Original Article

Three-dimensional assessment of the nasopharyngeal airway in Down syndrome during the mixed dentition period: a case-control study

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ABSTRACT

Objective: In this retrospective case-control study, we aimed to evaluate the nasopharyngeal airway volume of children with Down syndrome (DS) and compare the results with those of control participants well matched for sex and age.

Materials and Methods: Fifteen children with DS (mean age = 9.43 ± 0.38 years; 8 boys, 7 girls) and 15 control participants (mean age = 9.51 ± 0.40 years; 8 boys, 7 girls) were enrolled. The nasopharyngeal airway volume and the cross-sectional morphology were measured with cone-beam computed tomography taken for orthodontic treatment. All measurements were assessed by analysis of covariance (ANCOVA) using Bonferroni post hoc pairwise comparison tests. Covariates were body height and body weight, and the ANB angle and the mandibular plane angle. Significance was set at $P < .0019$.

Results: Nasal airway, superior airway, and total airway volumes of DS participants were significantly smaller than those of the control participants in ANCOVA results adjusted for ANB angle and mandibular plane angle ($P = .000$). In ANCOVA results adjusted for body height and body weight, no statistically significant differences in the volume measurements were found.

Conclusion: The results indicate that the nasopharyngeal airway volume differs between children with and without DS and that the airway volume tends to be smaller in DS children than in children without DS. (*Angle Orthod*. 2025;95:78–85.)

KEY WORDS: Down syndrome; Children; Obstructive sleep apnea; Nasopharyngeal airway; Cone-beam computed tomography (CBCT); Volume; Orthodontics

INTRODUCTION

Down syndrome (DS) is the most common chromosomal condition and has various clinical manifestations.[1] It occurs in approximately 1 per 800 births worldwide. In Japan, DS occurs in approximately 2200 live births annually, approximately 22 per 10,000.[2] The potential for development and socialization of patients with DS has increased in recent years. Patients with DS often have congenital heart disease, infections caused in part by immunodeficiencies, neurodevelopmental disorders, and orthopedic problems.[3] Sleep disorders, thyroid abnormalities, and dysphagia are also symptoms related to DS.[3]

It has been reported that obstructive sleep apnea (OSA) sometimes occurs in children from the neonatal stage to adolescence,[4,5] and children with DS have higher prevalence rates of OSA (32–66%).[6–11] The pathophysiology of pediatric OSA is often associated with upper airway collapsibility, anatomic narrowing of the nasopharyngeal airway, neuropsychological dysfunction, or a combination of these.[4,5] Anatomic narrowing of the airway in children is caused by adenotonsillar hypertrophy, obesity, inflammation of the upper airways, micrognathia, macroglossia, nasal obstruction, and craniofacial anomalies.[4,5] Particularly in children with DS, it is known that OSA is associated with anatomic and physiologic factors, such as midfacial and mandibular hypoplasia with relative macroglossia, a high-arched and narrow palate,

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Table 1. Patient Demographics

Patient	Number of Patients (Male, Female)	Age, y, Mean ± SD	Body Height, cm[3], Mean ± SD	*P* Value	Body Weight, kg, Mean ± SD	*P* Value
Down syndrome	15 (8, 7)	9.43 ± 1.48	120.33 ± 9.21	.00*	24.13 ± 5.26	.03*
Control	15 (8, 7)	9.51 ± 1.54	133.57 ± 8.84		29.11 ± 6.65	

* $P < .05$ statistically significant.

adenoid and tonsil hypertrophy, incomplete tracheal rings, muscular hypotonia, and obesity.[12,13]

Various factors that cause airway obstruction also affect craniofacial growth.[14] Airway obstruction can cause skeletal alterations during the growth period, and this condition is commonly known as "long adenoid facies." Characteristics of the long adenoid face include increased lower facial height and mandibular plane angle and constriction of the maxillary dental arch.[15] Therefore, improvement of airway obstruction at an early growing stage is a key strategy for achieving correct craniofacial development.

Three-dimensional (3D) assessment of the nasopharyngeal airway, including volumetric analysis, allows a more detailed understanding of the anatomical differences of each individual. Cone-beam computed tomography (CBCT) facilitates accurate craniomaxillofacial assessment[16] and has recently been used as an effective tool to evaluate the nasopharyngeal airway.[17–20] Although the anatomical difference in the nasopharyngeal airway is known to be a risk factor for OSA, few authors have measured and assessed the nasopharyngeal airway in patients with DS.[21] In addition, no authors have used CBCT to evaluate the nasopharyngeal airway in patients with DS during the growing stage.

