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A prospective CBCT study of upper airway changes after rapid maxillary expansion

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ABSTRACT

Objective: The aim of this prospective study was to investigate the upper airway changes after rapid maxillary expansion utilizing CBCT.
Methods: 16 children (10 male, 6 female) with a mean age of 12.73 $\pm$ 1.73 years underwent RME as part of their comprehensive orthodontic treatment with4,6-banded hyrax expanders. The screws were activated 2 turns a day. Depending on the expansion amount (2.7–6.3 mm), the activation period ranged from 2 to 3 weeks. CBCT images were taken immediately before (T1) and three months after expansion (T2) in upright position, with patients' heads kept in consistent position. All CBCT data were processed with the software EZ3D2009. After orienting the CBCT images, a set of linear, area and volumetric parameters of the upper airway were measured and calculated. Student paired t test and one-way ANOVA were applied. The significance level of $P < 0.0033$ was used according to the Bonferroni correction.
Results: After expansion, with molar-to-molar width increasing 4.4 $\pm$ 1.3 mm and molars tipping 6.2 $\pm$ 6.2°, the nasal floor width and nasal lateral width increased 1.6, 1.5, and 1.6 mm and 1.3, 1.7, and 1.4 mm from the anterior to the posterior part, respectively. And there was no difference among the anterior, median and posterior part. The lower nasal volume increased 1348.5 mm^3 with the percentage change being 8.1%. The pharyngeal airway showed no positive change.
Conclusion: RME can expand the nasal cavity and the expansion pattern may follow the parallel opening configuration. However, the influence on the pharyngeal airway is limited.

1. Introduction

Rapid maxillary expansion (RME) was first introduced in 1860s by Angell [1] for the treatment of maxillary constriction. After that, it has become a conventional orthodontic treatment. It is usually performed when maxillary constriction, posterior crossbite, arch length discrepancies and black corridors are observed in growing patients. But recently more and more researchers have found that RME may help to expand upper airway and improve breath function. Cameron [2] found out that the nasal width increased 4.16 mm in participants and 1.52 mm in controls utilizing postero-anterior cephalograms after 5 years follow-up. Monini [3] conducted RME on patients who both had maxillary constriction and snoring or nasal obstruction. The rhinomanometry results showed that the nasal flow increased and nasal resistance decreased after expansion.

There is still a lack of three-dimensional researches and noconsensus about the upper airway changes after RME. Smith [4] considered that the nasopharyngeal airway was expanded, with no change in oropharyngeal and hypopharyngeal airway. On the contrary, Ribeiro [5] found out that the oropharyngeal airway was widened with no change in nasopharyngeal airway. Because most of these three-dimensional researches are retrospective, the results can be biased by different head posture. Thus, we conducted this prospective study to evaluate the upper airway changes after RME.

2. Materials and methods

Based on a previous research which had estimated the sample size and concluded that there should be at least 8 subjects, [6] our research comprised 16 children (10 male; 6 female) with a mean age of 12.73 $\pm$ 1.73 years (range, 10-15 years) who were treated at the orthodontic department of Peking University School and Hospital of Stomatology since March 2011 and needed RME as part of their comprehensive orthodontic treatment. The inclusion criteria were constricted maxilla with or without posterior crossbite, upper first premolars and first molars erupted. The exclusion criteria were age above 15 years, severe adenoid or tonsil hypertrophy, severe periodontal disease, other simultaneous orthodontic treatment,

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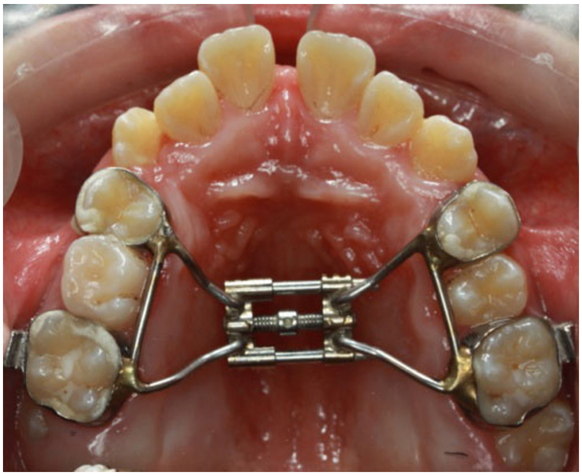

Fig. 1. 4,6-banded hyrax expanders.

history of systemic disease or presence of a craniofacial congenital syndrome which might affect the craniofacial growth. The study was approved by the institutional review board of the medical school of Peking University and informed consent was obtained from the parents of all subjects.

