Developmental Changes in Pharyngeal Airway Depth and Hyoid Bone Position from Childhood to Young Adulthood

Chang-Min Sheng[a]; Li-Hsiang Lin[b]; Yu Su[c]; Hung-Huey Tsai[d]

ABSTRACT

Objective: (1) To test the hypothesis that there are no developmental changes in the pharyngeal airway depth and hyoid bone position from childhood to adulthood in normal Taiwanese persons, (2) to identify any sexual dimorphism, and (3) to find the predictive value of selective variables for the hyoid bone position.

Materials and Methods: Lateral cephalometric radiographs of 239 normal Taiwanese (132 females and 107 males; aged 7–27 years) were separated into three stages according to dental age. Twenty-three linear and 20 angular measurements were made in all subjects. Sexual dimorphism was analyzed by Student's *t*-test. Analysis of variance was used to compare the three stages in both genders. A stepwise regression analysis was carried out to predict the hyoid bone position. The level of significance for all analyses was set at $P < .05$.

Results: The pharyngeal airway depth increased from the mixed dentition stage to the permanent dentition stage in both genders. There was sexual dimorphism in the lower pharyngeal airway depth. The hyoid bone position showed an obvious difference in the permanent dentition stages between genders. The vertical position of the hyoid bone was associated with the mandibular morphology and position, but the relationship in males was reversed compared with that in females.

Conclusions: The hypothesis was rejected. There are developmental changes in the pharyngeal airway depth and hyoid position from childhood to young adulthood. Sexual dimorphism appeared in the lower pharyngeal airway and the direction of change in the vertical position of the hyoid bone. (*Angle Orthod.* 2009;79:484–490.)

KEY WORDS: Development; Change; Airway; Hyoid bone

INTRODUCTION

The pharynx is a tube-shaped structure that extends superoinferiorly from the cranial base to the level of the inferior surface of the sixth cervical vertebra.[1] It lies dorsal to the nasal and mouth cavity and is cranial to the esophagus, larynx, and trachea. The pharynx can be anatomically separated into three parts: the nasopharynx, oropharynx, and hypopharynx. In a midsagittal image, the nasopharynx extends from the nasal turbinates to the hard palate; the oropharynx can be subdivided into the retropalatal pharynx, from the hard palate to the caudal margin of the soft palate, and the retroglossal pharynx, which extends from the caudal margin of the soft palate to the base of the epiglottis; and the hypopharynx is from the base of the epiglottis to the larynx.[2] The pharynx plays an important role in respiration and deglutition.

The hyoid bone is connected to the pharynx, mandible, and cranium through muscles and ligaments.[3] It is the only bone of the body that has no bony articulations. The hyoid bone and its connecting muscles are also part of the oropharyngeal complex. Without the hyoid bone, our facility for maintaining an airway, swallowing, preventing regurgitation, and maintaining the upright postural position of the head could not be controlled as carefully.[4]

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A nasal breather may change to a mouth breather because of an obstruction in the nasal or pharyngeal airway.[5] Mouth breathing may be related to a specific malocclusion such as narrowing of the maxillary arch.[6] In addition, pharyngeal airway narrowing is a commonly described characteristic in obstructive sleep apnea/hypopnea syndrome (OSAHS) patients.[7] OSAHS affects mainly middle-aged males, and the prevalence increases with age.[8]

Many cephalometric studies have shown craniofacial abnormalities in OSAHS patients. Despite that observed alterations in craniofacial morphology are not uniform, a steeper mandibular plane angle, a shorter mandibular body length, and a low hyoid bone position were consistently reported by most investigations.[9] Gross changes in the hyoid bone position can be used to assess gross changes in the tongue position.[4] Kondo and Aoba[10] also stressed that lifting a low-postured tongue to improve airway patency was important for the treatment stability of a narrow maxillary arch.

Interpretation of the significance of variations in growth and function is dependent on an understanding of normal developmental changes. It is necessary to determine changes in the pharyngeal airway depth and hyoid bone position that occur in healthy subjects during their active growth years and beyond. We can benefit from such information in planning treatment and further investigations into breathing-disordered diseases. Most previous studies emphasized the treatment effect on pharyngeal airway size and hyoid bone position[11,12]; however, developmental changes of the pharyngeal airway and hyoid bone position have received little attention in the past. Bench[13] stated that the hyoid bone descends gradually from a position opposite the lower half of the third and the upper half of the fourth cervical vertebra at the age of 3 years to a position opposite the fourth cervical vertebra in adulthood. Tsai[14] reported that changes in pharyngeal structures were significantly greater in males than in females during development.