The aim of the present study was to assess the nasopharyngeal airway volume and potential anatomic risk of OSA in children with DS and compare the findings with those of control participants well matched for sex and age.

MATERIALS AND METHODS

This retrospective, cross-sectional study was conducted according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines. The participants included 15 children with DS (mean age = 9.43 ± 0.38 years; 8 boys, 7 girls) and 15 non-DS children (mean age = 9.51 ± 0.40 years; 8 boys, 7 girls) who visited the Department of Orthodontics, Showa University Dental Hospital, from August 2016 to August 2020. Participants with a history of cleft lip and palate, tracheomalacia, laryngomalacia, tonsillectomy, adenoidectomy, or previous orthodontic treatment were excluded. Participants in the control group were age and sex matched to the DS participants. The participants were classified according to their anteroposterior skeletal pattern using the ANB angle: Class I = $-1° \leq$ ANB $<$ 4°; Class II = ANB $\geq$ 4°; and Class III = ANB $< -1°$.[22,23] Vertical skeletal patterns were classified using the angle of the Frankfort horizontal (FH) plane to the mandibular plane (MP; FH/MP): hypodivergent = FH/MP $<$ 22°; normodivergent = 22° $\leq$ FH/MP $<$ 30°; and hyperdivergent = FH/MP $\geq$ 30°.[23] Patient demographics are shown in Tables 1 through 3 and Figure 1. Written informed consent was obtained from all participants and/or their parents, and the study was approved by the Ethics Committee of Showa University Dental Hospital (Approval No. SUDH0077).

CBCT examination was carried out for all participants to evaluate skeletal malocclusion and deformity, the skeletal relationship between the maxilla and mandible, impacted permanent teeth, the size of the permanent teeth to calculate arch length discrepancy, congenitally missing teeth, and condition of the temporomandibular joint. CBCT images were taken with a KaVo 3DeXam (KaVo Dental, Biberach, Germany). The scanning conditions were set at 120 kV and 5 mA, the voxel size was 0.4 mm, and the scanning time was 8.9 seconds. Participants were seated comfortably, with a natural head position after adjustment of the chin rest, and were asked to bite but not move or swallow during the scan. The CBCT images were saved in Digital Imaging and Communication in Medicine format.

To evaluate the nasopharyngeal structures, the CBCT images were examined using Invivo5 dental radiology software (Anatomage, San Jose, Calif). The images were reoriented, using the FH plane as a reference plane to standardize the measurements and to minimize errors (Figure 2).[19,20] The FH plane was defined by right and left porions (the most laterosuperior point of the external auditory meatus) and the right and left orbitales (the most inferior point of the lower margin of the bony orbit). Five cross-sectional planes: the anterior nasal plane (Ana), posterior nasal plane (Pna), upper pharyngeal plane (Uph), middle pharyngeal airway (Mph),

Table 2. Horizontal Skeletal Classifications

	Down Syndrome (Male, Female)	Control (Male, Female)
Skeletal Class I, $-1° \leq$ ANB $<$ 4°	8 (3, 5)	5 (2, 3)
Skeletal Class II, ANB $\geq$ 4°	4 (3, 1)	7 (5, 2)
Skeletal Class III, ANB $< -1°$	3 (2, 1)	3 (1, 2)
Total	15 (8, 7)	15 (8, 7)

Table 3. Vertical Skeletal Classifications[a]

	Down Syndrome (Male, Female)	Control (Male, Female)
Hyperdivergent, FH/MP $\geq$ 30°	1 (1, 0)	3 (1, 2)
Normodivergent, 22° $\leq$ FH/MP $<$ 30°	5 (3, 2)	9 (5, 4)
Hypodivergent, FH/MP $<$ 22°	9 (4, 5)	3 (2, 1)
Total	15 (8, 7)	15 (8, 7)

[a] Vertical skeletal patterns were classified by the angle of the Frankfort horizontal plane to the mandibular plane (FH/MP).

