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The Effects of Maxillary Protraction with Rapid Maxillary Expansion on the Upper Airway

Bingshuang Zou[1], Mona Hamoda[1], Weitao Liu[2]*, Alan A Lowe[1], Gang Li[2]

[1]Department of Oral Health Sciences, Faculty of Dentistry, The University of British Columbia, Vancouver, Canada

[2]Department of Orthodontics, School and Hospital of Stomatology, Peking University, Beijing, China

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***Corresponding author:** Weitao Liu, Department of Orthodontics, New Private practise at Institute for clinical research and application of sunny dental, Beijing, 100022, China

Abstracts

Background: The aim of this study was to evaluate area and volumetric changes in the upper airway after maxillary protraction with rapid maxillary expansion (MP/RME) using cone-beam computed tomography (CBCT) in Class III patients, and to relate these to the changes in cephalometric measurements.

Methods: Forty skeletal Class III Chinese patients (mean age: 9.6 years; range: 8-12 years) treated with MP/RME were retrospectively recruited. Pretreatment (T1) and post-treatment (T2) three-dimensional (3D) CBCT scans were used to measure the nasopharyngeal, velopharyngeal, glossopharyngeal, and hypopharyngeal airway changes in terms of volume, sagittal and cross-sectional area. Two-dimensional (2D) linear measurements in the upper airway space, adenoid, tongue, soft palate, and hyoid were performed on the cephalograms derived from 3D scans. Measurements at T1 and T2 were compared with paired t tests. A Spearman correlation analysis was used to evaluate the correlation between T1, T2, and treatment changes from both 3D and 2D measurements.

Results: Significant volumetric increases were found in the nasopharynx ($P < 0.001$), velopharynx ($P < 0.01$), and total upper airway ($P < 0.001$). The nasopharyngeal space (PNS- UPW) showed a significant increase ($P < 0.001$) on cephalograms. The 2D adenoid dimension had a positive correlation with the nasopharynx measurements on CBCT.

Conclusion: The volume of the nasopharynx and velopharynx increased significantly after MP/REM treatment. When compared with a 3D normal sample, the results suggest that MP/RME would not inhibit the anticipated increase of upper airway volumes in Class III children in the short-term. Dimensional measurements of the adenoid on cephalometric images are related with the area and volumetric parameters of the nasopharyngeal airway.

Keywords: Upper Airway; Cone-Beam CT; Cephalometry; Class III Malocclusion; Maxillary Protraction

Abbreviations: CBCT: Cone-Beam Computed Tomography; MP: Maxillary Protraction RME: Rapid Maxillary Expansion; NPS: Nasopharyngeal Space; BAMP: Bone-Anchored Maxillary Protraction; CSA: Cross-Sectional Area; SD: Sagittal Diameter; TD: Transverse Diameter; MSA: Mid-Sagittal Area; MAA: Minimum Axial Area; ANR: Adenoid Nasopharyngeal Ratio; RCT: Randomized Controlled Trial; OSA: Obstructive Sleep Apnea; ICC: Intraclass Correlation Coefficients; DICOM: Digital Imaging and Communications in Medicine Files

Background

Treatment of skeletal Class III malocclusions is a challenging orthodontic correction: it is associated with maxillary undergrowth, mandibular overgrowth, or the combination of both conditions. Maxillary protraction with rapid maxillary expansion (MP/RME) treatment is commonly used for the Class III malocclusion in growing patients who exhibit maxillary undergrowth [1,2]. The main effects of this treatment in growing patients include the forward displacement of maxilla, backward displacement of the mandible, clockwise rotation of the mandibular plane and counterclockwise rotation of the palatal plane [3-6]. Interest in the upper airway has increased steadily due to improved understanding of the relationship between craniofacial morphology and obstructive sleep apnea (OSA) [7-10]. The effects of maxillary protraction (MP) with or without rapid maxillary expansion (RME) on the upper airway have been extensively investigated using two-dimensional (2D) cephalograms in Class III subjects [11-20]. Recently, airway studies have used three-dimensional (3D) cone beam computed tomography (CBCT) to assess the upper airway since it offers numerous advantages compared to lateral cephalograms, including volumetric (rather than linear) measurements that are distortion-free [21]. CBCT was reported to provide a low-radiation rapid scan capability to assess patients' airway using highly correlative linear, cross-sectional area, sagittal area, and volumetric measurements that include assessing the morphometry of the airway [22,23]. To date, a few studies using CBCT [24-27] to assess the effects of MP/REM on upper airway have been published; however, the results are inconsistent due to small sample size, different methods involved in the MP procedure, different demarcation of the pharyngeal airway, or the specific control group used. Pamporakis et al. [24] reported that MP/RME treatment actually inhibited the normal expected increase of pharyngeal volume when compared with a different ethnical normal sample.

