Three-Dimensional Evaluation of the Upper Airway in Children of Skeletal Class III

Jingjing Zhang, PhD, Weitao Liu, DDS, PhD, Weiran Li, DDS, MDS, and Xuemei Gao, DDS, MDS

Abstract: The present study was aimed to investigate the relationship of the upper airway size and craniofacial structures in 3 dimensions in growing children of skeletal Class III. Forty-seven children (19 boys and 28 girls, 9.6 ± 1.3 years of age, range 8.0–12.4 years) were selected. Twenty-three children with normal vertical development were divided into groups of insufficient maxilla and overdeveloped mandible for the airway comparison between different sagittal skeletal patterns. Thirty-two children with the same sagittal development were divided into groups of low angle, normal angle, and high angle for the comparison between different vertical skeletal developments. The upper airway and craniofacial structures were measured in cone beam computed tomography images using DOLPHIN 11.7 software. Mann–Whitney *U* test and Kruskal–Wallis test were used to analyze the airway differences between groups. Spearman correlated analysis was done between the upper airway size and the craniofacial pattern in the transverse dimension. The results showed that the nasopharynx was the only affected airway part between groups of insufficient maxilla and overdeveloped mandible ($P < 0.05$). The high angle group showed smaller upper airway compared with the groups of normal angle and low angle ($P < 0.05$). The skeletal transverse dimension was correlated with the height of velopharynx, hypopharynx, and total airway with small gender differences.

Key Words: CBCT, children, skeletal pattern, upper airway size

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The relationship between the craniofacial pattern and respiratory function has been investigated since the 19th century.[1] It has been demonstrated that mutual associations exist between the skeletal pattern and airway size and ventilation in both children and adults, especially in the anteroposterior dimension.[2–16] Previous studies using lateral cephalograms and cone beam computed tomography (CBCT) have reported decreased upper airway size in skeletal Class II and enlarged airway in skeletal Class III.[17] Characteristic skeletal feature as a retruded mandible has also been identified to be an important factor in children and adults with obstructive sleep apnea.[18–20] Most of the studies were done in patients with skeletal pattern of Class I or II without concerning the conditions in Class III.

Though a number of studies have been performed on the relationship between the sagittal skeletal pattern and upper airway size, the studies on the effect of vertical skeletal pattern are limited,[8,9,14–16] and few studies have been done on the related effect of transverse dimension. Celikoglu et al[16] have reported decreased airway size in patients with hyperdivergent vertical pattern compared with normal and hypodivergent patterns, but Grauer et al[14] have negative findings. Related studies have been done extensively in adults, but not in children. Therefore, the relationship between vertical skeletal pattern and upper airway size in children is still under debated.

Most previous studies have used lateral cephalogram as study material instead of three-dimensional (3D) images of CBCT or magnetic resonance imaging. In fact, CBCT has the advantages of a relatively low dose of radiation and comprehensive 3D view and provides the images of the craniofacial structures and upper airway simultaneously.[21,22] The accuracy of CBCT images has been demonstrated.[23–25]

The present study was a retrospective CBCT study including 47 children with skeletal Class III malocclusion. The primary goals included to compare the size of the upper airway in skeletal Class III children with different sagittal patterns (insufficient maxilla, and protruded mandible); to compare the upper airway size in skeletal Class III children with different vertical patterns (low, normal, and high angles); and to investigate whether the upper airway size was affected by the skeletal pattern in transverse dimension.

METHODS

Patient Selection

The present study was set retrospectively and the protocol was approved by Ethics Committee of Peking University School and Hospital of Stomatology (PKUSSIRB-20152002). All the included children were selected from the patient pool in the Department of Orthodontics, Peking University School and Hospital of Stomatology from December 2010 to June 2012. The CBCT scans before treatment were part of the diagnostic records collected to evaluate the impacted teeth or for orthodontic treatment needs. The inclusion criteria were: age <18 years; upper and lower first molars erupted and established occlusion; mixed dentition at first visit; skeletal Class III (ANB <3.3°); and pretreatment CBCT images existed. The exclusion criteria were: history of cleft lip or palate; history of orthodontic treatment; chronic mouth breathing; body mass index (BMI) >25 kg/m^2; hyperplasia of tonsils or adenoids, or history of tonsillectomy or adenoidectomy; and snoring or other sleep disorders written in the medical records.

