Effect of Rapid Maxillary Expansion on Upper Airway Morphology: A Retrospective Comparison of Normal Patients versus Patients with Enlarged Adenoid Tissue.

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Objectives The present study evaluated the effect of rapid maxillary expansion (RME) on the morphology of the upper airway (UA) by calculating cross-sectional areas and volumes and comparing the effect in patients with a normal-sized adenoid with the effect in patients with an enlarged adenoid. Study design: Seventeen patients met the inclusion criteria. We constructed 3D models of the UA on cone-beam computed tomography images to calculate cross-sectional areas and volumes at the levels of the nasopharyngeal, retropalatal, and retroglossal airways. Patients were divided into two groups: group 1 was comprised of patients with an adenoidal nasopharyngeal (AN) ratio < 0.6 *and group 2 with an AN ratio* ≥ 0.6. *Paired samples t-tests assessed any area and volumetric changes of the UA after RME. Changes in degree of nasal obstruction, calculated as the AN ratio, was then compared for the two groups. An independent samples t-test compared volumetric changes in the nasopharynx between the two groups before and after RME.*

Results Changes in cross-sectional areas and volumes of the UA due to RME were not significant. The effects of RME on AN ratio (11 % vs 0 %) and nasopharyngeal volume (36.8 % vs 5.97%) were somewhat larger in group 2 patients who had adenoid-associated nasal obstruction compared with group 1 patients with a normal-sized adenoid; however, the differences were not significant. Conclusions After RME, the patients with an enlarged adenoid had more increases in nasopharyngeal volume compared with those with normal adenoid, despite there was no significant difference.

Keywords: Adenoid hypertrophy; Upper airway; Rapid maxillary expansion; 3D.

INTRODUCTION

Abnormal alignment of the teeth and jaws often benefit from orthodontic treatment. Since 1860, rapid maxillary expansion (RME) has been used to increase the transverse dimensions of the maxillary arch of orthodontic patients 1. RME achieves this by widening the mid-palatal suture 2. During expansion of the maxillae, the lateral walls of the nasal cavity and the adjacent structures surrounding the nasopharynx move outward 3. This mechanism has led some researchers to speculate that RME may increase nasal space and reduce nasal obstruction, which could improve respiratory function and thus be a beneficial therapy for patients with obstructive sleep apnea 4-7. Villa et al suggested starting RME treatment as soon as symptoms of obstructive sleep apnea appear in children who have moderate adenoid hypertrophy (AH) and malocclusion 5. The adenoid, one of the lymphoid tissues that make up Waldeyer's ring, is located on the posterior nasopharyngeal wall 8. A study comprising a random sample of 4778 patients reported an AH prevalence of 34.46% 9. During the course of childhood and adolescence, the adenoid changes in size. At birth, the adenoid is small. It progressively enlarges over the first 4 years

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of life and then tends to regress during adolescence. Fujioka et al 10 originally introduced the adenoidal nasopharyngeal (AN) ratio as a method for determining the degree of nasal obstruction in children and adolescents on lateral radiographs. Duan et al found the AN ratio to be a useful and reliable method for diagnosing AH and posterior upper airway obstruction 11.

Early evaluations of the effect of RME on nasal obstruction reduction using acoustic rhinometry, cephalometric radiographs, and computed tomography were inconclusive 12-15. Cone-beam computed tomography (CBCT) has been widely applied in dentistry since its introduction at late nineties. CBCT imaging allows segmentation and visualization of the upper airway (UA) in three dimensions with lower radiation doses and costs compared with conventional computed tomography 16. In a CBCT study, Chang et al found that only the cross-sectional area of retropalatal airway at the level of the basion-posterior nasal spine line was significantly increased after RME 17. Almuzian found that after RME, the nasopharyngeal volume was significantly increased whereas the upper retropalatal volume was significantly reduced 18.

So far, no consistent conclusions on area and volume changes of the UA after RME can be found in the literature, especially, no previous publications have studied the outcome of RME associated with adenoid size by applying CBCT images 19. The aim of this study was to evaluate the effect of RME on the morphology of the UA in patients with and without adenoid hypertrophy.

