Upper airway in children with unilateral cleft lip and palate evaluated with computational fluid dynamics

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Introduction: Children with unilateral cleft lip and palate (UCLP) exhibit snoring and mouth breathing. They are also reported to show obstructive sleep apnea syndrome. However, their upper airway ventilation condition is not clearly understood. Therefore, this study was performed to evaluate upper airway ventilation condition in children with UCLP with the use of computational fluid dynamics. **Methods:** Twenty-one children (12 boys, 9 girls; mean age 9.1 years) with UCLP and 25 children (13 boys, 12 girls; mean age 9.2 years) without UCLP who required orthodontic treatment underwent cone-beam computed tomography (CBCT). Nasal resistance and upper airway ventilation condition were evaluated with the use of computational fluid dynamics from CBCT data. The groups were compared with the use of Mann-Whitney *U* tests and Student *t* tests. **Results:** Nasal resistance of the UCLP group (0.97 Pa/cm^3/s) was significantly higher than that of the control group (0.26 Pa/cm^3/s; $P < 0.001$). Maximal pressure of the upper airway (335.02 Pa) was significantly higher in the UCLP group than in the control group (67.57 Pa; $P < 0.001$). Pharyngeal airway (from choanae to base of epiglottis) pressure in the UCLP group (140.46 Pa) was significantly higher than in the control group (15.92 Pa; $P < 0.02$). **Conclusions:** Upper airway obstruction in children with UCLP resulted from both nasal and pharyngeal airway effects. (Am J Orthod Dentofacial Orthop 2019;156:257-65)

Clefts of the lip and palate (CLP) are the most frequently occurring congenital facial deformities, with an incidence rate of 0.65% in newborns. In subjects with unilateral cleft lip and palate (UCLP), maxillary retrognathism, a smaller mandible with an obtuse gonial angle, greater anterior facial heights, and retroclined maxillary incisors are observed.[1,2] Furthermore, children with UCLP experience both morphologic and breathing problems.[3-6] Parents of children with UCLP have often reported that their children snore and breathe noisily during sleep,[5] and patients with reduced nasal airways have been reported to be predisposed to mouth breathing.[3,4] Sobral et al[7] reported that patients with UCLP exhibited mild obstructive sleep apnea syndrome (OSAS). Therefore, these upper airway (nasal to hypopharyngeal airway) problems have been studied in both 2-[5,8] and 3-dimensional (3D) approaches.[5,9-12]

In previous nasal airway studies, cross-sectional area[13,14] and volume[5,10,14] of nasal airway were reported to be smaller in children with UCLP than in non-CLP children. However, in cases of UCLP, it is more difficult (because of altered nasal septum[15] and nasal mucosa hypertrophy[16]) to determine nasal airway ventilation condition by means of morphologic evaluations. Rhinomanometry[3,14,17] allows evaluation of the nasal airway ventilation regardless of nasal airway shape. In contrast, pharyngeal airway axial cross-sectional area[5,8] and pharyngeal airway volume[9] of UCLP children are smaller than those of non-CLP children.

However, upper airway ventilation condition does not comprise separate ventilation of nasal or pharyngeal airways; rather, it comprises the combined ventilation conditions of the nasal and pharyngeal airway. Recently,

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computational fluid dynamics (CFD) has been used for evaluation of the airway ventilation condition.[18,19] CFD reproduces the flow of air regardless of the shape of the upper airway and provides an analysis of the range of the airway. The present study aimed to evaluate the upper airway ventilation condition for children with UCLP by means of CFD, which had previously been restricted to studies of the nasal[5,10,13,14,17] or pharyngeal[5,8,9,12,20] airway ventilation condition.