inferior pharyngeal airway (Iph), and five volumes of the pharyngeal airway were configured (Table 4). The five cross-sectional planes were defined as Ana was perpendicular to the FH plane through the anterior nasal spine; Pna was perpendicular to the FH plane through the posterior nasal spine; Uph was parallel to the FH plane through the posterior nasal spine; Mph was parallel to the FH plane through the caudal margin of the soft palate; and Iph was parallel to the FH plane through the superior margin of the epiglottis. The five pharyngeal airway volumes were defined as the nasal airway was the airway formed by the anterior and posterior nasal planes; the superior pharyngeal airway was the airway formed by the posterior nasal plane and the upper pharyngeal plane; the middle pharyngeal airway was the airway formed by the upper and middle pharyngeal planes; the inferior pharyngeal airway was the airway formed by the middle and lower pharyngeal planes; and the total airway was the airway extending from the anterior nasal plane to the lower pharyngeal plane.

To separate and extract the airway space from the craniofacial region, a threshold tool with the histogram adjusted as a guide to −523.9 Hounsfield units was used.[20,24] The defined nasopharyngeal airway volumes were calculated in cubic millimeters, and the airway width, length, and area were measured in the sectional views (frontal and axial) in the cross-sectional lines (Figures 2 and 3). Reconstructed volumes were calculated automatically; lengths in the cross-sectional plane were measured manually; and areas were measured automatically.

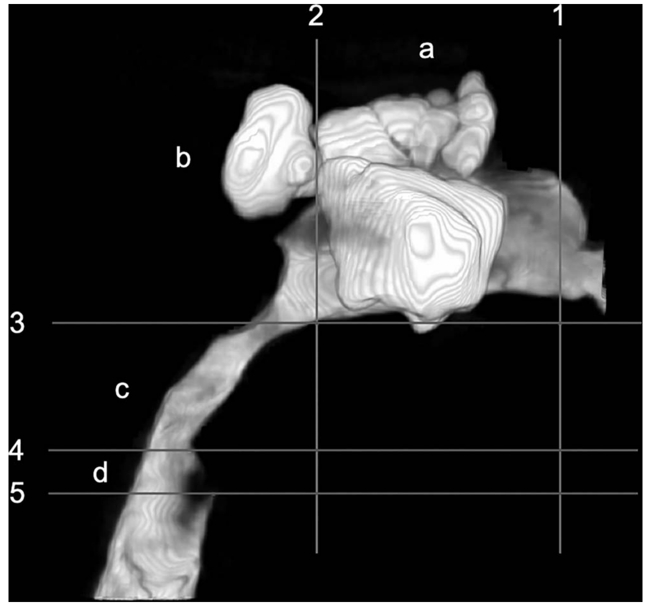

Figure 2. Five cross-sectional planes of the pharyngeal airway. (1) Anterior nasal plane (Ana); (2) posterior nasal plane (Pna); (3) upper pharyngeal plane (Uph); (4) middle pharyngeal plane (Mph); (5) lower pharyngeal plane (Lph); (a) nasal airway volume; (b) superior pharyngeal airway volume; (c) middle pharyngeal airway volume; (d), inferior pharyngeal airway volume; (a) + (b) + (c) + (d) total airway volume.

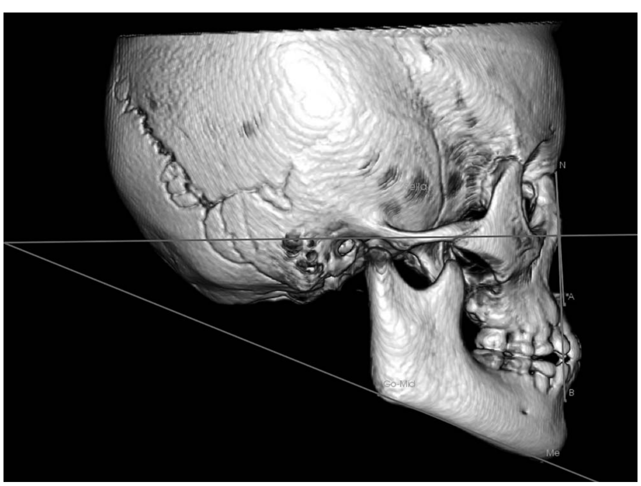

Figure 1. Sagittal view images reoriented using the Frankfort horizontal (FH) plane, defined by the right and left porion (Po), and right and left orbitale (Or). The anteroposterior skeletal pattern was classified by the angle of ANB and the vertical skeletal pattern was classified by the angle of FH plane to the mandibular plane.