MATERIALS AND METHOD

Data were retrospective. All patients had been referred to the Department of Orthodontics at the Stomatological hospital, Dalian, China for RME between January 2013 and December 2016. The inclusion criteria were patients younger than 15 years who had had RME for orthodontic indications and for whom there were pre- and post-RME CBCT scans. The pre-RME CBCT scan was made in the 7 days before cementation of the expander (T0), and the post-RME CBCT scan was taken at the end of the retention phase (T1). The exclusion criteria were previous orthodontic or orthopedic treatment; major craniofacial abnormalities; previous soft-tissue surgery for respiratory obstruction, such as tonsillectomy, adenoidectomy, and adenotonsillectomy; neuromuscular diseases; and other systemic diseases based on the anamneses. An experienced radiologist reviewed all CBCT scans and ensured that the field of view (FOV) covered the nasopharyngeal, retropalatal, and retroglossal airways. Images with inappropriate head positioning, such as head extension and head rotation, were excluded.

The ethics committee of China, (DLKQLL201604, Dalian Stomatological Hospital) and the ethics committee of Norway (2018/1547 REK Vest, University of Bergen) approved the study.

RME procedure

RME involved banding a fixed Hyrax expander to the maxillary first premolars and first molars. The patient, or the patient's guardian, rotated the expansion screw twice a day at home. An orthodontist monitored progress in expansion once a week until the desired expansion was achieved, with 2–3 mm of overexpansion to compensate for relapse after the procedure 17. The expander remained in place, and the expansion screw stationary, for at least 3 months after completed expansion to allow for new bone formation and for the mid-palatal suture to stabilize.

CBCT scans

The CBCT scans had been made with an FOV of 16 x 13 cm at 120 kVp, 5 mA and a scanning time of 14.7 seconds (3D eXam; KaVo, Biberach an der Riss, Germany). Voxel size was 0.2 mm, and contrast resolution was 14-bit depth. All CBCT examinations followed standardized clinical routines, that is, with the Frankfort horizontal plane parallel to the floor, the teeth in maximum intercuspation, and the patient breathing calmly with no swallowing. For analysis, we imported all CBCT images into Dolphin imaging software (Dolphin Imaging & Management Solutions, Chatsworth, Calif, USA) in the digital imaging and communications in medicine (DICOM) format.

Adenoidal nasopharyngeal ratio

Before identifying any landmarks, we created 3D renderings of the CBCT scans: the renderings were oriented along axial planes that paralleled the Frankfurt horizontal planes; the mid-sagittal planes intersected the nasion and anterior nasal spine; and the coronal plane was adjusted to the level of porion. We defined the degree of nasal obstruction as the AN ratio, which represents the degree of obstruction on lateral radiographs as the ratio of the thickness of the adenoid to the width of the nasopharynx. Fujioka et al. 10, who first coined the term, defined A as the thickness of the adenoid on a 2D image as the perpendicular distance between the point of convexity of the adenoid shadow and the anterior margin of the basiocciput, and N as the distance between the posterosuperior edge of the hard palate and the anteroinferior edge of the spheno-occipital synchondrosis. The present study modified this measurement procedure in order to apply the AN ratio to 3D imaging. We measured A by scrolling through the sagittal slices to identify the sagittal slice that showed maximal convexity of the adenoid, and where the intersecting axial view also showed maximal convexity. To measure N, we identified the posterosuperior point of the hard palate and the anteroinferior point of the spheno-occipital synchondrosis on the mid-sagittal plane (Fig. 1).

All patients were divided into two groups according to the AN ratio at baseline (T0): group 1 comprised individuals with an AN ratio < 0.6 and group 2, with AN ratio ≥ 0.6.

