ORIGINAL ARTICLE

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Effects of maxillary protraction therapy on the pharyngeal airway in patients with repaired unilateral cleft lip and palate: A 3-dimensional computed tomographic study

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Introduction: The purposes of this study were to assess the effects of maxillary protraction therapy on the pharyngeal airways in patients with repaired unilateral cleft lip and palate (UCLP) 3 dimensionally. **Methods:** Eighteen patients with repaired UCLP and anterior crossbite (ages, 10.4 ± 1.3 years) were enrolled in the study group. Hyrax appliances and reverse headgears were used. Cone-beam computed tomography volume scans were taken before and immediately after treatment. Fourteen patients (ages, 9.6 ± 1.7 years) with UCLP who did not receive orthopedic treatment served as the control group. The volumes of the pharyngeal airways, cross-sectional areas, sagittal diameters, and transversal diameters of 3 levels of airway cross-section were measured. **Results:** After protraction, the volumes of the pharyngeal airway increased significantly. Cross-sectional area, sagittal diameter, and transversal diameter of the upper and lower pharyngeal airways also had significant increases. These changes were significant when compared with the untreated subjects except for the transversal diameter of the lower pharyngeal airway. Dimensions of the middle pharyngeal airway remained unchanged. **Conclusions:** Maxillary protraction therapy significantly affects airway dimensions in patients with repaired UCLP 3 dimensionally. (Am J Orthod Dentofacial Orthop 2016;149:673-82)

Patients with cleft lip and palate (CLP) are usually characterized by maxillary retrusion and anterior crossbite after cleft repair. Midface retrusion in patients with CLP often results in personal, social, and psychological problems, along with functional difficulties.[1] Maxillary protraction is an effective way to relieve mild to moderate anterior crossbite for preadolescents, and it will lead to skeletal changes as well as improvements in the lateral profile.[1-8] Normalization of the sagittal jaw relationship and elimination of the dysfunction will result in normal function and mastication.[4] Since improvements of the soft tissue profile and the sagittal jaw relationship in early childhood are obviously important, maxillary protraction has been recommended.[1,8,9]

Pharyngeal size plays an important role in speech and respiratory function. It is well known that many patients with CLP still have speech problems even after palatoplasty surgery. In addition, it was reported that patients with CLP had an increased risk of obstructive sleep apnea.[10-13] The pharynx is close behind the maxilla and the mandible. Movement of the jaws may have an effect on the dimensions of the pharyngeal airway. Several studies have reported the skeletal response of maxillary protraction in patients with CLP.[2-8] However, only a limited number of reports have explored the effects of maxillary protraction on the pharynx, and most focused on noncleft patients.[8,14-21] Moreover, those studies were all based on cephalograms; thus, only sagittal depth of the pharyngeal airway was assessed.

Therefore, the aim of this study was to assess the effects of maxillary protraction therapy on the pharyngeal airway in patients with repaired unilateral CLP (UCLP) 3 dimensionally.

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MATERIAL AND METHODS

A longitudinal study was carried out according to the Declaration of Helsinki guidelines and approved by the ethics committee of Peking University in Beijing, China. All patients in the study group and their parents were informed of the purpose of this study and signed an informed consent form.

The study group was selected according to the following screening criteria: (1) operated nonsyndromic UCLP, (2) concave profile with overjet between −4 and 0 mm, (3) palatoplasty surgery before 3 years old, (4) no pharyngeal flap surgery, and (5) growth of body height had not accelerated. Patients who met the screening criteria were asked to have a cone-beam computed tomography (CBCT) scan. Also, from the CBCT synthetic cephalograms, patients whose cervical vertebral maturation stage was 1 or 2 and whose ANB angle was between -4° and 0° were included.[22]

Patients in the study group were treated by an author (W.L.). Hyrax appliances with bands on the first molars and premolars (or deciduous molars) were used. The hyrax appliance incorporated the maxillary left and right first molars and premolars (or deciduous molars); this made a firm anchorage to transfer the orthopedic force effectively to the maxilla through the teeth during protraction. Two hooks were soldered and extended from the permanent first molars to the region of the deciduous molars or premolars. The transverse dimensions of the maxillary dental arches were sufficient in all patients; thus, maxillary expansion was not conducted. Bite-block appliances in the mandibular arch were used to eliminate incisor interference (Fig 1). The patients were instructed to wear facemasks (Tiantian Dental Equipment, Hunan, China; Fig 2) for at least 12 hours per day. The protraction force was 450 to 500 g equally on both sides and directed 20° to 30° downward and forward in relation to the occlusal plane. Maxillary protraction was stopped after achieving about 2 mm of positive overjet, occluding the posterior teeth, and after at least 8 months of treatment.

