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Original Article

Evaluation of pharyngeal airway volume for different dentofacial skeletal patterns using cone-beam computed tomography

Yu-Chuan Tseng [a,b], Feng-Chun Tsai [a,b], Szu-Ting Chou [a,b], Chung-Yao Hsu [c,d], Jung-Hsuan Cheng [a,b], Chun-Ming Chen [a,e*]

[a] School of Dentistry, Kaohsiung Medical University, Kaohsiung, Taiwan
[b] Department of Orthodontics, Kaohsiung Medical University Hospital, Kaohsiung, Taiwan
[c] School of Medicine, Kaohsiung Medical University, Kaohsiung, Taiwan
[d] Department of Neurology, Kaohsiung Medical University Hospital, Kaohsiung, Taiwan
[e] Department of Oral and Maxillofacial Surgery, Kaohsiung Medical University Hospital, Kaohsiung, Taiwan

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KEYWORDS
Pharyngeal airway volume;
Skeletal pattern;
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Smallest cross-sectional area

Abstract *Background/purpose:* Understanding of the three-dimensional airway space in three skeletal patterns is important in orthodontic treatment. This study investigated differences between the volume of pharyngeal airway sections and the smallest cross-sectional area in three skeletal patterns by using cone-beam computed tomography (CBCT).
Materials and methods: The 90 patients were collected to measure total pharyngeal airway volume (TP), velopharyngeal airway volume (VP), glossopharyngeal airway volume (GP), oropharyngeal airway volume (OP), hypopharyngeal airway volume (HP), and the smallest cross-sectional areas (SCA) of the upper respiratory tract as well as other relevant anatomical structures. The mean values differences between classes were analyzed using ANOVA. Pearson's test was used to compare classes in terms of the correlations between different factors.
Results: Patients in skeletal classes I and III exhibited significantly higher SCA values (322.6 mm^2 and 344.5 mm^2 respectively) than those in skeletal class II (240.8 mm^2). Subjects from skeletal classes I and III exhibited significantly higher values of VP, HP, and OP than those in skeletal class II. Skeletal classes I and III exhibited significantly higher TP values (31190.1 mm^3 and 30696.2 mm^3, respectively) than those in skeletal class II (22386.0 mm^3). Non-significant relationships were discovered between pharyngeal airway and skeletal pattern. Conversely, significant relationships were found between TP and gender, ANB, SNB, hyoid and pogonion positions.

* Corresponding author. Department of Oral and Maxillofacial Surgery, Kaohsiung Medical University Hospital, No. 100, Shih-Chuan 1st Road, Kaohsiung, 80708, Taiwan.
E-mail address: komschen@gmail.com (C.-M. Chen).

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Conclusion: The skeletal class II has smaller airway volume than those in skeletal class I and III. The pharyngeal airway volumes could serve as a guide in differentiating the different skeletal classes in clinical settings.

Introduction

With advances in medical care, the pharyngeal airway space of orthodontic patients is beginning to attract attention. The pharyngeal airway can be divided into three sections, namely the nasopharyngeal, oropharyngeal, and laryngopharyngeal airways. The nasopharyngeal and the oropharyngeal airways are demarcated by the retropalatal region of maxilla, whereas the oropharyngeal and the laryngopharyngeal airways are demarcated by the tip of the epiglottis.[1] Among these three sections of the pharyngeal airway, the oropharyngeal airway is the airway section that is most likely to be affected by the size and position (i.e., forward or backward) of the tongue. The base of the tongue is linked with the hyoid bone, and muscles link the airway between the soft palate and the tongue.[2]

If the structure of a patient's pharyngeal airway is not completely understood before the administration of orthodontic treatment, the airway space changes that occur during orthodontic treatment process may easily be overlooked. Thus, the retraction of dentition due to orthodontic treatment may result in the compression of the tongue space and thereby jeopardizing the pharyngeal airway space.[3,4] The maxilla—mandible bone patterns can be used to categorize patients into three skeletal patterns. Therefore, prediction of the three-dimensional airway space of patients in these three skeletal patterns is important before the orthodontic treatment. This study investigated differences between the skeletal patterns in terms of the volume of each airway section and smallest cross-sectional area (SCA) by using cone-beam computed tomography (CBCT).The related factors such as the maxilla—mandible relationship, sex, age, other anatomical structures (including the front and back position of the hyoid bone), angle and distance all of which can potentially affect the airway size, and the smallest SCA were also analyzed.