3D Airway reconstruction

Three-dimensional models of the UA were constructed as described previously 20. We then drew four reference lines on the midsagittal plane of the CBCT image that divided the UA into the nasopharyngeal, retropalatal, and retroglossal airways, as Chang et al suggested 17,21. After defining the axial planes at three inferior cross-sections – between the three airways and the UA – we were able to calculate the cross-sectional areas of the nasopharyngeal, retropalatal, and retroglossal spaces (Table 1). The Dolphin imaging software calculated the volumes of these spaces after we had manually defined the boundaries of the three airways (Fig. 2). One radiologist (XF) made all measurements under identical viewing conditions in a room with dimmed light. To assess measurement error, 10 CBCT images were randomly selected and the same operator (XF) measured the nasopharyngeal volumes again 1 week later.

Figure 1: Calculating the adenoidal nasopharyngeal (AN) ratio. (A) Perpendicular distance between maximum convexity of the adenoid shadow and the anterior margin of the basiocciput. (B) Distance between the posterosuperior edge of the hard palate and the anteroinferior edge of the spheno-occipital synchondrosis.

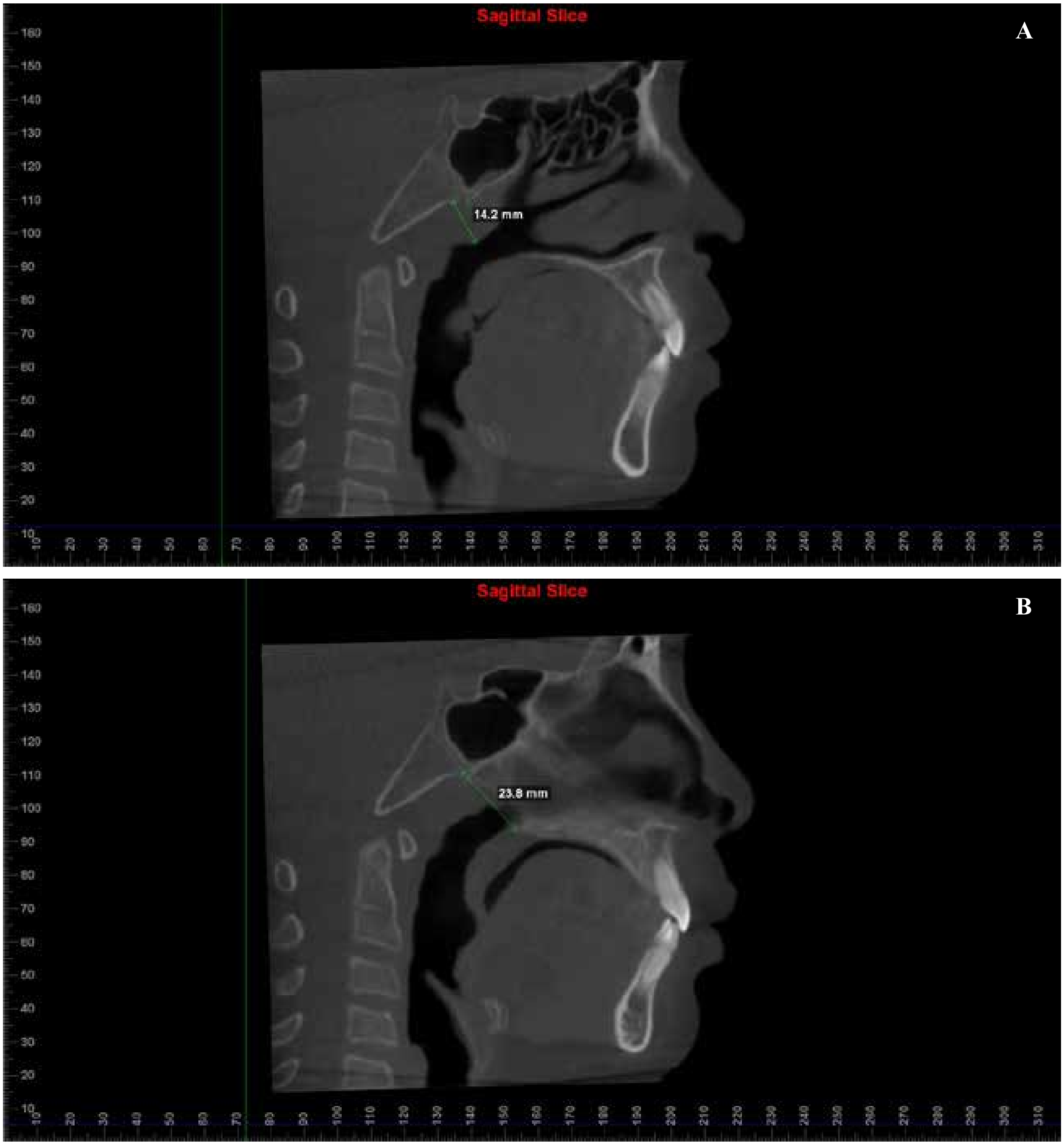
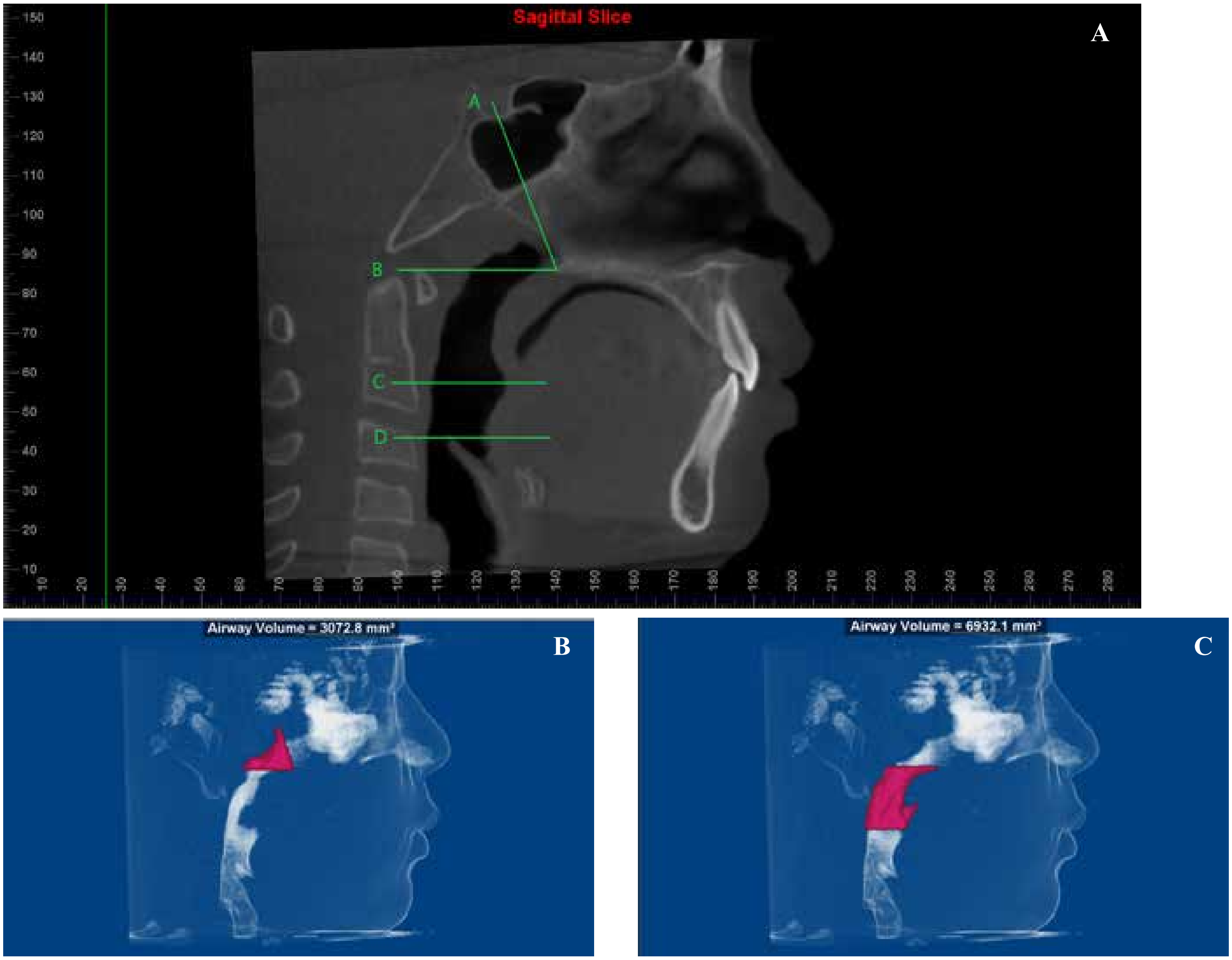