Forty-seven children (19 boys and 28 girls, 9.6 ± 1.3 years of age, range 8.0–12.4 years, BMI 16.4 ± 2.1 kg/m^2) were selected.

From the Department of Orthodontics, Peking University School and Hospital of Stomatology, Beijing, China.
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Address correspondence and reprint requests to Prof Xuemei Gao, DDS, MDS, Department of Orthodontics, Peking University School and Hospital of Stomatology, 22 Zhongguancun South Avenue, Haidian District, Beijing 100081, China; E-mail: xmgao@263.net
JZ and WL contributed equally to the work.
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The children were all of Han Chinese. The sagittal skeletal pattern was Class III (ANB $-1.7 \pm 2.1^\circ$, range -8.1° to 1.7°), and the vertical skeletal pattern varied from low angle to high angle (MP/SN $33.2 \pm 4.6^\circ$, range 25.6°–47.0°). As the airway size is strongly affected by the head posture,[26–28] the craniocervical inclination of all the included children was examined to ensure that the inclinations were within the normal range of 90° to 110°.[27]

Patients were divided into groups according to their skeletal pattern in the sagittal and vertical dimensions. The airway comparisons between different sagittal and vertical skeletal patterns were done respectively. The grouping criteria were based on the normal values of Chinese children with mixed dentition (SNA $82.3 \pm 3.5^\circ$, SNB $77.6 \pm 2.9^\circ$, and MP/SN $35.8 \pm 3.6^\circ$).[29] Insufficient development was considered when the measurement was smaller than (mean – SD) (standard deviation [SD]), and overdevelopment when larger than (mean + SD).

Twenty-three children with normal vertical development were selected for the comparison between different sagittal skeletal patterns to eliminate the possible confounding influence of vertical pattern. These 23 children were allocated into 2 groups of insufficient maxilla (SNA $<78.8^\circ$, SNB $77.6 \pm 2.9^\circ$; $n = 9$; 3 boys and 6 girls; age 9.7 ± 1.4 years; BMI $16.4 \pm 2.0\,kg/m^2$) and overdeveloped mandible (SNA $82.3 \pm 3.5^\circ$, SNB $>80.5^\circ$; $n = 14$; 4 boys and 10 girls; age 9.5 ± 1.3 years; BMI $17.0 \pm 2.6\,kg/m^2$) according to the sagittal development of the maxilla and mandible.

Similarly, 32 children with the same sagittal development as normal maxilla and protruded mandible (SNA $82.3 \pm 3.5^\circ$, and SNB $>80.5^\circ$) were selected for the investigation of the airway effect of the vertical skeletal development. They were classified into 3 groups as the low angle group (MP/SN $<32.2^\circ$; $n = 12$; 6 boys and 6 girls; age 9.8 ± 1.3 years; BMI $15.8 \pm 1.5\,kg/m^2$), normal angle group (MP/SN $35.8 \pm 3.6^\circ$; $n = 11$; 3 boys and 8 girls; age 9.4 ± 1.2 years; BMI $16.5 \pm 1.9\,kg/m^2$), and high angle group (MP/SN $>39.4^\circ$; $n = 9$; 4 boys and 5 girls; age 8.7 ± 0.7 years; BMI $16.0 \pm 0.9\,kg/m^2$). Detailed grouping information is shown in Table 1.