MATERIAL AND METHODS

Because of the retrospective nature of this study, an exemption was granted in writing by the Institutional Review Board of our university, and the requirement to obtain informed consent was waived (#657). Patients who visited a large private orthodontic practice for orthodontic treatment from 2010 to 2015 in our city were included in this retrospective study. The inclusion criteria for the study were: (1) patients who were 7-11 years of age; (2) patients who had undergone diagnostic cone-beam computed tomography (CBCT) for nonroutine orthodontic treatment (to minimize radiation exposure, we performed the scans only when the diagnostic benefits outweighed the risks of radiation exposure); and (3) patients who had a craniocervical inclination of 95°-105°.[21] Exclusion criteria included previous orthodontic, tonsillectomy, or adenoidectomy treatment. However, it has been reported that nasopharyngeal size[3] and nasal ventilation conditions[17] differ according to the cleft type. Therefore, our study involved only patients with UCLP. Lip closure by Millard-type lip repair had been performed (average age 3.8 ± 1.2 months) in most patients, and closure of the palate had been performed by pushback palatoplasty and the Furlow method (average age 8.6 ± 3.9 months). No patient had undergone bone graft. Control patients exhibited Class I malocclusion (2° < A-nasion-B angle (ANB) < 4°), a Frankfort mandibular plane angle (FMA) of 25°-33°, which is the normal value for Japanese children, and other conditions (asymmetries, transverse relationships, impacted teeth, supernumerary teeth, ectopic eruption patterns, root health, skeletal growth, incidental pathology) that can benefit from advanced 3D imaging using similar or even less radiation than a 2D series.[22] Exclusion criteria for the control group were: (1) craniofacial or growth abnormalities; (2) systemic disease; (3) temporomandibular joint disorder; and (4) nasal disease at the time of examination. The UCLP and control groups consisted of 12 boys and 9 girls (average age 9.1 ± 0.9 years) and 13 boys and 12 girls (average age 9.2 ± 0.8 years), respectively. Children in the control group were closely matched for sex and age with children in the UCLP group.

Table I. Maxillofacial form

	UCLP (n = 21)		*Control (n = 25)*		
Measure	*Mean*	*SD*	*Mean*	*SD*	P
SNA (°)	79.29	3.27	80.88	2.57	0.071
SNB (°)	78.38	3.56	77.80	2.30	0.508
ANB (°)	0.90	3.57	3.08	0.92	0.012*
FMA (°)	32.02	5.34	28.86	2.22	0.018*

*Statistically significant at $P < 0.05$.

For CBCT scanning, each child was seated in a chair with the Frankfort horizontal plane parallel to the floor and was asked to hold their breath at the end of expiration without swallowing, because the pharyngeal airway caliber (when awake) is the smallest at this time. The head and neck were supported and fixed during the CBCT scan.[19] CBCT (Alphard 3030; Asahi Roentgen, Kyoto, Japan) was set to a maximum of 80 kV, a maximum of 2 mA, and an exposure time of 17 seconds. Using a modified protocol, we obtained cephalogram-like data via the CBCT. A 3D coordinate system and image were constructed with the use of a medical image analysis system (Imagnosis VE; Kobe, Japan). The planes were defined as described previously.[23] From these constructed cephalometric images, the anteroposterior positions of both maxilla and mandible were evaluated with the use of the sella-nasion-A (SNA) angle, sella-nasion-B (SNB) angle, ANB angle, and FMA (Table I).

Volume-rendering software (Intage Volume Editor; Cybernet Systems, Tokyo, Japan) was used to manually create 3D images and evaluate the intermaxillary molar and nasal width,[24] hyoid height, and pharyngeal and intraoral airway volume (Fig 1). Hyoid height was the distance from the palatal plane to the most superior and anterior point of the hyoid bone. Pharyngeal and intraoral airway volumes were measured between the palatal plane and base of epiglottis plane and between the palate and tongue, respectively.[25]

The 3D nasal airway was manually generated from the CBCT data with the use of volume-rendering software (Intage Volume Editor) (Fig 2).[25] The airway was segmented primarily on the basis of image intensity with the threshold set midway between the soft tissue and clear airway value. Subsequently, with the use of mesh-morphing software (DEP Mesh Works/Morpher; IDAJ, Kobe, Japan), the 3D model was converted to a smoothed model without losing the patient-specific pattern of the airway shape. The models were exported to CFD software (Phoenics; CHAM Japan, Tokyo, Japan) in stereo lithography format. CFDs of the nasal airway

