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Original Article

Cephalometric Correlation Among Pharyngeal Airway Dimensions and Surrounding Structures in Growing Thai Orthodontic Patients with Normodivergent Facial Pattern

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Abstract

Objective To assess sexual dimorphism and correlation among pharyngeal airway dimensions, bony and soft tissue variables, and skeletal ages.

Materials and Methods Four hundred and eighteen pretreatment lateral cephalometric radiographs (183 males, 235 females) of growing Thai orthodontic patients (6-20 years old; mean age, 13.95±3.62 years; divided into 3 skeletal ages, pre-pubertal (CS 1,2), pubertal (CS 3,4), and post-pubertal (CS 5,6)), Faculty of Dentistry, Chulalongkorn University were collected from 2007-2014. Twelve angular, 13 linear, and 3 area cephalometric measurements were analyzed. Sexual dimorphism was assessed by Student's *t*-test. Pearson's and Spearman's correlation coefficients were applied to explain variable correlations, including the new angular measurements and the existing linear measurements of tongue and hyoid positions.

Results Sexual dimorphism was found only in the post-pubertal period. Nasopharyngeal, oropharyngeal, and total pharyngeal area measurements, and airway width at the level of tongue base highly and positively correlated with vertical tongue and hyoid position, tongue length, and skeletal ages. Other airway variables also showed significant correlation to mandibular position, vertical and horizontal hyoid and tongue position, and tongue thickness. Angular measurements of tongue and hyoid horizontal position highly correlated with linear measurements. Angular measurements of tongue and hyoid vertical position showed significantly moderate to high correlation with linear measurements.

Conclusion Males had larger airway dimensions than females in post-pubertal period. Skeletal ages, hyoid position, tongue position and dimension, including mandibular position correlated with upper pharyngeal airway dimensions. The new angular measurements might be easier and practical parameters used to measure hyoid and tongue position.

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Key words: *Growing patients; Hyoid; Normodivergent facial pattern; Pharyngeal airway; Soft palate; Tongue*

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Introduction

During the past few decades, upper pharyngeal airway dimensions and their relationship to craniofacial complex in normal population (Tourne, 1991; Mislik et al, 2014) and the patients with obstructive sleep apnea (OSA) has been interesting issues for orthodontists (Ping-Ying Chiang et al, 2012). Orthodontic and/or orthopedic treatments affect not only the alignment of teeth, but also the soft tissue profile, hyoid and tongue position, and upper pharyngeal airway dimensions. The downward and backward displacement of mandible and tongue from treatment might cause reduction in pharyngeal airway and development of sleep-disordered breathing (SDB). SDB ranges from chronic or habitual snoring to upper airway resistance and to OSA. Anatomic factors that predispose the airway to collapse during inspiration, such as narrow pharynx, combined with an insufficient neuromuscular compensation during sleep to maintain airway patency were the factors involved in OSA development (Young et al, 2002; Mislik et al, 2014). The prevalence of OSA in children ranges from 0.7% to 2% (Ping-Ying Chiang et al, 2012), as well as in Thai children (0.69%) (Anuntaseree et al, 2001). OSA in childhood can lead to improper development of craniofacial complex and OSA in adulthood (Ping-Ying Chiang et al, 2012). Previous studies, including the studies in Thai population, aimed at comparison of airway dimensions among vertical and horizontal skeletal patterns, based on FMA and ANB angles, in non-growing normal population (Pornsuksiri et al, 2013), and in patients with nasopharyngeal pathology (Banhiran et al, 2013; Jamsirirojrat et al, 2013).However, there were some pharyngeal airway studies (Ceylan and Oktay, 1995; Preston et al, 2004; Abu Allhaija and Al-Khateeb, 2005; Takemoto et al, 2011; Ping-Ying Chiang et al, 2012; El and Palomo, 2013; Mislik et al, 2014) in growing population, but, mostly in nasopharyngeal region and a specific range of age group. Also, there still be a controversy in sexual effect on pharyngeal airway dimensions. Moreover, it had been reported that the position of hyoid bone correlated with apnea-hypopnea index (AHI), used in diagnosis of OSA (Ping-Ying Chiang et al, 2012). The existing parameters used to describe hyoid and tongue positions were linear measurements, i.e. Hy-FH, V-FH, S per-Hy, S per-V, MP-H (Samman et al, 2003; Aydemir et al, 2012), which might not be suitable for the subjects with smaller or larger facial size than average, and angular measurements might reduce the diagnostic error. Therefore, the purposes of this study were to retrospectively assess sexual dimorphism, and correlation among pharyngeal airway dimensions, bony and soft tissue variables, and skeletal ages; and to develop and test the ability of new parameters in measuring hyoid and tongue position.

