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# Cephalometric norms for the upper airway of 12-year-old Chinese children

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## Abstract

**Objective:** To establish cephalometric norms for the upper airway of 12-year-old Chinese children, and to assess these norms with regard to gender, age, ethnicity and other craniofacial structures.

**Methods:** Lateral cephalograms were obtained from a random sample of 425 12-year-old Chinese children (224 boys and 201 girls) to establish the Chinese norms, and from a matched group of 108 12-year-old Caucasian children (61 boys and 47 girls) as an ethnic comparison. Published data on the upper airway norms of Chinese adults were used to make age comparisons. Nine upper airway and 14 craniofacial variables were measured.

**Results:** Chinese boys tended to have a thicker soft palate ( $P = 0.008$ ), and less depth in the retropalatal ( $P = 0.011$ ), retroglossal ( $P = 0.034$ ) and hypopharyngeal ( $P < 0.001$ ) pharynx than Chinese girls, whereas no gender dimorphism was found in Caucasian children. Ethnic differences were found in the depth of the retroglossal oropharynx in both genders and the position of the hyoid bone in boys. Compared with Chinese adults, the overall size of the upper airway in Chinese children was smaller. The mandibular body length and the craniocervical inclination were found to be statistically significantly, albeit weakly correlated with upper airway variables.

**Conclusions:** Cephalometric norms for the upper airway of Chinese 12-year-old children were established, indicating gender-specific differences, and some ethnic differences were found in comparison with those of 12-year-old Caucasian children. An association between the mandibular body length and the craniocervical inclination with upper airway variables was also noticeable.

**Keywords:** Cephalometry, Chinese, Children, Upper airway

## Introduction

Increasing evidence has shown an association between craniofacial anomalies and/or soft-tissue hypertrophy and pediatric sleep-disordered breathing (SDB) [1-3]. SDB represents a spectrum of breathing disorders during sleep that encompasses a continuum of diagnoses ranging from partial upper airway obstruction (primary snoring and upper airway resistance syndrome) to complete upper airway obstruction (obstructive hypoventilation and obstructive sleep apnea syndrome [OSAS]) [4]. In an updated clinical practice guideline on childhood OSAS from the American Academy of Pediatrics, SDB was defined simply as OSAS with additional snoring [5]. The

prevalence of children with OSAS ranges from 1 to 5%, and the reported prevalence of habitual snoring varies widely from 1.5 to 27.6% [5]. If untreated, pediatric SDB may result in serious problems such as a failure to thrive, neurocognitive deficits, behavioral abnormalities and cardiovascular changes [6]. The common modalities of treatment for pediatric SDB include adenotonsillectomy, continuous positive airway pressure (CPAP), oral appliances and pharmacologic treatment [7].

The soft-tissue morphology of the upper airway that may related to pediatric SDB includes narrowed pharyngeal airways, and larger adenoids, tonsils and soft palates [8-10]; the related hard-tissue morphology includes an increased intermaxillary angle, a retrognathic mandible [11,12], an increased mandibular angle, a longer lower anterior facial height [13,14], narrow dental arches and deep palatal height [15,16], and an inferiorly positioned hyoid bone [17,18].

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**Table 1 Demographic data of the study samples**

	n	Age range		Range		
		Mean	SD	Median	Minium	Maxium
Chinese children						
Male	224	12.5	0.3	12.5	12.0	12.9
Female	201	12.5	0.3	12.5	12.0	12.9
Difference <sup>a</sup>		0.0				
Chinese adults						
Male	29	-	-	-	18.0	35.0
Female	45	-	-	-	16.0	42.0
Difference <sup>b</sup>		-				
Caucasian						
Male	61	12.5	0.2	12.5	12.0	12.9
Female	47	12.4	0.3	12.5	12.0	12.9
Difference <sup>a</sup>		0.1				

<sup>a</sup>None of the differences between the samples were statistically significant.

<sup>b</sup>Statistically significance could not be calculated.

Both upper airway and craniofacial structures can be observed in the same lateral cephalograms, and lateral cephalometric radiography was therefore considered to be a useful screening tool to assess upper airway structures, and identify subjects at risk of SDB [19,20]; its validity has been tested using three-dimensional computed tomography (CT) and magnetic resonance imaging (MRI) [21,22].

To assess the upper airway structures of individual patients from lateral cephalograms, reference norms are required. However, there is limited data on cephalometric norms of upper airway. McNamara [23] provided reference values for the upper pharynx and lower pharynx of Caucasian adults, whereas Samman et al. [24] presented cephalometric norms for the upper airway of Chinese adults. Until now, no cephalometric norms for upper airway of Chinese children has been established. Consequently, the objective of this retrospective study was to obtain upper airway norms for Chinese children, and study the association between airway dimensions and craniofacial structures.