Figure 2: **(A) Four lines on the mid-sagittal slice of a cone-beam computed tomography image: line A connects the midpoint of sella turcica and the posterior nasal spine, line B connects the posterior nasal spine and the wall of the posterior airway, line C connects the tip of uvula and the wall of the posterior airway, and line D connects the tip of the epiglottis with the anterior and posterior walls of the airway. (B) Nasopharyngeal airway with line A forming the superior border and line B forming the inferior border. (C) Retropalatal airway with line B forming the superior border and line C forming the inferior border. (D) Retroglossal airway with line C forming the superior border and line D forming the inferior border.**



Data analysis

The data were processed using the Statistical Package for the Social Sciences (SPSS Statistics, version 25.0, IBM, New York, NY, USA). Significance was set at p less than 0.05. Intraclass correlation coefficients (ICCs) were calculated to indicate measurement reliability.

To evaluate the effect of RME on UA morphology, we used the paired samples t-test to compare cross-sectional areas and volumes at T0 and T1. AN ratios were calculated, and we made between-group comparisons at T0 and T1 using the paired samples t-test. The percentage change in nasopharyngeal volume, calculated as [(T1–T0)/T0]100 was assessed and compared for the two groups using an independent samples t-test.

In making the sample size calculation for the present study, we used the findings of Smith et al, that a significant increase in nasopharyngeal volume was observed after RME 22. To achieve statistical power of 80% at a significance level of 0.05, we would need a sample size of 11 subjects to detect a mean change of 361 mm^3 in nasopharyngeal volume between T0 and T1.

RESULTS

Seventy-two patients at the Department of Orthodontics underwent RME between January 2013 and December 2016. We excluded 49 patients who had not had a CBCT examination before the procedure, 1 patient who underwent an adenotonsillectomy during RME, 2 patients who had not had a CBCT examination after RME, and 3 patients who were older than 15 years. The present study had a final study sample of 17 patients aged 12.2±1.3 years (6 female, 11 male; Fig.3). The average period of expansion was 4 weeks, and the mean time interval between CBCT scans at T0 and T1 was 5.7 months.

After RME, the areas and volumes of the UA of the three spaces we were studying tended to increase. Volume increase was most pronounced at the nasopharyngeal level, by a mean of 18.66% (n = 17). However, neither this change, nor any of the other changes, were significant (Table 2). Among the 17 patients, ten patients formed group 1 (mean age 11.9±1.29 years); seven patients formed group 2 (mean age 12.6±1.27 years). Table 3 lists the means and standard deviations of the AN ratios for the two groups at T0 and T1. In group 1, the mean AN ratio was consistent at T0 and T1 whereas in group 2, the mean AN ratio varied from 0.72 to 0.64, had decreased by 11% at T0 and T1, but the difference was not significant. Mean nasopharyngeal volume had increased by 5.97% in group 1 and 36.8% in group 2 at T1 when compared with T0, but the differences between the two groups were not significant (Fig. 4). The ICC of the 3D volume measurements was 0.98, indicating excellent reliability.