Materials and Methods

Subject selection

Four hundred and eighteen pretreatment lateral cephalometric radiographs of growing Thai orthodontic patients in the Orthodontic department, Faculty of Dentistry, Chulalongkorn University, taken by usual standardized method from Kodak 8000C or 9000C Digital panoramic and cephalometric system (Carestеam, Rochester, New York) at the Department of Radiology from 2007-2014, were collected in digital format (JPEG file). The inclusion criteria were growing patients (age ≤ 20 years old); with skeletal normal bite (FMA 21°-29°) (Sorathesn, 1984); no history of nasopharyngeal pathology, tonsillectomy, or adenoidectomy; no history of systemic, congenital disease, nor accident that affected maxillofacial structures; no history of orthodontic treatment, orthognathic surgery or orthopedic treatment. Unclear lateral cephalometric radiographs; abnormal shape of soft palate, beside from 6 normal shapes (You et al, 2008), and tongue; and craniocervical angles below 90° or exceeding 110° (Hellsing, 1989; Muto et al, 2002; Muto et al, 2006; Alves et al, 2012) were excluded. Sex and skeletal ages; the pre-pubertal (CS 1,2), the pubertal (CS 3,4), and the post-pubertal (CS 5,6) according to previous studies (Baccetti et al, 2005) (Fig. 1), were determined.

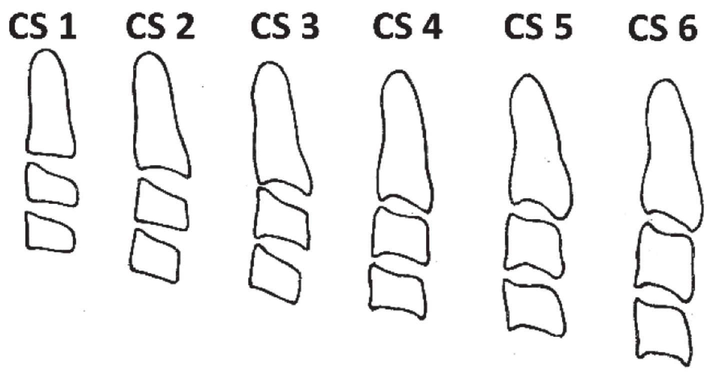

Fig. 1 Schematic representation of the stages of cervical vertebral maturation (Baccetti et al, 2005) : CS1 (The lower borders of all the three vertebrae (C2-C4) are flat. The bodies of both C3 and C4 are trapezoid in shape.) demonstrated that the peak in mandibular growth will occur on average 2 years after this stage; CS2 (A concavity is present at the lower border of C2. The lower borders of C3-C4 are flat. The bodies of both C3 and C4 remained trapezoid in shape.) demonstrated that the peak in mandibular growth will occur on average 1 year after this stage; CS3 (Concavities at the lower borders of both C2 and C3 are present. The bodies of C3 and C4 may be either trapezoid or rectangular horizontal in shape.) demonstrated that the peak in mandibular growth will occur during the year after this stage; CS4 (Concavities at the lower borders of C2, C3, and C4 now are present. The bodies of both C3 and C4 are rectangular horizontal in shape.) demonstrated that the peak in mandibular growth has occurred within 1 or 2 years before this stage; CS5 (The concavities at the lower borders of C2, C3, and C4 still are present. At least one of the bodies of C3 and C4 is squared in shape.) demonstrated that the peak in mandibular growth has ended at least 1 year before this stage; CS6 (The concavities at the lower borders of C2, C3, and C4 still are evident. At least one of the bodies of C3 and C4 is rectangular vertical in shape.) demonstrated that the peak in mandibular growth has ended at least 2 years before this stage.

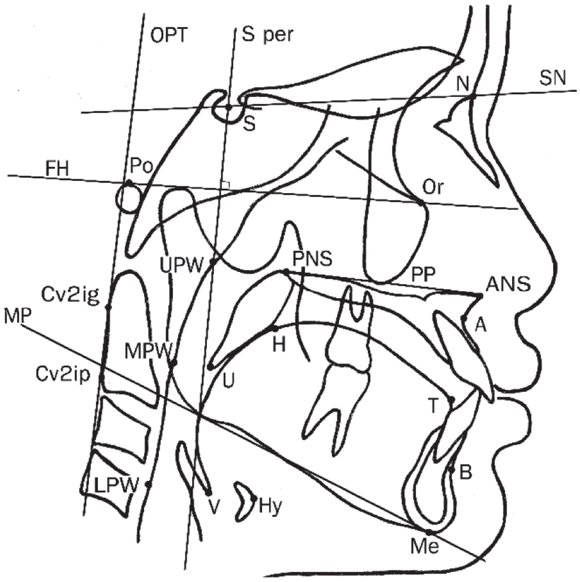

Fig. 2 Cephalometric landmarks and reference lines: S Sella; N Nasion; A A-point; B B-point (Sorathesn, 1984; Aydemir et al, 2012); Po Porion; Or Orbitale (Samman et al, 2003; Aydemir et al, 2012); PNS Posterior Nasal Spine (Samman et al, 2003; Martin et al, 2006); ANS Anterior Nasal Spine; Me Menton (most inferior point of bony chin); U Uvula (tip of uvula), V Vallecula (intersection of epiglottis and base of tongue); UPW Upper pharyngeal wall; MPW Middle pharyngeal wall; LPW Lower pharyngeal wall (intersection of the line parallel to PP from PNS, U, and V, respectively, to the posterior pharyngeal wall); T tip of tongue; H most superior point of tongue in relation to the line from V to T; Hy (most antero-superior point of Hyoid) (Samman et al, 2003); Cv2ig (most supero-posterior point on the body of the second cervical vertebra); Cv2ip (most infero-posterior point on the body of the second cervical vertebra); OPT (line through Cv2ig-Cv2ip) (Muto et al, 2002); FH Frankfort horizontal plane (line through Po-Or) (Sorathesn, 1984; Aydemir et al, 2012); S per (vertical line from S perpendicular to FH) (Mislik et al, 2014); MP Mandibular plane (line from Me tangent to the lower border of mandible behind antegonial notch) (Sorathesn, 1984)