The purposes of this cross-sectional study were threefold: (1) to investigate changes in the pharyngeal airway depth and hyoid bone position during development from the early mixed dentition to young adulthood in normal Taiwanese persons, (2) to identify any sexual dimorphism in these developmental changes, and (3) to evaluate the predictive value of selective variables for the hyoid bone position.

MATERIALS AND METHODS

We reviewed the lateral cephalometric radiographs from the files of our orthodontic department between 1997 and 2006 and selected 239 Taiwanese subjects (132 females and 107 males), aged 7 to 27 years. All subjects included in this study had natural dentition and no craniofacial anomalies, syndromes, clefting, or symptoms or signs of dysfunction of the masticatory system. Standard lateral cephalometric radiographs with the teeth in habitual occlusion and with the head oriented horizontally with the Frankfort plane were taken with a cephalostat in accordance with standard cephalometric procedures. The materials were divided into three stages according to dental age: mixed dentition (stage 1), early permanent dentition (stage 2), and complete permanent dentition (stage 3) (Table 1).

Table 1. Number and Age Distribution of the Materials

	Male		Female	
	Number	Age	Number	Age
Mixed dentition (stage 1)	21	9.66 ± 1.39	24	10.06 ± 1.49
Early permanent dentition (stage 2)	29	13.58 ± 2.13	43	13.37 ± 2.03
Permanent dentition (stage 3)	57	22.48 ± 1.24	65	22.09 ± 1.54
Total	107	17.51 ± 5.67	132	17.14 ± 5.36

All radiographs were digitized and traced by the same person, and 32 landmarks were identified (Figure 1), which were used to perform 23 linear and 20 angular measurements. There were 5 linear items for the pharyngeal airway depth (Figure 2), 1 angular and 7 linear items for the hyoid bone position (Figure 3), and still another 30 items describing the craniofacial morphology (Table 2).

All landmarks were coordinated with the x- and y-axes. The line passing through point Or and Po was designated the x-axis. The line passing through point S and perpendicular to the x-axis was designated the y-axis. All measurements were performed using the computerized cephalometric analysis software Winceph (version 6.0, Rise Co, Japan).

Thirty randomly selected lateral cephalometric radiographs were traced and measured twice 2 weeks later to estimate the error that might occur with this method. The error for each parameter was calculated based on Dahlberg's formula ($error^2 = \Sigma d^2/2n$).[15] The greatest error occurring among linear measurements was the distance from ANS to PNS (0.9 mm) and among angular measurements was the angle formed by the epiglottis, hyoid bone, and tongue tip (2.5°). Differences between the means of the first and second tracings for each variable were tested by means of a paired *t*-test, and all were within an acceptable range.

Student's *t*-test was used to analyze sexual dimorphism in each stage. Analysis of variance was used to compare the mean values of each measurement among the three stages in both genders. Stepwise regression analyses were used to explore the relation-