Fig 1. Hyrax appliance (*upper*) and bite-block (*lower*).

Fig 2. Facemask.

CBCT volume scans were taken before (T0) and immediately after treatment (T1) using a dental-imaging system (DCT Pro; VATECH, Gyeonggi-do, Korea). All CBCT scans were taken with the following conditions: sitting position, natural head position, intercuspal occlusion, tongue in a relaxed position, and natural breath. The imaging protocol used a 20×19-cm field of view to include the entire craniofacial anatomy. The voxel resolution was 0.4 mm. The CBCT data sets were exported in DICOM file format.

For ethical reasons, we did not include a prospective control group. Instead, retrospective longitudinal data, derived from the computed tomography database of Peking University's CLP treatment center, served as the control group. The data sets were acquired using a high-resolution multidetector computed tomography (MDCT) device (BrightSpeed Edge; General Electric, Fairfield, Conn). MDCT volume scans were taken with the following conditions: supine position, Frankfort horizontal plane perpendicular to the floor, intercuspal occlusion, tongue in a relaxed position, and natural breath. The slice thickness was 1.25 mm. The inclusion criteria were the same as for the study group. Two sets of MDCT images at a time interval of 6 to 24 months were required. The patients did not receive orthopedic treatment because maxillary protraction was not offered when they were treated. They also did not receive pharyngoplasty surgery, tonsillectomy, or adenoidectomy during the observation period. Fourteen patients (9 boys, 5 girls) were included in the control group. The mean age of the patients at the first observation (T0) was 9.6 ± 1.7 years (range, 6.9-12.8 years). The MDCT data sets were also exported in DICOM file format.

When calculating the sample size needed in the study group, both the treatment effect and the variance of the difference were set at 1.5 mm according to the results of a previous study.[23] The power was set at 0.75, and the significance level was set at 0.05. Then the sample size was calculated using PASS software (version 11.0; NCSS, Silver Spring, Md). The minimum size needed was 16 in the treated group. To allow for losses, 20 patients who met the criteria were asked to participate the study. However, 2 refused to participate because of the remoteness of their home. Thus, 18 children (13 boys, 5 girls) were included in the study group. Their mean age at T0 was 10.4 ± 1.3 years (range, 7.6-12.4 years).

Using software (version 11.7; Dolphin Imaging & Management Solutions, Chatsworth, Calif), sagittal, axial, and coronal slices as well as the 3-dimensional (3D) reconstructions of the images were created. Landmarks used for setting reference planes and measurement planes are illustrated in Table I. The 3D reference system was constructed as follows: basion was selected as the origin of coordinates. The horizontal plane was parallel to the Frankfort horizontal plane, which was constructed on the bilateral porions and the noncleft side of orbitale. The midsagittal plane was drawn perpendicular to the horizontal plane, passing through sella and basion. The coronal plane was at right angles to the horizontal plane and the midsagittal plane, passing through basion.

The spatial positions of each landmark were represented as numeric values on each axis. The coordinates of all landmarks were then exported to an Excel spreadsheet (version 15.0; Microsoft, Redmond, Wash). Measurements of the dentofacial morphology were calculated based on the coordinates of the related landmarks.

The volume of the pharyngeal airway was calculated using the sinus/airway module of the Dolphin Imaging software. The superior limit of the pharyngeal airway was taken as a line connecting the posterior maxilla and basion. The inferior limit was taken as a line parallel to the Frankfort horizontal plane, passing through the tip of the epiglottis. The posterior limit was delimited by the posterior pharyngeal wall, and the anterior limit was delimited by the anterior wall of the pharynx, soft palate, and tongue. After the boundary was confirmed, a seed point was added in the airway cavity. The detection sensitivity of the airway space was set individually. The seed point extended to the area that had a similar gray scale according to the detection sensitivity. Then the airway volume was calculated automatically (Fig 3). Areas, sagittal diameters, and transversal diameters of the 3 levels of airway cross-sections were measured. The most superior and inferior cross-sectional planes of the pharyngeal airway were defined as the upper pharyngeal airway (UPA) and the lower pharyngeal airway (LPA). The cross-sectional plane passing through the tip of the uvula and parallel to the Frankfort horizontal plane was defined as the middle pharyngeal airway (MPA). The images of UPA, LPA and MPA were exported in JPEG file format. Dimensions of the 3 planes were measured using Photoshop (version 12.0; Adobe Systems, San Jose, Calif) image processing software (Fig 4).

