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ORIGINAL ARTICLE

Gender-related difference in the upper airway dimensions and hyoid bone position in Chinese Han children and adolescents aged 6–18 years using cone beam computed tomography

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Abstract
Objective. To investigate the gender-related differences in upper airway dimensions and hyoid bone position in Chinese Han children and adolescents (6–18 years) using cone-beam computed tomography (CBCT). ***Materials and methods.*** CBCT-scans of 119 boys and 135 girls were selected and divided into four groups (group 1: 6–9 years; group 2: 10–12 years; group 3: 13–15 years; group 4: 16–18 years). The airway dimensions including the cross-sectional area (CSA), anteroposterior (AP) and lateral (LAT) width, length (L), mean CSA and volume (VOL) of upper airway segmentations and hyoid bone position including 11 linear and three angular measurements were investigated using Materialism's interactive medical image control system (MIMICS) 16.01 software. Gender-related differences were analyzed by two independent sample *t*-tests. ***Results.*** No gender-related difference was found in values of the facial morphology, airway dimensions and hyoid bone position for group 1 ($p > 0.05$). The children and adolescents in groups 2, 3 and 4 showed significant gender-related differences in the measurement results of facial morphology, airway dimensions and hyoid bone positions ($p < 0.05$). What's more, the measurement values of boys were obviously larger than those of girls except some measurements in group 2. ***Conclusions.*** The measurements of airway dimensions and hyoid bone positions have gender-related differences in children and adolescents aged 10–18 years. These results could be taken into consideration during orthodontic diagnosis and treatment.

Key Words: *upper airway dimensions, hyoid bone position, Chinese children and adolescents, cone-beam computed tomography*

Introduction

The oropharyngeal complex consists of the hyoid bone, the corresponding muscles and the pharyngeal airway [1]. The upper airway dimensions are associated with the surrounding tissues and the hyoid bone which plays an important role in maintaining a patent airway and mandibular movement [2,3]. Recently, evaluation of the airway has become an important diagnostic test in dentistry [4]. The anatomic anomalies, such as micrognathism, retrognathism, hyperdivergent growth patterns, reduced cranial base length and steep mandibular plane angles, may cause narrow airway space and small volume [5,6].

It has been reported that the pharyngeal airway dimensions and hyoid bone position may change after repositioning osteotomies during combined orthodontic/orthognathic surgical treatment [7]. Mandibular setback surgery can cause relative narrowing of the pharyngeal airway and a significant posterior movement of the hyoid bone [8,9]. Additionally, hyoid bone moves inferoposteriorly and the pharyngeal airway volume is decreased after bimaxillary surgery [10]. However, the effects of bimaxillary surgery on the pharyngeal airway space remain controversial. Some studies have suggested that bimaxillary surgery may prevent narrowing of the upper airway and even increase the airway, compared with mandibular setback surgery [11]. The upper airway is of interest to orthodontists for investigating the possibility of modifying the airway by dental treatment.

With the introduction of computed tomography (CT), the three-dimensional (3D) diagnosis of the

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patients is accessible in dentistry. Cone beam CT (CBCT), as a new and effective diagnosis method to evaluate upper airways, generates more comprehensive information than the 2D radiographs [12,13]. CBCT can effectively evaluate the soft tissue and the surrounding airway space in the upright position, as well as analysis of airway dimensions [14,15]. Therefore, CBCT scanning before orthodontic treatment may be helpful for a clear, specific and clinical diagnosis of airway space and hyoid bone positions [16]. Many studies have reported that accurate 3D images of local dental and bony structures could be obtained by CBCT, which is helpful for exact localization, pretreatment evaluation and surgical approach of supernumerary teeth [17–19]. What's more, CBCT images could clearly and accurately reflect the detailed information about the cyst, which is more helpful for diagnosis and treatment of the jaw bone cyst than traditional technologies [20,21]. Careful supervision in changes in upper airway dimensions and hyoid bone position during growth and development and the relationship of them is important. Normative data of the airway dimensions and hyoid bone position during physical development should be taken into account in orthodontic diagnosis and treatment [4], which might reduce the adverse effects on the airway during treatment.

Recently, multiple studies using CBCT to assess the airway dimensions and/or hyoid bone positions have been reported. Some studies focused on the intrinsic relationship between facial morphology and airway dimensions [22], while some investigated the differences of pharyngeal airway size between normal and abnormal (such as obstructive sleep apnea, cleft lip and palate and mouth-breathing) people [23–25]. However, the studies of gender-related differences in upper airway and/or hyoid bone positions using CBCT were few [26] and no related study has been reported in Chinese Han children and adolescents. The purpose of this study was to evaluate the gender-related changes in the hyoid bone position and the pharyngeal airway space of Chinese Han children and adolescents (6–18 years) using CBCT.

Materials and methods

Subjects

From December 2010 to December 2012, eligible CBCT scans of Chinese Han children and adolescents aged 6–18 years who first visited Stomatology Hospital of Shandong University for dental treatment because of dental diseases (such as supernumerary teeth and jawbone cyst) were selected. Informed consent had been obtained from all parents of patients before CBCT scanning. This study was reviewed and approved by the Research Ethic Committee of Shandong University Dental School.