Figure 3: Flowchart of patient selection

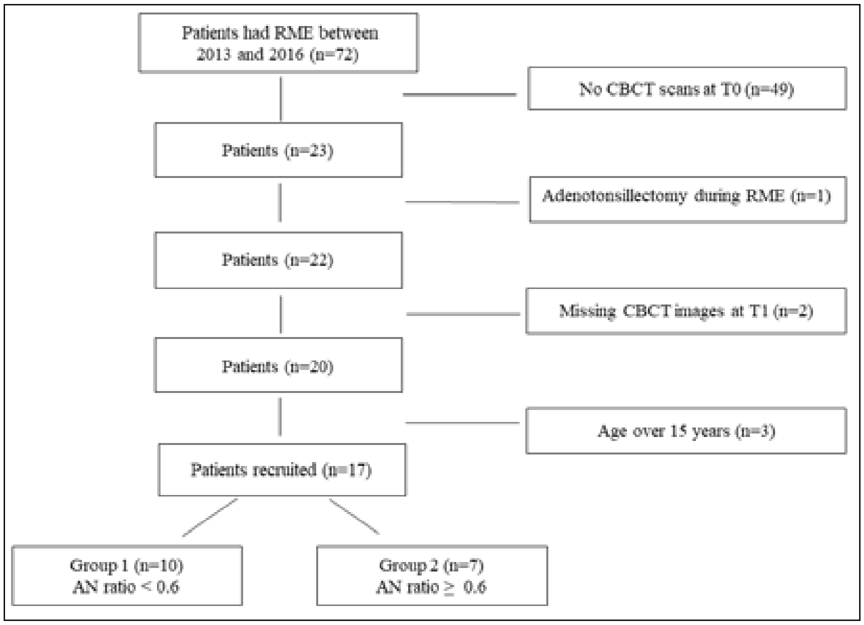


Figure 4: Nasopharyngeal volume (mean [SD]) in group 1 and group 2 at (A) baseline before rapid maxillary expansion (RME; T0) and (B) after RME (T1). (C) Nasopharyngeal volume after RME (mean change [range]) in groups 1 and 2