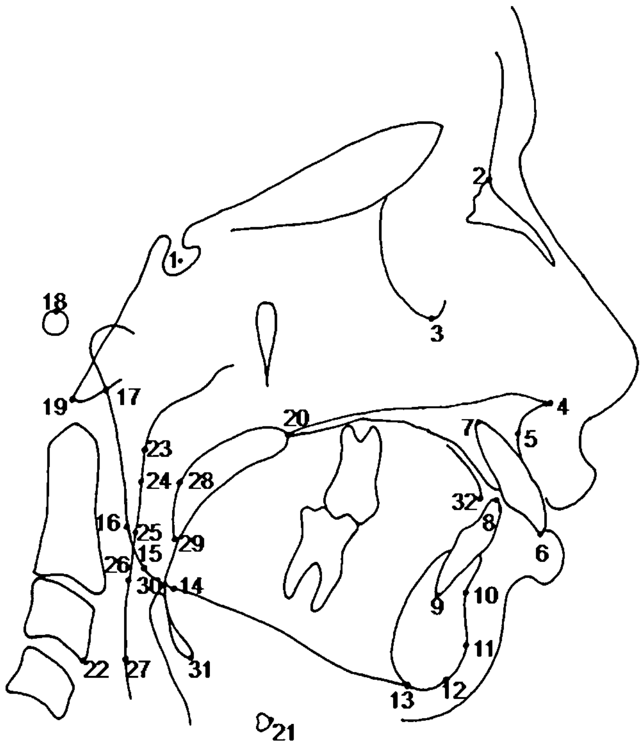

Figure 1. Landmarks. 1 indicates S; 2, N; 3, Or; 4, ANS; 5, A; 6, U1; 7, U1R; 8, L1; 9, L1R; 10, B; 11, Pog; 12, Gn; 13, Me; 14, GoL; 15, Go; 16, GoP; 17, Ar; 18, Po; 19, Ba; 20, PNS; 21, H (hyoid bone); 22, C3 (the most anteroinferior point of the third vertebra); 23, SPU (the point on the posterior pharyngeal wall along the palatal plane); 24, SPM (the point on the posterior pharyngeal wall where the distance to SAM is the shortest); 25, SPML (the point on the posterior pharyngeal wall where the distance to P is the shortest); 26, SPL (the point on the posterior pharyngeal wall where the distance to SAL is the shortest); 27, SPLL (the point on the posterior pharyngeal wall where the distance to E is the shortest); 28, SAM (the point on the soft palate where the postpalatal airway is narrowest); 29, P (the tip of the soft palate); 30, SAL (the point on the tongue along the mandibular lower border); 31, E (epiglottis); 32, TT (tongue tip).

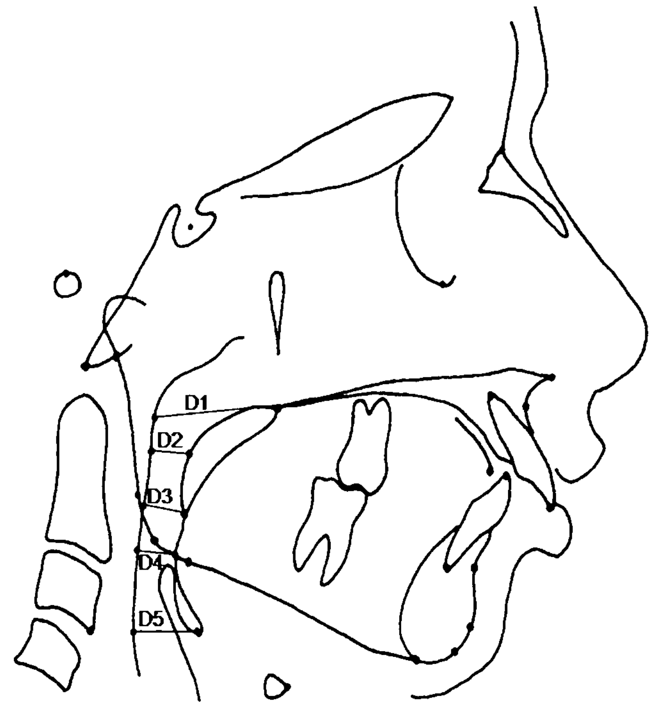

Figure 2. Measurements of pharyngeal airway depth. D1 indicates the distance between landmark 20 and 23; D2, the distance between landmark 24 and 28; D3, the distance between landmark 25 and 29; D4, the distance between landmark 26 and 30; D5, the distance between landmark 27 and 31.

ships between craniofacial morphology and hyoid bone position. All statistical analyses were performed by the Microsoft Excel statistical software package (Office 2007) and SigmaStat (version 2.0), with a 5% level of significance ($P < .05$).

RESULTS

Table 3 shows the mean values and standard deviations of measurements of the pharyngeal airway depth among each stage for both genders. Results indicated that except for the retroglossal-pharyngeal depth (D4) of females, all other measurements in both genders significantly increased from stages 1 to 3. Sexual dimorphism appeared in the lower part of the pharyngeal airway in stages 1 (D5) and 3 (D4 and D5).