## Materials and methods

### Subjects

The materials used were lateral cephalograms obtained from 12-year-old children during an oral health survey performed in 1984-85 at the Department of Orthodontics and Paediatric Dentistry of the University of Hong Kong [25]. In the survey, approximately 600 Chinese school children were selected by a partially stratified random sampling from 10 schools in Hong Kong, and approximately 100 Caucasian school children, whose parents originated from the United Kingdom, were chosen from two expatriate schools in Hong Kong [26]. Lateral cephalometric radiographs were taken as part of a comprehensive oral/dental/

**Table 2 Cephalometric landmarks and measurements of the upper airway**

Variables	Definition
<i>Landmarks</i>	
Po	Porion, the mid point of the line connecting the most superior point of the external auditory canal on both sides
Or	Orbitale, the lowest point on the average of the left and right inferior borders of the bony orbit
ANS	Anterior nasal spine, the tip of the median, sharp bony process of the maxilla
PM	Pterygo-maxillare, the point at the junction fo the pterygo-maxilla and the posterior nasal spine
U	Uvula, the tip of the uvula
UPW	Upper pharyngeal wall, point of intersection of the line NL to the posterior pharyngeal wall
MPW	Middle pharyngeal wall, intersection of the perpendicular line from U to the posterior pharyngeal wall
LPW	Lower pharyngeal wall, intersection of the perpendicular line from V to the posterior pharyngeal wall
V	Vallecula, the intersection of the epiglottis and the base of the tongue
AH	Anterior hyoid, the most anterior and superior point on the body of the hyoid bone
C2	2nd cervical vertebrae, the point at the most anterior-inferior position on the second cervical vertebrae
C3	3rd cervical vertebrae, the point at the most anterior-inferior position on the third cervical vertebrae
FH	Frankort horizontal plane, line joining the Or to the Po
NL	Nasal line, line joining the ANS and Pm
CV	Cervical vertebrae, the line joining the C2 and C3
<i>Measurements</i>	
PM-U (mm)	Length of soft palate, distance from PM to U
SPT (mm)	Soft palate thickness, represents the maximal thickness of the soft palate measured perpendicular to PM-U line
NL/PM-U (°)	Inclination of the long axis of the soft palate relative to the nasal line
PM-UPW (mm)	Depth of the nasopharyngeal airway space from PM to UPW
U-MPW (mm)	Depth of the oropharyngeal airway space from U to MPW
PASmin (mm)	The shortest distance between the base of the tongue and the posterior pharyngeal wall, the narrowest sagittal airway space
V-LPW (mm)	Depth of the hypopharyngeal airway space from V to LPW
AH-FH (mm)	Position of the hyoid bone in vertical plane, from AH perpendicular to FH
AH-CV (mm)	Position of the hyoid bone in horizontal plane, from AH to CV and parallel to FH

facial examination. The lateral cephalograms used in this study were selected according to the following criteria: 1, children aged 12.0 -13.0 years; 2, who had not received or were not receiving ongoing orthodontic treatment; and 3, the upper airway structures were clear and no swallow action was detected in the cephalograms. After exclusions,

lateral cephalograms from 224 male and 201 female 12-year-old Chinese school children, and 61 male and 47 female 12-year-old Caucasian school children were studied (Table 1).

#### Ethics issue

The present study was approved by the Institutional Review Board of the University of Hong Kong/Hospital Authority Hong Kong West Cluster (IRB Reference Number: UW 12-405).

#### Radiographic technique

One X-ray machine (GE1000, General Electric, Milwaukee, Wits) was used to obtain all lateral cephalograms. The magnification was 8.8% for the midsagittal structures. The lateral cephalograms were obtained during a natural head posture, in which the subjects looked at the reflection of their eyes in a mirror placed 200 cm in front of them after first tilting their head forward and backward with decreasing amplitude until a comfortable position of natural balance was found [25].

#### Cephalometric analysis

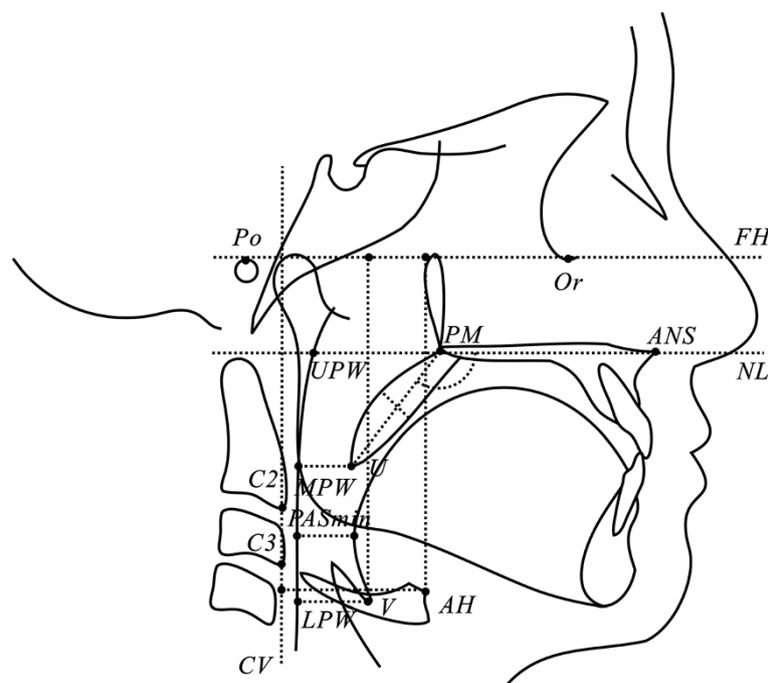
The sample of Chinese children was used to establish cephalometric norms for the upper airway of Chinese boys and girls, respectively. The sample of Caucasian children was used for an ethnic comparison. Published data on the upper airway norms of Chinese adults were

used for an age comparison [24]. The demography of all samples is presented in Table 1.