Nguyen et al. [25] compared airway volumes and minimum cross-section area changes among Class III patients with bone-anchored maxillary protraction (BAMP) alongside an untreated Class III control and concluded that BAMP treatment did not hinder the development of the oropharynx, but they failed to incorporate the nasopharyngeal airway which was considered to be an important part of the airway study. Chen et al. [26] evaluated the changes in the upper airway in Class III patients undergoing MP/RME treatment in comparison with an untreated control group and ultimately suggested that the treatment led to a significant increase in the volume of the nasopharynx and velopharynx. However, the control group of a certain point of time was not able to deliver the dynamic information of the upper airway and unsuitable to serve as a control. Ozbilen et al. [27] evaluated and compared the changes in the pharyngeal airway and maxillary sinus volume after RME and alternate rapid maxillary expansion and constriction followed by facemask therapy and found that the different expansion devices and protocols used with MP therapy do not affect the forward movement of the maxilla and PA volumes. And also, no control group was included due to ethical issue. The aim of the present study was to evaluate the upper airway after MP/RME procedure by the means of CBCT and lateral cephalometry with the following objectives: to investigate area and volumetric changes of the upper airway in skeletal Class III patients undergoing MP/RME treatment; and to compare the 3D CBCT changes to the changes in 2D linear measurements from lateral cephalograms.

Methods

Samples

Forty Class III patients (28 females and 12 males; age range, 8-12 years; mean age, 9.6 years; standard deviation, 1.6 years) were retrospectively selected from the records of the Department of Orthodontics, School and Hospital of Stomatology, Peking University, China, during the period from 2010 to 2012. All the patients were treated using MP/RME and with pretreatment and posttreatment CBCTs. The other inclusion criteria were: (1) a skeletal Class III relationship (ANB < 0°) with maxillary hypoplasia (SNA < 80°), (2) no previous orthodontic/orthopedic treatment, (3) no systematic diseases, craniofacial anomalies or temporomandibular joint disorders, (4) no history of tonsillectomy/adenoidectomy. The project was approved by the Clinical Research Ethics Board at the University of British Columbia, Canada (H14-02933). A sample calculation based on previous studies [10,28] showed that at least 17 subjects would be necessary to detect a difference of 65 mm^2 in the minimal cross-sectional area and 2500 mm^3 in the pharyngeal airway volume with a power of 0.8 and significance level of 0.05.

Treatment Protocol

The RME appliance used was a Hyrax appliance (Dentaurum, Ispringen, Germany) banded on the maxillary first premolars and first molars (Figure 1). Parents were instructed to activate the expansion screw twice a day for a period of 10 to 14 days. At the end of expansion, maxillary protraction with a facemask commenced (Figure 2). The elastic direction was 15° to 30° downward from the occlusal plane, delivering a force between 400 - 500g per side. Patients were instructed to wear the appliance for at least 14 hours a day, and the treatment was continued until the anterior cross bite was overcorrected with a Class II or Class I molar relationship and a minimum overjet of 3 mm. The average treatment time was 13.0 ± 4.1 months.

Figure 1: Hyrax expander.

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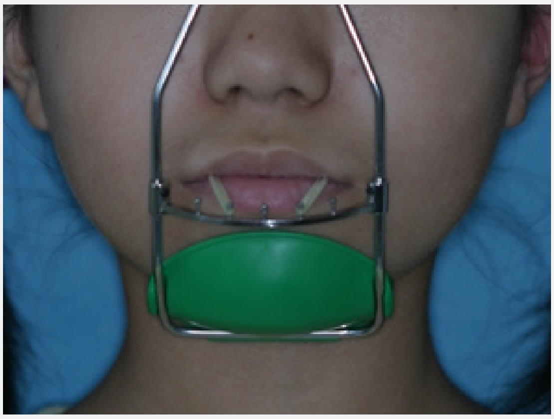

Figure 2: Maxillary protraction facemask.