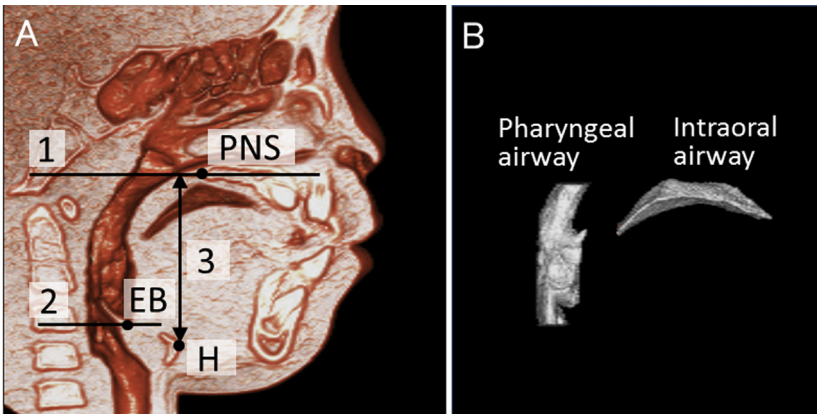

Fig 1. Measurement of airway volumes and hyoid height. **A,** Landmarks and planes for the axial airway section. *1*, PL plane, a plane parallel to the hard palate passing through the PNS; *2*, EB plane, a plane parallel to the PL plane passing through the EB; *3*, hyoid height, the distance from PL plane to H; *EB*, base of the epiglottis; *H*, the most superior and anterior point of the hyoid bone; *PNS*, posterior nasal spine. **B,** Pharyngeal airway between the PL and EB planes; intraoral airway between the palate and the tongue.

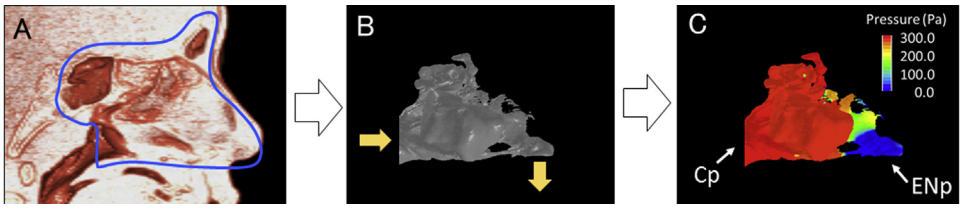

Fig 2. Calculation of nasal resistance by means of computational fluid dynamics. **A,** Extraction of the nasal airway. **B,** Construction of the three-dimensional nasal airway model and numeric simulation (expiration air mass flow 200 mL/s; *arrows*). **C,** Evaluation of the nasal airway pressure; *Cp*, choanae pressure; *ENp*, external nares pressure.

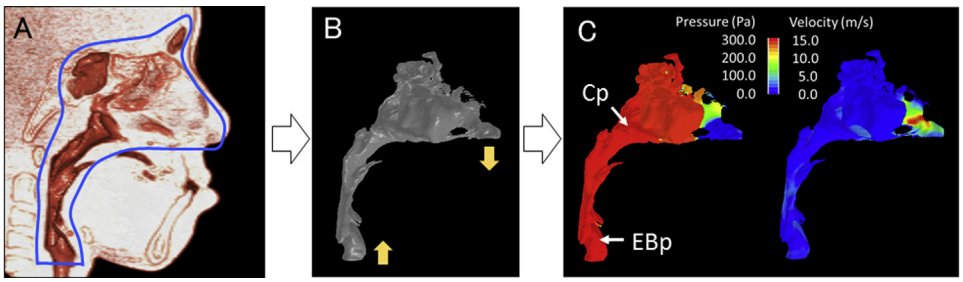

Fig 3. Evaluation of upper airway ventilation condition by means of computational fluid dynamics. **A,** Extraction of the upper airway. **B,** Construction of the 3D upper airway model and numeric simulation (expiration air mass flow 200 mL/s; *arrows*). **C,** Evaluation of the upper airway ventilation condition (*left*, pressure; *right*, velocity); *Cp*, choanae pressure; *EBp*, base of epiglottis pressure.

models were analyzed under the conditions of airflow at a velocity of 200 mL/s and nonslippery wall surface; simulations were repeated 1000 times to calculate mean values. The simulation estimated airflow pressure; in this simulation, air flowed from the choanae horizontally and was exhaled through both external nares. The nasal airway model resistance conformed to postnasal rhinomanometry and was calculated from air mass flow and

the difference in pressure between the external nares and choanae, according to Ohm's law.[25] However, the nasal airway model resistance values vary based on the threshold of air in the airway model construction. Therefore, we regulated the threshold of the nasal airway model so that the nasal airway model resistance value obtained in CFD corresponded to the nasal resistance value for rhinomanometry.