Cone Beam Computed Tomography Acquisition, Export, and Measurements

All CBCT images were acquired using the same machine (DCT PRO Dentofacial CBCT System, VATECH, Gyeonggi-do, Korea) according to a standard protocol (90 kV, 7 mA, 20 cm × 19 cm FOV, 0.40 mm voxel resolution, and 15 seconds scan time). Patients were instructed to sit upright with a natural head position, and maximum intercuspation of the teeth with normal respiration and no swallowing during the scanning process. The datasets were exported in Digital Imaging and Communications in Medicine format and then transferred into the Dolphin 11.7 software package (Dolphin Imaging & Management Solutions, Chatsworth, CA). Each 3D image was reoriented using the Frankfort plane as the horizontal reference plane. The sagittal reference plane was constructed from the nasion point and perpendicular to the horizontal reference plane. The axial reference plane was constructed as the plane passing the sella and perpendicular to the horizontal and sagittal planes.

The upper airway was analyzed from the top of the airway to the horizontal level of the C3 point (the most anterior and inferior point of the third cervical vertebra), and it was divided into 3 parts, the nasopharynx, velopharynx, and hypopharynx, according to the corresponding cross-sectional slices. The nasopharynx (Naso-) was defined as the region from the top of the airway to the plane passing the posterior nasal spine; the velopharynx (Velo-) as the region from the posterior nasal spine to the tip of the soft palate; and the hypopharynx (Hypo-) as the region from the tip of the soft palate to the level of C3 point. Each region was reconstructed and

TABLE 1. Grouping Information in Sagittal and Vertical Dimensions of the Children With Skeletal Class III Malocclusion

			Skeletal Measurements							
	N	Group Name	SNA (°)	*P* Value	SNB (°)	*P* Value	ANB (°)	*P* Value	MP/SN (°)	*P* Value
Sagittal skeletal differences	23	Insufficient maxilla (n = 9)	76.8 (76.3, 77.3)	0.000*	78.8 (77.6, 79.8)	0.000*	−1.7 (−3.7, −0.8)	0.637	33.1 (32.2, 33.7)	0.467
		Overdeveloped mandible (n = 14)	80.4 (79.3, 81.5)		82.4 (81.6, 83.4)		−1.4 (−3.3, −0.4)		33.6 (32.2, 34.7)	
Vertical skeletal differences	32	Low angle (n = 12)	81.9 (79.6, 83.3)	0.458	82.9 (81.8, 85.7)	0.086	−1.6 (−3.1, −1.1)	0.676	28.5 (27.2, 30.4)	0.000†
		Normal angle (n = 11)	80.6 (79.1, 81.7)		82.4 (81.7, 83.3)		−1.3 (−2.9, −0.6)		32.7 (32.2, 34.7)	
		High angle (n = 9)	80.8 (79.4, 81.6)		82.0 (80.7, 82.3)		−1.5 (−2.4, 0.1)		39.9 (39.5, 40.9)	

Mann–Whitney *U* test for the comparison between groups of sagittal differences.
Kruskal–Wallis test for the comparison between vertical differences.
*$P < 0.01$.
†$P < 0.01$.