Table 4 shows the mean values and standard deviations of the measurements for the hyoid bone position among each stage for both genders. Few measurements exhibited significant differences between males and females in stages 1 (H4, H7) and 2 (H2, H4), but the means of H2, H3, H4, H5, H6, and H7 were greater and that of H8 was smaller in males than females in stage 3. The distance between the hyoid bone and epiglottis (H4) remained constant from stages 1 to 3 in both genders. The distance from the hyoid bone to the mandibular plane did not significantly change from stages 1 to 3 in females; no significant differences were present in the angle formed by the epiglottis, hyoid bone, and tongue tip from stages 1 to 3 in males.

The stepwise regression analysis showed that the distance from the hyoid bone to the mandibular plane (H7) could be predicted by the facial angle in males (Figure 4) and Ar-Go in females (Figure 5). On the other hand, Ar-Go in males and the facial angle in females had predictive values for the distance between the hyoid bone to the C3-Me plane (H6) (Figures 6 and 7).

DISCUSSION

During inhalation, the conjoint activity of the intercostal muscles and the diaphragm creates negative airway pressure. Once this pressure surpasses the

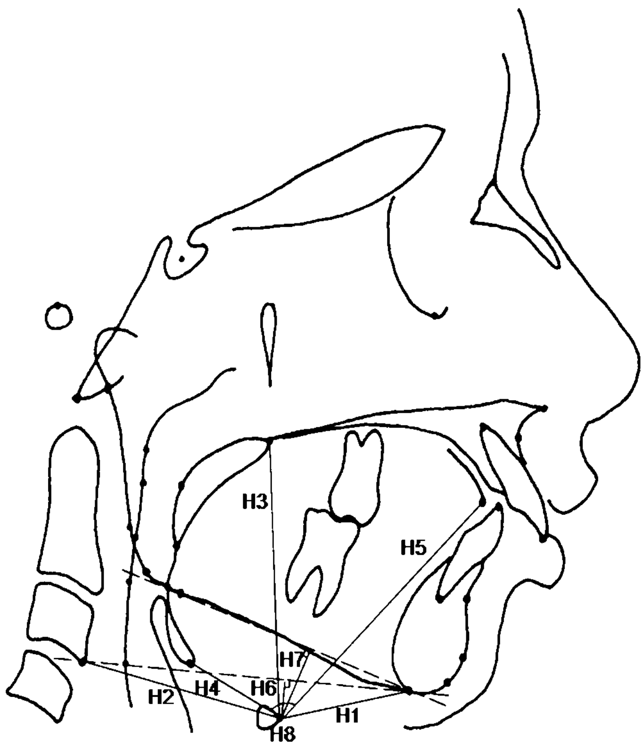

Figure 3. Measurements of hyoid bone position. H1 indicates H-Me; H2, H-C3; H3, H-PNS; H4, H-E; H5, H-TT; H6, the perpendicular distance from hyoid bone to the plane formed by C3 and Me; H7, the perpendicular distance from hyoid bone to the mandibular plane; H8, the angle formed by E, H, and TT.

force generated by the pharyngeal muscles, the pharynx will collapse and occlude the airway. The patency of the pharyngeal airway is mainly dependent on the activity of the oropharyngeal muscles.[16] Three pharyngeal segments tend to collapse—the retropalatal pharynx, the retroglossal pharynx, and retroepiglottic pharynx (posterior to the epiglottis)—because the anterior and lateral walls of these segments have no bony support.[17] That was the reason why we focused on developmental changes over the five sites we selected in the pharyngeal airway.

Martin et al[18] conducted a study on 60 men and 54 women (median age, 35 years; range, 16–74 years) and concluded that all upper airway dimensions, except the oropharyngeal junction, decreased with increasing age in both men and women. Our study revealed that the depth of the pharyngeal airway significantly increased from childhood to young adulthood in both genders, except that of the retroglossal-pharyngeal airway depth (D4) in females. The average chronologic age of our subjects was younger than that of Martin's subjects, and the difference between the two studies implies that the developmental pattern of the pharyngeal sagittal depth in young people might differ from that in middle-age persons.

