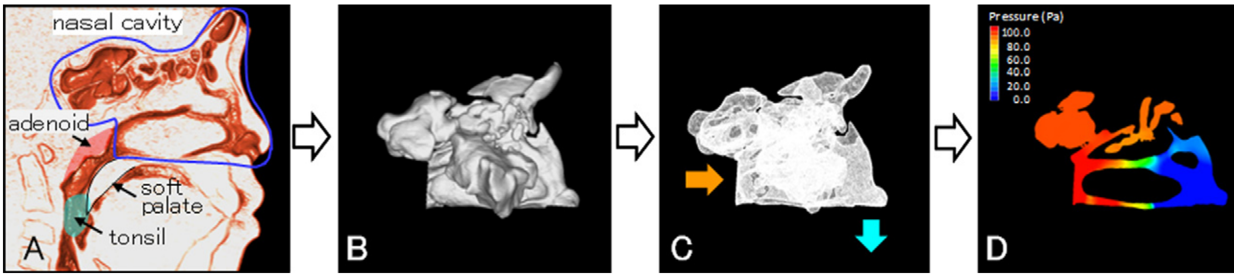

Fig 3. Steps in the evaluation of nasal airway ventilation by computed fluid dynamics: **A,** extraction of the nasal airway data; **B,** volume rendering and smoothing; **C,** construction of the stereolithographic model and numeric simulation; **D,** evaluation of the nasal airway ventilation condition.[6]

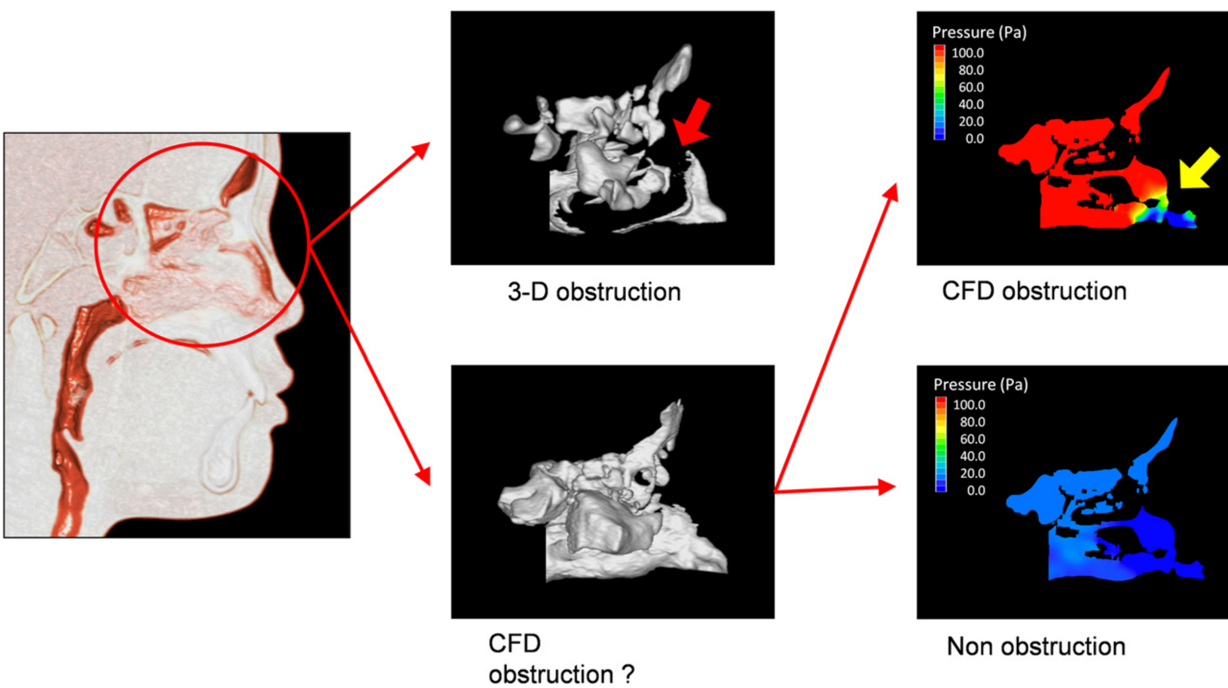

Fig 4. Classification of nasal airway obstruction by using 3D models and computed fluid dynamics (*CFD*) (3D obstruction, *red arrow*; CFD obstruction; *yellow arrow*).[6]

volume, and 62.31 mm^3 for oropharyngeal airway volume. Intraclass correlations were used to calculate the reliability between the first and second measurements. The values ranged from 0.965 to 0.998 (P <0.001; df = 8). According to all repeated analyses, the method errors were considered negligible.