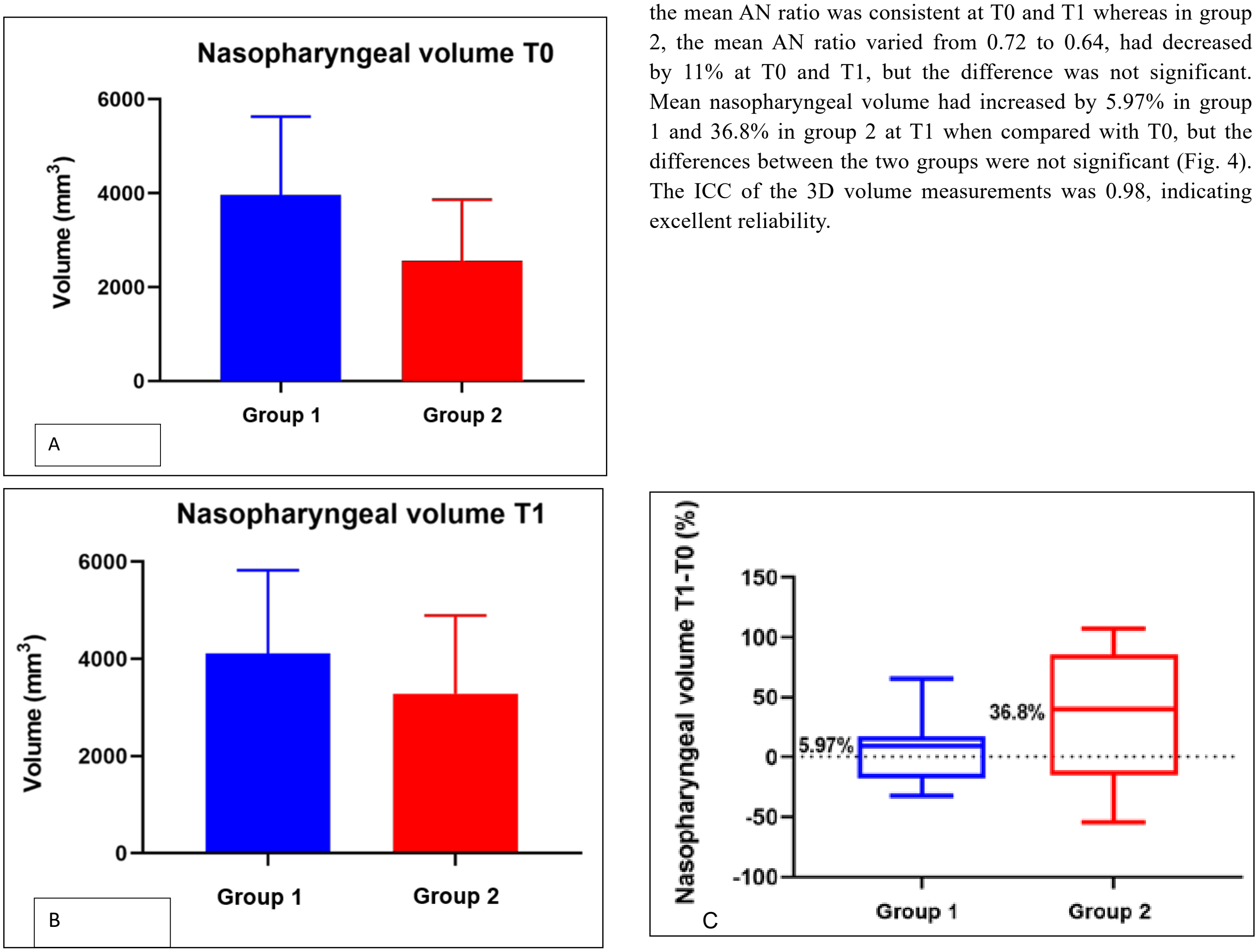


Table 1 **Description of the 3D pharyngeal airway measurements made on cone-beam computed tomography images of the midsagittal plane. Cross-sectional areas were calculated on the relative axial plane**

		Measurement description
References lines		
	A	Connects the midpoint of the sella turcica and the posterior nasal spine
	B	Intersects the posterior nasal spine; parallels the Frankfort plane
	C	Intersects the tip of the soft palate; parallels the Frankfort plane
	D	Intersects the tip of the epiglottis; parallels the Frankfort plane
Cross-sectional areas		
Nasopharyngeal		The intersection of the upper airway and line B
	Retropalatal	The intersection of the upper airway and line C
	Retroglossal	The intersection of the upper airway and line D
Volumes		
Nasopharyngeal		Airway formed by lines A and B
	Retropalatal	Airway formed by lines B and C
	Retroglossal	Airway formed by lines C and D

Table 2 **Airway area and volume measurements on cone-beam computed tomography images before (T0) and after (T1) rapid maxillary expansion, and the change [(T1–T0)/T0%] in area and volume parameters during the treatment period (n = 17 participants)**

	T0		T1		Change (%)		*p*-value
	Mean	SD	Mean	SD	Mean	SD	
Area (mm^2)							
Nasopharyngeal	320.16	113.10	319.31	115.78	2.82	34.93	0.965
Retropalatal	193.54	82.91	209.55	89.96	13.25	33.62	0.266
Retroglossal	237.96	95.74	241.25	107.32	3.18	27.20	0.776
Volume (mm^3)							
Nasopharyngeal	3383.24	1648.17	3769.95	1670.48	18.66	43.83	0.168
Retropalatal	5450.11	1534.19	5781.52	2188.29	4.92	23.29	0.283
Retroglossal	4497.22	2488.35	4590.56	2161.19	8.22	30.35	0.746

Table 3 **Comparison of adenoidal nasopharyngeal ratios in groups 1 (n = 10) and 2 (n = 7) before (T0) and after (T1) rapid maxillary expansion**