Cephalometric measurements

All cephalometric landmarks (Fig. 2) and measurementsof pharyngeal airway dimensions (linear airway widths and airway areas) and surrounding structures (skeletal variables, positions and dimensions of soft palate, tongue, and hyoid) were calibrated and measured using Image J software version 1.47 (National Institutes of Health, Bethesda, Maryland, USA) on Microsoft Window 7.0, wide screen laptop with resolution of 1600 x 900. Twelve angular measurements (Fig. 3A) consisted of 5 skeletal variables; maxillary and mandibular positions (SNA and SNB), sagittal maxillo-mandibular relationship (ANB), vertical facial pattern (FMA), and cranio-cervical angulation (OPT-SN), and 7 positions of surrounding structures; horizontal tongue position (SNV and NSV), horizontal hyoid position (SNHy and NSHy), vertical tongue position (MP-Me-V), vertical hyoid position (MP-Me-Hy), which were the new variables, and soft palate angulation (ANS-PNS-U). Thirteen linear measurements (Fig. 3B) comprised 5 airway widths; airway widths at the level of palate, uvula tip, and tongue (PNS-UPW, U-MPW, and V-LPW), McNamara's upper and lower pharynx dimensions (McU and McL),

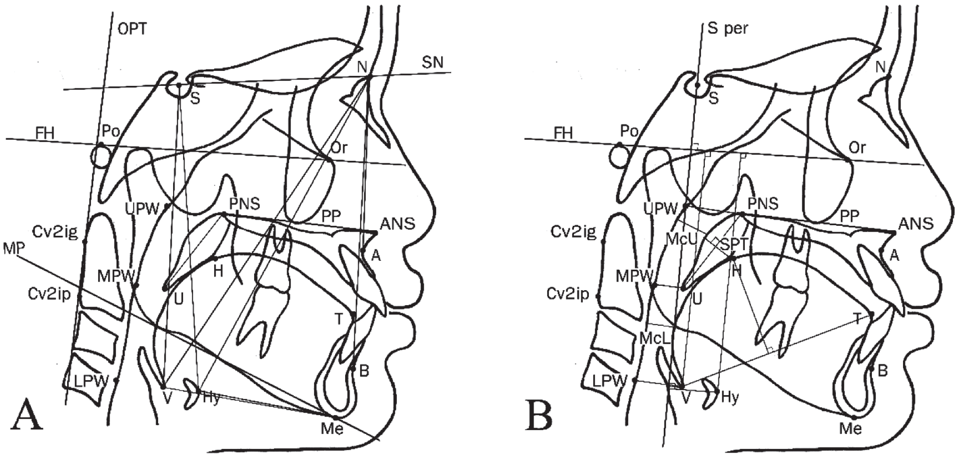

Fig. 3 Cephalometric angular and linear measurements. *A, angular measurements;* SNA; SNB; ANB (Sorathesn, 1984; Aydemir et al, 2012); FMA (Sorathesn, 1984); OPT-SN angle (Muto et al, 2002); ANS-PNS-U angle (Samman et al, 2003); New angular measurements; NSHy (angle formed by SN line and line passing through S and Hy); NSV (angle formed by SN line and line passing through S and V); SNHy (angle formed by SN line and line passing through N and Hy); SNV (angle formed by SN line and line passing through N and V); MP-Me-Hy; MP-Me-V (angle formed by MP line and line passing through Me and Hy; V, respectively), *B, linear measurements;* S per-Hy; S per-V (distance perpendicular to S per line from Hy; V, respectively) (modified from previous studies (Samman et al, 2003; Mislik et al, 2014)); Hy-FH; V-FH (distance perpendicular to FH from Hy; V, respectively); PNS-U (distance from PNS to U); SPT (maximal thickness of soft palate measured perpendicular to PNS-U line); VT; H-VT (distance from H perpendicular to VT line); PNS-UPW; U-MPW; V-LPW (Samman et al, 2003); McU McNamara's upper pharynx dimension (distance from posterior outline of anterior half of soft palate to the closest point on the posterior pharyngeal wall); McL McNamara's lower pharynx dimension (distance from intersection of posterior border of tongue and inferior border of mandible to the closest point on the posterior pharyngeal wall) (McNamara, 1984)

4 dimensions of surrounding structures; soft palate length and thickness (PNS-U andSPT), tongue length and thickness (VT and H-VT), and 4 positions of surrounding structures; vertical tongue and hyoid positions (VFH and HyFH), horizontal tongue and hyoid positions (S per-V, and S per-Hy). Three area measurements (Fig. 4) were nasopharyngeal, oropharyngeal, and total pharyngeal areas (NasoA, OroA, and TotalA). All figures illustrated in this article were drawn from Thai subjects, however, the definitions given in the legends referred to the previous studies as mentioned.