RESULTS

After RME, the intraoral airway volume decreased significantly in the RME group (Table I), whereas total pharyngeal airway volume, retropalatal airway volume, and oropharyngeal airway volume all increased significantly in the RME group. In the control group, total pharyngeal and oropharyngeal airway volumes both increased significantly from before to after RME. However, intraoral and retropalatal airway volumes did not change significantly. The intraoral airway volume of the RME group (1212.9 mm^3) was significantly greater than that of the control group (415.1 mm^3) before RME. The intraoral airway volume treatment change in the RME group (−933.3 mm^3) was significantly less than that of the control group (155.1 mm^3). As a result, there was no significant difference for intraoral airway volume between the 2 groups after RME.

Table I. Statistical comparisons of airway volumes

	Before RME (T1)					*After RME (T2)*				
	RME (n = 28)		*Control (n = 20)*		*Group differences*	*RME (n = 28)*		*Control (n = 20)*		*Group differences*
	Mean	*SD*	*Mean*	*SD*	P	*Mean*	*SD*	*Mean*	*SD*	P
Intraoral airway (mm^3)	1212.9	1370.9	415.1	803.1	0.024	279.7	472.0	570.2	1031.4	0.251
Total pharyngeal airway (mm^3)	6370.7	2291.7	6489.3	1946.2	0.851	9386.1	2440.6	7715.6	2151.1	0.018
Retropalatal airway (mm^3)	3315.8	1141.9	3418.5	967.7	0.746	4729.8	1553.7	3746.2	1129.9	0.020
Oropharyngeal airway (mm^3)	3054.9	1633.4	3070.8	1206.6	0.971	4656.3	1607.2	3969.3	1731.8	0.164

*Significant changes between T1 and T2 ($P < 0.05$).

Table II. Statistical comparisons of nasal ventilation conditions

	Before RME (T1)					*After RME (T2)*					*Treatment change*				
	RME[†] *(n = 22)*		*Control*[‡] *(n = 19)*		*Group differences*	*RME*[‡] *(n = 27)*		*Control (n = 20)*		*Group differences*	*RME*[†] *(n = 22)*		*Control*[‡] *(n = 19)*		*Group differences*
	Mean	*SD*	*Mean*	*SD*	P	*Mean*	*SD*	*Mean*	*SD*	P	*Mean*	*SD*	*Mean*	*SD*	P
Maximum pressure (Pa)	120.91	84.18	42.56	24.02	<0.001	89.08	72.27	39.41	20.35	0.026	−47.25	62.37*	−3.00	23.79	0.014
Maximum velocity (m/sec)	12.27	5.99	7.87	3.88	0.016	10.72	6.38	7.41	3.28	0.106	−2.68	5.19*	−0.44	4.36	0.129

*Significant change between T1 and T2 ($P < 0.05$); [†]Six subjects diagnosed with 3D obstruction; [‡]One subject diagnosed with 3D obstruction.

The total pharyngeal airway volume treatment change in the RME group (3015.4 mm^3) was significantly greater than that of the control group (1226.3 mm^3), and the retropalatal airway volume treatment change of the RME group (1413.9 mm^3) was significantly greater than that of the control group (327.8 mm^3). However, the oropharyngeal airway volume treatment change of the RME group (1601.4 mm^3) did not differ significantly from that of the control group (898.5 mm^3).