Table 4. Landmark Definitions[a]

Landmark	Definition
Anterior nasal plane	Perpendicular to FH plane through ANS
Posterior nasal plane	Perpendicular to FH plane through PNS
Upper pharyngeal plane	Parallel to FH plane through PNS
Middle pharyngeal plane	Parallel to FH plane through the caudal margin of the soft palate
Lower pharyngeal plane	Parallel to FH plane through the superior margin of the epiglottis
Nasal airway	Airway formed by the anterior and posterior nasal planes
Superior pharyngeal airway	Airway formed by the posterior nasal plane and upper pharyngeal plane
Middle pharyngeal airway	Airway formed by the upper and middle pharyngeal plane
Inferior pharyngeal airway	Airway formed by the middle and lower pharyngeal plane
Total airway	Airway extending from anterior nasal plane to lower pharyngeal plane

[a] FH indicates Frankfort horizontal plane; ANS, anterior nasal spine; PNS, posterior nasal spine.

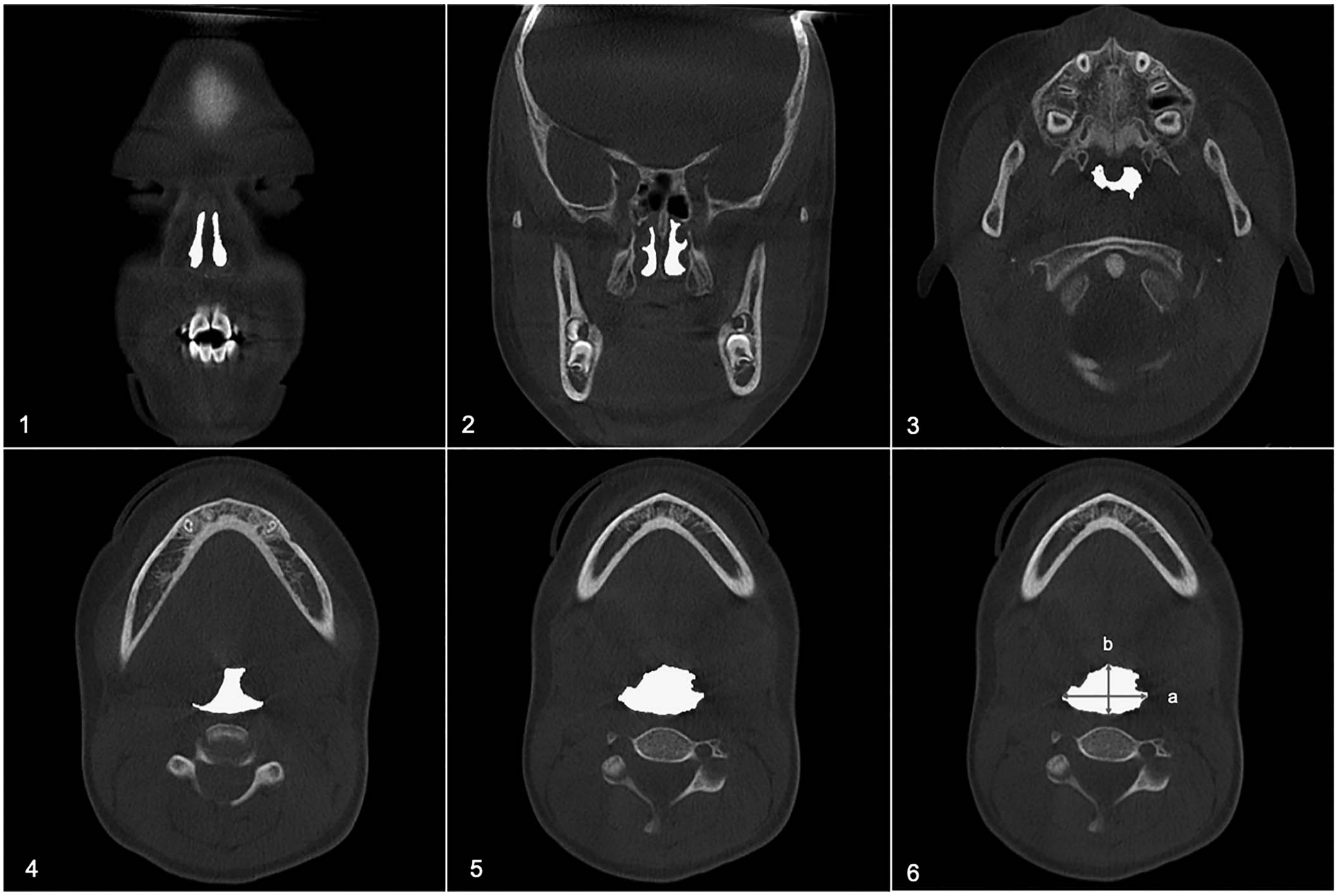

Figure 3. Cross-sectional views of the pharyngeal airway in the five planes. (1) Frontal slice of the anterior nasal plane; (2) frontal slice of the posterior nasal plane; (3) axial slice of the upper pharyngeal plane; (4) axial slice of the middle pharyngeal plane; (5) axial slice of the lower pharyngeal plane; (6) (a) the width of the airway defined by the greatest distance in the right and left directions of the airway cross-section, (b) the height of the airway defined by the greatest distance in the anteroposterior or vertical direction of the airway cross-section. The colored regions indicate the cross-sectional area of the airway.

Statistical Analysis