According to examination of medical history and CBCT images, the inclusion criteria [27] included (1) clinically facial symmetry; (2) class I molar relationship, normal overjet and overbite; (3) no centric relation/centric occlusion (CR/CO) discrepancy; (4) no previous orthodontic treatment; (5) reasonably aligned upper and lower incisors without severe crowding; (6) no missing permanent teeth; (7) acceptable oral hygiene without obvious periodontal disease; and (8) natural dentitions.

Meanwhile, the exclusion criteria included (1) craniofacial surgery previously; (2) congenital anomalies, such as cleft lip and palate; (3) dysfunction of the masticatory system; (4) symptoms of respiratory or pharyngeal pathology, such as adenoid hypertrophy, tonsillitis, a history of adenoidectomy or tonsillectomy; (5) breathing problems, such as mouth breathing habit, complaint of airway restriction, nasal obstruction, snoring and obstructive sleep apnea. Besides, any CBCT scans in which the airway was not clear, not fully contained in the volume or contained artifacts were excluded [28].

All the subjects were divided into four groups by age: group 1 (6–9 years old); group 2 (10–12 years old); group 3 (13–15 years old); group 4 (16–18 years old) [29,30].

CBCT image processing

Patients were instructed to sit upright, place their jaw at maximum intercuspation and rest the lips and tongue. The Frankfort horizontal (FH) plane of the patients was parallel to the floor [10]. Patients were asked to breathe normally through the nose without swallowing and avoid moving their heads or tongues during the scanning process. The Galileos CBCT scanner (Sirona, Bensheim, Germany) was used for acquisition of images at 85 kV, 7 mA and 14 s per revolution, with resolution accurate enough to 0.15 mm. Then, CBCT images were saved in DICOM (digital imaging and communications in medicine) format [27].

Segmentation and measurement

The DICOM files that met the criteria were imported into the MIMICS (Materialism's interactive medical image control system) 16.01 software, which made the volume-rendered images visualized in the axial, coronal and sagittal directions. On multiple planar reconstruction images, the skull was reoriented to the FH. In the frontal view, the mid-sagittal plane was fixed through the center of the anterior nasal spine and the posterior mid-point of the spine [13] (Figure 1A). In the mid-sagittal view, 13 landmarks (N: nasion, S: sella, Ba: basion, A: A-point, B: B-point, Me: menton, ANS: anterior nasal spine, PNS: posterior nasal spine, UT: the tip of uvula, EB: the

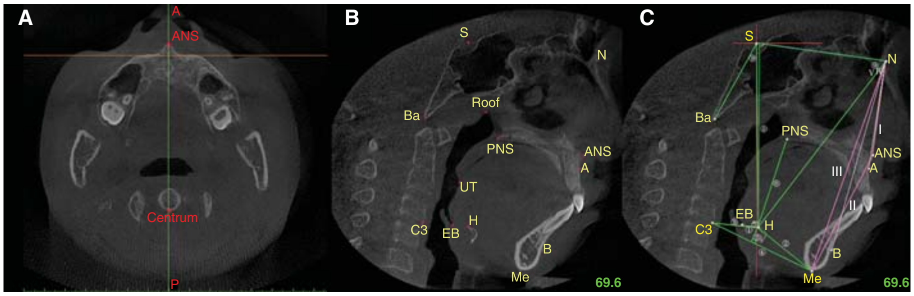

Figure 1. Cone beam computed tomography (CBCT) images were reoriented to the Frankfort horizontal (FH) plane. (**A**) The mid-sagittal plane was fixed through the center of the anterior nasal spine (ANS) and was established at the posterior mid-point of the spine. (**B**) In the mid-sagittal view, 13 landmarks were defined for the following analysis. (**C**) The measurements of hyoid bone and facial pattern were taken by 11 linear and three angular measurements.

base of epiglottis, H: hyoid bone, C3: third vertebra, Roof: the roof of nasopharynx) were defined for following work (Figure 1B, Table I). The measurements of the hyoid bone and facial pattern were taken by 11 linear (N-Me, N-ANS, ANS-Me, C3-Me, H-X, H-Y, C3-H, H-EB, H-PNS and H-Me) and three angular (A-N-B, H-C3-Me, H-S-Ba and H-N-S) measurements (Figure 1C).

To isolate the desired airway section, the threshold was the Hounsfield units (HU) value ranged from

Table I. Definitions of landmarks, reference planes and airway compartments.