Among the patients without a morphologic obstruction, the pressure after RME (89.08 ± 72.27 Pa; n = 27) was significantly lower than before RME (120.91 ± 84.18 Pa; n = 22) (Table II). Similarly, the velocity after RME (10.72 ± 6.38 m/sec; n = 27) was significantly lower than before RME (12.27 ± 5.99 m/sec; n = 22). There were no significant maximum pressure or velocity changes in the control group at the 2 measurement times. The maximum pressure of the RME group was significantly greater than that of the control group both before and after RME, and the treatment change was also significantly larger. The maximum velocity of the RME group was significantly greater than that of the control group before RME.

Table III shows the correlations between nasal airway ventilation conditions and intraoral airway volume. Before and after RME, maximum pressure and velocity were significantly correlated with intraoral airway volume. The treatment changes in maximum pressure and velocity were significantly correlated with intraoral airway volume. However, at each interval and treatment change, maximum pressure and velocity were not significantly correlated with any other pharyngeal airway volume (total, retropalatal, or oropharyngeal). At each interval and treatment change, intraoral airway volume was not significantly correlated with any other pharyngeal airway volume.

Comparisons of intraoral airway volumes among the 3 groups showed significant differences both before and after RME (Table IV). Treatment changes of intraoral airway volume also differed significantly among the 3 groups. The treatment change in intraoral airway volume of the improvement group (−1515.8 mm^3) was significantly greater than that of the ventilation group (−114.8 mm^3). The volumes and volume changes of the total pharyngeal, retropalatal, and oropharyngeal airways did not differ significantly among the 3 groups either before or after RME.

Table I. (Continued)

Treatment change				
RME (n = 28)		Control (n = 20)		Group differences
Mean	*SD*	*Mean*	*SD*	P
−933.3	1308.8*	155.1	1096.7	0.004
3015.4	1297.6*	1226.3	1782.5*	<0.001
1413.9	1172.0*	327.8	958.4	0.001
1601.4	1459.9*	898.5	1335.9*	0.095

Table III. Spearman rank correlation coefficients and *P* values (in parentheses) between intraoral airway volume and ventilation condition

	Before RME		*After RME*		*Treatment change*	
	Maximum pressure	*Maximum velocity*	*Maximum pressure*	*Maximum velocity*	*Maximum pressure*	*Maximum velocity*
Intraoral airway volume before RME (n = 22)†	0.617 (0.002)*	0.630 (0.002)*	–	–	–	–
Intraoral airway volume after RME (n = 27)‡	–	–	0.473 (0.013)*	0.518 (0.006)*	–	–
Intraoral airway volume treatment change (n = 22)†	–	–	–	–	0.599 (0.003)*	0.520 (0.013)*

*Statistically significant at $P < 0.05$; †Six subjects had 3D obstruction; ‡One subject had 3D obstruction.

DISCUSSION

The main purpose of this study was to clarify the effect of RME on changes of tongue posture and pharyngeal airway volume in children with nasal obstruction. Improvement of nasal airway ventilation[6,29-31] and increases in the volume of the bone and soft tissues of the palate have been reported as secondary effects of RME.[32] However, the effect of RME on tongue posture and pharyngeal airway volume and their association with improved nasal airway ventilation have not been firmly established. So, this study used 3D computed tomography and computed fluid dynamics to clarify the change of tongue posture by RME.

The purpose of our study was to clarify the relationship between nasal airway ventilation condition and tongue posture. Previous studies have evaluated tongue posture, hyoid posture, and tongue height by using cephalograms[33,34] and reported changes of the hyoid distance from −0.4 to −1.9 mm after RME.[13,35,36] However, in our study, the relative lingual position of the palate was used to evaluate tongue posture. Ozbek et al[13] cephalometrically evaluated the relative tongue posture for the palate as 8 different tongue-to-palatine bone distances. However, in subjects with a low tongue posture, variability in the shape of the dorsum of the tongue and dehiscence of the palate make it difficult to quantitatively evaluate tongue posture from 2-dimensional cephalograms (Fig 5). Therefore, we measured the intraoral airway to estimate tongue posture relative to the palate as an indirect evaluation method of low tongue posture. Our intraoral airway measurement expresses the actual volume between the palatal mucosa and the dorsum of the tongue. When the tongue contacts the palate without a gap, this value becomes zero, indicating that tongue posture is not low. Also, this method can evaluate the degree of the low tongue posture without being affected by various forms of the palate and the tongue. Therefore, we believe that our method (intraoral airway) is better able to evaluate low tongue posture.[23]