The landmarks and reference lines of the upper airway are shown in the Table 2 and Figure 1. The variables for upper airway measurements included eight linear variables and one angular variable (three variables for the soft palate, four variables for the upper airway depth and two variables for the position of the hyoid bone), which were selected from a previous study on Chinese adults [24]. The analysis of the craniofacial morphology included six linear and eight angular conventional measurements (Table 3 and Figure 2) [11,27]. The analysis was carried out using CASSOS software (Soft Enable Technology Limited, Hong Kong, China). All of the linear measurements were corrected according to the magnification.

#### Method error

One examiner (MG) carried out all of the measurements. During the pilot study, the measurements of 10 randomly selected cephalograms were calibrated by another examiner (YQY), and the method error was calculated by Dahlberg's formula [28],  $ME = \sqrt{\sum d^2 / 2n}$ , which is the repeated measurements of 30 randomly selected cephalograms on separated occasions at a 2-week interval.  $\Sigma d$  is the difference between two measurements of a pair, and  $n$  is the number of double measurements. The method errors for the linear and angular measurements



**Figure 1** Landmarks and measurements of the upper airway.

**Table 3 Cephalometric landmarks and measurements of the craniofacial structures**

Variables	Definition
<i>Landmarks</i>	
S	Center of the sella turcica
N	Nasion, the deepest point in the concavity of nasofrontal suture
A	A point, the deepest point in the concavity of the anterior maxilla between the anterior nasal spine and the alveolar crest
Ui	Upper incisor tip
Li	Lower incisor tip
B	B point, the deepest point in the concavity of the anterior mandible between the alveolar crest and the pogonion
Gn	Gnathion, the most anteroinferior point on the bony chin
Me	Menton, the most inferior point on the body chin
Go'	Gonion' point, the intersection of the tangents of inferior and posterior borders of the mandible
Ar	The intersection of the posterior border of the ramus with inferior surface of the cranial base
Cd	Condylion, the most posterosuperior point of the condylar head
c2sp	The most superior posterior point of the second cervical vertebra
c2ip	The most inferior posterior point of the second cervical vertebra
c4ip	The most inferior posterior point of the fourth cervical vertebra
MxPI	Maxillary plane, equal to NL (ANS-PM)
MnPI	Mandibular plane, line joining Me and Go
OPT	Odontoid process tangent, line joining c2sp and c2ip
<i>Measurements</i>	
SNA (°)	The angle between the S-N line and the N-A line
SNB (°)	The angle between the S-N line and the N-B line
ANB (°)	The angle between the N-A line and the N-B line
MnPI/SN (°)	Mandibular plane angle, the angle between the MnPI and the S-N line
MxPI/MnPI (°)	Maxillomandibular plane angle, the angle between the MxPI and the MnPI
MxMn-DF (mm)	Masiilomandibular difference, the length of Cd-Gn minus the length of Co-A
TAFH (mm)	The distance from N to Me
TPFH (mm)	The distance from S to Go
Y axis/FH (°)	The angle between S-Gn line and FH plane
Overjet (mm)	The distance between Ui and Li, parallel to the FH plane
Overbite (mm)	The distance between Ui and Li, perpendicular to the FH plane
OPT-SN (°)	The angle between the OPT and the S-N line
c2sp-c4ip-SN (°)	The angle between the c2sp-c4ip line and the S-N line
Body length (mm)	The distance between Go'-Me

were not statistically significant and did not exceed 1 mm and 1°, respectively.

### Statistical analysis

The measurements of the upper airway are presented as the mean, median, standard deviation, range and 95% confidence interval. The Mann-Whitney *U*-test was used to calculate the gender, age and ethnic differences, and the levels of statistical significance were  $P < 0.05$ ,  $P < 0.01$ , and  $P < 0.001$ . The association between the upper airway and the craniofacial structures was analyzed using Spearman rank correlation, and the statistical significance was set at levels of  $P < 0.05$  and  $P < 0.01$ . Statistical analyses were performed using SPSS software (IBM SPSS Statistics 20, IBM Corp.).

## Results

### Gender differences

In Chinese children, boys had smaller values than girls for almost all of the variables, except for the soft palate thickness (Table 4). The gender differences were statistically significant for soft palate thickness ( $P = 0.008$ ), the depth of the retropalatal ( $P = 0.011$ ) and retroglossal ( $P = 0.034$ ) pharynx, and for the depth of the hypopharynx ( $P < 0.001$ ). No significant gender difference was observed in the Caucasian sample (Table 5).