In addition, we conducted an expiration simulation (air flowing perpendicular to the lower pharyngeal plane at a velocity of 200 mL/s) using a method similar to that described above for the nasal airway (Fig 3).[26] We estimated maximal pressure and maximal velocity upper airway (from nare to base of epiglottis). The nasopharyngeal and pharyngeal airway (total pharyngeal airway, from choanae to base of epiglottis) pressure was calculated as the difference between the pressure of the base of epiglottis and that of the choanae.

The distance in the midsagittal plane from the posterior outline of the soft palate to the closest point of the adenoid tissue on CBCT images was used to classify the relative sizes of the adenoids into 4 groups: grade 1, <25% obstruction; grade 2, 25%-50% obstruction; grade 3, 50%-75% obstruction; and grade 4, >75% obstruction. The narrowest distance between the tonsils in the midcoronal plane was used to classify the relative sizes of the tonsils into 5 groups: grade 1, no hyperplasia of the tonsils; grade 2, the tonsils extend one-fourth of the way to the midline; grade 3, tonsils extend halfway to the midline; grade 4, tonsils extend three-fourths of the way to the midline; grade 5, tonsils completely obstruct the airway, also known as "kissing" tonsils.[19]

Statistical analysis

For each measurement, *t* test and Mann-Whitney *U* test were used to compare differences between the UCLP and control groups, depending on the data distribution. Fisher exact test clarified the distributions of airflow types, adenoid sizes, and tonsil sizes in both groups. For all tests, $P < 0.05$ was considered to be statistically significant.

To estimate statistical power, power analysis was conducted with the use of the obtained mean and SD values. All measurements were repeated after 1 week by the same investigator (T.I.), and the Dahlberg formula[27] was used for calculation of the measurement error. The measurement errors for the cephalometric images were from 0.353° to 0.426°. The error of the nasal width was 0.082 mm, of the intermaxillary width 0.052 mm, of the hyoid position 0.062 mm, of the pharyngeal airway volume 0.012 cm^3, and of the intraoral airway volume 0.007 cm^3. And the error of the nasal resistance was 0.0031 $Pa/cm^3/s$, of the maximal pressure 1.365 Pa, of the maximal velocity 0.05 m/s, and of the total pharyngeal airway pressure 0.432 Pa. According to all repeated analyses, the method error was considered to be negligible.

Table II. Comparison of UCLP and control children

	UCLP (n = 21)		*Control (n = 25)*		
Measure	*Mean*	*SD*	*Mean*	*SD*	P
Nasal width (mm)	25.54	2.18	24.17	1.36	0.018*
Intermaxillary width (mm)	34.24	2.46	34.29	1.95	0.932
Pharyngeal airway volume (cm^3)	5.79	1.85	7.11	2.34	0.042*
Intraoral airway volume (cm^3)	1.21	1.43	0.48	0.93	0.043*
Hyoid position (mm)	49.66	4.00	45.86	3.97	0.002†

*Statistically significant at $P < 0.05$.
†Statistically significant at $P < 0.01$.

RESULTS

The nasal width of the UCLP group (25.54 ± 2.18 mm) was significantly larger than that of the control group (24.17 ± 1.36 mm; $P = 0.018$; Table II). However, the intermaxillary molar widths did not differ significantly between groups. The pharyngeal airway volume of the UCLP group (5.79 ± 1.85 cm^3) was significantly smaller than that of the control group (7.11 ± 2.34 cm^3; $P = 0.042$; Table II). The intraoral airway volume of the UCLP group (1.21 ± 1.43 cm^3) was significantly larger than that of the control group (0.48 ± 0.93 cm^3; $P = 0.043$). The hyoid height of the UCLP group (49.66 ± 4.00 mm) was significantly less than that of the control group (45.87 ± 3.97 mm; $P = 0.002$).