Statistical analyses were performed using SPSS Statistics, version 25 (IBM Corp., Armonk, NY). To assess intraoperator error, all measurements on the CBCT images were remeasured at a separate session with a 2-week or greater interval under identical conditions. The measurement error was estimated according to intraclass correlation coefficient (ICC) assessment. The Shapiro-Wilk test and Leven's test were used to confirm normality and equality of variance among the measurements. Analysis of covariance (ANCOVA) with Bonferroni post hoc pairwise comparison tests for the corrected means were used to compare the 26 measurements of the volume, area, and length of the nasopharyngeal airway among the groups and between individual differences, with body height and body weight as covariates. Additionally, as covariates with the ANB angle and the mandibular plane angle, ANCOVA with Bonferroni post hoc pairwise comparison tests were also conducted. Significance probability adjusted with Bonferroni was set at $P < .0019$.

Power analyses were performed using G*Power Ver. 3.1.9.4 (Franz Faul, Universität Kiel, Germany) to calculate a priori required sample sizes at a two-sided significance level of 5% and a power of 80%. A sample size of at least 14 patients for each group was calculated to be adequate to detect the difference in total airway volume as a primary measurement between control and DS patients, assuming mean volumes of 21,000 mm^3 and 17,000 mm^3, respectively, with a common standard deviation of 3600 mm^3. Post hoc power analysis was also carried out using G*power version 3.1.9.6 (Franz Faul) for calculation of detection power at a two-sided significance level of 5% and a sample size of 15 in each group.

RESULTS

ICC analyses revealed an average score of 0.94. The random error evaluation according to the ICC indicated that the magnitude of measurement error was sufficiently small.

Table 5. Descriptive Statistics[a]