Table I. Landmarks

Landmark	*Definition*
S	Sella, center of sella turcica
N	Nasion, most anterior point of the frontonasal suture in the median plane
Ba	Basion, most anterior point of the foramen magnum
Po	Porion, most superior point of each external acoustic meatus
Or	Orbitale, most inferior point of each infraorbital rim
PM	Posterior maxilla, most posterior point of the hard palate on the noncleft side
U	Tip of the uvula
A	Point of maximum concavity in the alveolar process of the maxilla
B	Point of maximum concavity in the alveolar process of the mandible
Go	Gonion, point of maximum convexity at the mandibular angle on each side
Me	Menton, most inferior point of the chin on the outline of the mandibular symphysis
EP	Tip of the epiglottis

Statistical analysis

Paired t tests were used to assess the changes during the treatment or the observation period in the 2 groups. An independent-sample t test was carried out to compare the T0 and T1 measurements and the T1 to T0 changes between the groups. The data were analyzed with software (version 11.0; SPSS, Chicago, Ill). Statistical significance was tested at $P < 0.001$, $P < 0.01$, and $P < 0.05$.

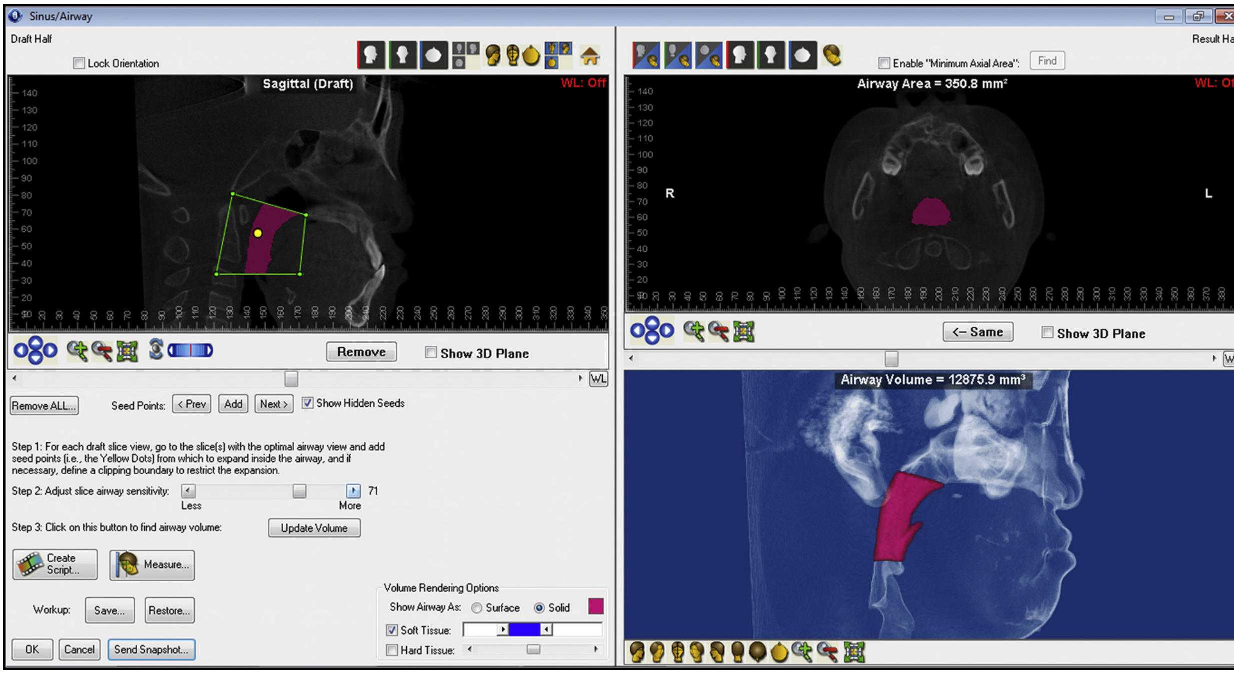

Fig 3. Volumetric quantification of the pharyngeal airway. Superior limit, a line connecting the posterior maxilla and basion. Inferior limit, a line parallel to the Frankfort horizontal plane, passing through the tip of the epiglottis. Posterior limit, the posterior pharyngeal wall. Anterior limit, the anterior wall of the pharynx, soft palate, and tongue.