### Age differences

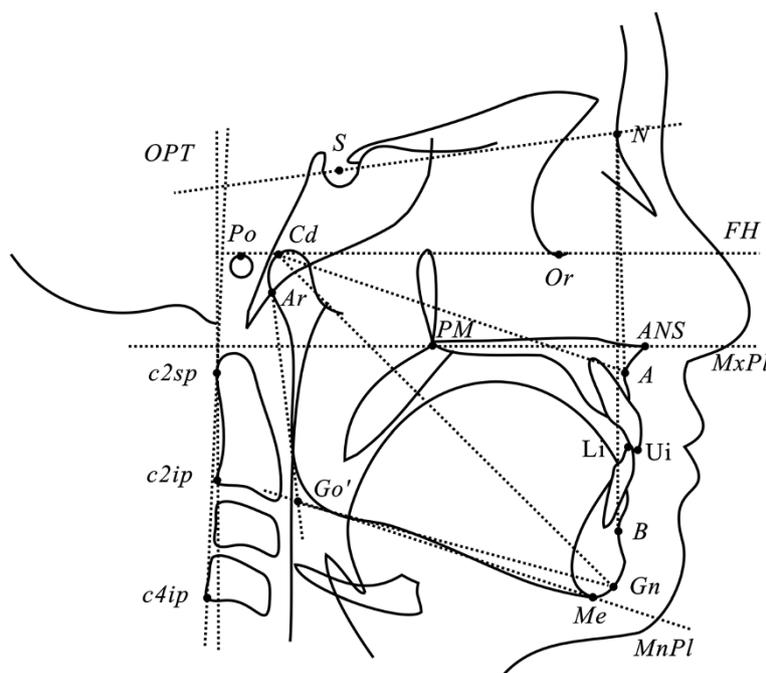
Chinese adults had statistically significant larger values than Chinese children in both genders for all of the variables except for the inclination of the soft palate in males, and the differences were larger in males (Table 6).

### Ethnic differences

The 12-year-old Chinese children had larger values for all variables (Table 7). In males, the statistically significant differences were found in the shortest distance of the oropharynx ( $P = 0.019$ ), and the position of the hyoid bone in the vertical and horizontal planes ( $P = 0.014$  and  $P = 0.001$ ); and in females, statistically significant differences were found in the depth of the retroglossal pharynx ( $P = 0.005$ ) and that of the hypopharynx ( $P = 0.01$ ).

### Correlations between the upper airway and other craniofacial structures

The correlations between the upper airway and craniofacial structures were weak, and no correlation coefficient exceeded 0.5. In Chinese children, the variables of the body length of the mandible and the craniocervical inclination were significantly associated with most of the upper airway variables. The vertical and horizontal position of the hyoid bone was significantly associated with anterior and posterior facial height (Table 8). The results for



**Figure 2** Landmarks and measurements of the craniofacial structures.

the Caucasian children were generally similar to those of the Chinese children (Table 9).

## Discussion

### The rationale for the selection of the upper airway variables

In a lateral cephalogram, the observable SDB-related upper airway structures include: the pharynx, the adenoid, the soft palate, the tonsil, the tongue, and the hyoid bone. The pharynx can be divided anatomically into three parts: the nasopharynx, the oropharynx, and the hypopharynx. The oropharynx can be subdivided into the retropalatal and retroglossal pharynxes [29]. In the present study, we therefore selected four variables to represent four parts of the pharynx. The pharyngeal lymphoid tissues, such as the adenoid and tonsils, were not measured because they begin to atrophy from their maximal size during the pre-pubertal years [30]. No tongue measurement was adopted in the present study because the tongue contour was not clear in the cephalograms without barium sulfate paste [31].

### The influence of gender on the dimensions of upper airway

In the present study it was found that Chinese boys had a thicker soft palate and less depth in the retropalatal, retroglossal and hypopharyngeal regions of the upper airway. It has suggested that these characteristics were related to pediatric SDB [8,10], which may explain why Hong Kong boys had a higher prevalence of OSAS than Hong Kong girls (5.8% versus 3.8%) [32]. In the present

there was no difference in the upper airway dimensions of Caucasian boys and girls. Interestingly, no gender difference has been reported in the prevalence of OSAS in Caucasian children by most of studies [5]. Therefore, the upper airway dimensions may be a crucial risk factor of pediatric SDB. However, this seems not to be valid in adults, because men generally have a larger size of pharyngeal lumen than women, but have a higher prevalence of SDB; Subsequently, other factors such as differences in hormones, chemosensitivity and tissue properties may be more important in adult SDB than airway dimensions [29].