Materials and methods

A total of 90 patients with their CBCT images (New Tom VGi evo, Imola, Italy) were recruited and investigated at the Department of Dentistry, Kaohsiung Medical University Hospital. Patients with the following characteristics were excluded from the sample: (1) craniofacial symptoms; (2) tumors in the pharyngeal airway space; (3) orthognathic surgery; and (4) facial bone injury in the craniofacial area. Based on their skeletal relationships, the participants were divided into three groups, with each group comprising 30 patients. For analysis, the x-y coordinate axis was constructed. This coordinate system had its origin set at the point N with its horizontal axis (x-axis) formed at an angle of 7° downward relative to the reference line (NS line) (Fig. 1).[5] Patients with $0° \leq$ ANB $\leq 4°$ were assigned to skeletal class I whereas patients with ANB$>4°$ were assigned to skeletal class II and those with ANB$<0°$ were assigned to skeletal class III.

The patient's characteristics including age, ANB, SNA, SNB, body length (BL), body weight (BW) and body mass index (BMI) were collected. Before CBCT images were taken, the patients were instructed to place their maxilla and mandible in the centric occlusion position and maintained natural head position while being illuminated; CBCT images were captured in this upright position by using Soteria DcmRecons (version Alpha v0.7.0; Soteria Biotech Ltd., New Taipei City, Taiwan). Images were reconstructed after defining the head position according to the standard horizontal plane established by the bilateral parallel porion and the right orbitale.

The pharyngeal airway can be divided into three sections (Fig. 2), namely the velopharyngeal, glossopharyngeal, and hypopharyngeal airways. The velopharyngeal and glossopharyngeal airways are together known as the oropharyngeal airway. The upper bound of the velopharyngeal airway is the airway cross-section that is parallel to the standard horizontal plane which passes through posterior nasal spine (PNS).The border between the velopharyngeal and oropharyngeal airways is parallel to the standard horizontal plane and it passes through the lower tip at the end of the soft palate. The border between the oropharyngeal and hypopharyngeal airways is the airway cross-section that is parallel to the standard horizontal plane and passes through the upper tip at the end of the epiglottis. The lower bound of the hypopharyngeal airway is the airway cross-section that is parallel to the standard horizontal plane and passes through the most anterior point of the fourth cervical vertebra (C4).

The respective volumes of these three sections of the pharyngeal airway were calculated, and the SCA of the pharyngeal airway was calculated under the axial view (Fig. 3). All measurements of present study were recorded as follows:

(1) Total pharyngeal airway volume (TP): The upper bound of the pharyngeal airway passes through PNS and is parallel to the standard horizontal plane; the lower bound passes through C4 and is parallel to the standard horizontal plane.
(2) Velopharyngeal airway volume (VP): The upper bound of the velopharyngeal airway passes through PNS and is parallel to the standard horizontal plane; the lower bound passes through tip at the end of the soft palate and is parallel to the standard horizontal plane.