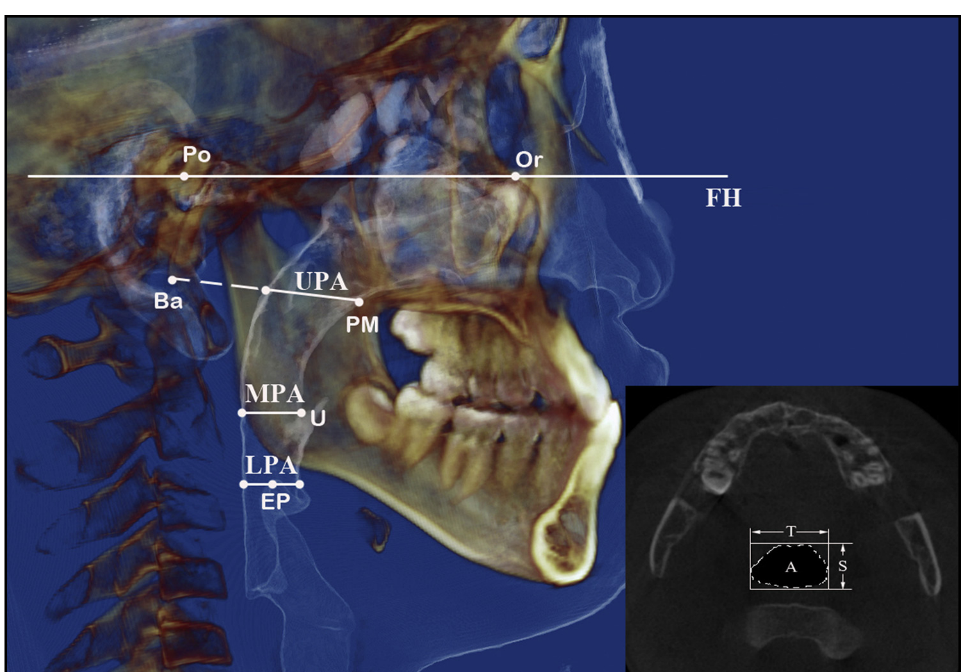

Fig 4. Three specific cross-sections of the pharyngeal airway and qualitative assessment of *A*, Cross-sectional area, *S*, sagittal diameter, and *T*, transversal diameter of the pharyngeal airway. See Table I for definitions of the abbreviations.

For the error measurements, 5 randomly selected pairs of MDCT and CBCT data sets were measured twice by Z.F., at an interval of 2 weeks. Correlations and mean differences between the double measurements were then analyzed.

RESULTS

The intraclass correlation coefficients between the double measurements were all over 0.9, indicating high reliability. Mean differences between the double measures and the intraclass correlation coefficient values are shown in Table II.

All 18 patients in the study group were successfully treated. Age distribution, treatment or observation duration, and sex distribution showed no significant differences between the groups, as illustrated in Tables III and IV.

After treatment with maxillary protraction, the projection of the SNA angle on the midsagittal plane (SNA′) increased by 1.75° ± 1.83° (P <0.001), the projection of the SNB angle on the midsagittal plane (SNB′) decreased by 1.81° ± 1.43° (P <0.001), the projection of the ANB angle on the midsagittal plane (ANB′) increased by 3.56° ± 1.71° (P <0.001), and the projection of the mandibular plane on the midsagittal plane (MP′/SN) increased by 2.22° ± 1.93° (P <0.001; Table V). The differences in these changes were significant when compared with the untreated subjects (P <0.05; Table V).