All subjects used 4,6-banded hyrax expanders (Fig. 1) which were all fabricated in the same laboratory according to the same method. Parents were instructed to activate the expanders 2 turns a day until the palatal cusps of the upper first molars contacted the buccal cusps of the lower first molars. The active expansion period ranged from 2 to 3 weeks according to the expansion amount

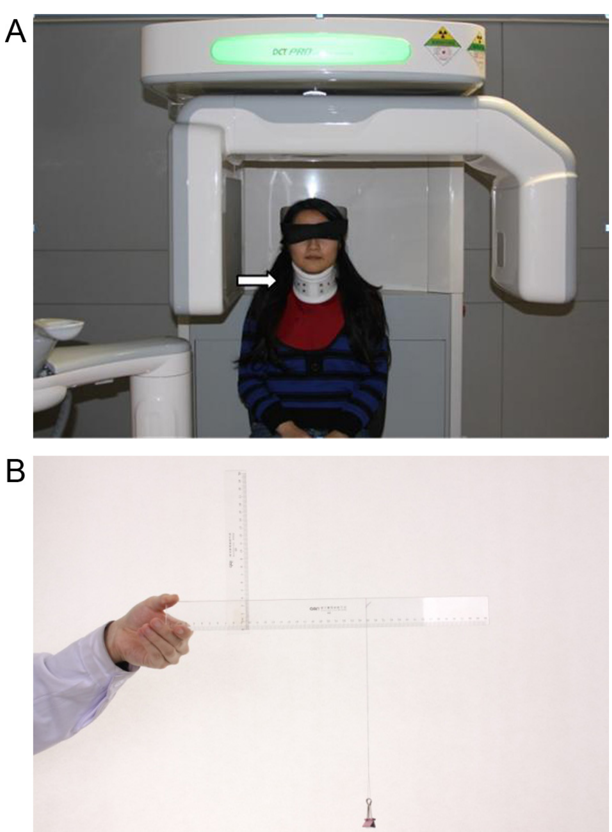

Fig. 2. (A) A cervical collar (arrow) was used to immobilize patient's head. (B) A cross ruler with a plumb line was used to ensure that the Frankfort plane was parallel to the ground.