Imaging Procedure

The CBCT scans were taken before bonding of the Hyrax expander (Pretreatment) and immediately after removal of the appliances (Posttreatment), with a VATECH machine (DCTPRO-050Z, VATECH Co, Ltd, Hazing, Korea). The scanning protocol was 90 kV, 7 mA, 15 × 15 cm field of view, 0.4 mm voxel, and a scanning time of 12 seconds. The scans were taken with the patients in an upright position. The patients were told to maintain a natural head position with the teeth in occlusion, breathe normally, and not to swallow during the examination. All CBCT images were saved and exported as Digital Imaging and Communications in Medicine files (DICOM).

CBCT Measurements

The Dolphin Imaging software (version 11.7; Dolphin Imaging & Management Solutions, Chatsworth, California, USA) was used for 3D measurements in the upper airway. The horizontal reference plane was defined bilaterally by the porion to orbitale line (Frankfort horizontal plane, FH) in the mid-sagittal view and oriented with the inferior orbital rim of the orbits parallel to the true horizontal in the frontal view [23]. The upper airway was divided into four distinct anatomic regions (Figure 3) as described by Li et al. [29] and Chen et al. [26] studies: (1) the nasopharynx, which was defined from choanae to the posterior nasal spine (PNS) plane; (2) the velopharynx, which was defined from PNS plane to the plane through the tip of the uvula (U); (3) the glossopharynx, which was defined from U plane to the plane passing the top of epiglottis (Et); and (4) the hypopharynx region, which was defined from Et plane to the plane going through the base of epiglottis (Eb). Cross-sectional area (CSA) of the upper airway was respectively measured on each axial slice going through PNS (for nasopharynx), U (for velopharynx), Et (for glossopharynx) or Eb (for hypopharynx) by following the perimeter of the airway with the cursor (Figure 4). The sagittal diameter (SD) and transverse diameter (TD) on the axial slice were also measured to calculate the ratio SD/TD in order to evaluate the shape of the upper airway. The cross-sectional configuration turns more circular when the ratio increases, while it turns more elliptic if the ratio decreases. With the sinus/airway analysis, boundary position, seed point, and update volume options, the airway volume and mid-sagittal area (MSA) for each segment, and minimum axial area (MAA) for the upper airway were automatically computed and recorded (Figure 5). The threshold value was set at 70 to 75 units after consecutively observing that this scope provided the most ideal airway selection without adding or leaving out upper airway space [30].

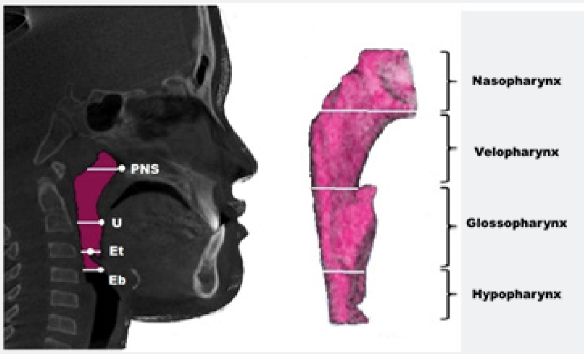

Figure 3: Segmentation of the airway: nasopharynx, velopharynx, glossopharynx, and hypopharynx. Separated by planes going through PNS (posterior nasal spine), U (tip of the uvula), Et (top of epiglottis), and Eb (base of epiglottis) points on the mid-sagittal slice.

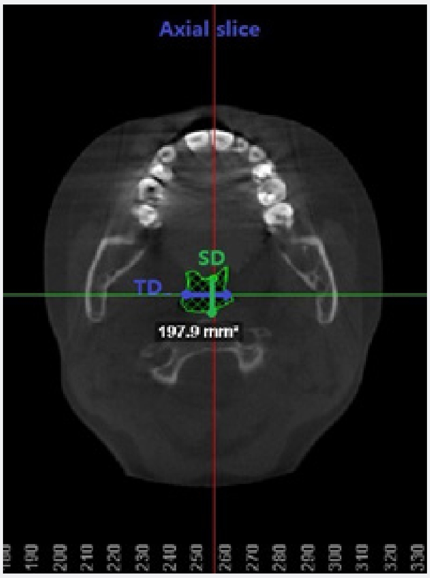

Figure 4: Illustration of airway cross-sectional area measurement (197.9mm^2, recorded as CSA for velopharynx) in an axial slice through the plane of U (tip of uvular). SD, sagittal diameter; TD, transverse diameter. SD/TD ratio was used for describing the configuration of the upper airway.