There was no sexual difference in the depths of the

Table 2. Measurements of Craniofacial Morphology

Linear Measurements	Angular Measurements
S-N	Facial angle
N-ANS	Convexity
ANS-Me	A-B plane
N-Me	Y-axis
S-Go	FH-SN
Ar-Go	SNA
Go-Me	SNB
ANS-PNS	ANB
C3-Me	Nasal floor to SN
P-PNS	Mandibular plane to SN
Facial height ratio	Nasal floor to mandibular plane
	Ramus plane to SN
	Gonial angle
	U1 to SN
	L1 to mandibular plane
	Interincisal angle
	Saddle angle (N-S-Ar)
	Artical angle (S-Ar-Go(P))
	ANS-PNS-E

retropalatal-pharyngeal airway (D1-D3); however, this phenomenon existed in the retroepiglottic-pharyngeal airway (D5) during childhood. The dimensions of the retroglossal- and retroepiglottic-pharyngeal airway (D4 and D5) increased more with age in males than in females; therefore, a smaller depth in males during childhood produced no sexual difference in the early permanent dentition stage, and more obvious sexual dimorphism appeared in adulthood.

A previous study concluded that there was no sexual dimorphism in hyoid bone position in normal Taiwanese children from the deciduous dentition to the early permanent dentition, and the hyoid bone position was consistently above the line connecting C3 and Me.[4] Our data showed similar findings. We performed eight measurements on the hyoid bone position. Only two measurements showed a significant difference between genders in the mixed dentition and early permanent dentition stages, respectively, whereas seven measurements revealed significant differences in the permanent dentition stage, indicating that gender's effects on the hyoid bone position might begin during the period of adolescence because of the active growth of teenagers.

The epiglottis is suspended at its base by the hyoepiglottic ligament and the hyoid bone. During inspiration, the patency of the retroepiglottic pharynx relies on the activity of the hyoid muscles. The actions of these muscles (the geniohyoid, sternohyoid, and thyrohyoid muscles) bring the hyoid bone to a forward position and stabilize the retroepiglottic pharynx by tensing the hyoepiglottic ligament.[16,19] Our study showed that the distance between the hyoid bone and epiglottis did not significantly change in either gender from childhood to young adulthood; however, sexual

Table 3. The Results of Statistics Analysis of Measurements for Pharyngeal Airway Depth among each Stage (ANOVA) and between Males and Females (Student's t-test)

Measurement, mm	Sex *t*-Test	Stage 1		Stage 2		Stage 3		
		Mean	SD	Mean	SD	Mean	SD	ANOVA[a]
D1	Female	23.58	5.31	26.52	4.02	28.55	2.79	$P \leq .001$
	Male	23.34	3.64	27.46	3.25	28.54	3.77	$P \leq .001$
	t-test	NS		NS		NS		
D2	Female	10.18	2.76	12.41	2.83	14.03	2.56	$P \leq .001$
	Male	9.85	1.77	12.50	3.06	13.39	3.01	$P \leq .001$
	t-test	NS		NS		NS		
D3	Female	9.85	2.88	10.76	2.28	12.18	2.34	$P \leq .001$
	Male	9.15	1.88	13.24	6.28	12.78	3.25	$P \leq .001$
	t-test	NS		NS		NS		
D4	Female	11.66	2.81	12.29	3.00	12.93	3.12	NS
	Male	10.05	2.68	13.11	2.56	15.59	3.37	$P \leq .001$
	t-test	NS		NS		$P \leq .001$		
D5	Female	15.02	3.06	16.36	2.83	16.85	2.83	$P = .031$
	Male	13.11	2.28	16.80	3.23	20.25	2.81	$P \leq .001$
	t-test	$P = .022$		NS		$P \leq .001$		

[a] ANOVA indicates analysis of variance.

dimorphism in the hyoid bone position was evident during young adulthood, which might affect the activity of the muscles and ligaments attached to the hyoid bone, leading to gender differences in the retroepiglottic-pharyngeal airway depth in young adults.

A previous investigation suggested that the use of the relative position of the hyoid bone with both the vertebra and mandible may be a more accurate and easier way of evaluating the vertical hyoid bone position compared with using other reference points or planes.[20] From our data, we found that the direction of change in the hyoid bone relative to C3-Me differed

Table 4. The Results of Statistics Analysis of Measurements among each Stage (ANOVA) and between Males and Females (Student's t-test)