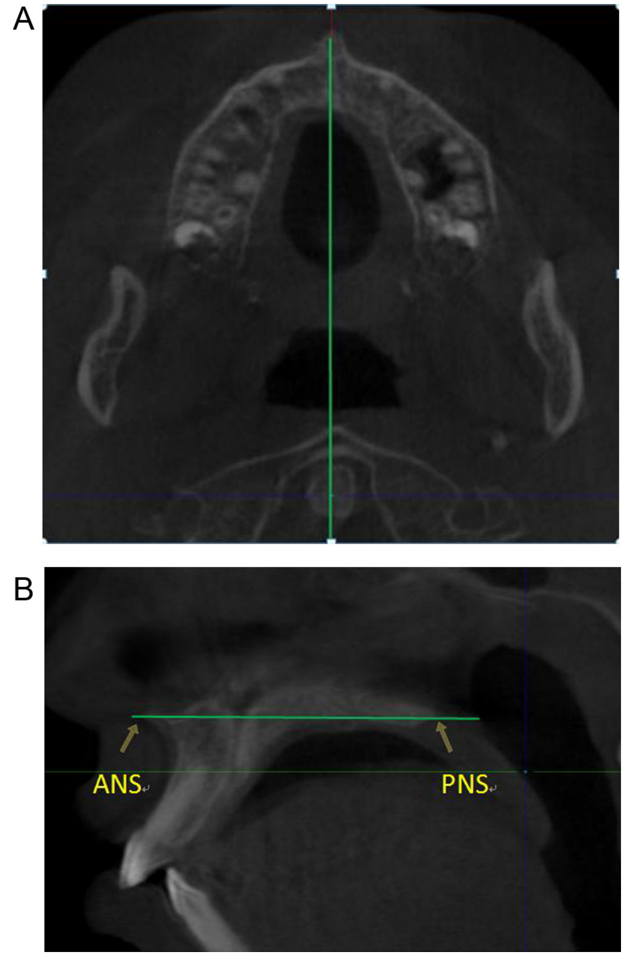

Fig. 3. The figures show how the CBCT images were oriented. (A) The midsagittal plane was adjusted on the line connecting the midpoints of the nasopalatine foramen and the spine. (B) The axial plane was adjusted on the palatal plane extending from anterior nasal spine (ANS) to posterior nasal spine (PNS).

(2.7–6.3 mm). Then the screw was locked with the light-cured composite. The retention period lasted 3 months.

All images were acquired with the CBCT scanner VATECH (DCTPRO-050Z, VATECH Co, Ltd, Korea) immediately before (T1) and 3 months after expansion (T2). The scans were taken with the patients in upright position. A cervical collar and a cross ruler were used to ensure that the patients kept still during image acquisition and the Frankfort plane was parallel to the ground (Fig. 2). All subjects were asked to occlude in the centric occlusion, breathe smoothly and not to swallow. The procedure was accomplished in the presence of the first author.

All CBCT data were transferred to a computer and measured using the software Ez3D2009 (version 1.0, E-WOO Technology Co, Ltd. Korea). Before landmark identification, the CBCT images were oriented with the Ez3D2009 software as follows: the midsagittal plane was defined as the line connecting the midpoints of the nasopalatine foramen and the spine in the axial view, the axial plane was adjusted on the palatal plane which extended from the anterior nasal spine (ANS) to the posterior nasal spine (PNS) in the sagittal view (Fig. 3).

Then 2 sessions of parameters were measured.

Session 1: The coronal session included the dental and nasal measurements. The molar width and molar tipping were evaluated on the coronal scan that bisected the palatal root of the upper first molars (Fig. 4). The measurement of the nasal cavity consisted of two steps. Firstly, the hard palate was divided into three equal

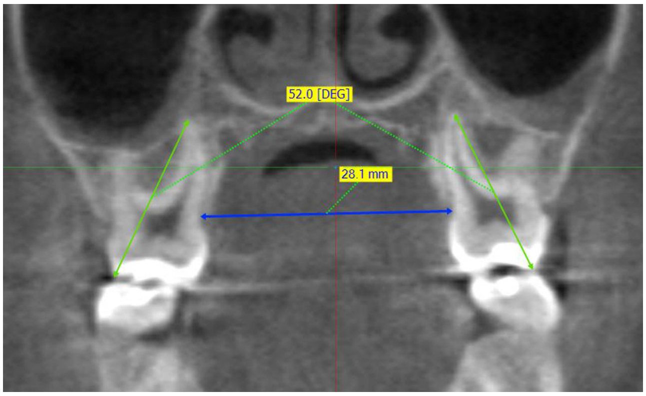

Fig. 4. Molar-to-molar width (MW) and molar tipping (MT).

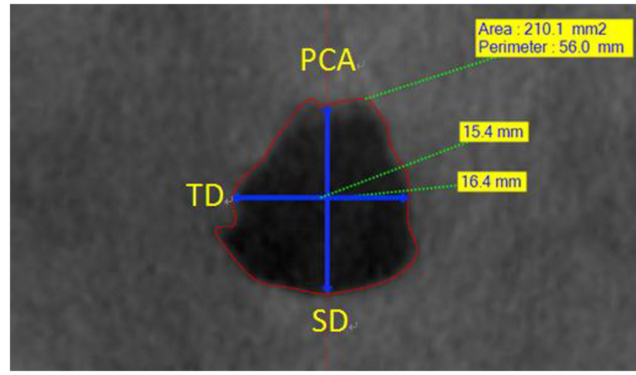

Fig. 6. The measurement of the pharyngeal airway cross-sectional area (PCA), sagittal dimension (SD) and transverse dimension (TD).

parts of which the midpoints were defined and numbered 1–3. Then measurements were evaluated on coronal scans passing through points 1–3 (Fig. 5).