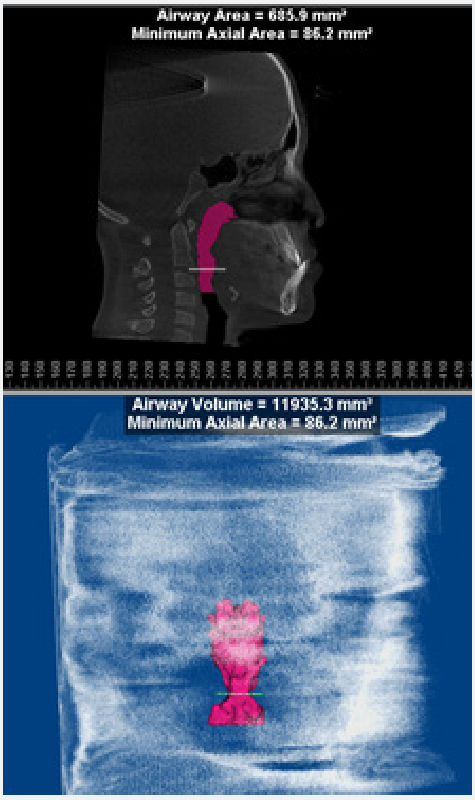

Figure 5: Illustration of automatic calculations of the total mid-sagittal area (685.9 mm^2, recorded Total MSA), minimum axial area (86.2 mm^2, recorded as minimum CSA) and total upper airway volume (11935.3 mm^3, recorded as Total Volume).

Cephalometrics

The cephalograms were derived from the 3D scans using Dolphin Imaging and the images were measured directly for cephalometric analysis, which included the upper airway, adenoid, tongue, soft palate, and hyoid dimensions. The following landmarks were localized to obtain respective linear measurements (Figure 6).

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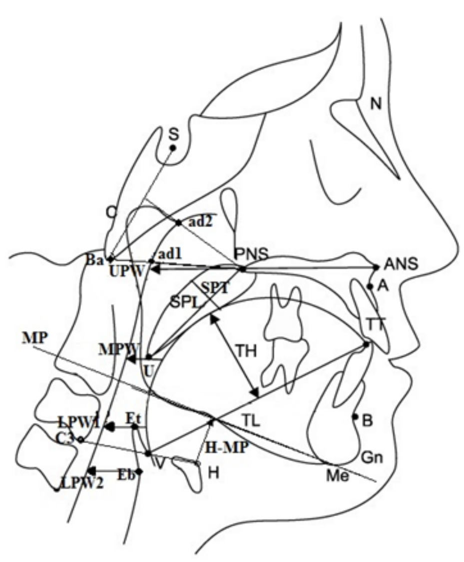

Figure 6: Reference points, lines and linear measurements on the lateral cephalograms used in the study. PNS: posterior nasal spine; U: tip of uvula, the most posteroinferior point of the uvula; Et: top of epiglottis; Eb: base of epiglottis; UPW: upper pharyngeal wall, intersection of a horizontal line through PNS with the posterior pharyngeal wall; MPW, middle pharyngeal wall, intersection of a horizontal line through U with the posterior pharyngeal wall; LPW1, lower pharyngeal wall, intersection of a horizontal line through Et with the posterior pharyngeal wall; LPW2, lower pharyngeal wall, intersection of a horizontal line through Eb with the posterior pharyngeal wall; ad1, intersection of the line from Ba to PNS with the posterior pharyngeal wall; ad2, intersection of the line from PNS to the midpoint of the line from Ba to S with the posterior pharyngeal wall; V: vallecula, the intersection of epiglottis and the bas of the tongue; TT: tip of tongue; H: the most anterior-superior point of hyoid; C3: the most anterior-inferior point of the third cervical vertebrae; TL, tongue length, distance between V and TT; TH, tongue height, maximum perpendicular height from tongue dorsum to line V-TT; SPL, soft palatal length, distance between PNS and U; SPT, soft palatal thickness, maximum thickness of soft palatal measured on line perpendicular to PNS-U; H-MP, distance along perpendicular line from H to MP (mandibular plane); H-C3, distance between H and C3.