Nasal resistance of the UCLP group (0.97 ± 1.07 $Pa/cm^3/s$) was significantly higher than that of the control group (0.26 ± 0.40 $Pa/cm^3/s$; $P < 0.001$; Table III). Maximal pressure of the upper airway in the UCLP group (335.02 ± 336.57 Pa) was significantly higher than that of the control group (67.57 ± 86.63 Pa; $P < 0.001$). Maximal velocity of the upper airway in the UCLP group (18.18 ± 11.71 m/s) was significantly greater than that of the control group (9.49 ± 8.97 m/s; $P = 0.002$). Total pharyngeal airway pressure of the UCLP group (140.46 ± 195.55 Pa) was significantly higher than that of the control group (15.92 ± 13.51 Pa; $P < 0.02$).

The incidence of adenoid hypertrophy (grades 3 and 4) in the UCLP group was 61.9%, whereas the incidence in the control group was 20.0% (Table IV). The different

Table III. Comparison of ventilation conditions between UCLP and control children

	UCLP ($n = 21$)		Control ($n = 25$)		
Measure	*Mean*	*SD*	*Mean*	*SD*	P
Nasal resistance ($Pa/cm^3/s$)	0.97	1.07	0.26	0.40	<0.001†
Maximal pressure (Pa)	335.02	336.57	67.57	86.63	<0.001†
Maximal velocity (m/s)	18.18	11.71	9.49	8.97	0.002†
Total pharyngeal airway pressure (Pa)	140.46	195.55	15.92	13.51	0.02*

*Statistically significant at $P < 0.05$.
†Statistically significant at $P < 0.01$.

Table IV. Subject distributions based on adenoid size

	Grade				
Group	*1*	*2*	*3*	*4*	P
UCLP	2	6	9	4	0.016*
Control	11	9	4	1	

*Statistically significant at $P < 0.05$ (Fisher exact test).

Table V. Subject distributions based on tonsil size

	Grade					
Group	*1*	*2*	*3*	*4*	*5*	P*
UCLP	3	5	9	3	1	0.121
Control	2	13	3	5	2	

*Fisher exact test.

distribution of adenoid hypertrophy between the groups was statistically significant according to Fisher exact test ($P = 0.033$). The distribution of tonsil hypertrophy between the groups was not significantly different (Table V).

DISCUSSION

The main purpose of this study was to evaluate, by means of CFD, the ventilation condition of the upper airway (from nare to base of epiglottis) of children with UCLP. Our results showed that upper airway obstruction in children with UCLP resulted from the effects of both nasal and total pharyngeal airways (Table III; Figs 4 and 5).

Previous methods of evaluating the nasal airway ventilation condition of patients with UCLP include X-rays,[5,8] computed tomography,[5,10] rhinomanometry,[13,14,17] and acoustic rhinometry.[14] Because the nasal airway has a complicated lumen, evaluation of the nasal airway ventilation condition is extremely difficult when solely using morphologic data. One must evaluate the cross-sectional area, as well as the cross-sectional form and continuity of the lumen. Rhinomanometry data are thought to be affected by adenoid, soft palate, and tonsil; acoustic rhinometry could not evaluate the rear section of a narrowing area. CFD simulates the magnitudes of air pressure and velocity, such that the function of the entire nasal airway can be evaluated more precisely than in morphologic evaluation. Furthermore, CFD can evaluate the ventilation conditions of the nasal airway alone, without the effects of the adenoids, palatine tonsils, and soft palate, as well as the upper airway, from the nasal airway to the hypopharyngeal airway. Furthermore, it can show the air flow of the nasal airway. Therefore, we used CFD to evaluate the ventilation conditions in the nasal and upper airways of UCLP children.