### The influence of age on the dimensions of the upper airway

In the present study, the 12-year-old Chinese children, especially the boys, were found to have much growth potential in all of the upper airway structures from childhood to adulthood. The soft palate tended to increase in length, thickness, and inclination, the depth of the pharynx increased at all of the levels, and the hyoid bone moved anteriorly and inferiorly. Chinese boys had more prominent upper airway changes than Chinese girls. In 12-year-olds, Chinese boys had less depth of the pharynx, but they had a larger pharynx in adulthood, showing that Chinese boys have a later spurt in growth compared with Chinese girls. This phenomenon is corresponding to the sexual dimorphism in craniofacial growth [33]. The similar finding was also reported by other lateral cephalometric analysis or 3-dimensional CT research [34,35]. In addition, Taylor et al. [36] reported that the growth of the oropharynx

**Table 4 Cephalometric norms of upper airway in Chinese subjects and gender differences**

Variables	Boys								Girls						Gender difference	P value	
			Range		95% CI				Range		95% CI						
	Mean	SD	Median	Min	Max	Lower	Upper	Mean	SD	Median	Min	Max	Lower	Upper			
<i>Soft palate</i>																	
PM-U	Length of the soft palate	29.6	3.4	29.9	21.0	38.0	29.2	30.1	29.3	3.4	29.1	22.0	45.3	28.9	29.8	0.3	0.271
SPT	Soft palate thickness	8.3	1.2	8.3	4.1	11.9	8.2	8.5	8.0	1.4	7.9	2.8	12.7	7.8	8.2	0.3	0.008 **
NL/PM-U	Inclination of the long axis of the soft palate relative to the nasal line	125.9	6.1	125.5	109.1	144.2	125.1	126.7	126.9	5.4	127.1	112.9	144.8	126.2	127.7	-1.0	0.058
<i>Depth of upper airway</i>																	
PM-UPW	Depth of the nasopharyngeal airway space	21.0	3.5	21.2	4.7	28.4	20.5	21.4	20.9	3.5	20.9	11.1	28.4	20.4	21.4	0.1	0.553
U-MPW	Depth of the retropalatal pharyngeal airway space	8.7	2.2	8.6	3.4	14.8	8.4	9.0	9.2	2.4	9.2	3.5	16.0	8.9	9.6	-0.6	0.011 *
V-LPW	Depth of the hypopharyngeal airway space	13.4	3.0	13.9	5.0	19.9	13.0	13.8	14.5	3.1	14.7	5.2	23.2	14.1	15.0	-1.1	<0.001 ***
PASmin	Depth of the retroglossal pharyngeal airway space	8.4	2.5	8.4	2.3	14.3	8.1	8.8	9.0	2.7	8.8	2.8	16.5	8.7	9.4	-0.6	0.034 *
<i>Position of the hyoid bone</i>																	
AH-FH	Position of the hyoid bone in the vertical plane	75.2	5.9	75.2	60.8	95.3	74.3	75.9	74.1	6.0	73.9	58.9	99.1	73.2	74.9	1.1	0.04
AH-CV	Position of the hyoid bone in the horizontal plane	30.1	3.4	30.1	21.1	37.9	29.6	30.5	30.2	3.0	30.4	22.9	41.1	29.8	30.7	-0.2	0.775

\* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ .

**Table 5 Cephalometric values of upper airway in Caucasian subjects and gender differences**

Variables	Boys								Girls								Gender difference	P value
	Mean	SD	Median	Range		95% CI		Mean	SD	Median	Range		95% CI					
				Min	Max	Lower	Upper				Min	Max	Lower	Upper				
<i>Soft palate</i>																		
PM-U	Length of the soft palate	29.9	3.9	29.7	20.2	42.6	28.8	30.9	29.4	3.3	29.2	23.5	37.9	28.4	30.4	0.5	0.377	
SPT	Soft palate thickness	8.3	1.3	8.4	5.2	11.8	8.0	8.7	7.9	1.1	7.9	5.8	10.8	7.6	8.2	0.4	0.055	
NL/PM-U	Inclination of the long axis of the soft palate relative to the nasal line	124.6	6.3	125.0	111.0	140.0	123.0	126.2	126.8	6.8	125.0	113.0	147.0	124.8	128.8	-2.2	0.296	
<i>Depth of upper airway</i>																		
PM-UPW	Depth of the nasopharyngeal airway space	21.0	3.6	21.6	9.9	27.3	20.1	21.9	21.1	4.1	21.0	8.2	31.7	19.9	22.3	-0.1	1.000	
U-MPW	Depth of the retropalatal pharyngeal airway space	9.1	2.4	9.1	3.1	13.8	8.5	9.7	9.2	2.3	8.8	4.3	14.2	8.5	9.8	-0.1	0.889	
V-LPW	Depth of the hypopharyngeal airway space	13.1	2.5	13.5	8.0	19.7	12.5	13.8	13.1	3.4	13.6	7.4	21.0	12.2	14.1	0.0	0.973	
PASmin	Depth of the retroglossal pharyngeal airway space	7.5	2.8	7.4	2.8	13.8	6.8	8.2	7.9	2.8	7.3	4.1	14.7	7.1	8.7	-0.4	0.562	
<i>Position of the hyoid bone</i>																		
AH-FH	Position of the hyoid bone in the vertical plane	73.1	5.4	72.8	62.6	84.2	71.7	74.4	72.8	5.2	72.2	60.1	85.9	71.3	74.3	0.3	0.633	
AH-CV	Position of the hyoid bone in the horizontal plane	28.6	2.9	28.8	22.0	35.5	27.8	29.3	29.4	3.0	29.4	24.2	35.6	28.5	30.3	-0.8	0.208	