Statistical Analysis

The statistical analyses were carried out using SPSS (Version 17.0; SPSS, Chicago, USA). Conformity of the parameters to normal distribution was assessed by the Kolmogorov-Smirnov (K-S) test. Since the data were normally distributed, both 3D and 2D measurements before and after MP/RME were compared by using the paired t test with Bonferroni adjustment for multiple analyses. The treatment changes (after to before MP/RME) were summarized with descriptive statistics (means and standard deviations). The 3D airway measurements were correlated with 2D cephalometric variables by means of Spearman correlation coefficients before, after and the change. All analyses were based on a significance level of 0.05. Repeated measurements on 10 randomly selected subjects were made after a two-week interval, and the intra examiner reliability was assessed using Student t test and intraclass correlation coefficients (ICC).

Results

Table 1: Means, SD in parenthesis of the upper airway measurements on CBCT scans at T1, T2, and between T1 and T2, and P values (paired t-test with Bonferroni adjustment).

Measurements		T1	T2	T2-T1	Significance
CSA (mm^2)	Nasopharynx	402.8(161.1)	463.1(180.1)	60.4(119.3)	0.002**
	Velopharynx	203.7(87.3)	227.3(140.8)	23.5(125.8)	0.105
	Glossopharynx	215.0(83.3)	237.7(107.9)	22.7(107.3)	0.175
	Hypopharynx	212.9(74.9)	224.9(71.7)	11.9(69.3)	0.875
	Minimum CSA	129.3(68.0)	155.4(115.7)	26.1(109.5)	0.203
SD/TD (%)	Nasopharynx	61.0(13.3)	66.6(19.1)	5.53((19.5)	0.125
	Velopharynx	50.8(18.6)	52.5(34.2)	1.7(23.9)	0.587
	Glossopharynx	51.8(27.7)	58.6(78.2)	6.8(81.4)	0.879
	Hypopharynx	38.6(7.9)	37.9(7.8)	-0.7(6.5)	0.298
MSA (mm^2)	Nasopharynx	111.7(55.3)	153.8(68.3)	42.1(40.1)	0.000***

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	Velopharynx	286.8(62.0)	324.1(84.5)	37.3(73.6)	0.585
	Glossopharynx	151.8(79.5)	167.2(81.6)	15.4(45.8)	0.737
	Hypopharynx	85.0(44.1)	106.5(48.5)	21.4(54.5)	0.260
	Total	634.8(168.0)	751.5(192.5)	116.7(163.6)	0.001**
Volume (mm^3)	Nasopharynx	3105(1493)	4433(1741)	1328(1043)	0.000***
	Velopharynx	5871(2417)	7555(3595)	1684(2735)	0.005**
	Glossopharynx	2755(1854)	3318(2180)	562(1742)	0.221
	Hypopharynx	2002(1150)	2543(1402)	540(1450)	0.573
	Total	13726(5712)	17850(7600)	4124(5901)	0.000***

CSA, cross-sectional area; SD/TD, sagittal to transverse diameter ratio on axial slice; MSA, mid-sagittal area; *P<0.05; **P<0.01; ***P<0.001.

The intra examiner reliability test showed no statistically significant difference between the readings and the intraclass correlation coefficients for all measurements was ≥ 0.90. After MP/RME treatment, significant skeletal and dentoalveolar changes included: SNA increased by 2.54° ± 1.8° (P < 0.01); ANB increased by 3.0°± 1.6° (P < 0.05); FMA (FH-mandibular plane angle) increased by 1.5°± 3.0°; A point moved forward by 2.5 mm ± 4.7 mm (P < 0.05) and downward by 1.7 mm ± 3.3 mm, which resulted in significant forward displacement of the maxilla and increase of the ANB angle. The measurements of the various designated segments of the upper airway before and after MP/RME on CBCT scans are listed in Table 1. Since 19 paired t tests were reported in this table, the Bonferroni adjustment was used to control the type I error rate. The results indicated that there was a significant increase in the nasopharyngeal airway: CSA (cross-sectional area at PNS plane) of 60.4 mm^2 (15%, P < 0.01), MSA (mid-sagittal area) of 42.1 mm^2 (37.7%, P < 0.001), and volume of 1328 mm^3 (42.8%, P < 0.001). For the velopharynx segment, only volume changed significantly from 5871 ± 2417 mm^3 to 7555 ± 3595 mm^3 after treatment (P < 0.01). There was no significant difference (P > 0.05) found either in area or volumetric measurement in the lower part of the pharyngeal airway (glossopharynx and hypopharynx). The minimum CSA did not show significant change post-treatment (P >0.05). The configuration of each segment represented by sagittal/transverse diameter ratio (SD/TD) showed no significant change after treatment (P > 0.05).