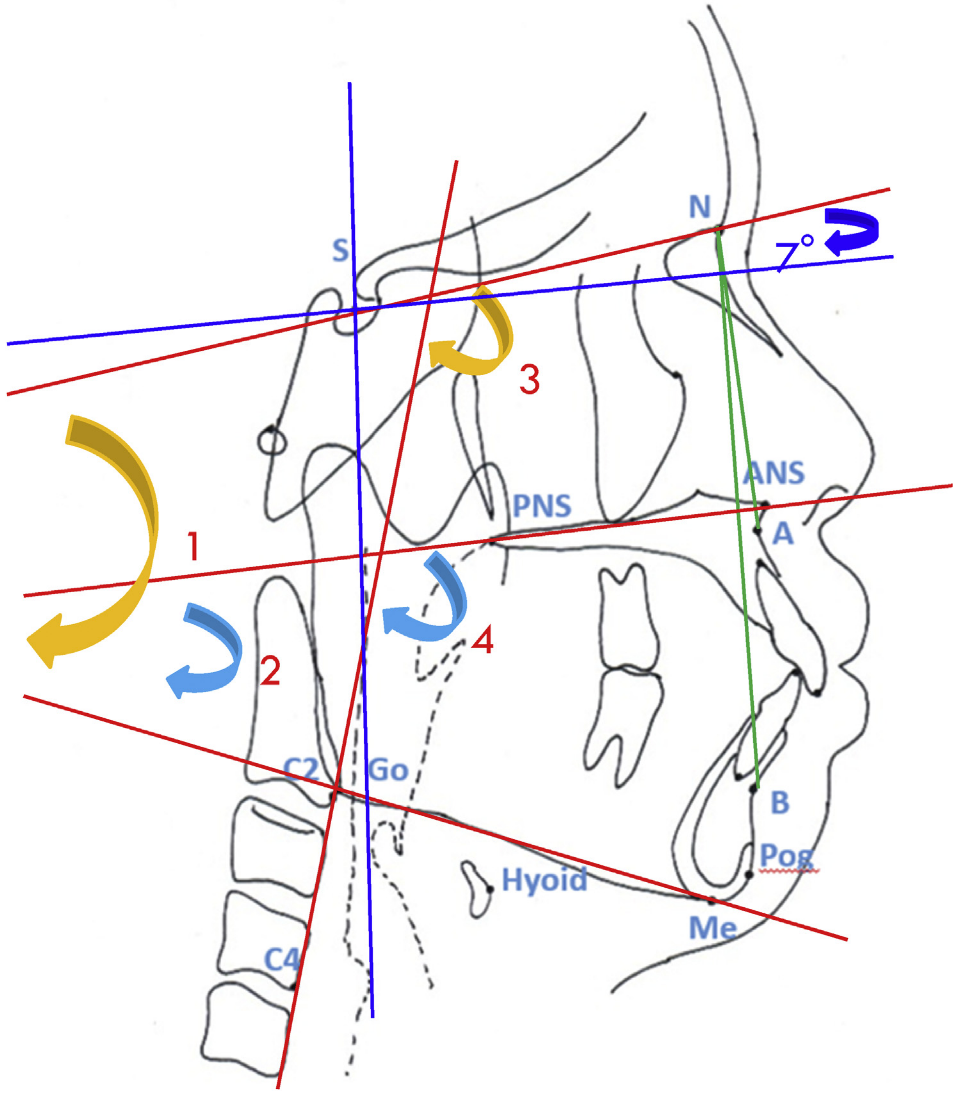

Figure 1 X-axis (blue line): Constructed by drawing a line through nasion 7° down from SN line. Y-axis (blue line): a line through sella (S) perpendicular to the X-axis. The measured angles: (1) SNMP angle (2) PPMP angle (3) C2C4SN angle (4) C2C4PP angle.

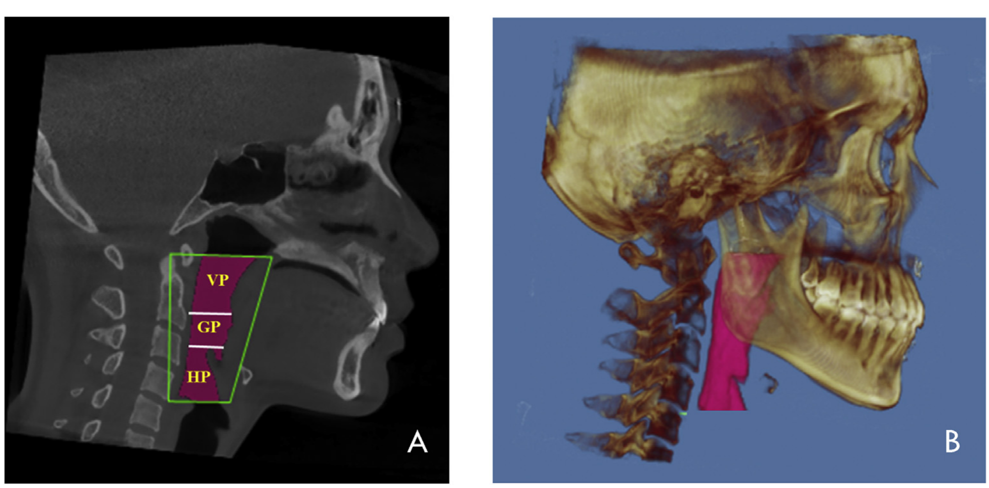

Figure 2 (A) VP: velopharyngeal airway volume; GP: glossopharyngeal airway volume; HP: hypopharyngeal airway volume (B) Pink color: 3-dimensional pharyngeal volume.