Session 2: The axial session included all the pharyngeal measurements. This procedure was accomplished in two steps. Firstly, we defined the nasopharyngeal and oropharyngeal airway which were divided by the hard palate. Secondly, parameters such as the cross-sectional area, sagittal dimension and transverse dimension were measured and T/S was calculated (Fig. 6). The definitions of all the measurements were shown in Table 1.

All parameters were measured by the first author in a certain period of time. Then all images were remeasured two weeks later. Intraclass correlation coefficient (ICC) was used to test the intrareliability. If the ICC was equal to or greater than 0.75, the

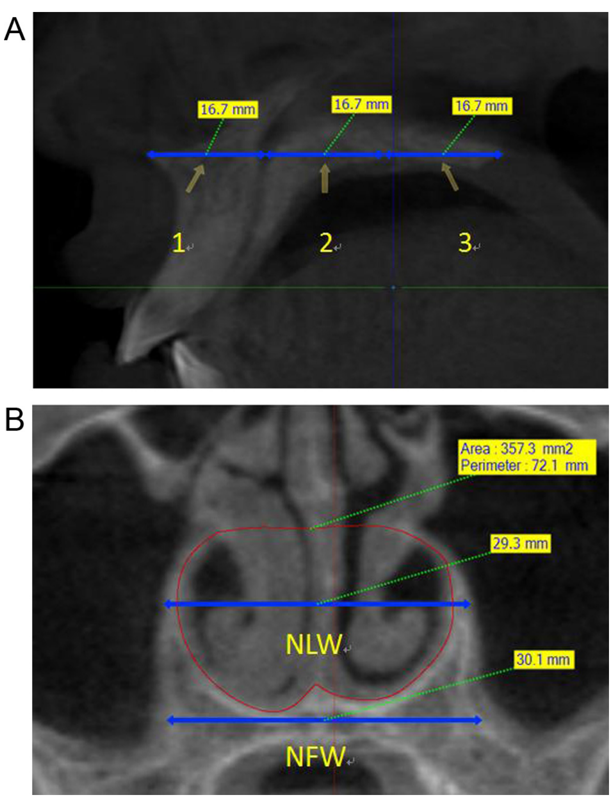

Fig. 5. (A) The hard palate which extended from ANS to PNS was divided into three equal parts, and the midpoint of each part was defined and numbered 1–3 which stood for the anterior, median and posterior part. All the nasal measurements would be evaluated on coronal scans passing through these midpoints. (B) The measurements of the nasal floor width (NFW) and nasal lateral width (NLW). The cross-sectional area was measured for volume calculation.

mean values of the two measurements were calculated and presented as the final results. Or the process would have been repeated two weeks later.

All CBCT data were analyzed in the softwareSPSS19.0. Normality was assessed with the Kolmogorov–Smirnov test. After that, the student paired *t* test was used to investigate the difference between the measurements before and after treatment. Then one-way ANOVA was done to test the difference among the anterior, median and posterior part of the nasal cavity. According to the principle of Bonferroni correction, with 15 paired *t* tests in total, the original significance level should be divided by 15. So $P < 0.0033$ was supposed to be applied. However, the Bonferroni correction could only be precisely used when tests were less than 10, or the results could be too conservative. So this was just for reference, we should get a comprehensive result combining both theory and practice.

3. Results

After expansion, both the dental and nasal measurements increased significantly. The results are shown in Table 2. In addition, the width change from anterior to posterior part showed no difference via one-way ANOVA test.As for pharyngeal measurements, the nasopharyngeal airway experienced no change while the oropharyngeal airway might narrow a little and the T/S might increase a little bit with their significance level between 0.05 and 0.0033.

4. Discussion

With the widespread application of RME, researchers have found that it has positive effect on some respiratory diseases and SDB (sleep-disordered breath) [7–11]. The mechanism has been investigated by means of rhinomanometry, acoustic rhinometry and computational fluid dynamics [12–16]. All had detected a reduction of airway resistance.