The volume of the pharyngeal airway increased by 3001.89 ± 4127.96 mm^3 (P <0.01; Table V) in the treated group, whereas the increment was not significant in the control group. The exploratory analysis of differences in the changes from T0 to T1 between the treated patients and the untreated subjects showed that the mean group differences were significant (P <0.05; Table V).

Cross-sectional area, sagittal diameter, and transversal diameter of the UPA and LPA also showed significant increases (P <0.05; Table V) in the treated group; however, the changes were not significant in the control group, except for the transversal diameter of the LPA. Differences of the changes were significant between the 2 groups (P <0.05; Table V), except for the transversal diameter of the LPA.

All measurements of the MPA remained unchanged in both groups (P >0.05; Table V). Independent t tests also showed no significance in the mean group differences for the dimensions of the MPA (P >0.05; Table V).

DISCUSSION

The pharyngeal structure of patients with CLP is different from the noncleft population because of the congenital deformity. Rose et al[24] and Oosterkamp et al[25] found that the pharyngeal morphology of CLP and obstructive sleep apnea patients demonstrated substantial similarities. Pharyngeal size plays an important role in speech and respiratory function. The skeletal response of maxillary protraction in both children without clefts[26-29] and those with CLP[2-8] have been studied. However, only a few studies have evaluated the effect of maxillary protraction on pharyngeal structure, and all of these studies were based on cephalograms.[14-21] Although lateral cephalometric measurements are useful for measuring sagittal depth of the airway, they cannot depict the 3D airway anatomy. We evaluated changes of the pharyngeal airway during protraction using CBCT and MDCT. Compared with conventional cephalogram, computed tomography has the distinct advantage of viewing anatomic structures 3 dimensionally. Therefore, not only sagittal depth, but also transverse diameter, area, and volume of the pharyngeal airway were analyzed in this study.

Early treatment of Class III malocclusion has been advocated for a long time. In a meta-analysis, Kim et al[30] reported that the younger group had greater treatment changes during protraction facemask therapy. The ages of the treated subjects in this study (mean age, 10.4 ± 1.3 years; range, 7.6-12.4 years) seemed too old for ordinary Class III patients to receive maxillary protraction. However, it was reported that the growth curves

Table II. Mean differences and intraclass correlation coefficient (ICC) values between double measurements

Measured variable	*Mean difference (SD)*	*ICC*
Dentofacial morphology		
SNA′ (°)*	0.11 (0.63)	0.99
SNB′ (°)*	0.05 (0.49)	0.99
ANB′ (°)*	0.01 (0.37)	0.98
MP′/SN (°)†	0.08 (1.11)	0.98
Volume (mm^3)	278.5 (568.22)	1.00
Upper pharyngeal airway		
Area (mm^2)	16.99 (32.19)	0.97
Sagittal diameter (mm)	0.60 (1.75)	0.97
Transversal diameter (mm)	0.46 (0.49)	0.99
Middle pharyngeal airway		
Area (mm^2)	5.16 (10.17)	1.00
Sagittal diameter (mm)	0.02 (0.68)	0.98
Transversal diameter (mm)	0.35 (0.59)	0.99
Lower pharyngeal airway		
Area (mm^2)	2.26 (15.62)	0.97
Sagittal diameter (mm)	0.12 (0.44)	0.98
Transversal diameter (mm)	0.42 (0.76)	0.98

*SNA′, SNB′, and ANB′ are the projections of the SNA, SNB, and ANB angles on the midsagittal plane, respectively; †MP′ is the projection of the mandibular plane (constructed on menton and the midpoint of right and left gonions) on the midsagittal plane.

Table III. Comparisons of ages and treatment and observation durations between the groups

	Treated patients		*Untreated patients*		
	Mean (range)	*SD*	*Mean (range)*	*SD*	*P*
T0 (y)	10.37 (7.58-12.42)	1.31	9.62 (6.92-12.83)	1.74	0.173
T1 (y)	11.81 (9.08-14.58)	1.52	10.96 (8.75-13.83)	1.72	0.153
Duration (mo)	17.17 (8.00-26.00)	5.43	16.14 (8.00-24.00)	5.88	0.613