Pretreatment and posttreatment changes in the upper airway space, adenoid, tongue, soft palate, and hyoid on lateral cephalograms were shown in Table 2. There was a significant increase in the sagittal dimension of nasopharynx (PNS-UPW) of 2.4 mm (15.8%, P < 0.001), PNS-ad1 of 2.4 mm (13.4%, P < 0.001) and PNS-ad2 of 2.8 mm (28.5%, P < 0.001). No significant linear change was detected in the tongue, soft palate, and hyoid after treatment (P > 0.05). The dimensional measurements of the upper airway and its surrounding hard and soft tissue on lateral cephalograms were compared with respective area and volume variables on CBCT scans (Table 3). A significant positive correlation was found between 2D adenoid dimensions (PNS-ad1 and PNS-ad2) and 3D nasopharynx variables (cross-sectional area, mid-sagittal area, and volume) before, after, and the treatment change. Total volume of the upper airway and total mid-sagittal area showed a strong positive correlation with PNS-ad1 (P < 0.01).

Table 2: Means, SD in parenthesis of the upper airway space, adenoid, tongue, soft palate (SP), and hyoid on lateral cephalograms in mm on cephalograms at T1, T2, and between T1 and T2, and P values (paired t-test with Bonferroni adjustment).

***P<0.001

Measurements	T1	T2	T2-T1	Significance
PNS-UPW	15.2(4.2)	17.6(4.5)	2.4(3.9)	0.000***
U-MPW	9.6(2.9)	9.9(2.8)	0.3(3.1)	0.590
Et-LPW1	9.9(3.0)	10.8(3.5)	0.9(3.1)	0.674
Eb-LPW2	10.8(2.6)	11.2(2.7)	0.4(2.3)	0.256
PNS-ad1	17.9(4.1)	20.7(4.0)	2.4(2.3)	0.000***
PNS-ad2	9.8(3.2)	11.2(3.1)	2.8(3.3)	0.000***
TL	57.5(6.7)	60.7(7.4)	3.2(7.0)	0.291
TH	25.6(2.7)	26.4(3.6)	0.8(3.7)	0.634
SPL	29.6(3.9)	30.4(4.6)	0.8(5.1)	0.584
SPT	8.8(1.3)	8.7(1.8)	-.02(1.9)	0.402
H-MP	3.4(4.6)	4.4(5.0)	1.0(4.4)	0.231
H-C3	30.2(4.8)	31.5(4.6)	1.3(4.0)	0.205

Table 3: Spearman correlation coefficients between measurements on lateral cephalograms and CBCT scans.

	PNS-ad1			PNS-ad2		
	T1	T2	T2-T1	T1	T2	T2-T1
Nasopharynx CSA	0.718***	0.655***	0.552***	0.838***	0.610***	0.375*
Nasopharynx MSA	0.795***	0.780***	0.466**	0.872***	0.876***	0.590***
Nasopharynx Volume	0.781***	0.775***	0.490**	0.838***	0.845***	0.460**
Total MSA	0.486**	0.506**	0.444**	0.460**	0.522**	0.265
Total Volume	0.486**	0.422**	0.427**	0.460**	0.445**	0.258

Discussion

The interest in dedicated CBCT scanners for the oral maxillofacial region has increased exponentially since their introduction in the late 1990s [31]. Owing to its easy access, low cost, decreased radiation compared to medical CT, and especially its capability to define the boundaries between soft tissue and air spaces accurately, CBCT technology has emerged as a potential alternative for obtaining a thorough 2D and 3D evaluation of the upper airway at relatively modest costs [22]. Upper airway analysis has become increasingly relevant mainly due to the relationship between morphological airway characteristics, craniofacial morphology, and OSA [9, 10,21,27]. However, it is apparent that no amount of radiation can be regarded as being small enough to ignore, and it is clinicians' ethical obligation to justify the proper use of CBCT examinations [32]. For children it is crucial that dental CBCT examination should be fully justified over conventional radiography. The present study was a retrospective one, and part of the samples were from a previous study [33] and all scans have been approved by the Institutional Review Board of the Medical School of Peking University and informed consents were obtained from the parents of all subjects. For ethical reasons, there was no control group of untreated Class III or normal samples available for this study. However, the 3D growth study of Li et al. [29] provided detailed data concerning normal growth of the upper airway between the ages of 6 and 12 years old. There was another study by Chen et al. [26] evaluating upper airway changes in Class III patients (with a mean age of 9.56 ±0.22 years at T1 and 10.32 ±0.33 years at T2) treated with protraction headgear and RME and comparing them with an untreated Class III control (with a mean age of 10.4 ±0.42 years) by CBCT. More importantly, all three studies Li et al. [29], Chen et al. [26], and the present study - were performed with the same ethnic group (Chinese population) and restricted to identical airway boundaries; thus, facilitating comparison of the data among the three studies.