**Table 6 Cephalometric values of the upper airway for interethnic differences (Chinese versus Caucasian)**

Variables	Boys		Girls			
	Mean	P value	Mean	P value		
<i>Soft palate</i>						
PM-U	Length of the soft palate	-0.2	0.681	-0.1	0.954	
SPT	Soft palate thickness	0.0	0.827	0.0	0.714	
NL/PM-U	Inclination of the long axis of the soft palate relative to the nasal line	1.3	0.252	0.2	0.456	
<i>Depth of upper airway</i>						
PM-UPW	Depth of the nasopharyngeal airway space	0.0	0.914	-0.2	0.738	
U-MPW	Depth of the retropalatal pharyngeal airway space	-0.4	0.146	0.1	0.724	
V-LPW	Depth of the hypopharyngeal airway space	0.3	0.314	1.4	0.01	**
PASmin	Depth of the retroglossal pharyngeal airway space	0.9	0.019	1.1	0.005	**
<i>Position of the hyoid bone</i>						
AH-FH	Position of the hyoid bone in the vertical plane	2.1	0.014	1.3	0.114	*
AH-CV	Position of the hyoid bone in the horizontal plane	1.5	0.001	0.9	0.074	**

\* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ .

has two periods of accelerated change (6-9 years and 12-15 years) and two periods of quiescence (9-12 years and 15-18 years) for the growth of oropharynx, but Mislik et al. [37] found there was no radical change in the retropalatal and retroglossal oropharynx from 6 to 17 years of age, and considered that the upper airway dimensions were formed and matured during the early periods of growth. Because the chronological regularity of growth of Chinese children is still unclear, we consider that the norms obtained from 12-year-old Chinese children are only relevant to the age around 12-year-old. Wu et al. [38] used the same sample of 12-year-old Chinese children data to get the Chinese norms of McNamara's analysis and suggested that the norms were suitable for around 10-14 years age.

Whether the age range of 10-14 years old is also suitable for upper airway needs further investigation.

**The influence of ethnicity on the dimensions of the upper airway**

The prevalence of SDB has been reported to show ethnic/racial differences. African-Americans were considered to have a higher incidence of OSAS than Caucasians [39], and Indians were reported to have a greater risk of SDB than Chinese [40]. No published research has compared the prevalence of pediatric SDB between Chinese and Caucasian children. The present study found the ethnic differences in the upper airways in 12-year-old Caucasian and Chinese children. Both genders of Chinese children

**Table 7 Cephalometric values of the upper airway for age differences (adults versus children)**

Variables	Males			Females			
	Mean	P value		Mean	P value		
<i>Soft palate</i>							
PM-U	Length of the soft palate	4.7	<0.001	***	1.3	0.009	**
SPT	Soft palate thickness	1.8	<0.001	***	0.9	<0.001	***
NL/PM-U	Inclination of the long axis of the soft palate relative to the nasal line	1.4	0.119		1.4	0.039	*
<i>Depth of upper airway</i>							
PM-UPW	Depth of the nasopharyngeal airway space	4.9	<0.001	***	3.2	<0.001	***
U-MPW	Depth of the retropalatal pharyngeal airway space	1.2	0.017	*	0.7	0.027	*
V-LPW	Depth of the hypopharyngeal airway space	5.3	<0.001	***	2.0	<0.001	***
PASmin	Depth of the retroglossal pharyngeal airway space	1.7	0.002	**	1.0	0.008	**
<i>Position of the hyoid bone</i>							
AH-FH	Position of the hyoid bone in the vertical plane	17.2	<0.001	***	4.4	<0.001	***
AH-CV	Position of the hyoid bone in the horizontal plane	6.3	<0.001	***	1.0	0.009	**

\* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ .

**Table 8 Results of Spearman's correlation analysis for Chinese samples**

		Soft palate			Depth of the upper airway				Position of the hyoid bone								
		PM-U	SPT	NL/PM-U	PM-UPW	U-MPW	V-LPW	PASmin	AH-FH	AH-CV							
SNA (°)	Coefficient	-0.044	0.061	-0.167	**	0.047	0.085	0.042	0.042	0.011	0.064						
	P value	0.367	0.211	0.001		0.337	0.082	0.389	0.392	0.826	0.185						
SNB (°)	Coefficient	-0.104	*	0.066	-0.210	**	0.038	0.156	**	0.101	*	0.123	*	-0.019	0.138	**	
	P value	0.032		0.173	0.000		0.439	0.001	0.037	0.011	0.703	0.004					
ANB (°)	Coefficient	0.124	*	-0.015	0.095	0.026	-0.133	**	-0.083	-0.135	**	0.045	-0.099	*			
	P value	0.010		0.753	0.049	0.595	0.006	0.089	0.005	0.358	0.041						
MnPI/SN (°)	Coefficient	0.000	-0.046	0.044	-0.111	*	-0.115	*	-0.099	*	-0.068	0.000	-0.121	**			
	P value	0.997	0.349	0.368	0.022	0.018	0.042	0.164	0.997	0.012							
MxPI/MnPI (°)	Coefficient	-0.088	-0.102	*	0.179	**	-0.023	-0.070	-0.039	-0.025	0.061	-0.099	*				
	P value	0.071	0.035	0.000	0.632	0.153	0.428	0.603	0.212	0.042							
MxMn-DF (mm)	Coefficient	0.019	0.174	**	-0.191	**	-0.056	0.110	*	0.154	**	0.089	0.263	**	0.251	**	
	P value	0.701	0.000	0.000	0.252	0.023	0.001	0.067	0.000	0.000							
TAFH (mm)	Coefficient	0.237	**	0.208	**	-0.018	0.112	*	0.062	0.126	*	0.042	0.489	**	0.304	**	
	P value	0.000	0.000	0.718	0.021	0.203	0.009	0.383	0.000	0.000							
TPFH (mm)	Coefficient	0.201	**	0.210	**	-0.080	0.138	**	0.138	**	0.198	**	0.068	0.417	**	0.389	**
	P value	0.000	0.000	0.100	0.004	0.004	0.000	0.161	0.000	0.000							
Y axis/FH (°)	Coefficient	0.122	*	-0.083	0.065	-0.013	-0.159	**	-0.057	-0.141	**	0.139	**	-0.058			
	P value	0.012	0.086	0.184	0.789	0.001	0.245	0.004	0.004	0.230							
Overjet (mm)	Coefficient	0.084	-0.034	0.090	-0.001	-0.180	**	-0.081	-0.232	**	0.181	**	-0.089	*			
	P value	0.085	0.487	0.062	0.990	0.000	0.095	0.000	0.000	0.000	0.068						
Overbite (mm)	Coefficient	0.135	**	-0.048	0.023	0.019	-0.134	**	-0.044	-0.150	**	0.080	-0.126	**			
	P value	0.005	0.324	0.637	0.690	0.006	0.369	0.002	0.100	0.009							
OPT-SN (°)	Coefficient	0.179	**	-0.053	0.336	**	-0.089	-0.017	0.299	**	0.212	**	0.142	**	0.335	**	
	P value	0.000	0.278	0.000	0.066	0.726	0.000	0.000	0.000	0.003	0.000						
c2sp-c4ip-SN (°)	Coefficient	0.195	**	-0.055	0.316	**	-0.103	-0.043	0.289	**	0.169	**	0.171	**	0.278	**	
	P value	0.000	0.257	0.000	0.033	0.375	0.000	0.000	0.000	0.000	0.000						
Body length (mm)	Coefficient	0.051	0.158	**	-0.024	0.166	**	0.204	**	0.206	**	0.224	**	0.290	**	0.302	**
	P value	0.296	0.001	0.627	0.001	0.000	0.000	0.000	0.000	0.000	0.000						

\*Correlation is significant at the 0.05 level.

\*\*Correlation is significant at the 0.01 level.

had a larger depth of retroglossal oropharynx than their Caucasian counterparts, and Chinese boys had a more anterior and inferior position of the hyoid bone. It is impossible to predict the difference in the risk of SDB between Chinese or Caucasian children based on these findings, because the larger size of pharynx is considered an advantage for airway patency but the anterior and inferior position of the hyoid bone is a disadvantage [17].

#### The associations between the upper airway and other craniofacial structures

The present study found that the associations between the craniofacial structures and the upper airway were generally weak, but the mandibular length and craniocervical

inclination were found to have more prominent associations with most of the upper airway variables than the other craniofacial structures in both Chinese and Caucasian ethnicities. Ozdemir et al. [41] also reported the a positive association between mandibular body length (GnGo) and minimal posterior airway space (MPAS). The finding seems to indicate that skeletal Class II malocclusion is a risk factor for pediatric SDB. The influence of craniocervical inclination on the dimensions of upper airway has been reported in a number of studies [42-44]. An increase in the craniocervical extension tends to increase the depth of the pharynx, and it was reported to be one of the craniofacial characteristics of children with SDB [19].