However, despite years of study, the morphological change of the upper airway is still under debate, especially the pharyngeal airway. Zhao reported no increase in retropalatal, retroglossal and oropharyngeal airway volume after expansion [17]. Smith found that the nasopharyngeal airway volume had a significant increase of 16.2% while the oropharyngeal airway volume decreased a little which was not significant and the author attributed it to the lowering of the palatine vault [4]. Conversely, Ribeiro pointed out that the oropharyngeal airway experienced a volume increase of 239 mm^3 while nasopharyngeal airway did not. But the author inferred that it might be due to the lack of standardized position of the head and tongue at the time of image acquisition [5].

Table 1
The definitions of the measurements.

Measurements	Definitions
Coronal session	
Molar-to-molar width (MW)	The width between the lingual alveolar crests of the upper first molars (Fig. 4)
Molar tipping (MT)	The angle formed by the lines traced from the mesialbuccal cusps to the palatal root apexes of the left and right upper first molars (Fig. 4)
Nasal floor width 1–3 (NFW1–3)	The distance between the two intersections of the line tangent to the nasal floor with the palate or the buccal contour of the maxilla on both sides (Fig. 5)
Nasal lateral width 1–3 (NLW1–3)	The sum of the distance of both the left and right most external points of the cortical bone of the nasal cavity to the midsagittal plane (Fig. 5)
Lower nasal volume (NV)	Multiply the palatal length (ANS-PNS) by the average area of cross-section 1–3 of the lower portion of the nasal cavity
Axial session	
Pharyngeal airway cross-sectional area (PCA)	5 cross sections of the nasopharyngeal airway and 10 cross sections of the oropharyngeal airway are measured. Then the average cross-sectional area is calculated (Fig. 6)
T/S	Transverse dimension divided by the sagittal dimension (Fig. 6)
Pharyngeal volume (PV)	Multiply the pharyngeal airway length by the average cross-sectional area

Table 2
Dental and nasal changes.

Measurements	T1	T2	Difference	*P*
MW (mm)	32.4 ± 3.1	36.8 ± 4.2	4.4 ± 1.3	0.000*
MT (°)	59.3 ± 9.0	65.5 ± 8.8	6.2 ± 6.2	0.008*
NFW1 (mm)	11.8 ± 4.0	13.4 ± 4.1	1.6 ± 1.1	0.001*
NFW2 (mm)	24.0 ± 7.1	25.4 ± 7.1	1.5 ± 0.4	0.000*
NFW3 (mm)	26.4 ± 4.3	28.0 ± 4.7	1.6 ± 0.9	0.000*
NLW1(mm)	28.0 ± 1.8	29.3 ± 2.0	1.3 ± 1.1	0.008*
NLW2 (mm)	31.4 ± 2.3	33.1 ± 3.1	1.7 ± 1.1	0.001*
NLW3 (mm)	30.1 ± 2.9	31.5 ± 3.5	1.4 ± 0.9	0.001*
NV(mm^3)	16521.7 ± 1729.1	17870.2 ± 1996.6	1348.5 ± 640.1	0.000*

MW, molar-to-molar width; MT, molar tipping; NFW1-3, nasal floor width 1–3; NLW1–3, nasal lateral width 1–3; NV, lower nasal volume.
* Significant.

In our study, there is no significant change occurring in the nasopharyngeal airway while the oropharyngeal airway might decrease a little. We consider there are several reasons. Firstly, the breathing stage of the patients is difficult to control which has influence on the airway size. Secondly, there is a large variance among the sample which we can tell from the standard deviation (Table 3). Last but not least, the average expansion amount is about 4.4 ± 1.3 mm, which may be not large enough to expand the pharyngeal airway. And molars tip $6.2 \pm 6.2^{\circ}$, which will also offset the effect. But there may be a trend that the oropharyngeal airway becomes oval with the T/S increasing a little. This kind of pharyngeal shape change may help to improve the respiration [18]. But since the change is very small, its contribution to respiratory function is limited.

The lower nasal volume increased significantly after expansion, with the absolute change being 1348.5 mm^3 and the percentage change being 8.1%. Görgülü [19] evaluated the overall nasal cavity volume and observed an average increase of 12.14%. Doruk [20] obtained a comparable result of 13.28%. Due to the fact that the separation of the nasomaxillary complex occurs in a triangular pattern with the wider base toward the inferior part [21], the lower portion of the nasal cavity experiences a major increment and could reveal the nasal volume changes to some extent [6]. In addition, we only investigate the skeletal nasal cavity to eliminate the influence of mucosa edema or turbinate hypertrophy.