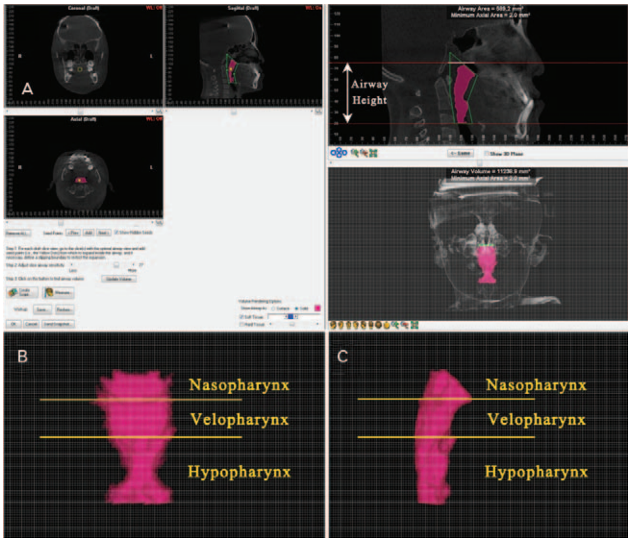

FIGURE 1. Airway measurements of the volume (V), height (H), and the minimum cross sectional area (Min) using Dolphin 11.7 software package. (A) Pink area defines the airway portion of interest, and the green plane locates the minimum cross sectional area. V, H, and Min were automatically calculated. (B) Front view of the evaluated upper airway. The airway was divided into nasopharynx, velopharynx, and hypopharynx by 2 horizontal planes passing the posterior nasal spine and the tip of the soft palate. (C) Lateral view of the evaluated upper airway.

measured using Dolphin 11.7. The airway parameters were volume (V), height (H), minimum cross-sectional area (Min), and mean cross-sectional area (Mean). The Dolphin software automatically calculated V and H and determined the Min of each region (Fig. 1). Mean was computed as the V/H ratio. Measurements of the craniofacial structures[30] were done in 3 dimensions (Table 2, Fig. 2).

TABLE 2. Measurements of Craniofacial Structures in Sagittal, Vertical, and Transverse Dimensions

Sagittal dimension, degree, measured in the lateral cephalogram generated by CBCT	
SNA	Angle between subspinale and sella at nasion, representing the position of the maxilla in relation to the cranium
SNB	Angle between supraemental and sella at nasion, representing the position of the mandible in relation to the cranium
ANB	Angle between subspinale and supraemental at nasion, representing the relationship of maxilla and mandible in relation to the cranium
Vertical dimension, degree, measured in the lateral cephalogram generated by CBCT	
MP/SN	Angle between the mandibular plane and SN plane, representing the mandibular inclination
Transverse dimension, mm	
NBW	The width of nasal base, measured in the coronal plane passing through the mesial buccal cusps of upper first molars
ZMP-ZMP	Distance between bilateral zygomatic points (ZMP)
Go-Go	Distance between bilateral gonions (Go)

CBCT, cone beam computed tomography.

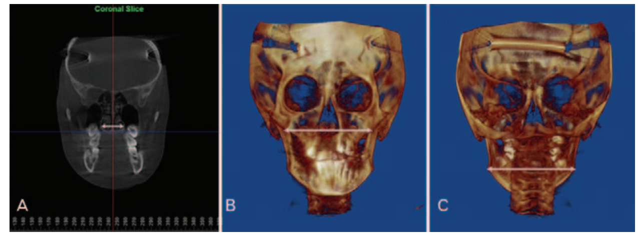

FIGURE 2. Measurements of the transverse dimension of the skeletal structures in Dolphin 11.7 software package. (A) Measurements of nasal base width in the coronal plane passing through the bilateral mesial buccal cusps of upper first molars. (B) Measurement of transverse dimension at zygomatic level (ZMP-ZMP). (C) Measurement of transverse dimension at the level of mandibular angle (Go-Go).

Measurement Reliability and Statistical Analysis

Ten children were randomly selected for reliability testing. All measurements were reobtained 2 weeks later by the same researcher. The intraclass correlation coefficient was 0.967 ($P<0.001$). The method error (ME) was calculated as: $ME=(\sum d^2/2n)^{1/2}$ (where d is the deviation between the 2 measurements and n is the number of paired double measurements).[31] Method error varied from 0.00 to 0.21 mm for linear measurements, from 0.00° to 0.29° for angular measurements, from 9.9 to 27.5 mm^2 for area measurements, and from 65 to 198 mm^3 for volume measurements.