In our results, the nasal resistance of the control group was 0.26 $Pa/cm^3/s$ (Table III). Crouse et al[28] reported that nasal resistance in 9- to 10-year-old normal children ranged from 3.0 to 5.0 $cmH_2O/L/s$. This value corresponds to ~0.3-0.5 $Pa/cm^3/s$ in our study unit. Kobayashi et al[29] reported normal nasal airway resistance of elementary school children (~9 years of age) to be 0.35 ± 0.17 $Pa/cm^3/s$. So, in our study, we defined the nasal obstruction value as 0.5 $Pa/cm^3/s$ and it was considered to indicate obstruction with 100 Pa of pressure at an inflow of 200 mL per second.[26] Because nasopharyngeal airway and soft palate were not included in the assessments of our control group, our values were slightly smaller than those of the reported normal groups. However, we suspect that values similar to those of an approximately normal person were obtained. Moreover, the ventilation condition evaluation by CFD confirmed a value similar to that obtained with the use of conventional rhinomanometry.

The nasal resistance of the UCLP group (0.97 $Pa/cm^3/s$) was ~4 times greater than that of the control group (0.26 $Pa/cm^3/s$; Table III). A previous morphologic study reported[13] that in adult subjects with UCLP, a cross-section of the affected side nasal airway is 50% smaller than a cross-section of the unaffected side nasal airway. Farzal et al[10] reported that the nasal airway volumes of 7-12-year-olds with UCLP (7097 ± 2596 mm^3) and bilateral CLP (6715 ± 2115 mm^3) were significantly smaller than those of the control group (9932 ± 1807 mm^3). The nasal resistance of subjects with UCLP is greater than that of control subjects.[14,17,30] Mani et al[14] reported nasal resistance of adults with

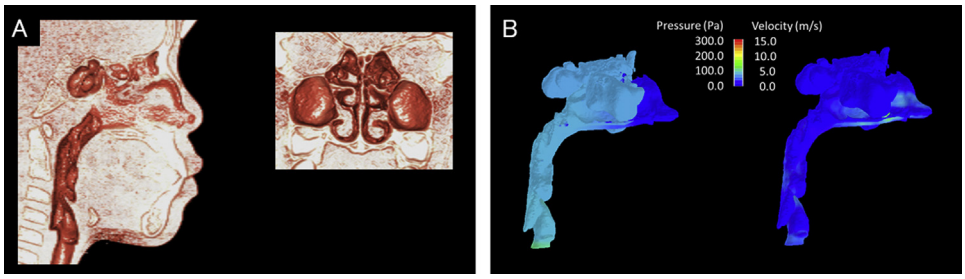

Fig 4. Upper airway ventilation condition of control children according to computational fluid dynamics. **A,** Left: sagittal view, adenoid and tonsil hypertrophy not found; right: frontal view, deviated nasal septum and mucosal hypertrophy not found. **B,** Left: the pressure of all parts of the upper airway is low (*blue*); right: the velocity of all parts of the upper airway is slow (*blue*). Upper airway obstruction of control children was not detected.

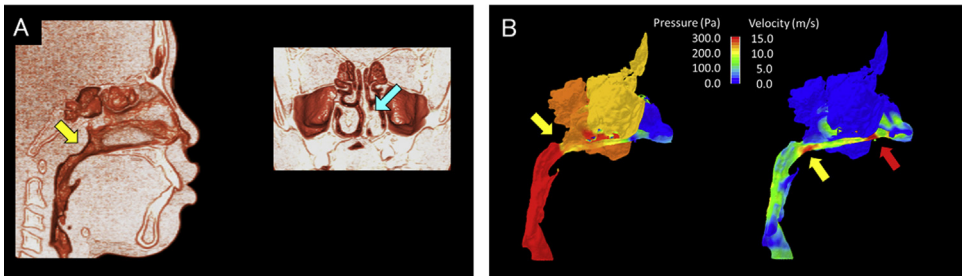

Fig 5. Upper airway ventilation condition of children with unilateral cleft and palate according to computational fluid dynamics. **A,** Left: sagittal view, adenoid hypertrophy revealed (*yellow arrow*); right: deviated nasal septum and nasal mucosal hypertrophy revealed (blue *arrow*). **B,** Left: backward part of the nasal airway pressure was high (*orange*), and abrupt pressure change was shown at adenoid (*yellow arrow*); furthermore, pharyngeal airway pressure was extremely high (*red*); right: nasal airway (*red arrow*) and nasopharyngeal airway (*yellow arrow*) velocities were high, because deviated nasal septum and nasal mucosa exhibit hypertrophy and adenoid exhibits hypertrophy; pharyngeal airway velocity was relatively fast in comparison with control children (*light green*). As a result, upper airway obstruction in children with unilateral cleft and palate was indicated by nasal, nasopharyngeal, and pharyngeal airway obstruction.