**Table 9 Results of Spearman's correlation analysis for Caucasian samples**

Variables		Soft palate			Depth of the upper airway				Position of the hyoid bone	
		PM-U	SPT	NL/PM-U	PM-UPW	U-MPW	V-LPW	PASmin	AH-FH	AH-CV
SNA (°)	Coefficient	-0.010	0.111	0.001	0.178	-0.088	0.040	-0.075	-0.068	0.033
	P value	0.919	0.252	0.991	0.066	0.365	0.684	0.439	0.484	0.738
SNB (°)	Coefficient	-0.064	0.223 *	-0.106	0.119	-0.098	-0.009	-0.099	-0.032	0.081
	P value	0.508	0.021	0.276	0.221	0.311	0.925	0.308	0.742	0.404
ANB (°)	Coefficient	0.135	-0.134	0.252 **	0.200 *	-0.069	0.064	-0.005	-0.093	-0.029
	P value	0.162	0.166	0.008	0.038	0.476	0.510	0.958	0.337	0.769
MnPI/SN (°)	Coefficient	0.026	-0.057	0.103	-0.137	0.145	-0.027	0.065	0.117	-0.043
	P value	0.788	0.557	0.291	0.157	0.133	0.781	0.506	0.229	0.657
MxPI/MnPI (°)	Coefficient	-0.022	-0.105	0.236 *	0.019	0.104	-0.055	-0.064	0.204 *	-0.100
	P value	0.824	0.281	0.014	0.842	0.285	0.573	0.510	0.034	0.302
MxMn-DF (mm)	Coefficient	0.050	0.274 **	-0.079	-0.065	0.094	-0.052	0.023	0.423 **	0.153
	P value	0.609	0.004	0.417	0.502	0.332	0.592	0.813	0.000	0.113
TAFH (mm)	Coefficient	0.240 *	0.180	0.120	0.041	0.086	0.217 *	0.188	0.444 **	0.302 **
	P value	0.012	0.063	0.215	0.673	0.373	0.024	0.051	0.000	0.001
TPFH (mm)	Coefficient	0.257 **	0.269 **	-0.082	0.062	-0.081	0.271 **	0.152	0.348 **	0.291 **
	P value	0.007	0.005	0.397	0.521	0.402	0.005	0.117	0.000	0.002
Y axis/FH (°)	Coefficient	0.188	-0.139	0.003	-0.141	-0.115	0.083	-0.030	0.178	-0.079
	P value	0.051	0.153	0.978	0.147	0.236	0.395	0.757	0.065	0.415
Overjet (mm)	Coefficient	-0.053	-0.199 *	0.140	0.037	-0.057	-0.050	-0.165	0.096	0.033
	P value	0.583	0.039	0.150	0.701	0.560	0.608	0.087	0.322	0.736
Overbite (mm)	Coefficient	0.063	-0.034	0.117	0.120	-0.154	-0.076	-0.206	-0.064	-0.150
	P value	0.519	0.729	0.229	0.215	0.112	0.436	0.033	0.510	0.120
OPT-SN (°)	Coefficient	0.199 *	-0.239 *	0.417 **	0.038	0.302 **	0.353 **	0.404	0.201 *	0.326 **
	P value	0.039	0.013	0.000	0.693	0.001	0.000	0.000	0.037	0.001
c2sp-c4ip-SN (°)	Coefficient	0.213 *	-0.209 *	0.376 **	0.013	0.253 **	0.336 **	0.360	0.202 *	0.278 **
	P value	0.027	0.030	0.000	0.892	0.008	0.000	0.000	0.036	0.004
Body length (mm)	Coefficient	-0.079	0.073	0.206 *	0.318 **	0.280 **	0.136	0.212	0.210 *	0.235 *
	P value	0.414	0.451	0.033	0.001	0.003	0.159	0.028	0.029	0.014

\*Correlation is significant at the 0.05 level.

\*\*Correlation is significant at the 0.01 level.

### The limitations of the present study

Firstly, because the samples were not from a study that focused on the upper airway, no history-related investigation of the upper airway was made, such as diagnosis of SDB, snoring, enlarged tonsils, or history of adenotonsillectomy, etc. Secondly, the original lateral radiograph technique was not adopted especially for the upper airway, i.e., the radiographs were taken at the end of expiration, by holding the latter position and refraining from swallowing while the film was exposed [31]. These two factors had some influence on the dimensions of the upper airway, but as the present study was based on a large sample size, and we excluded the cephalograms in which a swallowing action was detected, the reference values derived in this study can represent the

norms of children in this age group. Thirdly, transversal airway dimension could not be analyzed due to the limitation of two-dimensional lateral cephalometry.

### Conclusions

1. Cephalometric norms for the upper airway of Chinese children have been established providing gender-specific standards. Chinese boys tend to have more risk factors of upper airway for SDB than Chinese girls.
2. Ethnic differences were found in the upper airway dimensions between Chinese and Caucasian children. Chinese children had a greater depth of the retroglottal oropharynx, and Chinese boys had a

more anterior and inferior position of the hyoid bone than Caucasian boys.

3. Generally, the associations between the upper airway and craniofacial structures were weak, but the mandibular body length and the craniocervical inclination seemed to have a more prominent correlation with the upper airway than other craniofacial structures.

#### Competing interests

The authors declare that they have no financial and non-financial competing interest. This study was funded by the research funding of the University of Hong Kong.

#### Authors' contributions

MG carried out the cephalometric analysis, drafted and finalized the manuscript. CPJM, RWKW, UH and YQY participated the design of the study, interpreted the data and revised the manuscript. All authors read and approved the final manuscript.

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