Statistical analysis

Twenty samples were randomly traced and measured twice (2 weeks apart) by the same investigator to estimate the intraobserver reliability using the intraclass correlation coefficient (ICC). The sexual dimorphism in each skeletal age was assessed by Student's *t*-test. The correlation among upper pharyngeal airway dimensions, bony and soft tissue parameters, and skeletal ages was examined using Pearson's and Spearman's correlation coefficients. All statistical analyses were performed using SPSS version 22.0 for Windows with 95% confidence

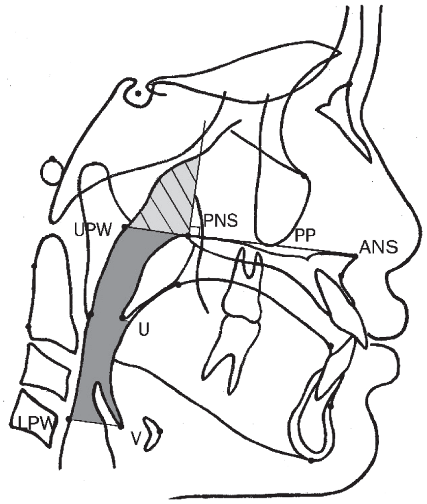

Fig. 4 Cephalometric area measurements; Nasopharyngeal area (between line from PNS perpendicular to PP and PP and roof of nasopharynx) (modified from previous study (Martin et al, 2006)); Oropharyngeal area (Samman et al, 2003) (between PP and V-LPW behind the tongue and soft palate); Total upper pharyngeal airway area (consisted of oropharyngeal area and nasopharyngeal area)

Table 1 Demographic data of subjects

Skeletal Age	Male			Female		
	N	Range (yr.)	Mean±S.D. (yr.)	N	Range (yr.)	Mean±S.D. (yr.)
Pre-pubertal	61	7-12	9.44±1.54	51	6-12	8.82±1.32
Pubertal	67	10-18	12.55±1.77	100	8-20	12.68±2.49
Post-pubertal	55	13-20	17.80±2.02	84	11-20	15.96±2.48
Total	183	7-20	13.09± .80	235	6-20	13.05±3.62

intervals. The present research was retrospective study of radiographic images, and all the protocol used in this study has been approved by The Human Research Ethics Committee of the Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand (HREC-DCU 2015-005).

Results

There are 418 subjects included in this study; 112 pre-pubertal (male:female = 61:51), 167 pubertal (male:female = 67:100), and 139 post-pubertal (male:female = 55:84) (Table 1). ICC showed good intraobserver reliability, ranged from 0.841 to 0.998 with the average of 0.959. Means and standard deviations of upper pharyngeal airway dimensions and tongue and hyoid position, including sexual dimorphism, were reported in Tables 2-4. Significant sex difference of pharyngeal airway dimensions was found mainly in the post-pubertal period. However, nasopharyngeal and total pharyngeal areas (NasoA and TotalA) in the pre-pubertal and McNamara's upper pharynx dimension (McU) in the pubertal period also presented significant sex difference. Pearson's and Spearman's correlation coefficients between upper pharyngeal airway dimensions and skeletal ages, and

Table 2 Means and standard deviations of upper pharyngeal airway dimensions and surrounding structures, including sexual dimorphism in the pre-pubertal period

Variables*		Pre-pubertal						
		Male		Female		Total		p-value
Group		Mean	S.D.	Mean	S.D.	Mean	S.D.	
Skeletal	SNA(°)	82.49	2.98	82.19	3.07	82.35	3.01	0.605
	SNB(°)	78.67	3.20	78.59	3.82	78.63	3.48	0.894
	ANB(°)	3.81	2.92	3.60	3.19	3.72	3.03	0.718
Soft palate	AnsPnsU(°)	129.92	6.02	130.06	5.86	129.98	5.92	0.902
	PnsU(mm)	29.17	2.77	28.73	2.93	28.97	2.84	0.415
	SPT(mm)	8.37	0.97	8.03	1.14	8.21	1.06	0.087
Tongue	SNV(°)	50.35	3.31	49.54	3.91	49.98	3.60	0.235
	NSV(°)	96.94	3.71	97.22	4.51	97.07	4.08	0.719
	MpMeV(°)	15.98	5.06	16.13	5.61	16.05	5.30	0.883
	SperV(mm)	3.19	4.94	3.06	5.59	3.13	5.22	0.898
	VFH(mm)	71.19	5.31	67.87	6.03	69.68	5.86	0.002**
	VT(mm)	61.63	5.25	58.86	5.40	60.37	5.47	0.007**
	Hvt(mm)	29.06	2.72	28.30	3.62	28.71	3.17	0.203
Hyoid	SNHy(°)	57.04	3.54	56.10	3.90	56.61	3.72	0.185
	NSHy(°)	88.86	4.09	89.03	4.55	88.94	4.29	0.833
	MpMeHy(°)	17.68	6.96	16.65	8.44	17.21	7.65	0.480
	SperHy(mm)	16.47	5.70	15.71	6.08	16.12	5.86	0.499
	HyFH(mm)	74.42	5.65	70.36	5.97	72.57	6.12	< .001**
Airway	PnsUpw(mm)	21.41	3.94	20.32	3.32	20.91	3.69	0.118
	McU(mm)	8.42	2.40	8.17	2.63	8.30	2.50	0.608
	UMpw(mm)	9.86	3.15	9.63	2.70	9.76	2.94	0.677
	McL(mm)	10.87	3.18	10.56	2.70	10.73	2.96	0.586
	VLpw(mm)	13.09	3.04	13.20	2.64	13.14	2.85	0.838
	NasoA(mm^2)	279.39	66.53	246.53	59.17	264.43	65.11	0.007**
	OroA(mm^2)	516.89	131.24	481.14	114.99	500.61	124.84	0.132
	TotalA(mm^2)	796.28	172.55	727.67	135.26	765.03	159.73	0.023*
	N	61		51		112		