Symbol	Description	Definition
Landmarks		
N	Nasion	The most anterior point of the frontonasal suture in the midsagittal plane
S	Sella	The central point of the pituitary fossa of the sphenoid bone
Ba	Basion	The most posterior inferior point of the occipital bone at the anterior margin of the foramen magnum
A	A-point	The deepest anterior point in the concavity of the upper labial alveolar process
B	B-point	The deepest anterior point in the concavity of the lower labial alveolar process
Me	Menton	The most inferior point on the mandibular symphysis
ANS	Anterior nasal spine	The most anterior point of the pre-maxillary bone
PNS	Posterior nasal spine	The posterior point of the hard palate
UT	The tip of uvula	The posterior point of the soft palate
EB	The base of epiglottis	The base point of epiglottis
H	Hyoid bone	The highest point of the hyoid bone
C3	Third vertebra	The most inferior and anterior point on the corpus of the third cervical vertebrae
Roof	The roof of nasopharynx	The highest point of the airway in the midsagittal plane
Cross-sectional planes		
FH	Frankfort horizontal plane	An axial plane though orbitale point and porion point on both sides
Plane 1	Nasal roof plane	The plane parallel to FH plane through Roof point
Plane 2	Anterior nasal plane	The plane perpendicular to the FH plane passing through PNS point
PNS plane	Nasal floor plane	The plane parallel to FH plane through PNS point
UT plane	Soft palate plane	The plane parallel to FH plane through UT point
EB plane	Epiglottal plane	The plane parallel to FH plane through EB point
H Plane	Hyoid bone plane	The plane parallel to FH plane through H point
Pharyngeal airways		
NP	Nasopharynx	The pharyngeal airway above the PNS plane
OP	Oropharynx	The pharyngeal airway formed between the PNS and EB plane
PP	Palatopharynx	The pharyngeal airway formed between the PNS and UT plane
GP	Glossopharynx	The pharyngeal airway formed between the UT and EB plane
HyP	Hypopharynx	The pharyngeal airway formed between the EB and H plane

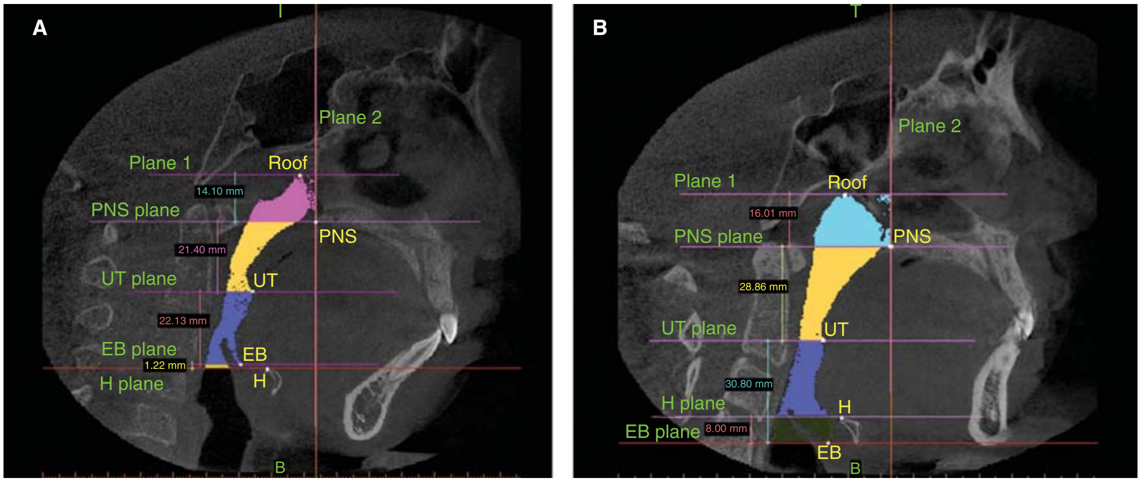

Figure 2. Definition of the upper airway. The superior border was the horizontal plane passing through Roof (Plane 1); the anterior border was defined by the vertical plane passing through posterior nasal spine (PNS) (Plane 2); oropharynx was further divided into palatopharynx (PP) and glossopharynx (GP) by uvula tip (UT) plane; and the inferior border was the epiglottis base (EB) plane. The highest point of the hyoid bone (H) in the mid-sagittal image was selected as the mark point of hyoid bone. (A) H point was below the EB plane; (B) H point was above the EB plane.

−1024 to −300. Then, a layer of the airway structures was defined and color-coded [31]. The pharyngeal airway is comprised of three areas: nasopharynx (NP), oropharynx (OP) and hypopharynx (Hyp) [5,32]. The regions of interest in the upper airway were defined as follows (Figure 2): the superior border was the horizontal plane passing through the Roof (Plane 1) [33]; the anterior border was the vertical plane passing through the posterior nasal spine (Plane 2) [34]; the inferior border was the epiglottis base (EB) plane [35]. The PNS plane was used to separate NP and OP and OP was further divided into the palatopharynx (PP) and glossopharynx (GP) by the uvula tip (UT) plane [36]. The lateral and posterior boundaries consisted of the pharyngeal walls, the anterior boundary, the anterior wall of the pharynx, the base of the tongue and the soft palate [37]. The highest point of the hyoid bone (H) in the mid-sagittal image was selected as the mark point of the hyoid bone [38], which was variably relative to EB (below or above the EB plane). The upper airway was divided into four segmentations by the reference planes and the corresponding 3D models were reconstructed [39] (Figure 3). The measure definitions of airway dimensions were shown in Table I. The volumes (VOL) of four airway segmentations (NP, PP, GP and Hyp), mean cross-sectional area (mean CSA) and length (L) on the seven defined planes were calculated. The lateral (LAT) and anteroposterior (AP) width, CSA on the four defined planes (PNS plane, UT plane, EB plane and H plane) were measured (Figure 4) according to the previously reported methods [24,40].