Statistical analysis was performed using SPSS 16.0 (Statistical Product and Service Solutions, SPSS Inc, Chicago, IL). χ^2 test was used to examine the gender distribution between groups. The Kolmogorov–Smirnov test was used to examine the distributions of continuous variables. The result showed that age and BMI in every group was normally distributed, but the measurements of craniofacial structures and airway size were not. Therefore, independent *t* test or ANOVA test was used to examine the differences of age and BMI, and nonparametric test was used for airway and craniofacial comparisons. Mann–Whitney *U* test was used for the comparison between 2 groups of insufficient maxilla and overdeveloped mandible. Kruskal–Wallis test was used for the comparison between 3 groups of low angle, normal angle, and high angle. When the result of Kruskal–Wallis test was significant, further comprehensive comparison was done using Mann–Whitney *U* test, and the significant level was adjusted by Bonferroni correction as 0.017. Spearman correlated analysis was done between the upper airway size and the craniofacial pattern in the transverse dimension. The significance level was set at 0.05.

RESULTS

The distributions of gender, age, and BMI between groups of insufficient maxilla and overdeveloped mandible were balanced (P values for gender, age, and BMI were 0.813, 0.751, and 0.571). The volume and mean cross-sectional area of nasopharynx in group of insufficient maxilla were significantly smaller than those in group of overdeveloped mandible ($P<0.05$). Detailed result of the comparison between different sagittal patterns is shown in Table 3.

The distributions of gender, age, and BMI between 3 groups of vertical skeletal developments were balanced (P values for gender, age, and BMI were 0.731, 0.120, and 0.590). The comparison of the airway size between 3 groups is shown in Tables 4 and 5. The airway size was significantly different in 3 groups of low angle, normal angle, and high angle ($P<0.05$) except for the height of nasopharynx and velopharynx (Table 4). The results of multiple comparisons showed that the airway measurements in the high

TABLE 3. Differences in the Airway Size Between Group of Children With Insufficient Maxilla and Group of Children With Overdeveloped Mandible

	Insufficient Maxilla (n = 9)			Overdeveloped Mandible (n = 14)			
	*P*25	*P*50	*P*75	*P*25	*P*50	*P*75	*P* Value
Naso-V (mm^3)	1253	2489	2645	2411	2777	2971	0.044*
Naso-H (mm)	5.95	10.20	13.60	7.48	8.05	9.23	0.361
Naso-Mean (mm^2)	173.0	228.4	257.6	317.3	334.1	357.2	0.000†
Velo-V (mm^3)	4106	5344	7146	4857	5198	5972	0.801
Velo-H (mm)	19.35	20.70	22.65	17.73	22.10	24.43	0.659
Velo-Min (mm^2)	147.7	185.6	273.6	127.5	160.7	204.9	0.208
Velo-Mean (mm^2)	222.2	247.5	339.7	215.2	239.6	324.6	0.829
Hypo-V (mm^3)	4474	6201	8050	5368	6067	6578	0.753
Hypo-H (mm)	23.30	26.80	29.70	20.93	23.65	27.63	0.165
Hypo-Min (mm^2)	118.2	144.8	210.2	148.0	170.5	191.4	0.659
Hypo-Mean (mm^2)	192.3	245.1	271.0	221.6	257.3	290.8	0.305
Total-V (mm^3)	9979	13622	17342	12717	13612	15080	0.614
Total-H (mm)	50.70	55.30	63.55	50.33	55.25	60.45	0.659
Total-Mean (mm^2)	197.5	240.3	271.7	240.7	260.3	283.7	0.224

Mann–Whitney *U* test.
*$P<0.05$.
†$P<0.01$.

angle group were significantly smaller than that in groups of normal angle or low angle ($P<0.017$), including the volume and mean cross-sectional area of nasopharynx, velopharynx, hypopharynx, and total airway and the height of hypopharynx and total airway (Table 5). There was no significant difference in the airway measurements between groups of normal angle and low angle.