	Down Syndrome		Control
	Mean ± SE	SD	Mean ± SE
Volume measurements, mm^3			
Nasal airway	16,636.60 ± 1960.77	7594.03	36,182.47 ± 2705.53
Superior pharyngeal airway	3019.47 ± 311.26	1205.50	8699.13 ± 1041.40
Middle pharyngeal airway	2462.13 ± 251.57	974.32	4260.60 ± 400.31
Inferior pharyngeal airway	1890.40 ± 320.41	1240.92	2120.87 ± 286.67
Total airway	24,008.60 ± 2392.80	9267.28	51,263.07 ± 3843.23
Area, mm^2, and linear, mm, measurements			
Ana area (right)	68.97 ± 4.26	16.50	99.87 ± 5.88
Ana width (right)	5.04 ± 0.17	0.67	6.81 ± 0.28
Ana height (right)	22.18 ± 0.73	2.82	28.01 ± 1.27
Ana area (left)	67.76 ± 5.66	21.92	90.01 ± 5.00
Ana width (left)	4.94 ± 0.26	1.01	6.16 ± 0.20
Ana height (left)	22.02 ± 0.77	2.98	27.71 ± 1.18
Pna area (right)	96.20 ± 8.52	32.99	150.85 ± 9.88
Pna width (right)	8.40 ± 0.38	1.49	11.79 ± 0.35
Pna height (right)	28.51 ± 1.43	5.52	27.80 ± 1.85
Pna area (left)	106.24 ± 9.52	36.89	135.38 ± 9.08
Pna width (left)	8.35 ± 0.39	1.49	11.66 ± 0.39
Pna height (left)	28.46 ± 1.51	5.85	28.29 ± 1.70
Uph area	237.77 ± 25.69	99.50	376.56 ± 37.47
Uph width	18.06 ± 0.90	3.49	25.44 ± 1.52
Uph height	19.90 ± 1.56	6.05	22.38 ± 1.29
Mph area	97.11 ± 17.65	68.35	164.61 ± 15.93
Mph width	14.08 ± 1.25	4.86	18.68 ± 1.03
Mph height	11.16 ± 0.93	3.60	13.30 ± 0.76
Lph area	128.36 ± 22.84	88.45	176.29 ± 9.80
Lph width	21.14 ± 1.20	4.66	23.20 ± 1.50
Lph height	8.93 ± 1.08	4.18	11.16 ± 0.97

[a] Ana indicates anterior nasal plane; Pna, posterior nasal plane; Uph, upper pharyngeal plane; Mph, middle pharyngeal plane; Lph, lower pharyngeal plane.

Table 5 shows the descriptive statistics for the volumetric and two-dimensional measurements of the nasopharyngeal airway for DS and control participants.

Table 6 shows the ANCOVA results adjusted for body height and body weight, and Table 7 shows ANCOVA results adjusted for ANB angle and mandibular plane angle. In the ANCOVA results adjusted for ANB angle and mandibular plane angle, the nasal airway, superior pharyngeal airway, and total airway volumes were significantly smaller in the DS group than in the control group. The ANCOVA results adjusted for ANB angle and mandibular plane angle showed significant differences for the nasal airway ($P = .000$), superior pharyngeal airway ($P = .000$), and total airway ($P = .000$). However, no significant differences were found in the volume measurements in the ANCOVA results adjusted for body height and body weight. The post hoc detection powers were 100.0%, 100.0%, 100.0%, 27.4%, and 100.0% for the nasal pharyngeal airway, superior pharyngeal airway, middle pharyngeal airway, inferior pharyngeal airway, and total airway volumes, respectively.

In the cross-sectional plane, significant differences were found in both the ANCOVA results adjusted for body height and body weight and the ANCOVA results adjusted for ANB angle and mandibular plane angle for the right-side Ana width and the right-side Pna width. Significant differences were also found in the ANCOVA results adjusted for ANB angle and mandibular plane angle in the right-side Ana area, the Ana height on both sides, the left-side Pna width, and the Uph width, but not in the ANCOVA results adjusted for body height and body weight (Tables 6 and 7). The post hoc detection power for the areas in the cross-sectional plane was 95.4% to 100.0%. For differences in the right- and left-side Pna heights, the post hoc power values were 14.5% and 6.7%, respectively. The post hoc power values for other widths and heights were 66.6% to 100.0%.

DISCUSSION

This was the first study to evaluate the nasopharyngeal airway in children with DS during the mixed dentition period using CBCT and to compare the results with those of control participants who were well matched for age and sex. Although some volumetric analyses and linear and area measurements in the nasopharyngeal airway were not significantly different between the DS and control participants, the results obtained from the analysis and measurements indicated that the nasopharyngeal

Table 6. Analysis of Covariance Adjusted for Body Height and Body Weight[a]