Statistical analysis

In total, 20 CBCT images were selected randomly and all measurements were repeated in these subjects by the same investigator 2 weeks after the first measurements. All analyses were performed using the Statistical Package for Social Sciences (SPSS) software (version 13.0, SPSS, Chicago, IL). The intraclass correlation (ICC) test was applied to assess the intra-examiner concordance (95% confidence interval) for all variables. The average airway length, volume, cross-sectional area and hyoid bone variables were also determined based on gender and age. Data were expressed as mean ± SD (standard deviation).

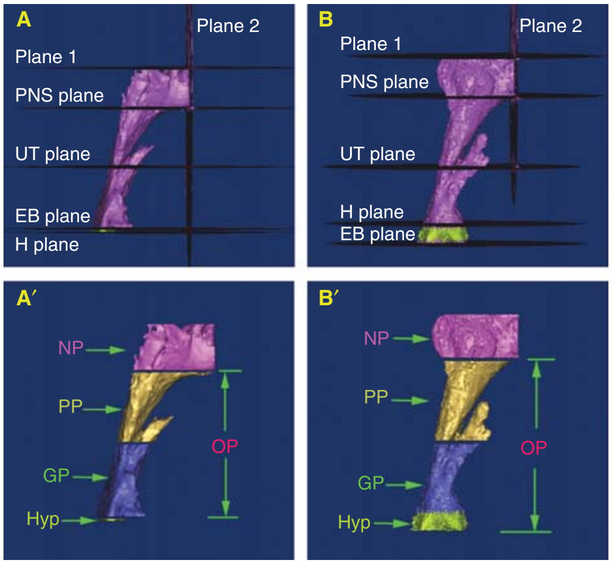

Figure 3. The upper airway was divided into four segmentations by the reference planes and the corresponding 3D models were reconstructed. The pharyngeal airway contains three areas including nasopharynx (NP), oropharynx (OP) and hypopharynx (Hyp). The posterior nasal spine (PNS) plane was used to separate NP and OP and the uvula tip (UT) plane further divided OP into palatopharynx (PP) and glossopharynx (GP). (A) H (hyoid bone) point was below the EB plane; (B) H point was above the EB plane.

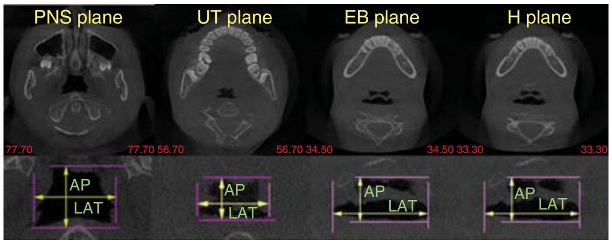

Figure 4. Measurements of the lateral (LAT) and anteroposterior (AP) width on the four defined planes (PNS plane, UT plane, EB plane and H plane).

The differences were evaluated with paired t-tests and $p < 0.05$ was considered as statistically significant.

Results

In this study, CBCT images of 254 patients (119 boys and 135 girls) were selected after examination of medical history and CBCT images. There were 99 boys (7.3 ± 1.2 years) and 22 girls (7.8 ± 1.4 years) in group 1; 41 boys (11.3 ± 0.8 years) and 48 girls (11.5 ± 0.8 years) in group 2; 31 boys (13.7 ± 0.9 years) and 44 girls (13.7 ± 0.9 years) in group 3; 18 boys (17.1 ± 0.9 years) and 21 girls (17.0 ± 0.9 years) in group 4 (Table II).

The ICC test showed that the concordance index of all the analyzed variables was greater than 0.98. The gender-related differences in the values of the facial morphology and hyoid bone position including 11 linear (N-Me, N-ANS, ANS-Me, C3-Me, H-X, H-Y, C3-H, H-EB, H-PNS and H-Me) and three angular (A-N-B, H-C3-Me, H-S-Ba and H-N-S) measurements for boys and girls in each group were shown in Table III. The gender-related differences in the measurement values of pharyngeal airway dimensions in each group were listed in Table IV. In group 1 (6–9 years), there was no difference in all measurement values between boys and girls. In groups 2, 3 and 4, significant differences were found in the measurement values of facial morphology, airway dimensions and hyoid bone positions between boys and girls ($p < 0.05$). Moreover, the measurement values of boys were significantly larger than those of girls, except some measurement values in group 2.

Discussion

Our study firstly reported the gender-related differences in the upper airway dimensions and hyoid bone position in Chinese Han children and adolescents aged 6–18 years by a relatively large sample size of CBCT images. The mid-sagittal view of CBCT images was selected to identify all landmarks and take linear measurements [31]. Furthermore, cross-sectional area as an effective indicator was used to evaluate the changes in the upper airway size [41]. It is important to standardize the patient's head during CBCT scanning, because head posture as an important factor in characterizing the pharyngeal airway might affect the measurements of upper airway [42] and hyoid bone position [43]. In our study, the patients' heads were initially oriented with FH plane parallel to the horizontal plane in the sagittal dimension, which was beneficial to measure the airway [10]. Moreover, the variations of the mandibular position and soft-tissue airway during CBCT scanning could be reduced since the patients were asked to breathe normally through the nose without swallowing and avoid moving their heads or tongues in this study [34].