The result of correlated analysis is shown in Table 6. Considering the gender differences in the upper airway, the analysis was done in boys and girls respectively. The height of hypopharynx and total airway in boys was correlated with the distance of bilateral zygomatic points (ZMP-ZMP) and gonions (Go-Go) (*r* 0.508–0.546, $P<0.05$). The height of velopharynx, hypopharynx, and total airway in girls was correlated with the distance of bilateral gonions (Go-Go) (*r* 0.456–0.519, $P<0.05$). The height of hypopharynx in girls was correlated with the width of nasal base, and the distances of bilateral zygomatic points (ZMP-ZMP) and gonions (Go-Go) (*r* 0.424–0.552, $P<0.05$).

DISCUSSION

Many previous studies have found a mutual association between the craniofacial pattern and upper airway size in children and adults, especially in the anteroposterior dimension.[4–16] Many of them used lateral cephalogram as study material and used the parameter of ANB as the indicator of different sagittal skeletal patterns.[6,9,11,12,15] The lateral cephalograms failed to present a comprehensive view of the upper airway. The relative relationship of maxilla and mandible revealed by ANB is not sufficient to present the overall development of the jaws in the sagittal dimension. Decreased size in the upper airway was found in children with dysplasia maxilla or

TABLE 4. Differences in the Airway Size Between Three Groups of Children With Different Vertical Developments

	Low Angle (n = 12)			Normal Angle (n = 11)			High Angle (n = 9)			
	P25	P50	P75	P25	P50	P75	P25	P50	P75	*P* Value
Naso-V (mm^3)	1804	2599	3200	2430	2854	2972	1174	1773	2681	0.032*
Naso-H (mm)	7.65	9.95	11.45	6.90	7.80	9.30	8.03	8.30	10.35	0.295
Naso-Mean (mm^2)	249.2	282.1	329.5	318.5	329.4	349.7	142.3	188.6	256.0	0.003†
Velo-V (mm^3)	5430	6896	9621	4849	5079	6341	3512	4820	5301	0.003†
Velo-H (mm)	21.45	23.60	24.63	17.50	19.10	24.30	20.55	22.40	23.35	0.172
Velo-Min (mm^2)	135.4	168.0	324.8	134.3	169.5	229.3	61.3	112.2	164.2	0.039*
Velo-Mean (mm^2)	241.6	279.5	397.0	210.8	254.9	329.3	160.9	228.2	237.2	0.013*
Hypo-V (mm^3)	5837	5950	8703	5506	6246	7018	2529	2745	4877	0.001†
Hypo-H (mm)	25.00	25.40	29.23	21.00	26.00	28.00	17.98	20.30	21.68	0.010*
Hypo-Min (mm^2)	138.3	165.9	248.8	149.7	169.6	189.9	68.4	97.6	157.5	0.023*
Hypo-Mean (mm^2)	194.5	238.5	348.1	217.3	259.4	299.2	122.2	155.0	200.6	0.005†
Total-V (mm^3)	12,682	14,716	20,020	12,455	14,038	15,703	7482	9085	12,357	0.002†
Total-H (mm)	56.08	61.20	65.03	50.50	55.50	60.00	47.48	51.50	55.70	0.026*
Total-Mean (mm^2)	214.4	249.8	337.8	246.3	265.1	285.5	141.6	186.5	207.6	0.002†

Kruskal–Wallis test.
*$P<0.05$.
†$P<0.01$.

TABLE 5. Multiple Comparisons for the Airway Measurements With Significant Differences in Three Groups of Children With Different Vertical Developments