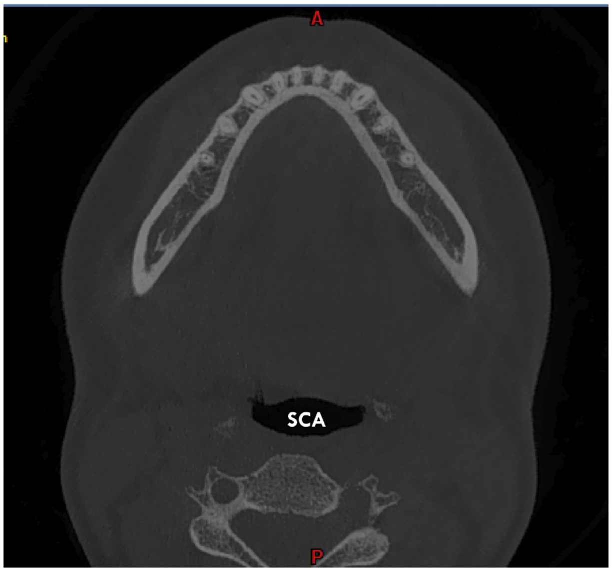

Figure 3 SCA: smallest cross-sectional area.

(3) Glossopharyngeal airway volume (GP): The upper bound of the glossopharyngeal airway passes through tip at the end of the soft palate and is parallel to the standard horizontal plane; the lower bound passes through upper tip at the end of the epiglottis and is parallel to the standard horizontal plane.
(4) Oropharyngeal airway volume (OP): VP + GP
(5) Hypopharyngeal airway volume (HP): The upper bound of the hypopharyngeal airway passes through upper tip at the end of the epiglottis and is parallel to the standard horizontal plane; the lower bound passes through C4 and is parallel to the standard horizontal plane.
(6) SCA is the smallest cross-sectional area of the upper respiratory tract (Fig. 3).
(7) SNMP angle: angle formed by Sella–Nasion plane to mandibular plane (Pog–Go plane)
(8) PPMP angle: angle formed by ANS-PNS plane to mandibular plane
(9) C2C4PP angle: angle formed by ANS-PNS plane to C2–C4 plane
(10) C2C4SN angle: angle formed by Sella–Nasion plane to C2–C4 plane
(11) Horizontal and vertical positions of hyoid (H)
(12) Horizontal and vertical positions of pogonion (Pog)

The statistical analyses in this study were conducted using the Statistical Package for Social Sciences (SPSS version 20; IBM, Armonk, NY). The analysis results were considered significant if the p value was <0.05.

The mean value differences of each group were compared using ANOVA; Tukey's HSD post hoc test was performed if the main group effect was significant. Pearson's correlation test was used to examine the correlation between various factors obtained in three different skeletal groups. The absolute values of correlation coefficient (r), 0–0.19 is regarded as very weak, 0.2–0.39 as weak, 0.40–0.59 as moderate, 0.6–0.79 as strong and 0.8–1 as very strong correlation. This was a retrospective study, and it was reviewed and approved by the Institutional Review Board of Kaohsiung Medical University Hospital (KMUHIRB-E (II)-20160066).

Results

The mean age of the Class I patients was 25.7 years. The numbers of female and male patients were 22 and 8 respectively. The Class II patients had a mean age of 24.8 years and the numbers of female and male involved were 20 and 10 respectively. The mean age of Class III patients was 24.4 years with the number of female and male patients being 25 and 15 respectively. As Table 1 has shown, the skeletal patterns exhibited no significant differences in SNA, age, BMI, BH, or BW. Table 2 shows that, in terms of facial divergence, patients in skeletal classes I and II exhibited significantly higher SNMP angle values than those in skeletal class III. Patients in skeletal class II exhibited significantly higher C2C4PP angle values than those in skeletal classes I and III. Patients in skeletal class II exhibited significantly higher C2C4SN angle values than those in skeletal class III.