*The mean difference is significant at the .05 level.

**The mean difference is significant at the .01 level.

Table 3 Means and standard deviations of upper pharyngeal airway dimensions and surrounding structures, including sexual dimorphism in the pubertal period

		Pubertal						
Variables*		**Male**		**Female**		**Total**		**p-value**
Group		**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	
Skeletal	**SNA(°)**	82.99	3.12	83.31	3.09	83.18	3.10	0.525
	SNB(°)	79.04	3.62	80.06	3.57	79.65	3.62	0.073
	ANB(°)	3.95	3.19	3.24	3.16	3.53	3.18	0.158
Soft palate	**AnsPnsU(°)**	128.47	5.85	129.50	5.54	129.09	5.67	0.254
	PnsU(mm)	31.45	3.72	30.63	3.28	30.96	3.48	0.136
	SPT(mm)	9.42	1.34	8.63	1.28	8.95	1.36	<.001**
Tongue	**SNV(°)**	51.41	3.34	51.89	2.87	51.70	3.07	0.324
	NSV(°)	97.23	4.07	96.67	3.52	96.90	3.75	0.352
	MpMeV(°)	17.82	5.75	18.34	5.57	18.13	5.63	0.556
	SperV(mm)	4.69	5.50	3.93	4.39	4.24	4.86	0.322
	VFH(mm)	80.14	7.31	77.78	6.40	78.73	6.86	0.029*
	VT(mm)	67.65	6.90	66.08	5.53	66.71	6.14	0.106
	Hvt(mm)	33.40	3.88	33.00	3.39	33.16	3.59	0.480
Hyoid	**SNHy(°)**	58.60	3.34	57.87	2.71	58.16	2.99	0.118
	NSHy(°)	88.33	3.92	88.98	3.44	88.72	3.64	0.259
	MpMeHy(°)	18.49	7.56	17.76	6.95	18.05	7.19	0.519
	SperHy(mm)	19.72	5.53	16.96	4.63	18.06	5.17	0.001**
	HyFH(mm)	82.42	6.95	78.91	5.51	80.32	6.35	0.001**
Airway	**PnsUpw(mm)**	22.84	3.82	23.28	3.29	23.10	3.51	0.433
	McU(mm)	9.09	2.62	10.00	2.58	9.63	2.62	0.027*
	UMpw(mm)	9.74	2.48	9.82	2.30	9.79	2.37	0.840
	McL(mm)	10.45	2.76	10.52	3.01	10.49	2.90	0.875
	VLpw(mm)	14.03	3.26	14.45	2.52	14.28	2.84	0.369
	NasoA(mm^2)	320.43	81.32	328.39	69.37	325.19	74.26	0.499
	OroA(mm^2)	589.40	155.47	584.66	135.79	586.56	143.57	0.835
	TotalA(mm^2)	909.82	200.45	913.05	175.58	911.76	185.37	0.913
	N	67		100		167		

*The mean difference is significant at the .05 level.

**The mean difference is significant at the .01 level.

Table 4 Means and standard deviations of upper pharyngeal airway dimensions and surrounding structures, including sexual dimorphism in the post-pubertal period