UCLP with the use of rhinomanometry, showing that the affected side was 2.7 Pa s/cm^3, the unaffected side 0.95 Pa s/cm^3, and both sides together 0.8 Pa s/cm^3. Their value was 4 times the resistance level of the normal adult (0.2 Pa/cm^3/s). Furthermore, they reported that high nasal resistance occurred because nasal airway cross-section of the affected side showed 50%-70% smaller area and 80% smaller volume. However, the nasal resistance of our UCLP group (0.97 Pa/cm^3/s) was different from the value of Mani et al (0.8 Pa/cm^3/s).[14] Laine-Alava et al[31] evaluated growth changes in nasal resistance of normal children (8-17 years of age), reporting that the nasal resistances of normal 9-year-old boys and girls were 2.8 Pa/cm^3/s and 3.7 Pa/cm^3/s, respectively; the resistances of normal 17-year-old boys and girls were 1.5 Pa/cm^3/s and 2.4 Pa/cm^3/s, respectively. Therefore, because the ages of those subjects (9 and 17 years old) were different, we expected that the nasal resistances would be different. However, the ratio of the resistance level in cases of UCLP, compared with control children, showed a 4-fold change, similar to that observed by Mani et al.[14] Thus, the nasal resistance values of the UCLP group in our study were reliable and children with UCLP were shown to have nasal obstruction.

Upper airway maximal pressure and velocity of the UCLP group were 335.02 Pa and 18.18 m/s. Wootton et al[18] evaluated the ventilation condition of obese children with nasal obstruction at inspiration (nasal resistance 0.83 Pa/cm^3/s) with the use of CFD (flow rate 281 cm^3/s); they reported that the upper airway maximal pressure at inspiration was −253.99 Pa (−2.59 cmH_2O). Because they measured CFD of inspiration, the signs of the values are different. Therefore, comparing the

absolute values of their results and our results, the pressure of their obese group was relatively smaller than that of our UCLP group. However, the upper airway pressure of obese children with nasal obstruction showed a value that was similar to our children with UCLP when considering differences in nasal resistance (0.97 vs 0.83 Pa/cm^3/s) and flow rate (200 vs 281 cm^3; Table III). A previous study reported that Class II children (mean age 9.3 years) with nasal obstruction, but without adenoid and tonsil hypertrophy, had considerable expiration upper airway pressure (220.26 Pa).[32] When upper airway obstruction is observed, it is reported that the upper airway velocity is fast.[26] The maximal upper airway velocity of dolichofacial Class II children with upper airway obstruction was reported as 15.5 m/s.

From these reports,[18,26,32] CFD showed that the upper airway maximal pressure and velocity in our children with UCLP had tendencies similar to those observed in patients with upper airway obstruction. Thus, we conclude that children with UCLP exhibit upper airway obstruction.

In this study, adenoid hypertrophy of the UCLP group was detected (Table IV). Imamura et al[8] reported that at 9.2 years, children with UCLP had significantly larger hypertrophy than control children. As a result, anterior-posterior depth of the nasopharyngeal airway of UCLP was shorter than in control children. Shahidi et al[11] found that the nasopharyngeal airway volume of subjects with UCLP was smaller than that of control subjects. Thus, the nasopharyngeal airway part of children with UCLP was small and nasopharyngeal airway obstruction could easily occur. In contrast, the present study showed that the UCLP group had smaller pharyngeal airway volume (from palatal plane to base of epiglottis plane; Table II). In previous studies, the pharyngeal airway size of patients with UCLP was evaluated by axial cross-section area[5] and volume.[9,11] These studies and our results show that the pharyngeal airway sizes of children with UCLP are small. These morphologic data show that airway obstruction occurs in the pharyngeal airway similarly to the nasopharyngeal airway.