	Down Syndrome (A), Mean	Control (B), Mean	Mean Difference (A-B)	95% Mean Difference Confidence Interval	*P* Value
Volume measurements, mm^3					
Nasal airway	21,575.97	31,243.10	−9667.13	−16,577.54 to −2756.73	.008
Superior pharyngeal airway	3633.51	8085.09	−4451.58	−7167.30 to −1735.856	.002
Middle pharyngeal airway	2763.87	3958.86	−1194.99	−2357.35 to −32.64	.044
Inferior pharyngeal airway	2267.01	1744.26	522.76	−582.27 to 1627.78	.340
Total airway	30,240.36	45,031.31	−14,790.95	−24,562.43 to −5019.46	.004
Area, mm^2, and linear, mm, measurements					
Ana area (right)	76.74	92.11	−15.36	−33.31 to 2.58	.090
Ana width (right)	5.11	6.74	−1.64	−2.50 to −0.77	.001*
Ana height (right)	24.300	25.89	−1.59	−4.63 to 1.44	.291
Ana area (left)	72.50	85.26	−12.76	−33.04 to 7.52	.207
Ana width (left)	4.86	6.24	−1.37	−2.25 to −0.49	.004
Ana height (left)	23.91	25.82	−1.91	−4.93 to 1.11	.205
Pna area (right)	106.96	140.09	−33.13	−67.20 to 0.93	.056
Pna width (right)	8.74	11.44	−2.69	−4.06 to −1.32	.000*
Pna height (right)	29.07	27.24	1.83	−4.65 to 8.31	.567
Pna area (left)	117.81	123.81	−6.00	−39.72 to 27.72	.717
Pna width (left)	8.96	11.05	−2.08	−3.37 to −0.80	.003
Pna height (left)	29.49	27.27	2.21	−4.00 to 8.43	.470
Uph area	254.34	359.99	−105.66	−230.67 to 19.35	.094
Uph width	20.00	23.50	−3.49	−7.74 to 0.76	.103
Uph height	18.99	23.29	−4.29	−9.85 to 1.26	.124
Mph area	107.27	154.45	−47.18	−112.31 to 17.96	.149
Mph width	15.38	17.39	−2.01	−6.25 to 2.24	.340
Mph height	10.96	13.49	−2.53	−5.89 to 0.83	.134
Lph area	140.59	164.06	−23.47	−91.11 to 44.17	.482
Lph width	22.94	21.40	1.54	−3.17 to 6.25	.508
Lph height	8.48	11.62	−3.14	−7.19 to 0.91	.123

[a] Ana indicates anterior nasal plane; Pna, posterior nasal plane; Uph, upper pharyngeal plane; Mph, middle pharyngeal plane; Lph, lower pharyngeal plane. Means are estimated marginal means after adjusting for covariates. Covariates were body height and body weight.

* $P < .0019$ statistically significant.

airway tended to be constricted in children with DS compared with control participants.

Midfacial hypoplasia, high-arched palate, and narrow maxilla are common anatomic abnormalities in nasal airway constriction.[4,5,13,21,25,26] These features of patients with DS may be correlated with nasal and nasopharyngeal airway constriction.[27,28] Additionally, micrognathia and the mandibular position affect inferior pharyngeal airway constriction, especially in children with a hyperdivergent, long face (ie, with a higher mandibular plane angle).[4,29] As previously reported, a small mandible is also a feature of patients with DS,[25] so it is possible that the micrognathia caused narrowing of the pharyngeal airway. A hypodivergent (ie, brachycephalic) mandibular position with easily enlarged airways is characteristic of patients with DS,[30,31] and two-thirds of the participants with DS in this study were hypodivergent. The results also suggested no significant differences in the middle pharyngeal airway and inferior pharyngeal airway volumes. One possible explanation for these results relates to the characteristics of craniofacial morphology. However, El and Palomo[32] reported no significant differences in middle pharyngeal airway and inferior pharyngeal airway volumes compared with patients who required orthodontic treatment with rapid expansion (ie, patients with a constricted maxillary arch) and a control group without rapid expansion. Patients with DS often need orthodontic treatment with rapid expansion because of a small maxilla. Therefore, the participants in the current study and the study of El and Palomo[32] had similar characteristics. These results indicate that midfacial hypoplasia may not greatly affect the volume of the middle pharyngeal and inferior pharyngeal airways. Craniofacial morphology and position are considered key factors related to the pharyngeal airway volume; however, further verification is required in DS patients.