		Post-Pubertal						
Variables*		**Male**		**Female**		**Total**		**p-value**
Group		**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	
Skeletal	**SNA(°)**	84.20	3.74	83.22	3.70	83.61	3.73	0.130
	SNB(°)	81.29	4.48	80.14	3.85	80.59	4.14	0.110
	ANB(°)	2.91	3.79	3.08	3.27	3.02	3.47	0.780
Soft palate	**AnsPnsU(°)**	125.62	6.99	130.04	5.90	128.29	6.69	<.001**
	PnsU(mm)	33.18	3.17	32.21	3.16	32.59	3.18	0.078
	SPT(mm)	9.93	1.39	8.77	1.18	9.23	1.39	<.001**
Tongue	**SNV(°)**	54.95	3.04	51.65	3.38	52.96	3.62	<.001**
	NSV(°)	95.60	4.05	97.35	3.58	96.66	3.86	0.008**
	MpMeV(°)	21.61	6.69	18.02	5.69	19.44	6.33	0.001**
	SperV(mm)	6.25	6.04	3.29	5.37	4.46	5.81	0.003**
	VFH(mm)	92.92	5.64	80.68	5.32	85.52	8.10	<.001**
	VT(mm)	72.22	5.35	68.15	5.40	69.76	5.72	<.001**
	Hvt(mm)	36.69	3.42	33.36	3.03	34.68	3.57	<.001**
Hyoid	**SNHy(°)**	61.32	3.30	57.30	3.26	58.89	3.82	<.001**
	NSHy(°)	87.74	4.25	89.71	3.54	88.93	3.94	0.004**
	MpMeHy(°)	22.06	9.25	16.27	7.14	18.56	8.50	<.001**
	SperHy(mm)	21.78	6.71	16.23	5.64	18.43	6.65	<.001**
	HyFH(mm)	93.86	6.14	80.95	5.11	86.06	8.40	<.001**
Airway	**PnsUpw(mm)**	25.14	3.25	25.17	2.78	25.16	2.96	0.963
	McU(mm)	11.84	2.76	11.23	2.36	11.47	2.54	0.161
	UMpw(mm)	11.20	3.28	9.69	2.82	10.29	3.09	0.004**
	McL(mm)	11.47	3.86	9.93	3.13	10.54	3.51	0.015*
	VLpw(mm)	17.94	3.03	15.51	2.68	16.47	3.05	<.001**
	NasoA(mm^2)	463.15	105.21	379.15	73.14	412.38	96.17	<.001**
	OroA(mm^2)	791.21	195.37	619.30	143.17	687.32	185.42	<.001**
	TotalA(mm^2)	1,254.36	255.05	998.45	179.28	1,099.71	246.09	<.001**
	N	55		84		139		

*The mean difference is significant at the .05 level.

**The mean difference is significant at the .01 level.

Table 5 Correlation Coefficients (r) among upper pharyngeal airway dimensions and the bony and soft tissue parameters

	PnsUpw	McU	NasoA^n	UMpw	McL	VLpw	OroA^n	TotalA^n
SkeAge^n	.432**	.434**	.601**	.079	-.033	.400**	.414**	.547**
SNA	.207**	.188**	.245**	.033	-.033	.085	.088	.174**
SNB	.176**	.385**	.304**	.265**	.229**	.237**	.281**	.322**
ANB	.004	-.261**	-.086	-.279**	-.304**	-.192**	-.235**	-.185**
AnsPnsU	.309**	-.105*	-.004	-.097*	-.096*	-.020	-.126**	-.077
SNHy	.044	.257**	.344**	-.035	-.044	.131**	.164**	.255**
SNV	.102*	.309**	.405**	-.011	-.015	.351**	.276**	.359**
NSHy	.029	-.144**	-.167**	.046	.040	.037	.041	-.036
NSV	.024	-.180**	-.200**	.046	.007	-.133**	-.040	-.106*
MpMeHy	-.099*	-.079	-.023	-.132**	-.055	.065	.092	.054
MpMeV	.018	.052	.122*	-.098*	-.086	.295**	.236**	.216**
SperHy	.010	.180**	.227**	-.009	-.016	.028	.061	.127**
HyFH^n	.303**	.324**	.530**	.049	-.003	.389**	.507**	.581**
SperV	-.045	.141**	.158**	-.040	-.002	.118*	.033	.078
VFH	.375**	.413**	.603**	.111*	.034	.542**	.576**	.661**
PnsU	.328**	.097*	.339**	-.260**	-.183**	.187**	.141**	.240**
SPT	.087	-.046	.208**	.005	.005	.013	.106*	.161**
VT	.413**	.320**	.444**	.259**	.136**	.322**	.509**	.555**
Hvt	.309**	.305**	.466**	-.019	-.061	.393**	.384**	.463**

^{n}The Spearman's correlation

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

position and dimensions of surrounding structures were presented in Table 5. Three airway area measurements and airway width at the level of tongue (V-LPW) significantly and positively correlated with vertical tongue (VFH) and hyoid (HyFH) positions, tongue length (VT), and skeletal ages (r=0.507-0.661; $p<0.01$). Other airway variables showed mild, but significant, correlation to mandibular position, vertical and horizontal hyoid and tongue position, and tongue thickness ($p<0.01$). Pearson's and Spearman's correlation coefficients among upper pharyngeal airway dimensions were presented in Table 6. Nasopharyngeal (PNS-UPW) and oropharyngeal (U-MPW and V-LPW) airway widths showed the highest correlation to nasopharyngeal and oropharyngeal areas, respectively. Oropharyngeal area also presented nearly perfect correlation to total pharyngeal area. ($p<0.01$). Pearson's and Spearman's correlation coefficients between new angular and existing linear measurements of tongue and hyoid positions were reported in Table 7. New angular measurements of horizontal tongue (NSV) and hyoid (SNHy and NSHy)