As shown in Table 2, the skeletal patterns did not exhibit significant differences in terms of hyoid position. In terms of the horizontal pogonion position, patients in skeletal class III exhibited a significantly more forward position compared with those in skeletal class II. However, the skeletal patterns did not exhibit significant differences in terms of vertical pogonion position. Table 3 presents a comparison of the upper respiratory tract SCA differences between the three skeletal patterns. The SCAs of patients in skeletal class I ($322.6\,mm^2$) and skeletal class III ($344.5\,mm^2$) were significantly larger than those of patients in skeletal class II ($240.8\,mm^2$). The skeletal classes I and III exhibited significantly higher VP, HP, and OP values than those in skeletal class II. For GP, patients in skeletal class I exhibited a GP value ($7817.6\,mm^3$) significantly higher than that of patients in skeletal class II ($4894.1\,mm^3$).Patients in skeletal class I and skeletal class III exhibited significantly higher TP values (31190.1 and $30696.2\,mm^3$, respectively) than that of patients in skeletal class II ($22386.0\,mm^3$).

The Pearson's test results presented in Table 4 and Table 5 indicate that SCA was not significantly correlated with age, BMI, skeletal pattern, C2C4PP, C2C4SN, SNMP, or PPMP. However, SCA was significantly correlated to ANB, SNB, hyoid position (vertical and horizontal), and horizontal pogonion position.TV was significantly related to gender, ANB, SNB, vertical hyoid position (vertical and horizontal) and pogonion position (vertical and horizontal). OP was significantly related to gender, ANB, SNB, hyoid position (vertical and horizontal) and horizontal pogonion position.

Discussion

The upper respiratory tract plays a key role in breathing, swallowing, and pronunciation.[6,7] The findings of our study showed that there was no significant age difference between the three skeletal pattern group. Patients recruited in all three skeletal pattern group were similar in terms of age and as a result, the development of their craniofacial

Table 1 Patient's characteristics in the skeletal patterns using One-way ANOVA with Tukey's HSD post hoc test.

Variables	Class I		Class II		Class III		Intergroup comparison*
	Mean	SD	Mean	SD	Mean	SD	
Age	25.7	6.52	24.8	3.69	24.4	4.12	—
ANB	1.7	1.19	6.7	1.60	−4.3	2.62	Class II > Class I > Class III
SNA	82.7	3.80	81.9	3.45	81.7	3.33	—
SNB	81.0	3.96	75.3	3.61	86.0	3.59	Class III > Class I > Class II
BMI	21.0	3.08	21.8	2.93	22.4	3.28	—
BL	165.2	7.28	166.4	8.64	168.0	7.46	—
BW	57.4	10.08	60.7	11.03	63.5	11.72	—

ANB: A point—Nasion—B point angle; SNA: Sella-Nasion to A Point angle; SNB: Sella-Nasion to B Point angle; BMI: body mass index; BL: body length; BW: body weight.
*Intergroup comparison: Statistically significant, $p < 0.05$.
—Not significant.

Table 2 The measured angles and landmarks in the skeletal patterns using One-way ANOVA with Tukey's HSD post hoc test.

Variables	Class I		Class II		Class III		Intergroup comparison*
	Mean	SD	Mean	SD	Mean	SD	
Angle (degree)							
SNMP	36.2	6.09	38.3	7.98	31.8	5.06	Class I > Class III, Class II > Class III
PPMP	25.5	5.81	27.6	7.82	22.7	4.74	Class II > Class III
C2C4PP	101.1	6.53	105.8	5.86	101.3	5.83	Class II > Class I, Class II > Class III
C2C4SN	111.8	8.16	116.5	7.78	110.3	8.37	Class II > Class III
Landmark (mm)							
Hyoid							
Horizontal	44.6	9.90	39.2	12.28	40.5	12.49	—
Vertical	94.2	12.20	93.2	11.47	93.6	11.79	—
Pognion							
Horizontal	89.4	11.51	81.9	12.97	92.7	14.00	Class III > Class II
Vertical	84.5	13.25	82.8	14.19	86.5	13.20	—

SNMP angle: angle formed by Sella—Nasion plane to Pognion—Gonion plane; PPMP angle: angle formed by ANS-PNS plane to Pognion—Gonion plane; C2C4PP angle: angle formed by ANS-PNS plane to C2(second cervical vertebra)-C4(fourth cervical vertebra) plane; C2C4SN angle: angle formed by Sella—Nasion plane to C2—C4 plane.
*Intergroup comparison: Statistically significant, $p < 0.05$.
—Not significant.