Table IV. Sex distributions in the groups

	Male	*Female*	*Total*	*P (Fisher exact test)*
Treated patients	13	5	18	0.712
Untreated patients	9	5	14	
Total	22	10	32	

of patients with CLP were different from those of the noncleft standard samples, and the pubertal growth maximum occurred later in patients with CLP.[31] According to Sun and Li,[32] more than 75% of the patients between 11 and 12 years of age were at cervical vertebral maturation stage 1 or 2, considered the prepubertal stages. Suda et al[33] reported that the forward movement of the maxilla and the increase in palatal length showed significant inverse correlations with bone age but not with chronologic age. In our study, although the patients' chronologic ages seemed too old, the cervical vertebral maturation stages were carefully evaluated from computed tomography synthetic cephalograms, and only patients at stages 1 and 2 were enrolled. Thus, all 18 patients in the study group were successfully treated.

Dentofacial morphology was evaluated first to determine the skeletal response of protraction treatment. In our 3D analysis, several projections such as SNA′, SNB′, and ANB′ were used instead of direct measurements because in cleft patients, Points A and B were not always on the midsagittal plane. Geometrically, the SNA, SNB, and ANB angles would be influenced by deviations of the landmarks from the MSP and therefore could not represent the sagittal skeletal relationship precisely. Using projections of the landmarks on the MSP can eliminate the influence of deviations from the MSP. The variable MP′/SN was created for a similar reason. These results agreed with the findings of previous studies that reported maxillary advancement and mandibular clockwise rotation during protraction.[2-8]

To date, no authors have evaluated the effect of maxillary protraction on volumetric changes of pharyngeal airways, especially in patients with CLP. Our results showed that with advancement of the maxilla, the volume of the pharyngeal airway was enlarged during protraction.

To further investigate the effects of protraction on the different levels of the pharyngeal airway, 3 specific airway cross-sections were analyzed. These cross-sections used in this study were mainly derived from previous studies.[15-19,34,35] A modified point, posterior maxilla, which represents the most posterior point of the palatal bone on the noncleft side, was used instead of posterior nasal spine since it does not form in patients with palatal clefts.

Compared with the untreated control group, sagittal depth of the UPA increased from T0 to T1 in the study group. This finding agreed with that of Tindlund et al.[8] Since the sagittal position of the maxilla moved forward (SNA′ increased), the soft tissue boundary of the UPA was enlarged. The transversal dimension of the UPA in the treated group also increased. Since maxillary expansion was not used in any patient, enlargement of the transverse diameter should also be attributed to the effect of protraction treatment. Fairburn et al[36] assessed 3D changes in the upper airways of patients with obstructive sleep apnea after maxillomandibular advancement and also reported that the transversal diameter of the upper airway increased after surgery. The explanation of this phenomenon may relate to neuromuscular adaptation. However, the exact mechanism cannot be answered in our study.

Sagittal diameter and area of the LPA increased significantly when compared with the untreated controls. One possible explanation for this finding is that the oral cavity was enlarged with the advancement of maxilla. Then the tongue tended to move forward, and eventually the space of the LPA increased. The LPA is close behind the mandible. Forward or backward movement of the mandible can also affect the size of the LPA. However, the main effect of protraction on the mandible was clockwise rotation. Geometrically, rotation caused more displacement on the anterior part but less displacement on the posterior part of the mandible. Thus, the effect of mandibular rotation on the size of the LPA was slight. This finding agrees with that of Kilinc et al,[15] who reported that maxillary protraction significantly increased the sagittal oropharyngeal airway dimensions.

Table V. Changes from T0 to T1 in the treated patients and untreated subjects and comparisons between the 2 groups