Although no significant differences were found in the linear and area measurements of the Uph cross-sectional plane in ANCOVA results adjusted for body height and body weight, the results in DS participants were smaller than those of control participants. These results indicate that children with DS may have adenoid and tonsil hypertrophy. In support of these results, authors of previous studies on OSA reported that patients with DS had enlarged adenoids and/or tonsils.[13,33] Adenoid and tonsil hypertrophy might be another risk factor caused by constricted airways in patients with DS.[13,33]

Table 7. Analysis of Covariance Adjusted for ANB Angle and Mandibular Plane Angle[a]

	Down Syndrome (A), Mean	Control (B), Mean	Mean Difference (A-B)	95% Mean Difference Confidence Interval	*P* Value
Volume measurements, mm^3					
Nasal airway	17,190.24	35,628.83	−18,438.59	−26,047.59 to −10,829.60	.000*
Superior pharyngeal airway	3048.74	8669.86	−5621.12	−8118.99 to −3123.25	.000*
Middle pharyngeal airway	2499.45	4223.28	−1723.83	−2774.73 to −672.92	.002
Inferior pharyngeal airway	1866.38	2144.89	−278.51	−1251.31 to 694.30	.561
Total airway	24,604.81	50,666.86	−26,062.05	−36,521.78 to −15,602.32	.000*
Area, mm^2, and linear, mm, measurements					
Ana area (right)	66.44	102.41	−35.96	−50.48 to −21.45	.000*
Ana width (right)	4.92	6.92	−2.00	−2.71 to −1.29	.000*
Ana height (right)	21.76	28.43	−6.67	−9.77 to −3.57	.000*
Ana area (left)	66.05	91.71	−25.66	−42.46 to 8.86	.004
Ana width (left)	4.92	6.18	−1.26	−2.02 to −0.50	.002
Ana height (left)	21.66	28.07	−6.41	−9.37 to −3.44	.000*
Pna area (right)	101.08	145.97	−44.90	−73.61 to −16.18	.003
Pna width (right)	8.59	11.59	−3.00	−4.14 to −1.86	.000*
Pna height (right)	28.23	28.08	0.174	−5.01 to 5.32	.952
Pna area (left)	107.33	134.29	−26.96	−57.37 to 3.45	.080
Pna width (left)	8.33	11.67	−3.34	−4.54 to −2.14	.000*
Pna height (left)	28.09	28.67	−0.58	−5.67 to 4.50	.816
Uph area	234.50	379.83	−145.32	−250.24 to −40.41	.009
Uph width	18.18	25.32	−7.14	−11.18 to −3.09	.001*
Uph height	19.89	22.40	−2.51	−7.18 to 2.16	.280
Mph area	99.80	161.92	−62.12	−112.25 to 11.99	.017
Mph width	14.28	18.48	−4.21	−7.88 to −0.53	.026
Mph height	10.99	13.46	−2.47	−5.11 to 0.17	.066
Lph area	126.57	178.08	−51.51	−108.59 to 5.56	.075
Lph width	21.38	22.97	−1.59	−5.80 to 2.62	.444
Lph height	8.44	11.65	−3.22	−6.43 to 0.01	.049

[a] Means are estimated marginal means after adjusting for covariates. Covariates were ANB angle and mandibular plane angle. Ana indicates anterior nasal plane; Pna, posterior nasal plane; Uph, upper pharyngeal plane; Mph, middle pharyngeal plane; Lph, lower pharyngeal plane.

* $P < .0019$ statistically significant.

Several studies reported that orthodontic treatment with rapid maxillary expansion and/or acceleration of maxillary growth using a facial protractor was effective in increasing the nasopharyngeal airway volume.[32,34–42] These orthodontic treatments may therefore have potential to relieve pediatric OSA. The management of pediatric OSA is essential for proper craniofacial growth and development during the mixed dentition period.

This study had some limitations. First, the sample size was small, and the detection power of the inferior pharyngeal airway volume and some area and linear measurements was insufficient. Further studies are required with larger sample sizes. Second, the anteroposterior and vertical skeletal pattern was heterogeneous because the control group in the present study was made up of age- and sex-matched individuals. Third, adenoid and tonsil hypertrophy was not considered in these measurements because CBCT does not accurately detect soft tissues. Fibroscopy assessment of the condition of the adenoids and tonsils should be included in further research. The findings of the present study indicate that these conditions are more likely to be potential risk factors for OSA. 3D assessment in the craniofacial region using CBCT is important not only for orthodontic treatment but also to detect potential anatomical risks for OSA.

CONCLUSIONS

- The findings of the present study indicate that the nasopharyngeal airway volume of DS participants tended to be smaller than that of control participants.

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