With the physical development in puberty, facial morphology, airway dimension and hyoid bone position increased and showed a difference between boys and girls [30]. In our study, measurements of facial morphology, upper airways dimensions and hyoid bone position showed no significant difference between boys and girls in group 1 (6–9 years), which might be due to the fact that the growth and development of boys and girls were similar at 6–9 years old. Li et al. [30] have reported that there is no gender-related difference in the volumes of nasopharynx and palatopharynx or the length of nasopharynx. Besides, Abramson et al. [35] found that the volume and mean CSA of normal upper airways had no gender-related difference in all age groups. This may showed that boys and girls of 6–9 years had similar nasopharynx and palatopharynx. In group 2 (10–12 years), the volume, AP, mean CSA and CSA of airway measurement values of boys were significantly smaller than girls, which might be due to the fact that girls tended to mature earlier than boys. However, Chiang et al. [26] have reported the boys and girls have similar airway volumes at 7–11 years old. Li et al. [30] have also declared that the upper airway dimensions were similar in Chinese boys and girls aged 10–12 years. In groups 3 and 4 (13–18 years), the measurements of facial morphology, the airway length and hyoid bone position showed significant gender-related differences. Li et al. [30] have suggested that boys have a longer length of palatopharynx and oropharynx and a larger volume of the oropharynx than girls over

Table II. The number and age of the male and female patients in each group.

Male/female	Group 1	Group 2	Group 3	Group 4
Number	99/22	41/48	31/44	18/21
Age (year)	7.3 ± 1.2/7.8 ± 1.4	11.3 ± 0.8/11.5 ± 0.8	13.7 ± 0.9/13.7 ± 0.9	17.1 ± 0.9/17.0 ± 0.9

Table III. Gender-related differences in the values of the facial morphology and hyoid bone position including 11 linear and three angular measurements in each group (Mean ± SD).

	Genders	Group 1	Group 2	Group 3	Group 4
N-Me (mm)	Male	98.0 ± 5.2	104.6 ± 5.4	108.8 ± 6.1	112.0 ± 7.0
	Female	96.1 ± 6.0	101.7 ± 10.7	105.2 ± 5.1*	107.6 ± 5.3*
N-ANS (mm)	Male	40.3 ± 3.1	43.8 ± 3.7	45.7 ± 3.0	46.6 ± 3.3
	Female	39.2 ± 3.5	44.8 ± 9.5	44.8 ± 2.7	45.4 ± 2.8
ANS-Me (mm)	Male	59.1 ± 3.9	62.4 ± 4.6	64.3 ± 4.1	66.6 ± 5.2
	Female	57.8 ± 4.4	60.5 ± 4.4	61.6 ± 4.2*	63.3 ± 4.1*
C3-Me (mm)	Male	59.8 ± 7.8	65.9 ± 8.3	69.6 ± 9.6	74.2 ± 9.2
	Female	59.1 ± 6.3	69.4 ± 7.3*	67.0 ± 6.9	72.2 ± 7.4
H-X* (mm)	Male	7.4 ± 7.7	7.6 ± 8.2	5.1 ± 9.6	7.4 ± 8.8
	Female	7.4 ± 9.8	4.2 ± 8.8	4.6 ± 7.7	4.7 ± 7.9
H-Y (mm)	Male	82.7 ± 7.0	94.1 ± 7.0	102.6 ± 5.4	105.6 ± 8.7
	Female	80.7 ± 4.9	92.1 ± 6.6	95.3 ± 5.2**	95.4 ± 4.0**
C3-H (mm)	Male	24.6 ± 3.4	25.4 ± 3.7	27.6 ± 2.2	31.4 ± 4.8
	Female	22.5 ± 4.3	26.4 ± 3.2	25.7 ± 3.1*	28.4 ± 9.7
H-EB (mm)	Male	10.5 ± 4.4	11.5 ± 4.2	8.7 ± 4.9	10.0 ± 4.3
	Female	9.3 ± 4.6	8.2 ± 2.7**	7.6 ± 2.9	9.0 ± 3.6
H-PNS (mm)	Male	46.6 ± 5.5	53.8 ± 5.5	61.7 ± 5.7	66.0 ± 5.3
	Female	44.6 ± 3.9	52.9 ± 5.1	55.2 ± 4.7**	54.0 ± 4.4**
H-Me (mm)	Male	36.8 ± 5.3	41.4 ± 6.3	42.7 ± 8.0	45.5 ± 8.0
	Female	37.3 ± 5.2	43.9 ± 5.2*	42.1 ± 6.2	46.5 ± 6.3
A-N-B (°)	Male	3.4 ± 2.3	3.3 ± 2.2	2.8 ± 2.0	2.1 ± 3.2
	Female	2.3 ± 2.8	2.7 ± 2.6	2.9 ± 2.8	2.1 ± 3.1
H-C3-Me* (mm)	Male	−1.9 ± 4.3	−1.0 ± 3.9	2.8 ± 3.8	4.4 ± 4.5
	Female	−1.9 ± 4.4	−1.2 ± 3.9	0.2 ± 4.2*	−2.6 ± 3.8**
H-S-Ba (°)	Male	37.2 ± 5.8	35.5 ± 4.5	32.9 ± 4.7	36.4 ± 4.7
	Female	39.7 ± 3.4	34.9 ± 5.8	36.2 ± 5.0*	36.6 ± 6.2
H-N-S (°)	Male	56.8 ± 3.5	60.0 ± 3.8	61.1 ± 4.8	61.1 ± 7.3
	Female	58.1 ± 3.6	58.7 ± 4.3	58.9 ± 4.5	58.9 ± 2.8