Group	N	T0		T1		*p*-value
		Mean	SD	Mean	SD	
1	10	0.49	0.07	0.49	0.15	0.81
2	7	0.72	0.12	0.64	0.16	0.08

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DISCUSSION

The geometric parameters of the cross-sectional areas and volumes had all increased after RME; most pronounced was the volume of nasopharynx. The increases, however, were not significant, which is in line with the results of other studies. Ribeiro et al 23 calculated volume changes in the nasal cavity, the nasopharynx, and the oropharynx on the CBCT images of 15 RME patients and reported that the volumes of the nasal cavity and the oropharynx, but not the nasopharynx, had increased significantly over a 4-month interval. Zhao et al 24 reported finding no significant changes in the volumes of retropalatal and retroglossal airways after RME. In contrast, other studies found nasopharyngeal volume to be significantly increased after RME 18,22,25. The discrepancies in findings in the previous literature may due to differences in study design and the applied sample size 26.

The CBCT images involved in this study were readily available from a large cohort study where the accuracy of tracing on 2D and 3D imaging was compared for patients who have received various orthodontic treatments. It was considered ethical to make use of the available material for research purposes (DLKQLL201604, 2018/1547 REK Vest). In that cohort study, only 17 patients had received RME and fulfilled the inclusion criteria. The limited number of cases could affect the certainty of our results. The authors want to emphasize that 3D imaging should not be routinely performed in order to obtain geometric information of the UA for orthodontic patients due to the increased radiation risk. If 3D imaging is indicated for UA examination, CBCT is preferred to multidetector computed tomography due to the reduced radiation dose 16.

AH is one of the most common causes of nasal obstruction and is considered to be a risk factor for Eustachian tube dysfunction. AH is also thought to affect speech and adversely alter facial growth and development 27-29. The present study calculated AN ratios from CBCT images, avoiding the limitations of 2D lateral cephalograms and improving measurement accuracy. Fujioka et al. reported that the AN ratio peaked at 0.59 at age 4, decreased to 0.38 at age 15 years, and stabilized and was considered non-clinically relevant after the age of 15 10. Thus, in the present study, we included patients under age 15 years for assessing changes in the AN ratio after RME 30. Even though the between-group comparison showed no significant differences in the change in AN ratios before and after RME, group 2 presented with a slight decrease in the AN ratio and a trend of enlarged nasopharyngeal volume. These morphological changes in the UA after RME might have two causes: the direct enlargement of the UA due to the force of expansion, and the physical regression of the adenoid tissue. We assume that the impact of the physical regression of the adenoid in the present study was limited, due to the relatively short course of the treatment. In our small group of patients with a narrow maxilla and enlarged adenoid, there is no significant morphological increase on the UA. However, we observed the changes of UA after RME and detected the effect of RME on specific patients with enlarged adenoid. This preliminary study provided imaging evidence to support the possibility of increasing the nasopharyngeal space by performing RME.

The present retrospective study only assessed the geometric dimensions of the upper airway; the severity of the nasal obstruction was based solely on imaging. No clinical evaluation of nasal obstruction was available as in other studies where clinical evidence of decreases in nasal obstruction were found after RME 5,6. In future, a prospective study that evaluated clinical symptoms of nasal obstruction could be useful in order to get a better understanding of the radiological and clinical changes in the case of child obstructive sleep apnea.

CONCLUSION

The effect of RME on volume changes of the nasopharyngeal airway and on the reduction of adenoid-associated nasal obstructions could not be statistically verified despite a tendency for an increase in volume in the nasopharyngeal region and a slight decrease in the AN ratio, particularly in patients with AH.

Conflicts of Interest

Xin Feng, Stein Atle Lie, Kristina Hellén-Halme, and Xie-Qi Shi declare that they have no conflicts of interest.

Human rights

All procedures were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1964 and later versions.

Informed consent

Informed consent was obtained from all study participants.

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The ethics committee of China, (DLKQLL201604, Dalian Stomatological Hospital) and the ethics committee of Norway (2018/1547 REK Vest, University of Bergen) approved the present study.

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