Table 6 Correlation Coefficients among upper pharyngeal airway dimensions

	PnsUpw	McU	NasoA[n]	UMpw	McL	VLpw	OroA[n]	TotalA[n]
PnsUpw	1.000	.707**	.738**	.351**	.196**	.373**	.525**	.685**
McU	.707**	1.000	.698**	.452**	.298**	.418**	.653**	.755**
NasoA[n]	.738**	.698**	1.000	.242**	.122*	.407**	.525**	.789**
Umpw	.351**	.452**	.242**	1.000	.753**	.436**	.725**	.613**
McL	.196**	.298**	.122*	.753**	1.000	.493**	.677**	.520**
VLpw	.373**	.418**	.407**	.436**	.493**	1.000	.722**	.682**
OroA[n]	.525**	.653**	.525**	.725**	.677**	.722**	1.000	.929**
TotalA[n]	.685**	.755**	.789**	.613**	.520**	.682**	.929**	1.000

[n]The Spearman's correlation
*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)

Table 7 Correlation Coefficients between new angular and existing linear measurements of tongue and hyoid positions

	SperHy	HyFH	SperV	VFH
SNHy	.701**	.394**	.572**	.436**
SNV	.559**	.412**	.589**	.562**
NSHy	-.753**	.065	-.674**	.000
NSV	-.654**	.003	-.715**	-.101*
MpMeHy	-.183**	.490**	-.176**	.357**
MpMeV	-.051	.457**	.028	.591**

[n]The Spearman's correlation
*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)

positions significantly correlated with linear measurements (tongue; S per-V and hyoid; S per-Hy) ($p < 0.01$). Significant correlations were also found between new angular measurements of vertical tongue (MP-Me-V) and hyoid (MP-Me-Hy) positions and linear measurements (tongue; VFH and hyoid; HyFH) ($p < 0.01$).

Discussion

Influences of sex and skeletal ages on upper pharyngeal airway dimensions

The present study demonstrated that all upper pharyngeal airway dimensions, except for airway width at the level of uvula tip (U-MPW) and McNamara's lower pharynx dimension (McL), significantly and positively correlated with skeletal ages, measured by cervical vertebral maturation. Upper pharyngeal airway dimensions showed no sexual dimorphism in the pre-pubertal and the pubertal periods, except for nasopharyngeal and total pharyngeal areas (NasoA and TotalA) in the pre-pubertal period, and McNamara's upper pharynx dimension (McU) in the pubertal period. These findings supported the study of Jeans et al that measurement of area gave more information than that of distance because the growth of nasopharynx in sagittal plane is mainly in height. Nevertheless, there was no significant sex difference in nasopharyngeal area in the pre-pubertal and the pubertal periods in the previous study (Jeans et al, 1981). Moreover, sexual difference in McNamara's upper pharynx dimension (McU) was 0.91 mm which might not be clinical significance. On the contrary, sexual dimorphism was found in the post-pubertal period in most airway variables, except the airway width at the level of palate (PNS-UPW) and McNamara's upper pharynx dimension (McU). Moreover, males had tendency to have insignificantly larger upper pharyngeal airway dimensions in the pre-pubertal, but insignificantly smaller upper pharyngeal airway dimensions in the pubertal period, then significantly larger upper pharyngeal airway dimensions in the post-pubertal period. These tendencies might result from the pubertal growth spurt pattern, as presented in general growth (Proffit, 2007), that males reached puberty later than females, and resulted in significant larger airway dimensions in the post pubertal period in male, both in nasopharynx, as reported by Preston et al (Preston et al, 2004), and orophaynx. However, Mislik et al (Mislik et al, 2014) found no sexual dimorphism in nasopharyngeal and oropharyngeal airway width in any chronological ages.

Correlation among upper pharyngeal airway dimensions

Jeans et al (Jeans et al, 1981) suggested the use of area measurement to explain pharyngeal airway growth and dimensions. Nevertheless, all upper pharyngeal airway dimensions from our study significantly correlated to each other in various degrees. PNS-UPW; U-MPW and V-LPW showed the highest correlation to nasopharyngeal area; and oropharyngeal area, respectively. Oropharyngeal area presented nearly perfect correlation to total pharyngeal area. PNS-UPW and U-MPW also presented significant difference between normal subjects and OSA patients from previous studies (Tangugsorn et al, 1995b; Banhiran et al, 2013; Jamsirirojrat et al, 2013). These demonstrated that linear measurements can be used as screening parameters in recognizing orthodontic patients at risk of compromised airway.

Correlation among various angular and linear measurements of tongue and hyoid position

Linear vertical position of hyoid and tongue (HyFH and VFH) positively correlated with angular position related to SN plane (SNHy and SNV) and mandibular plane (MP-Me-Hy and MP-Me-V). Linear horizontal hyoid and tongue position (S per-Hy and S per-V) positively correlated with SNHy and SNV, and negatively correlated with NSHy and NSV. These suggested that NSHy, NSV, MP-Me-Hy, and MP-Me-V, which showed the highest correlation to the linear measurements, were able to explain horizontal and vertical position of hyoid and tongue.