H-X: Front of the vertical line passed Sella (S) (anterior) was set as positive and behind of the vertical line passed through S (posterior) was set as negative. H-C3-Me: below the line formed by C3 and Me (C3-Me) was set as positive and above the line C3-Me was set as negative. N, nasion; S, sella; Ba, basion; A, A-point; B, B-point; Me, menton; ANS, anterior nasal spine; PNS, posterior nasal spine; UT, the tip of uvula; EB, the base of epiglottis; H, hyoid bone; C3, third vertebra; Roof, the roof of nasopharynx.
*$p < 0.05$, compared with males; *$p < 0.01$, compared with males.

13 years, while the length of the glossopharynx is similar between boys and girls in all age groups.

In present study, the cross-sectional area of PNS plane (CSA1) had no gender difference in all age groups and the CSA of EB plane (CSA3) of boys was larger than that of girls in group 4. Besides, our study showed no gender-related difference in anteroposterior dimension (AP) in groups 3 and 4. Li et al. [30] showed significant gender-related difference in CSA of UT plane in group 3 (and group 4) and in the EB plane in group 4. However, Samman et al. [44] and Shen et al. [45] showed significant gender-related differences in normal adult airway AP diameter. In our study, the C3-H of boys was larger than that of girls in group 3 and the H-C3-Me of boys was larger than that of girls in group 3 and 4. These results were consistent with previous studies. Tsai [46] showed that C3-H in boys was larger than that in girls in complete permanent dentition. Sheng et al. [2] showed the values of hyoid bone position (C3-H, H-C3-Me, H-PNS and H-EB) in boys were larger than those in girls in complete permanent dentition stage.

However, several limitations existed in our study. First, our study was a cross-sectional survey but not longitudinal research. Secondly, this retrospective study might collect inadequate information and lead to potential inaccuracies in history and clinical examination. Third, this study should be considered as a pilot one and the number of subjects available for this investigation was still small [35]. Despite the fact

Table IV. Gender-related differences in the measurement values of pharyngeal airway dimensions in each group (Mean ± SD).