Airway Parameters	Paired Groups	*P* Value
Naso-V (mm^3)	Low angle–Normal angle	0.854
	Normal angle–High angle	0.004*
	Low angle–High angle	0.033
Naso-Mean (mm^2)	Low angle–Normal angle	0.023
	Normal angle–High angle	0.003*
	Low angle–High angle	0.019
Velo–V (mm^3)	Low angle–Normal angle	0.019
	Normal angle–High angle	0.138
	Low angle–High angle	0.002*
Velo-Min (mm^2)	Low angle–Normal angle	0.667
	Normal angle–High angle	0.053
	Low angle–High angle	0.047
Velo-Mean (mm^2)	Low angle–Normal angle	0.242
	Normal angle–High angle	0.063
	Low angle–High angle	0.004*
Hypo-V (mm^3)	Low angle–Normal angle	0.806
	Normal angle–High angle	0.001*
	Low angle–High angle	0.000*
Hypo-H (mm)	Low angle–Normal angle	0.423
	Normal angle–High angle	0.018
	Low angle–High angle	0.002*
Hypo-Min (mm^2)	Low angle–Normal angle	0.854
	Normal angle–High angle	0.025
	Low angle–High angle	0.039
Hypo-Mean (mm^2)	Low angle–Normal angle	0.758
	Normal angle–High angle	0.002*
	Low angle–High angle	0.011*
Total-V (mm^3)	Low angle–Normal angle	0.389
	Normal angle–High angle	0.002*
	Low angle–High angle	0.001*
Total-H (mm)	Low angle–Normal angle	0.049
	Normal angle–High angle	0.239
	Low angle–High angle	0.009*
Total-Mean (mm^2)	Low angle–Normal angle	0.758
	Normal angle–High angle	0.001*
	Low angle–High angle	0.002*

Mann–Whitney *U* test; significant level as 0.017 (Bonferroni correction).
*$P < 0.017$.

TABLE 6. Correlated Analysis Between the Upper Airway Size and the Craniofacial Pattern in Transverse Dimension in 47 Children With Skeletal Class III Malocclusion

	NBW (mm)		ZMP-ZMP (mm)		Go-Go (mm)	
Upper Airway Parameters	Male	Female	Male	Female	Male	Female
Naso-V (mm^3)						
Coefficient	0.359	−0.036	0.387	0.286	0.240	0.263
P value	0.131	0.855	0.102	0.140	0.322	0.176
Naso-H (mm)						
Coefficient	0.258	0.130	0.203	0.337	−0.038	0.258
P value	0.286	0.510	0.404	0.079	0.878	0.184
Naso-Mean (mm^2)						
Coefficient	0.209	−0.097	0.251	0.007	0.209	0.494†
P value	0.390	0.625	0.300	0.972	0.391	0.007
Velo-V (mm^3)						
Coefficient	0.122	0.155	0.304	0.344	0.175	0.200
P value	0.619	0.431	0.206	0.073	0.473	0.308
Velo-H (mm)						
Coefficient	−0.060	0.240	0.416	−0.071	0.361	0.476*
P value	0.808	0.219	0.076	0.720	0.128	0.011
Velo-Min (mm^2)						
Coefficient	0.019	0.173	0.004	0.319	0.061	0.222
P value	0.937	0.378	0.986	0.098	0.803	0.257
Velo-Mean (mm^2)						
Coefficient	−0.023	0.089	−0.125	0.370	−0.282	0.042
P value	0.926	0.651	0.611	0.053	0.241	0.832
Hypo-V (mm^3)						
Coefficient	0.114	0.177	0.353	0.327	0.391	0.264
P value	0.642	0.369	0.138	0.089	0.098	0.175
Hypo-H (mm)						
Coefficient	0.175	0.424*	0.546*	0.552†	0.427	0.456*
P value	0.474	0.025	0.016	0.002	0.068	0.015
Hypo-Min (mm^2)						
Coefficient	−0.365	0.230	0.058	0.339	−0.019	0.159
P value	0.125	0.239	0.814	0.077	0.937	0.420
Hypo-Mean (mm^2)						
Coefficient	−0.032	−0.029	0.021	0.289	0.226	0.039
P value	0.898	0.884	0.932	0.135	0.351	0.843
Total-V (mm^3)						
Coefficient	0.161	0.158	0.333	0.344	0.289	0.164
P value	0.511	0.421	0.163	0.073	0.229	0.404
Total-H (mm)						
Coefficient	0.113	0.219	0.524*	0.365	0.508*	0.519†
P value	0.646	0.263	0.021	0.056	0.026	0.005
Total-Mean (mm^2)						
Coefficient	0.111	0.129	0.140	0.293	0.025	−0.008
P value	0.652	0.514	0.566	0.131	0.920	0.966