Measurement	Sex *t*-Test	Stage 1		Stage 2		Stage 3		
		Mean	SD	Mean	SD	Mean	SD	ANOVA[a]
H1, mm	Female	37.58	6.01	40.92	6.54	43.06	4.83	$P \leq .001$
	Male	34.24	6.07	40.17	6.12	44.60	6.49	$P \leq .001$
	t-test	NS		NS		NS		
H2, mm	Female	33.61	3.70	35.45	3.63	35.74	2.87	$P = .025$
	Male	33.43	3.05	38.52	4.25	41.08	3.69	$P \leq .001$
	t-test	NS		$P = .002$		$P \leq .001$		
H3, mm	Female	54.78	4.92	60.47	6.46	60.36	4.71	$P \leq .001$
	Male	57.56	4.88	60.61	6.72	71.66	5.40	$P \leq .001$
	t-test	NS		NS		$P \leq .001$		
H4, mm	Female	13.76	3.16	13.70	2.80	13.94	2.33	NS
	Male	15.67	2.80	16.64	3.58	15.61	3.08	NS
	t-test	$P = .037$		$P \leq .001$		$P \leq .001$		
H5, mm	Female	56.59	4.57	60.66	6.63	63.14	5.28	$P \leq .001$
	Male	56.49	5.13	59.49	4.74	68.24	6.01	$P \leq .001$
	t-test	NS		NS		$P \leq .001$		
H6, mm	Female	−1.88*	4.44	−2.34*	5.10	−4.09*	3.94	$P = .047$
	Male	−1.85*	5.05	−3.58*	4.04	1.69	5.50	$P \leq .001$
	t-test	NS		NS		$P \leq .001$		
H7, mm	Female	11.18	3.36	12.48	4.77	10.30	5.24	NS
	Male	8.96	3.66	10.66	5.92	14.46	6.12	$P \leq .001$
	t-test	$P = .041$		NS		$P \leq .001$		
H8, °	Female	138.76	15.53	144.37	13.05	148.36	11.18	$P = .007$
	Male	135.97	14.61	144.31	12.67	142.05	13.53	NS
	t-test	NS		NS		$P = .006$		

[a] ANOVA indicates analysis of variance.

* the hyoid bone is above the plane formed by C3 and Me.

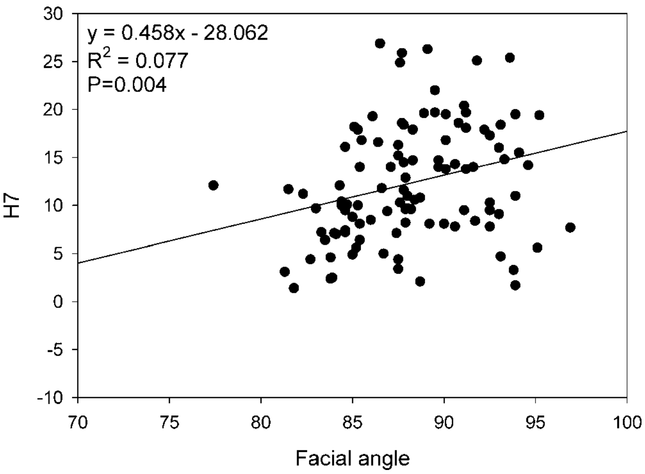

Figure 4. The dependent variable H7 can be predicted from the independent variable facial angle in males.

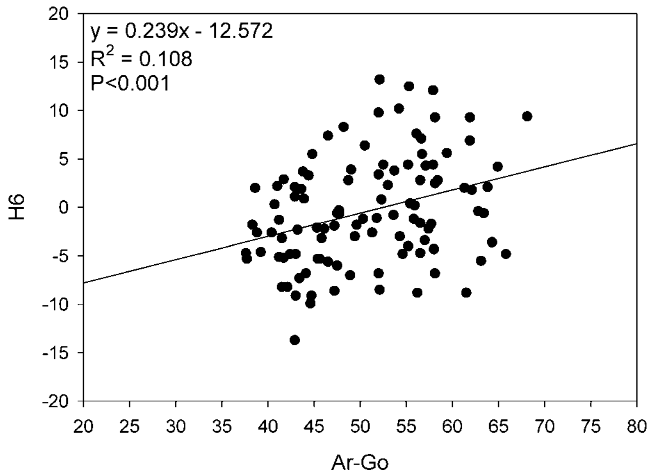

Figure 6. The dependent variable H6 can be predicted from the independent variable Ar-Go in males.