	Genders	Group 1	Group 2	Group 3	Group 4
L1 (mm)	Male	11.0 ± 3.0	12.2 ± 2.7	13.8 ± 2.2	15.7 ± 2.6
	Female	11.0 ± 2.6	13.0 ± 3.0	14.3 ± 3.2	15.3 ± 2.1
L2 (mm)	Male	20.8 ± 3.6	24.9 ± 3.3	25.5 ± 3.7	28.5 ± 2.6
	Female	20.5 ± 3.7	22.8 ± 3.0**	24.1 ± 3.3	25.7 ± 3.4**
L3 (mm)	Male	22.9 ± 3.9	26.8 ± 4.5	33.3 ± 4.6	35.5 ± 5.1
	Female	21.2 ± 4.5	28.2 ± 4.3	29.7 ± 4.6*	29.2 ± 4.2**
L4* (mm)	Male	1.6 ± 3.1	−0.0 ± 2.5	0.6 ± 2.7	−1.2 ± 3.2
	Female	1.1 ± 3.2	−1.0 ± 2.3	−1.1 ± 2.8*	−3.2 ± 2.6*
L5 (mm)	Male	43.7 ± 5.5	51.7 ± 5.8	58.8 ± 5.5	63.5 ± 6.5
	Female	41.6 ± 5.7	51.0 ± 5.2	53.8 ± 4.9**	55.0 ± 5.8**
L6 (mm)	Male	54.6 ± 6.5	63.8 ± 6.8	72.6 ± 5.6	79.2 ± 8.1
	Female	52.7 ± 6.3	64.0 ± 6.0	68.1 ± 5.8*	70.2 ± 5.4**
L7 (mm)	Male	56.2 ± 6.9	63.8 ± 6.7	73.4 ± 5.9	78.0 ± 7.1
	Female	53.8 ± 5.1	63.0 ± 5.9	68.3 ± 5.6**	67.1 ± 4.5**
SPL (mm)	Male	27.3 ± 3.0	30.9 ± 3.6	31.9 ± 3.8	35.7 ± 3.5
	Female	26.2 ± 2.4	29.2 ± 3.6*	31.1 ± 3.1	32.0 ± 2.9**
LAT1 (mm)	Male	24.6 ± 5.6	29.4 ± 5.4	31.8 ± 6.4	37.4 ± 5.7
	Female	25.2 ± 4.5	30.5 ± 4.7	32.1 ± 5.1	37.0 ± 6.2
AP1 (mm)	Male	18.5 ± 4.6	22.1 ± 5.0	23.4 ± 5.1	26.4 ± 5.3
	Female	18.5 ± 4.7	22.9 ± 4.5	23.9 ± 4.6	26.9 ± 4.3
LAT2 (mm)	Male	17.0 ± 4.2	21.3 ± 6.6	26.4 ± 8.7	28.8 ± 5.6
	Female	16.1 ± 4.2	23.8 ± 5.5	24.5 ± 6.3	29.8 ± 6. 4
AP2 (mm)	Male	11.9 ± 3.0	13.3 ± 3.9	14.8 ± 4.5	15.7 ± 4.3
	Female	12.9 ± 2.3	15.6 ± 3.5**	14.4 ± 4.0	17.1 ± 5.1
LAT3 (mm)	Male	26.5 ± 4.3	29.1 ± 6.6	35.1 ± 3.6	38.3 ± 3.8
	Female	26.2 ± 2.9	30.6 ± 3.7	32.2 ± 4.8*	32.8 ± 2.7**
AP3 (mm)	Male	9.5 ± 2.8	10.2 ± 3.5	13.7 ± 4.6	14.0 ± 1.9
	Female	10.3 ± 2.4	12.2 ± 2.8**	11.9 ± 2.9	14.0 ± 3.3
LAT4 (mm)	Male	25.4 ± 5.4	28.5 ± 7.1	35.2 ± 4.4	35.3 ± 5.8
	Female	25.9 ± 3.6	30.4 ± 3.5	32.7 ± 3.7	30.3 ± 5.2**
AP4 (mm)	Male	10.4 ± 2.8	10.5 ± 3.1	11.9 ± 2.4	14.8 ± 3.9
	Female	10.6 ± 2.3	12.7 ± 3.4**	13.6 ± 4.2	15.0 ± 4.2
R1 = LAT1/AP1	Male	1.4 ± 0.2	1.4 ± 0.2	1.4 ± 0.2	1.4 ± 0.2
	Female	1.4 ± 0.3	1.4 ± 0.3	1.4 ± 0.2	1.4 ± 0.2
R2 = LAT2/AP2	Male	1.5 ± 0.4	1.6 ± 0.5	1.8 ± 0.3	1.9 ± 0.4
	Female	1.3 ± 0.4	1.6 ± 0.4	1.8 ± 0.4	1.8 ± 0.4
R3 = LAT3/AP3	Male	3.0 ± 0.8	3.0 ± 0.9	2.8 ± 0.8	2.8 ± 0.4
	Female	2.7 ± 0.8	2.6 ± 0.7	2.8 ± 0.7	2.5 ± 0.8
R4 = LAT4/AP4	Male	2.5 ± 0.6	2.9 ± 0.9	3.0 ± 0.50	2.5 ± 0.5
	Female	2.6 ± 0. 8	2.6 ± 0.8	2.6 ± 0.8	2.2 ± 0.7
Mean CSA1 (mm^2)	Male	280.0 ± 98.5	352.2 ± 121.6	387.0 ± 111.9	468.8 ± 141.3
	Female	290.1 ± 102.5	360.7 ± 97.9	393.8 ± 116.9	519.4 ± 105.0
Mean CSA2 (mm^2)	Male	168.8 ± 67.1	231.0 ± 80.1	270.9 ± 101.3	341.6 ± 110.6
	Female	177.4 ± 50.7	266.6 ± 74.2*	270.7 ± 93.8	364.7 ± 120.1
Mean CSA3 (mm^2)	Male	116.7 ± 56.4	149.0 ± 72.1	228.4 ± 107.1	250.3 ± 98.1
	Female	121.9 ± 44.5	212.7 ± 70.2**	194.5 ± 81.5	255.1 ± 93.0

Table IV. (*Continued*).