Influences of dimensions and position of surrounding structures on upper pharyngeal airway dimensions

Maxillary position (SNA) and mandibular position (SNB) positively and significantly correlated with nasopharyngeal airway dimensions. Mandibular position (SNB) positively, and maxilla-mandibular relationship (ANB) negatively, correlated with oropharyngeal airway dimensions. These were in accordance with previous studies reporting that ANB angle and SNB angle correlated with cross-sectional oropharyngeal area (Iwasaki et al, 2009), oropharyngeal area (Ceylan and Oktay, 1995) and volume (El and Palomo, 2013), but not nasopharyngeal area (Ceylan and Oktay, 1995) or volume (El and Palomo, 2013). However, some studies found that nasopharyngeal and oropharyngeal airway width or volume had no significant correlation with ANB angle (Oh et al, 2011; Mislik et al, 2014), but significant correlation with SNA and SNB (Mislik et al, 2014).

Moreover, from the present study, upper pharyngeal airway dimensions significantly correlated with surrounding structures of pharynx. The more obtuse soft palate angulation (ANS-PNS-U) was, the smaller nasopharyngeal and upper oropharyngeal width, and oropharyngeal area would be. The exception was found in airway width at the level of palate, which might be an effect of shorter palate length. The more anterior position of hyoid and tongue (SNHy, NSHy, and S per-Hy; and SNV, NSV, and S per-V), and the lower hyoid and tongue position (HyFH, VFH, and MP-Me-V) resulted in the larger nasopharyngeal and lower oropharyngeal width and area. Soft palate length, tongue length and height (PNS-U, VT, and H-VT) positively correlated with nasopharyngeal and lower oropharyngeal airway dimensions. Nevertheless, the shorter soft palate and longer tongue correlated with larger upper oropharyngeal airway dimensions. The subject with thicker soft palate thickness (SPT) tended to have more acute soft palate angulation and more anteriorly positioned hyoid and tongue, causing larger pharyngeal airway area. These findings supported previous studies (Ping-Ying Chiang et al, 2012; Jamsirirojrat et al, 2013) reporting that patients with compromised airway had more retruded maxilla, larger ratio of adenoid to nasopharyngeal length, shorter airway width at the level of uvula tip, and inferiorly and posteriorly positioned hyoid in relation to mandibular plane. Enlargement of adenoids and tonsils is the major cause of sleep-disordered breathing in children (Ping-Ying Chiang et al, 2012; Mislik et al, 2014). Moreover, narrow upper pharyngeal airway, large tongue and soft palate, posterior position of cranial base, short mandible and/or retrognathia, long lower face height, high mandibular plane angle, and downward and backward position of hyoid were also the causes of OSA (Tangugsorn et al, 1995b, a; Abu Allhaija and Al-Khateeb, 2005; Ping-Ying Chiang et al, 2012).

Present study confirmed the previous findings that not only the ANB angle, but also dimension and position of surrounding structures that correlated with upper pharyngeal airway dimensions; the more anteriorly the maxilla, mandible and soft palate positioned, and the more antero-inferiorly the hyoid and tongue positioned, the larger the pharyngeal airway dimensions would be (as aforementioned). However, some studies suggested that vertical facial patterns also related to the pharyngeal airway dimension (Zhong et al, 2010) and OSA development, therefore it should be further studied.

Although we found that males had larger airway dimensions than females, the prevalence of OSA in males were greater (Young et al, 2002; Enciso et al, 2010). OSA was multifactorial syndrome, in which several anatomic factors (as previously mentioned), and the neuromuscular adaptation involved (Young et al, 2002). The more inferior positions of tongue and hyoid, which presented in males, were also responsible for the higher risk of OSA development due to their correlation with AHI (Ping-Ying Chiang et al, 2012; Jamsirirojrat et al, 2013). Therefore, the greater airway dimensions might not indicate the lesser risk of OSA development and both pharyngeal airway widths (PNS-UPW and U-MPW) and positions of tongue and hyoid should be assessed in regular orthodontic examination.

In addition, future work will focus on the validity of these bony and soft tissue variables in predicting airway dimensional changes from orthodontic treatment.

Conclusion

Males had tendency to have larger upper pharyngeal airway dimensions in the pre-pubertal period insignificantly, and in the post-pubertal period significantly. Female had tendency to have larger upper pharyngeal airway dimensions in the pubertal period insignificantly. Skeletal ages, tongue length and height, soft palate length and thickness, tongue and hyoid horizontal and vertical position, and sagittal mandibular position correlated with upper pharyngeal airway dimensions at almost all levels, and both linear and area measurements. We suggested the use of linear airway measurements, i.e. PNS-UPW and U-MPW, and angular tongue and hyoid position, i.e. NSHy, NSV, MP-Me-Hy, and MP-Me-V, as screening parameters in early recognition of patients who might be at risk of OSA. However, further research is needed to compare these new parameters between normal subjects and airway compromised patients in order to assess the effectiveness of parameters.

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