between genders. From the mixed dentition stage to the permanent dentition stage, the hyoid bone moved upward in females but upward and then downward in males. Through a stepwise regression analysis, we found that the vertical position of the hyoid bone had a strong relationship with the ramus length (Ar-Go) and the facial angle, but the tendency differed completely between genders. In females, a larger facial angle or longer ramus length indicated a more superiorly positioned hyoid bone; in males, the indication was reversed. We know that the geniohyoid and mylohyoid muscles are attached near or at the symphysis of the mandible, and the anterior belly of the digastric muscle also arises from a depression on the inner side of the lower border of the mandible. Adamidis and Spyropoulos[21] compared the hyoid bone position in class I to that in class III malocclusion and concluded that class III patients, especially boys, showed a different hyoid bone position, and they deduced that the suprahyoid muscles might affect mandibular growth. Spyropoulos et al[22] conducted animal studies and proved that the absence of the suprahyoid musculature affects both skeletal growth and the orientation of the mandible. Based on those results, we thought that the suprahyoid muscles play a vital role in relationships between the hyoid bone position and mandibular morphology or position, but there might be different ways of regulating them between males and females.

OSAHS is reported to affect 9% of males and 4% of females.[23] OSAHS patients suffer periodic cessation of airflow during sleep. It is a potentially life-threatening condition because epidemiologic studies have shown that sleep apnea is a risk factor for arterial hypertension.[24] Numerous cephalometric studies have tried to find discriminative characteristics of craniofacial morphology in OSAHS patients, and a steeper mandibular plane angle, a shorter mandibular body length, and a low hyoid bone position were consis-

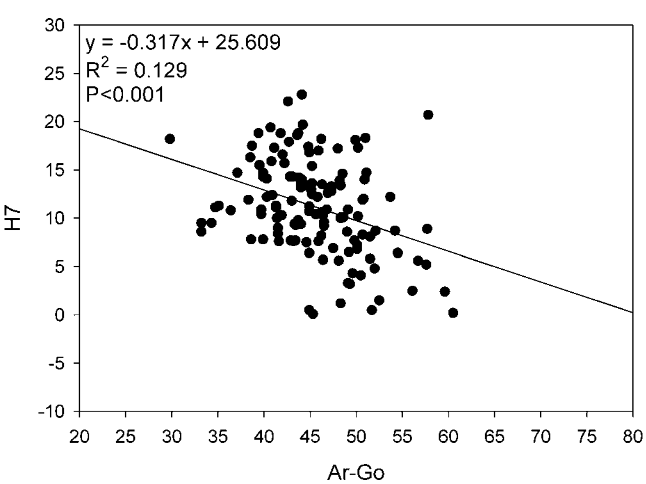

Figure 5. The dependent variable H7 can be predicted from the independent variable Ar-Go in females.

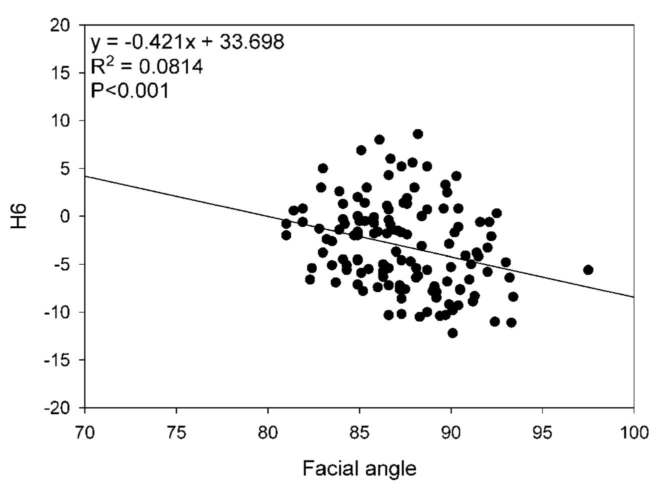

Figure 7. The dependent variable H6 can be predicted from the independent variable facial angle in females.

tently reported by most investigations.[9] Does this imply that a man with a short ramus length or smaller facial angle combined with an inferiorly positioned hyoid bone in his early 20s is predisposed to OSAHS in middle age? We consider it an interesting issue that deserves further investigation.

CONCLUSIONS

- Developmental changes occur in the pharyngeal airway depth and hyoid position from childhood to young adulthood.
- Sexual dimorphism appeared in the lower pharyngeal airway and the direction of change in the vertical position of the hyoid bone.
- The findings might shed some light on the reason why some breathing disorders are male predominant.

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