	Genders	Group 1	Group 2	Group 3	Group 4
Mean CSA4 (mm^2)	Male	95.6 ± 61.4	98.9 ± 53.1	148.7 ± 83.8	195.8 ± 80.2
	Female	105.4 ± 36.2	141.8 ± 59.5**	145.3 ± 72.5	205.8 ± 65.8
Mean CSA5 (mm^2)	Male	143.3 ± 57.5	191.1 ± 71.5	249.3 ± 100.9	285.0 ± 91.3
	Female	150.3 ± 44.3	239.9 ± 68.2**	230.3 ± 83.1	310.4 ± 103.0
Mean CSA6 (mm^2)	Male	170.6 ± 57.1	223.1 ± 68.2	275.5 ± 95.0	318.8 ± 91.5
	Female	180.5 ± 52.6	264.0 ± 62.5**	264.0 ± 83.7	356.0 ± 98.7
Mean CSA7 (mm^2)	Male	168.2 ± 56.4	222.2 ± 69.5	296.3 ± 98.9	316.8 ± 95.0
	Female	179.4 ± 53.7	265.6 ± 63.4**	289.6 ± 83.8	360.4 ± 100.2
CSA1 (mm^2)	Male	317.8 ± 127.3	442.7 ± 143.4	460.81 ± 137.3	581.5 ± 175.5
	Female	314.7 ± 100.2	438.2 ± 109.4	468.9 ± 151.3	651.7 ± 162.5
CSA2 (mm^2)	Male	100.7 ± 51.8	144.4 ± 87.9	190.6 ± 113.9	224.6 ± 116.4
	Female	106.5 ± 47.3	188.3 ± 67.9**	170.5 ± 95.8	259.3 ± 129.1
CSA3 (mm^2)	Male	137.7 ± 61.7	169.6 ± 74.6	254.1 ± 96.3	313.7 ± 80.2
	Female	136.0 ± 43.2	233.7 ± 73.1**	223.8 ± 73.9	263.9 ± 70.7*
CSA4 (mm^2)	Male	144.5 ± 57.4	169.5 ± 78.0	259.8 ± 85.4	298.9 ± 85.9
	Female	142.0 ± 41.1	237.1 ± 77.6**	232.7 ± 83.9	258.1 ± 69.2
VOL1 (mm^3)	Male	3,066.6 ± 1,259.1	4,386.7 ± 1891.7	5,365.9 ± 1,873.6	7,302.5 ± 2,448.5
	Female	3,267.1 ± 1,599.1	4,638.1 ± 1524.5	5,600.7 ± 1,998.6	7,905.5 ± 1,922.3
VOL2 (mm^3)	Male	3,442.2 ± 1,367.9	5,756.4 ± 2277.1	6,926.3 ± 2,889.7	9,715.4 ± 3,355.9
	Female	3,643.0 ± 1,261.9	6,158.9 ± 2121.8	6,486.8 ± 2,357.4	9,357.5 ± 3,083.4
VOL3 (mm^3)	Male	2,744.7 ± 1,537.7	4,036.8 ± 2131.4	7,764.3 ± 4,067.8	8,887.8 ± 3,675.8
	Female	2,601.9 ± 1,156.8	6,037.3 ± 2266.8**	5,777.1 ± 2,718.3	7,448.1 ± 2,849.6
VOL4* (mm^3)	Male	92.2 ± 336.5	−18.2 ± 282.6	128.8 ± 658.9	−477.9 ± 550.3
	Female	95.3 ± 390.0	−177.1 ± 414.6*	−264.4 ± 508.6*	−740.2 ± 683.9
VOL5 (mm^3)	Male	6,275.1 ± 2,646.7	9,928.4 ± 4029.1	14,846.3 ± 6,608.2	18,151.5 ± 6,448.5
	Female	6,322.7 ± 2,210.6	12,330.3 ± 3963.9**	12,402.8 ± 4,799.0	17,002.4 ± 5,521.3
VOL6 (mm^3)	Male	9,341.7 ± 3,265.4	14,361.8 ± 5043.5	20,212.2 ± 7,696.6	25,301.1 ± 8,144.5
	Female	9,589.8 ± 3,258.6	16,968.4 ± 4512.4*	18,003.5 ± 5,948.4	24,907.9 ± 6,619.9
VOL7 (mm^3)	Male	9,433.9 ± 3,206.5	14,343.2 ± 4998.8	20,341.0 ± 7,728.9	24,563.9 ± 8,311.7
	Female	9,685.0 ± 3,108.4	16,791.3 ± 4408.4*	17,739.1 ± 5,839.8	24,167.7 ± 6,703.7

L4, VOL4: below the plane passed through epiglottis base (EB plane) was set as positive and above EB plane was set as negative.
The volumes (VOL1, VOL2, VOL3, VOL4, VOL5, VOL6 and VOL7), mean cross-sectional area (mean CSA1, mean CSA2, mean CSA3, mean CSA4, mean CSA5, mean CSA6 and mean CSA7) and length (L1, L2, L3, L4, L5, L6 and L7) of airway segmentations on the seven defined planes; the lateral width (LAT1, LAT2, LAT3 and LAT4), anteroposterior width (AP1, AP2, AP3 and AP4), cross-sectional area (CSA1, CSA2, CSA3 and CSA4) on the four defined planes (PNS plane, UT plane, EB plane and H plane) were measured.
*$p < 0.05$, compared with males; *$p < 0.01$, compared with males.

that children had been instructed to breathe quietly by nose, not to swallow and move the head and tongue during CBCT-scanning, some children might not follow the instructions, especially the younger ones [25]. Besides, the scanning time was 14 s, which might be too long for children to control respiratory movements [35]. Moreover, the measurements of soft tissue, such as tongue and soft palate, were excluded. In further studies, we will emphasize the measurements of soft tissues and the assessment of airway function.

The measurements of airway dimensions and hyoid bone positions displayed differences between boys and girls beyond 10 years old. These results could be taken into consideration during orthodontic diagnosis and treatment.

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