Table 3 Pharyngeal airway spaces in the skeletal patterns using One-way ANOVA with Tukey's HSD post hoc test.

Variables	Class I		Class II		Class III		Intergroup comparison*
	Mean	SD	Mean	SD	Mean	SD	
CSA (mm^2)	322.6	100.04	240.8	84.70	344.5	125.88	Class I > Class II, Class III > Class II
VP (mm^3)	14994.7	5557.95	11160.8	4401.20	15467.1	5422.58	Class I > Class II, Class III > Class II
GP (mm^3)	7817.6	3855.36	4894.1	3024.09	6499.3	3326.27	Class I > Class II
HP (mm^3)	8377.7	3001.73	6331.0	3237.93	8846.3	3409.61	Class I > Class II, Class III > Class II
OP (mm^3)	22812.3	8793.61	16055.0	6670.92	21966.4	7167.82	Class I > Class II, Class III > Class II
TP (mm^3)	31190.1	10197.48	22386.0	8956.80	30696.2	9621.18	Class I > Class II, Class III > Class II

SCA: the smallest cross-sectional area of pharyngeal airway; VP: velopharyngeal airway volume; GP: glossopharyngeal airway volume; HP: hypopharyngeal airway volume; OP: oropharyngeal airway volume; TP: total pharyngeal airway volume.
*Intergroup comparison: Statistically significant, $p < 0.05$.
—Not significant.

bones and airway related soft tissues were stable. However, ANB and SNB differed significantly between the skeletal patterns. Nevertheless, the three skeletal patterns exhibited similar maxilla skeletal relationships and structures. The differences between skeletal patterns were mainly due to the patients' anterior—posterior mandibular relationships. BMI which measures one's weight relative to his/her height can be used to approximate body size. Sleep apnea

Table 4 Pearson test of pharyngeal airway in the patient's characteristics.

	Gender	Age	ANB	SNA	SNB	Skeletal	BMI
CSA	0.299*	−0.102	−0.406*	0.050	0.375*	0.080	−0.114
VP	0.400*	−0.097	−0.330*	0.117	0.349*	0.036	−0.029
GP	0.346*	−0.051	−0.155	0.091	0.182	−0.151	−0.049
HP	0.393*	−0.013	−0.331*	0.216*	0.420*	0.057	−0.098
OP	0.422*	−0.088	−0.291*	0.119	0.316*	−0.043	−0.041
TP	0.458*	−0.074	−0.331*	0.167	0.382*	−0.020	−0.067

SCA: the smallest cross-sectional area of pharyngeal airway; VP: velopharyngeal airway volume; GP: glossopharyngeal airway volume; HP: hypopharyngeal airway volume; OP: oropharyngeal airway volume; TP: total pharyngeal airway volume; BMI: body mass inde.
*Statistically significant, $p < 0.05$.

Table 5 Pearson test of pharyngeal airway in the measured angles and landmarks.

	SNMP	PPMP	C2C4PP	C2C4SN	HyoidX	HyoidY	PogX	PogY
CSA	−0.098	−0.127	−0.160	−0.104	0.291*	0.231*	0.520*	0.121
VP	−0.045	−0.086	−0.080	−0.032	0.289*	0.364*	0.540*	0.211*
GP	−0.077	−0.215*	0.060	0.147	0.286*	0.328*	0.404*	0.120
HP	−0.163	−0.070	−0.108	−0.162	0.196	0.331*	0.476*	0.276*
OP	−0.064	−0.153	−0.027	0.044	0.322*	0.391*	0.543*	0.195
TP	−0.102	−0.140	−0.055	−0.018	0.321*	0.414*	0.582*	0.242*