Go-Go, transverse distance between bilateral gonions; NBW, width of the nasal base; ZMP-ZMP, transverse distance between bilateral zygomatic points.
Spearman correlated analysis.
*$P < 0.05$.
†$P < 0.01$.

retruded mandible, without considering the value of ANB.[10,32–34] Therefore, we thought it would be better to explore the airway effect in a sample with sufficient variations in skeletal development: SNA ranging from 73.4° to 91.8°, SNB from 73.3° to 92.0°, MP/SN from 25.6° to 47.0°, and ZMP-ZMP from 75.7 to 96.0 mm. Cone beam computed tomography was used as study material to present 3D view of the upper airway.

Children with normal vertical development were selected for the comparison between different sagittal skeletal patterns to exclude the potential influence of the vertical pattern. Nasopharynx was the only affected part of the upper airway in the present study. It was coinciding with previous studies, but most of them concluded that the inferior part or the whole airway is affected.[5,9–11,35,36] The possible reason for the inconsistent findings might lie in the different patterns of the study samples: the children in the present study were of skeletal Class III, while the samples in previous studies were basically skeletal Class I or II. Though Iwasaki et al[13] found the enlarged oropharynx in children with skeletal Class III, he failed to report the development of the maxilla and mandible in his sample; thus, it is hard to tell whether the positive finding is caused by the insufficient maxilla or overdeveloped mandible. In addition, the constricted effect of insufficient maxilla on the superior part of the upper airway has been demonstrated in patients with skeletal pattern of Class III.[37] It seems that the constricted effect of under developed jaw is more evident than the enlarging effect of over developed jaw in children. This theory, however, needs further investigations.

The effect of vertical skeletal pattern on the upper airway size seemed evident. The whole upper airway and every dividing part were affected by the vertical skeletal pattern: the airway size in the hyperdivergent skeletal pattern was significantly smaller than that in normal and hypodivergent skeletal patterns. This is similar finding with Celikoglu et al,[16] who evaluated the upper airway size of 100 adult patients in 3 groups of low angle, normal, and high angle. However, Grauer et al[14] concluded that the upper airway size was not significantly different among groups of long, short, and normal groups of nongrowing patients. But he failed to report the sagittal relationship of the included patients. As stated by the authors, patients with long face were often classified as Class II or III, while patients with short face tended to be classified as Class I. Without considering the sagittal skeletal patterns, the results might be confounded with the effect of the sagittal pattern.

Grouping comparisons between different skeletal transverse dimensions were not done since there was no standard classification for children. Lee et al[38] demonstrated positive correlations between mid-face width and upper airway size in adult patients with obstructive sleep apnea. Grauer et al[14] found that there are significant correlations between the bizygonatic width on frontal radiographs and inferior, superior, and total airway volumes in normal adults. The present study obtained similar results in children that medium-leveled correlations existed between the skeletal width and the height of the velopharynx, hypopharynx, and total airway. But the potential mechanism needs further investigations.

The present study added knowledge to the existing evidence of the airway effect of craniofacial patterns in sagittal, vertical, and transverse dimensions. However, the limitations of patient number and ethical consideration place restraints on the sample size of the study. The main chief complaint of cross-bite at this age of children leads to the skeletal pattern of Class III in the study, whose effect on the upper airway might be different from Class I or II. As this was a retrospective study, it was difficult to control the consistency of developing status between every child. Further prospective studies in a large sample of children with various skeletal patterns and controlled developing status will allow a better understanding.

In conclusion, the upper airway was significantly smaller in high-angle group of children with skeletal Class III than that in normal-angle or low-angle group, while the nasopharynx was the only affected airway part by the sagittal skeletal pattern. The height of the upper airway was found to be correlated with the skeletal transverse dimension.

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