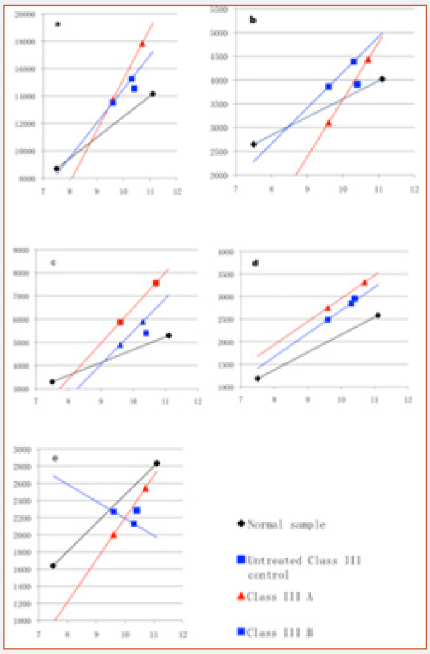

Figure 7: Comparison of the volume of different upper airway segments in Class III A (the present study) with normal sample (Li et al. study [28]), untreated Class III control and Class III B (from Chen et al. study [26]). a Total upper airway. b Nasopharyngeal airway. c Velopharyngeal airway. d Glossopharyngeal airway. e Hypopharyngeal airway. X-axis: years of age. Y-axis: mm^3 of volume.

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As shown in Figure 7a, the total upper airway volume after MP/RME in both Class III studies tended to increase significantly compared with the normal sample in the short-term. As for the long-term effect, there is no 3D study available at present, though there was only one 2D study illustrating that the nasopharyngeal airway dimensions were improved over a post-treatment period as long as four years [16], and future researches are still needed. Since some studies have demonstrated that not only children [9] but also adults [10] with Class III malocclusion had significant larger pharyngeal airway than those with Class I or Class II malocclusion, we had reasons to believe that this increase might be kept to some extent and MP/RME procedure would not hinder the normal expected growth as stated by Pamporakis et al. [24]. They studied 22 patients treated with MP/RME/ by CBCT scans and reported that the treatment inhibited the expected increase of pharynx volume, including that of the upper pharyngeal airway (nasopharynx) and lower pharyngeal airway. However, they compared their results with normal individuals from different races [29,34], which might be a confounding factor for their study since ethnicity was shown to be an important risk factor for OSA both in children [35] and adults [36]. Furthermore, their description of the airway boundary was vague, which might weaken their comparisons with other studies in a certain degree. When considering the changes of different segments (Figure 7b-e) separately, it is apparent that the volume of the nasopharyngeal (Figure 7b) and velopharyngeal airway (Figure 7c) increased significantly among the four airway segments.

And the increase rates of the two Class III samples were almost the same, which indicated that MP/RME might increase the nasopharynx and velopharynx volumes substantially compared with the normal sample and the untreated Class III control. In our study, significant increases were also found in other nasopharyngeal parameters as mid-sagittal area (MSA, P<0.001), cross-sectional area (CSA, P<0.01, Table 1), and 2D nasopharyngeal dimension (PNS-UPW, P <0.001), which accounted for the overall volumetric increase in the nasopharynx. This result is in agreement with previous 2D studies, which concluded that in young individuals diagnosed with maxillary deficiency and treated with reverse headgear, the nasopharyngeal airway dimensions were improved after treatment either in the short term [12-14], [18-20] or in the long-term [16]. Another 3D study carried out by Nguyen et al. [25] failed to include the nasopharynx in their examination of the effect of Class III bone-anchor maxillary protraction (BAMP) on airway, but they did find that BAMP treatment did not hinder the development of the oropharynx compared to an untreated Class III control group, though the effect of BAMP on the maxilla might be different from that of the traditional method with less dentoalveolar change and better vertical control [37].