	Control group			*Treated group*			*Differences between groups*		
	T0	*T1*	*Change*	*T0*	*T1*	*Change*	*T0*	*T1*	*Change*
Dentofacial morphology									
SNA′ (°)*	76.31 ± 2.80	75.10 ± 2.51	−1.21 ± 0.91[¶]	75.02 ± 3.66	76.77 ± 3.95	1.75 ± 1.83[¶]	−1.29 ± 1.18 NS	1.67 ± 1.21 NS	2.97 ± 0.53[§]
SNB′ (°)*	77.64 ± 3.09	78.56 ± 4.13	0.92 ± 2.57 NS	77.14 ± 4.05	75.33 ± 4.59	−1.81 ± 1.43[¶]	−0.51 ± 1.31 NS	−3.23 ± 1.57[‡]	−2.73 ± 0.71[§]
ANB′ (°)*	−1.34 ± 3.64	−3.47 ± 4.46	−2.13 ± 2.25[§]	−2.12 ± 1.79	1.44 ± 2.32	3.56 ± 1.71[¶]	−0.78 ± 0.98 NS	4.91 ± 1.22[¶]	5.69 ± 0.70[§]
MP′/SN (°)[†]	37.50 ± 5.05	37.08 ± 4.40	−0.42 ± 3.21 NS	37.77 ± 5.17	39.99 ± 5.91	2.22 ± 1.93[¶]	0.27 ± 1.82 NS	2.92 ± 1.89 NS	2.64 ± 0.91[§]
Pharyngeal airway									
Total volume (mm^3)	9162.9 ± 2226.4	9248.1 ± 3236.5	85.3 ± 3490.1 NS	9915.7 ± 3748.7	12917.6 ± 5192.8	3001.9 ± 4128.0[§]	752.8 ± 1133.1 NS	3669.4 ± 1586.4[‡]	2916.6 ± 1377.1[‡]
Upper pharyngeal airway									
Area (mm^2)	287.52 ± 72.74	268.38 ± 43.98	−19.14 ± 62.67 NS	419.78 ± 106.55	483.09 ± 117.66	63.30 ± 87.33[§]	132.26 ± 33.29[¶]	214.70 ± 33.20[¶]	82.44 ± 27.66[§]
Sagittal diameter (mm)	20.62 ± 3.94	19.94 ± 2.54	−0.69 ± 2.67 NS	24.49 ± 5.78	26.82 ± 5.21	2.32 ± 4.46[‡]	3.87 ± 1.81[‡]	6.88 ± 1.52[¶]	3.01 ± 1.35[‡]
Transversal diameter (mm)	24.74 ± 3.50	23.79 ± 2.30	−0.94 ± 3.40 NS	29.53 ± 3.13	30.84 ± 3.42	1.31 ± 2.18[‡]	4.80 ± 1.17[¶]	7.05 ± 1.06[¶]	2.25 ± 0.99[‡]
Middle pharyngeal airway									
Area (mm^2)	151.06 ± 73.10	146.39 ± 56.45	−4.68 ± 86.19 NS	223.82 ± 81.77	246.78 ± 98.77	22.97 ± 85.87 NS	72.75 ± 27.84[‡]	100.39 ± 29.62[§]	27.64 ± 30.65 NS
Sagittal diameter (mm)	11.65 ± 2.94	11.00 ± 2.68	−0.65 ± 3.25 NS	14.85 ± 3.05	14.92 ± 3.16	0.07 ± 2.89 NS	3.20 ± 1.07[§]	3.92 ± 1.06[¶]	0.72 ± 1.09 NS
Transversal diameter (mm)	18.19 ± 5.96	19.16 ± 4.20	0.96 ± 5.47 NS	23.02 ± 4.62	24.43 ± 5.35	1.41 ± 4.53 NS	4.83 ± 1.87[‡]	5.27 ± 1.74[§]	0.44 ± 1.77 NS
Lower pharyngeal airway									
Area (mm^2)	154.31 ± 48.25	160.92 ± 53.53	6.60 ± 57.71 NS	162.54 ± 60.19	213.42 ± 70.71	50.88 ± 61.44[§]	8.23 ± 19.72 NS	52.51 ± 22.75[‡]	44.28 ± 21.33[‡]
Sagittal diameter (mm)	8.39 ± 3.76	7.38 ± 3.24	−1.01 ± 2.64 NS	9.31 ± 2.39	10.94 ± 2.77	1.63 ± 1.86[§]	0.92 ± 1.09 NS	3.57 ± 1.06[§]	2.65 ± 0.80[§]
Transversal diameter (mm)	18.53 ± 5.54	21.10 ± 5.77	2.57 ± 3.98[‡]	25.06 ± 2.40	28.22 ± 3.13	3.16 ± 3.12[¶]	6.53 ± 1.45[¶]	7.12 ± 1.59[¶]	0.59 ± 1.26 NS

NS, Not significant.
*SNA′, SNB′, and ANB′ are the projections of the SNA, SNB, and ANB angles on the midsagittal plane, respectively; [†]MP′ is the projection of the mandibular plane (constructed on menton and the midpoint of right and left gonions) on the midsagittal plane; [‡]$P < 0.05$; [§]$P < 0.01$; [¶]$P < 0.001$.