After expansion, both nasal floor width and nasal lateral width increased (Table 2). And there is no difference among the width change of the anterior, median and posterior part. So the expansion pattern might follow the parallel opening configuration rather than the standard triangular opening pattern [22] or the pattern with the largest increase in the median part [5]. But it might have something to do with patients' age and the location of the screw.

There are several treatment options for maxillary deficiency of which the most commonly used are rapid and slow maxillary expansion (SME). RME is supposed to gain more skeletal response because the anchorage teeth do not have sufficient time to move and force is directly applied to the palatal suture. The reported ratios of dental to skeletal effects in SME range from 6:1 to 10:1 [23–26]. The skeletal gain in RME with hyrax appliance accounted for 38.5–39.2% (posterior) and 37.5–54.7% (anterior) of the total

Table 3
Pharyngeal changes.

Measurements	T1	T2	Difference	*P*
NPCA (mm^2)	242.9 ± 81.9	235.5 ± 97.0	-7.4 ± 76.5	0.712
NT/S	2.4 ± 0.9	2.7 ± 2.0	0.4 ± 1.3	0.269
NPV (mm^3)	2627.9 ± 1145.6	2449.2 ± 1210.5	-178.7 ± 884.7	0.447
OPCA (mm^2)	261.1 ± 85.9	224.7 ± 65.7	-36.3 ± 53.3	0.020
OT/S	1.6 ± 0.6	1.7 ± 0.6	0.1 ± 0.15	0.034
OPV (mm^3)	10883.0 ± 3631.1	9558.0 ± 2750.7	-1325.0 ± 2232.7	0.037

N, nasopharyngeal; O, oropharyngeal; PCA, pharyngeal cross-sectional area; T/S, transverse dimension divided by sigittal dimension; PV, pharyngeal volume.

expansion [22]. Pangrazio-Kulbersh [27] showed a larger skeletal expansion. So we chose RME to better expand the naso-maxillary complex.

As for the measurements of the pharyngeal airway, most researchers just focused on the volume changes, except that Zhao [17] had used the minimum cross-sectional area. Because PNS and the superior point of the epiglottis might change according to expansion, breathing or swallowing, the changes of volume could not directly reflect whether the airway was expanded or constricted. That is why we included the average cross-sectional area, as well as T/S to depict the airway changes in more detail.

The nasal and pharyngeal airway volumes were calculated by multiplying the overall length by the average cross-sectional area. Even with the errors, the volume calculated is comparable among patients. We did not use the automatic volume calculation function of this software after segmentating the area of interest by setting the threshold value, because the airway image extracted in this way is affected significantly by the threshold values which vary from person to person and it is difficult to determine an exact maximum or minimum value for an specific individual.

Although we only investigated the changes after three months follow-up, the long-term stability of the results is another important aspect of the treatment. To get a more stable result, firstly, a retention period is necessary. That is why the expanders stayed for three months before removed. Secondly, the causal factors need treated to prevent recurrence, such as adenoid hypertrophy, rhinitis, deviation of nasal septum, nasal turbinate hypertrophy, as well as the mouth breathing habit [28]. Bearing this in mind is important for the future study of long-term changes.

There are still some limitations of our research. Even though the head position is consistent before and after treatment, it is difficult to control the tongue position and the adjacent soft tissues associated with breathing and slight swallowing movements, especially when the image scanning time is as long as 30 s and the subjects are children. Because the expansion amount depends on the severity of the maxillary constriction, the effect on the pharyngeal airway may be not obvious in those whose problem is mild or moderate. In the future study, we should increase the sample size and choose subjects who need a larger expansion. In addition, patients' age may play an important role in the result. Those who are treated before the pubertal peak will display more skeletal effects [29]. We did not group the patients due to the small sample size. It should be improved in the future research.

5. Conclusion

After RME, the nasal cavity expands, which may play a major role in the breath function. The expansion pattern of the nasal cavity may follow the parallel opening configuration. But the influence on the pharyngeal airway is limited.

Conflict of interest statement

The authors do not have any conflict of interest.

Acknowledgments

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