In our previous study, the intraoral airway volume of similarly aged children with normal occlusion was 702.0 ± 289.2 mm^3.[23] Because the intraoral airway volume of our RME group before treatment was 1212.9 ± 1370.9 mm^3, we considered those subjects to have low tongue posture (Table I). After RME, the intraoral airway volume

Table IV. Comparisons among the 3 groups

	Ventilation (n = 8)		Improvement (n = 13)		Nonimprovement (n = 7)		Group differences	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	P	*Post hoc*[†]
Maximum pressure (Pa)								
Before RME[‡]	46.27	26.51	140.97	71.43	220.05	57.92	<0.001	1,2
After RME[§]	36.98	24.39	68.49	18.56	203.15	66.63	<0.001	2,3
Treatment change[¶]	−9.29	30.81	−76.50	73.14	−50.03	47.53	0.025	
Maximum velocity (m/sec)								
Before RME[‡]	7.39	3.87	13.38	2.72	19.25	7.84	0.005	1,2
After RME[§]	6.18	3.36	9.53	4.16	19.36	5.32	0.001	2,3
Treatment change[¶]	−1.21	5.36	−4.08	5.03	−2.11	5.72	0.461	
Intraoral airway (mm^3)								
Before RME	114.8	212.5	1638.8	1507.9	1677.0	1266.6	0.021	1
After RME	0.0	0.0	123.1	197.0	890.1	576.9	<0.001	2,3
Treatment change	−114.8	212.5	−1515.8	1481.2*	−786.9	1270.4	0.049	1
Total pharyngeal airway (mm^3)								
Before RME	6480.0	3029.1	6214.6	1611.3	6535.7	2763.2	0.948	
After RME	9056.3	2940.5	9680.8	1922.4	9072.9	3128.5	0.818	
Treatment change	2576.3	1392.3*	3466.2	1349.7*	2537.1	1105.7*	0.207	
Retropalatal airway (mm^3)								
Before RME	3579.7	901.3	3229.8	1056.0	3174.0	1599.0	0.752	
After RME	4753.4	1367.8	4709.5	1598.0	4740.3	1890.0	0.998	
Treatment change	1173.7	786.8*	1479.7	1550.3*	1566.4	733.8*	0.793	
Oropharyngeal airway (mm^3)								
Before RME	2900.3	2502.2	2984.8	1069.2	3361.8	1504.2	0.852	
After RME	4302.8	1886.2	4971.2	1595.0	4475.4	1401.7	0.631	
Treatment change	1402.5	1394.9*	1986.5	1684.7*	1113.6	996.1*	0.415	

*Significant change between before and after RME ($P < 0.05$); †Significant group differences based on Bonferroni test $P < 0.05$: *1*, ventilation vs improvement; *2*, ventilation vs nonimprovement; *3*, improvement vs nonimprovement; ‡Ventilation (n = 8), improvement (n = 10), nonimprovement (n = 4); §Ventilation (n = 8), improvement (n = 13), nonimprovement (n = 6); ¶Ventilation (n = 8), improvement (n = 10), nonimprovement (n = 4).

was reduced to 279.7 ± 472.0 mm^3, indicating that RME improved the low tongue posture (Figs 6 and 7).

In children with low tongue posture and constricted dentition, but without a respiratory disorder, Ozbek et al[13] in a cephalometric study reported that tongue posture becomes about 2 mm higher after dentition expansion by RME. However, the effect of RME on tongue posture in children with a respiratory disorder (nasal airway obstruction and habitual mouth breathing) was not clear.

Factors affecting tongue posture include mouth breathing,[37,38] nasal airway ventilation,[39-42] arch width,[13] and palatine tonsil hypertrophy.[42] Chronic upper airway obstruction has been associated with a low tongue posture.[39-42] The habitual mouth breather, who breathes through the mouth even though there is no obstruction in the airway, was considered to have a low tongue posture.[24] In our study, subjects with nasal airway obstruction showed a low tongue posture both before and after RME (Table III), indicating an association between nasal obstruction and low tongue posture regardless of RME treatment.