Oktay and Ulukaya,[19] Kaygısız et al,[16] and Lee et al[18] also reported increases in lower pharyngeal depth after protraction, although the changes were insignificant. The transversal diameter of the LPA increased as well in the study group; however, when compared with the controls, it was not significant. So, it can be concluded that the increase of transversal diameter of the LPA was partly caused by growth of the pharynx.

It is interesting that the dimensions of both the UPA and the LPA increased, but the size of the MPA remained unchanged. Several studies regarding velopharyngeal changes reported that after distraction osteogenesis treatment, the velar angle (angle between the soft palate and the palatal plane) of patients with CLP increased.[37,38] Geometrically, when the velar angle increases, the distance between the tip of the soft palate and the pharyngeal wall would decrease. Therefore, the increase in sagittal depth of the pharyngeal airway caused by distraction osteogenesis was compensated. Compensation in the velopharyngeal mechanism might also be assumed to explain the results in this study. Since the changes caused by maxillary protraction were more gradual than by maxillary distraction, the patients had more chance to adapt themselves to the velopharyngeal changes. Thus, the increases in the dimensions of the MPA were not significant.

Another interesting finding of this study was that age did not change the airway size in the control group. Sheng et al[39] reported that the pharyngeal airway depth increased from the mixed dentition stage to the permanent dentition stage. Schendel et al[40] also reported a consistent increase in the airway volume from ages 6 to 20 years. Our results were inconsistent with the previous studies.[39,40] The inconsistency may have 2 sources. First, the time interval was relatively short (16.1 months) when compared with previous studies (3-4 years). Second, the populations studied were different in this study and previous studies. Airway sizes are expected to change with growth of the maxillofacial skeleton. Since maxillary growth was restricted in patients with CLP, changes of airway size may also be reduced.

For ethical reasons, we did not include a prospective control group. Instead, a retrospective longitudinal MDCT data set was the control group. In the CLP treatment center of our university, the MDCT scans were usually taken before and 1 to 2 years after alveolar bone graft surgery as the preoperative examination and the postoperative evaluation, respectively. In this study, those MDCT data sets were used as the control group to assess growth changes of the pharyngeal airway. Although the technique of imaging was different between MDCT and CBCT, it was reported that measurements of the air cavity surrounded by soft tissue were accurate with both CBCT and MDCT.[41] One major difference between the CBCT and MDCT devices used in this study was that patients were examined in supine position with the MDCT and in upright position with the CBCT. Gravity can produce movements in pharyngeal structures in response to postural changes between the upright and supine positions.[42] In this study, all pharyngeal measurements in the treated group were greater than those in the control group at T0, and most of these differences were significant. Since age and sex distributions were balanced, and dentofacial morphologies were similar between the 2 groups at T0, these differences should mainly be attributed to the influence of gravity. In supine position, gravity makes the tongue and soft palate closer to the pharyngeal wall and narrows the dimensions of the airway. The different imaging modalities and body positions were major limitations of our study because they could affect the differences of pharyngeal changes between the 2 groups. However, the trend of the influence of growth should not be altered, whether the patients were examined in supine or upright position. In the control group, although there was no significance, most measurements showed negative changes. In this way, growth may decrease, or at least should not increase, the airway dimensions in the treated group. Therefore, although exact changes caused by treatment cannot be calculated, it can still be concluded that maxillary protraction treatment can increase the pharyngeal airway dimensions.

Another limitation of our study was that only a short-term evaluation was conducted. Since long-term stability is a major concern when treating Class III patients, posttreatment follow up is required in future studies. Speech and respiratory functions are of the utmost importance in the treatment of patients with CLP. Assessments of morphologic changes of the pharyngeal airway are indispensable when assessing speech and respiratory functions. Future studies could provide more information by including additional assessments such as polysomnography and nasoendoscopy examinations.

CONCLUSIONS

The dimensions of the pharyngeal airway as well as the jaw relationship were affected by maxillary protraction therapy. Maxillary protraction treatment could not only relieve mild to moderate anterior crossbite, but also potentially improve respiratory functions for preadolescent patients with CLP.

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