Furthermore, we used CFD as a functional evaluation method, and found that the total pharyngeal airway (from choanae to base of epiglottis) pressure of the UCLP group was 140.46 Pa. A previous study reported that in children[18] with OSAS who had adenoids and hyperplasia of palatine tonsil ventilation obstruction, the pharyngeal airway pressure (from choanae to the base of the epiglottis) was 200.79 Pa. The pressure of children with UCLP in our study is slightly smaller than that of children with OSAS. However, the total pharyngeal airway pressure of children with CLP is regarded as indicating airway obstruction. In contrast, the total pharyngeal airway pressure of the control group was 15.92 Pa. In a previous study, the pharyngeal airway pressure (between palatal plane and base of epiglottis plane) of 11.9-year-old normal children was 5.57 Pa.[33] Because the adenoid size of our control group was relatively small (Table IV), we suspect that the effect on the total pharyngeal airway (from choanae to base of epiglottis) pressure in our control group was small. Therefore, we considered that the pressure of the total pharyngeal airway (from choanae to base of epiglottis) of our control group was similar to that of normal children and that they did not exhibit total pharyngeal airway obstruction.

From these observations, we conclude that children with UCLP had total pharyngeal airway (from choanae to base of epiglottis) obstruction because of adenoid hypertrophy and small pharyngeal airway.

The nasal resistance value of the UCLP group (0.97 Pa/cm^3/s) in our study is larger than the value that was associated with nasal obstruction in a previous study (0.57 Pa/cm^3/s).[34] When nasal airway resistance is beyond nasal airway resistance (0.5 Pa/cm^3/s), mouth breathing occurs as well as nasal breathing.[19] And the breathing ratio of nose and mouth is affected by the nasal resistance. The nasal resistance value of the UCLP group (0.97 $\pm$ 1.04 Pa/cm^3/s) in our study was large and varied. Therefore although we did not evaluate the breathing situation of UCLP children directly, a previous study[35] reported that UCLP children had various breathing ratios of nose and mouth and expected more cases when the ratio of mouth breathing was high. Previous studies have reported that patients with UCLP exhibited mouth breathing,[3,4] a more inferiorly positioned hyoid,[6,36] and larger craniocervical angulation.[2] In our results, the morphologic features of children with UCLP were a lower hyoid position, larger intraoral airway volume, and larger FMA. In a previous study, larger intraoral airway volume was indicative of low tongue posture.[25]

It is thought that children with UCLP begin mouth breathing as a result of upper airway obstruction, and exhibit lower tongue and hyoid positions.[19] The UCLP children who have a high ratio of mouth breathing with nasal obstruction was similar to previous reports.[19] Furthermore, lower growth direction has been reported in children with UCLP.[2] From our study results, FMA appeared to grow larger through low tongue and lower hyoid position as a result of the upper airway obstruction, such that growth direction became downward. Thus, upper airway obstruction may be a contributing factor of the reported maxillofacial morphologic characteristics of CLP.[2,6,9,20]

LIMITATIONS

The main limitation of this study is that our CFD analysis was based on several assumptions, including steady flow, homogeneous fluid, and rigid walls, which limits its applicability to normal physiologic conditions. Therefore, we consider our findings to simply suggest tendencies similar to actual breathing. This study is not a clinical study. It is necessary to confirm these results in a clinical study that measures volume of air respired orally and nasally. Because of slightly undersized samples, the results had a small chance of accepting a false hypothesis (type II error). However, because each variable accepted significant difference. It was thought that there was little effect on results. Also owing to the small study sample, and to verify our data, independent study of another racial group or a much larger-scale study in our population is needed in future.

CONCLUSIONS

Children with UCLP had larger nasal resistance, larger adenoids, and smaller pharyngeal airway volume compared with control children. Moreover, they showed upper airway obstruction because of nasal, nasopharyngeal, and pharyngeal airway alterations.

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