Furthermore, we compared changes of tongue posture with changes in the nasal airway ventilation pattern after RME treatment (Table IV). In our study, the low tongue posture of the improvement group was improved by RME. However, low tongue posture did not improved in every subject in that group. This might be because habitual mouth breathing remained after removal of the cause of the nasal obstruction. On the other hand, children whose nasal airway obstruction remained after RME (nonimprovement group) still had a low tongue posture after RME. We believe that the low tongue posture did not improve because mouth breathing with nasal obstruction remained even after the dentition was expanded. Therefore, improvement of nasal airway obstruction might be more important than expansion of a constricted dentition to improve tongue posture.

In previous studies, the second cervical vertebra,[43] top of the epiglottis,[15,22] third cervical vertebra,[44] and base of the epiglottis[23,45] have been used as the inferior limit of pharyngeal airway volume. We used the base of the epiglottis, which corresponds to the base of the tongue, to evaluate changes of tongue posture in this study.

Zhao et al,[15] in their CBCT study, evaluated changes in the oropharyngeal airway after RME in 12-year-old

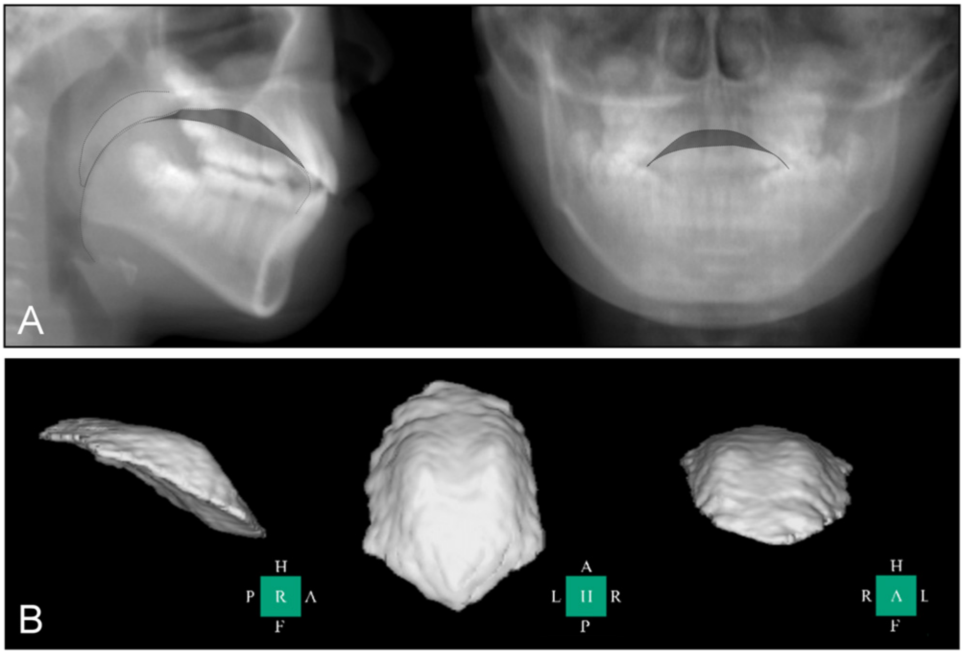

Fig 5. Estimate of low tongue posture in a patient: **A,** cephalometric image (left, lateral view; right, posteroanterior view); **B,** 3D views of the intraoral airway (right lateral, superior, and front).