We did not find any significant areal, volumetric or dimensional change in the lower part of the airway (glossopharynx and hypopharynx, Figure 7d and Figure 7e respectively) after MP/REM, and the slope of the trending line connecting pre-treatment and post-treatment volume was similar to the normal sample in the glossopharyngeal and hypopharyngeal airway, which implied that MP/RME treatment in our Class III children would not limit their normal growth. In Chen et al.'s study [26], even though the volumetric changing pattern of the glossopharynx resembled the normal sample and our study, it still showed a significant increase (P <0.05) in the volume and area measurements, which might due to failing to use Bonferroni correction to adjust the P value when several dependent or independent statistical tests are being performed simultaneously on a single data set [38]. However, they did attribute the significant change of glossopharynx on volume and shape to the result of growth, rather than treatment effect. The obvious discrepancy between Chen et al.'s study and the other two (Li et al.'s and our study) was presented in the hypopharyngeal airway region. Although the decrease tendency in the hypopharyngeal volume was not significant (P >0.05) in Chen et al.'s study, they found the shape of the hypopharynx became significantly flattened and they thought it might be a result of a series of combination factors, including the inferior-posterior displacement of the mandible and the hyoid, great inter-individual variability, MP/RME treatment and growth development during the treatment. In the present study, no significant displacement of the mandible or the hyoid was shown Table 2 and no shape change was detected in any segment of the upper airway, which might support the assumption that the clockwise rotation of the mandible after treatment might have potential influence on the surrounding structures including tongue and hyoid [13,16,19,26].

Both of the Class III groups showed a tendency, that is, the farther from the maxillary structure, the lower the effect on the upper airway, which has also been demonstrated after RME [38]. What causes this reduced effect on the airway regions farther from the nasopharynx, growth or treatment mechanism, if there is any discrepancy in the growth of different segments of the upper airway in Class III malocclusions is still not obvious. It might be crucial to evaluate the upper airway in different segments rather than as a whole. Nonetheless, the potential influence of the surrounding soft tissues, such as the adenoid and the tonsil could not be underestimated in this finding. The decrease of the adenoid dimension between ages 7 to 10 years is coupled with the treatment timing of MP/RME, while the tonsils are undergoing the second peak velocity at the same time [39]. The 2D finding on the significant decrease of the adenoid dimensions (PNS-ad1 and PNS-ad2) after MP/RME in this study also could be explained by the co-action of this theory and treatment effect. Many studies have reported a similar result after maxillary protraction with or without RME [12,14,16], [18-20].

A correlation between the upper airway, tongue, soft palate, and hyoid dimension on the cephalograms and area and volume of the airway measured from CBCT was analyzed with Spearman correlation coefficients and we found that both PNS-ad1 and PNS-ad2 had strong positive correlations with all 3D variables related to the nasopharynx, including CSA, MSA and volume before, after and the change of treatment. This agrees with previous studies trying to find a diagnostic method providing accurate information

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on the severity of nasopharyngeal obstruction for both dentists and medical specialists [40,41]. Although measuring adenoid on cephalograms is actually a 2D imaging modality that had limitations to represent 3D structures, 3D scans for the upper airway are still not routinely used due to radiation doses concerns as well as the inability to assess airway function. Feng et al. [42] reported that the measurement of the adenoid nasopharyngeal ratio (ANR) on lateral cephalograms might provide an initial screening method to estimate the nasopharyngeal volume of patients younger under the age of 15.

As for the total airway volume, they found that the correlation between ANR and total volume was dramatically reduced. In our study, we observed that PNS-ad1 was also significantly correlated with the total volume and MSA when considering before, after, and treatment change. Meanwhile, the change of PNS-ad2 did not show a significant correlation with total volume and MSA. Whether PNS-ad1 or PNS-ad2 could be used to estimate the upper airway variables in other samples with a wider range of age or malocclusion types encourages further investigation. This study presents certain shortcomings, mainly related to the retrospective nature, the lack of control groups and a long-term follow-up. To strengthen the study, we have drawn other 3D studies [26,29] on the same population and with a similar demarcation of the upper airway into our work and elaborately compared the data in the discussion part. However, future researches with a randomized controlled trial (RCT) design or a long-term follow-up will shed new light on the effects of MP/RME treatment on the upper airway.

Conclusion

Our study concluded that the volume of the nasopharynx, velopharynx and total upper airway in growing children with Class III malocclusion and maxillary deficiency increased significantly after MP/REM. Compared with a 3D normal sample, MP/RME did not limit the normal expected increase of the upper airway volume in the short-term. A significant correlation exists between 2D adenoid dimensions (PNS-ad1 and PNS-ad2) and 3D area and volume measurements in the nasopharyngeal airway.

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