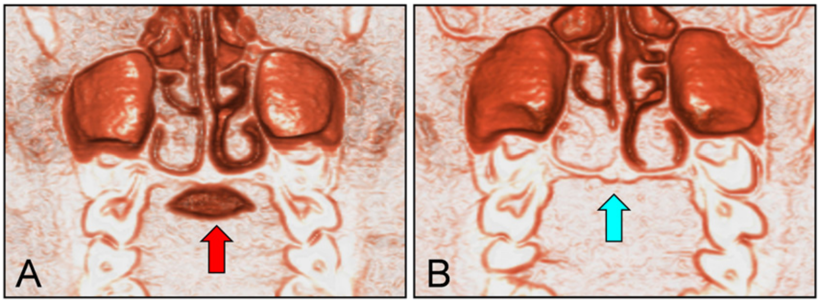

Fig 6. Improvement of low tongue posture after RME (frontal view) in a patient: **A,** before RME, tongue posture is low (*red arrow*); **B,** after RME, tongue posture has improved (*blue arrow*).

children. They found no significant volume enlargement after RME. However, the volume change in their RME group, approximately 1100 mm^3, was greater than that of their control group. Our findings were similar.

De Felippe et al[32] reported a palate volume increase of about 1300 mm^3 after RME. The position of the tongue and all tongue and pharyngeal soft tissues are important anatomic factors that affect the shape and size of the pharyngeal airway volume. Our results indicate that a low tongue moves toward the palate because nasal airway obstruction was reduced by RME (Table III). However, there was no significant association between intraoral airway volume and pharyngeal airway volume. As a result, we believe that total airway volume enlargement occurred by expansion of the palate volume rather than by upward tongue movement.

In our study, RME improved both tongue posture and nasal airway obstruction. RME has been shown to be an efficacious treatment for OSAS in children.[9-11] Kulnis et al[46] reported a relationship between a low hyoid position and OSAS in children. Seto et al[33] reported that a constricted maxillary dentition and a low hyoid position are characteristic of OSAS. Their results suggest that maxillary constriction with nasal obstruction can cause low tongue posture and consequent retroglossal narrowing. We concluded that RME should improve nasal obstruction and low tongue posture, and enlarge the pharyngeal airway. RME will contribute to the treatment of OSAS. Furthermore, RME caused relatively greater enlargement of the retropalatal airway than the oropharyngeal airway. So, RME might be effective for a ventilation disorder in the pharyngeal airway.

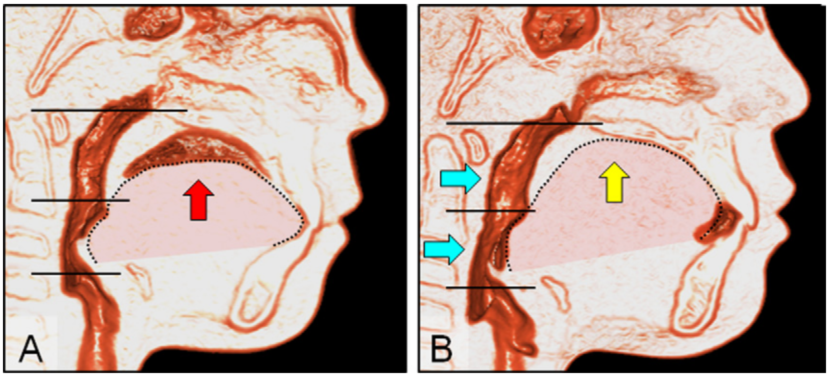

Fig 7. Improvement of low tongue posture and enlargement of the pharyngeal airway after RME in a patient: **A,** before RME, tongue posture is low (*red arrow*), and the oropharyngeal airway is narrow; **B,** after RME, tongue posture has improved (*yellow arrow*), and the pharyngeal airway has enlarged (*blue arrows*).

Because our study was retrospective, it was limited to children without adenoids or hyperplasia of the palatine tonsils.[42] Adenoids and hyperplasia of the palatine tonsils are common in pediatric OSAS. Therefore, data indicating airway enlargement by RME of children with these problems are still required. Future studies should also take the computed tomography data in the supine position during sleep to match the usual clinical examination. Furthermore, a study evaluating actual respiratory status is required in the future.

CONCLUSIONS

We comprehensively examined the effect of RME on nasal airway ventilation condition, tongue posture, and pharyngeal airway volume.

Children with nasal airway obstruction have a low tongue posture regardless of RME treatment.

Improvement of the nasal airway ventilation condition by RME is associated with improved low tongue posture.

RME enlarges the pharyngeal airway both with and without improvement in nasal obstruction.

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