SCA: the smallest cross-sectional area of pharyngeal airway; VP: velopharyngeal airway volume; GP: glossopharyngeal airway volume; HP: hypopharyngeal airway volume; OP: oropharyngeal airway volume; TP: total pharyngeal airway volume; HyoidX: horizontal position of hyoid; HyoidY: vertical position of hyoid; PogX: horizontal position of pogonion; PogY: vertical position of pogonion.
*Statistically significant, $p < 0.05$.

in patients is often accompanied by high BMI and large neck circumference.[8,9] The results of current study indicated no significant correlation between skeletal class and BMI. Therefore, the BMI values of the sample were evenly distributed. In other words, the results of the study were not affected by the patient's body size and they closely reflected the actual airway condition.

Studies[10,11] have reported that the hyoid bone and the muscle tissues attached to the hyoid bone play an important role in maintaining a normal airway space and that different mandible positions often result in different hyoid bone positions.Yamaoka[6] revealed that the tongue base position of patients in skeletal class II is typically more setback than that of those in skeletal class III. Battagel et al.[12] noted that patients with obstructive sleep apnea typically have a certain type of maxilla—mandible skeletal pattern that classify them as skeletal class II. In addition to having a more setback hyoid bone position, these patients often have especially high ANB. The results of our study did not reveal significant differences between the three skeletal patterns in terms of the vertical or horizontal hyoid position; however, patients in skeletal classes I and III exhibited a more forward hyoid bone position compared with those in skeletal class II.

The size of the oropharyngeal airway is affected by the size and position of the tongue. The base of the tongue is linked with the hyoid bone, and muscle groups link the airway between the soft palate and the tongue. The size of the airway is mainly presented in a three-dimensional space. Thus, the size of airway should be assessed based on the volume and smallest SCA. Abu Allhaija[13] indicated that for patients in skeletal class III, the forward position of hyoid bone increases their airway space. According to Opdebeeck,[14] patients with a longer face shape have a smaller airway space than those with a shorter face shape. El and Palomo[15] revealed that the position of mandible relative to the skull base also affects the oropharyngeal space. Studies examining the relationship between airway space and face shape have indicated that the patients in skeletal class II have a significantly smaller airway space than those in skeletal classes I and III; however, no significant differences in airway volume have been found between patients in skeletal classes I and III. These results are similar to those of the present study. Patients in skeletal class III exhibited more protruding mandible and more forward tongue position, thus widening the distance between the dorsum of the tongue and the posterior pharyngeal wall. This condition implies a larger airway volume for patients in skeletal class III than for those in skeletal classes I and II.

The results of correlation analysis conducted using Pearson's test indicated that sex is significantly correlated with airway space, regardless of whether the measurements are using SCA or other volume measurements. Male patients have significantly larger airway space than female patients. ANB, SNB, and all airway space measurement values with the exception of GP were significantly correlated. The tongue holding position of different skeletal patterns may offer space for movement. This physically feasible situation may have caused th lack of significant difference. However, the three skeletal patterns were not significantly correlated with airway space factors. Continuous variables such as ANB and SNB exhibited significant correlations with airway space.

Observation of facial angle and cervicocranio indicated no significant correlations between the measurement values with the exception of GP. No significant correlations were observed between SNMP (representing facial divergence), cervicocranio angle (C2C4PP and C2C4SN), or other airway space measurements. Observation of the landmarks indicated moderate correlation between Pog (horizontal) and airway space measured using SCA and all volumes of pharyngeal airways. There is a mild correlation between H (horizontal) and airway space measured using SCA and all volumes of pharyngeal airways. However, the correlation magnitude of H (vertical) and airway space was higher than that of Pog (vertical) and airway space. In other words, the correlations of Pog (horizontal) and hyoid (vertical)with the airway space were stronger than those of Pog (vertical) and hyoid (horizontal)with the airway space.

In conclusion, age and BMI had no significant relationship with skeletal patterns in the present study. Sex was shown to influence the size of airway volume. The volumes of each section of the airway were measured along with the SCA. The results indicated that patients in skeletal class II have smaller airway volume than those in skeletal classes I and III; the airway volume of the patients in skeletal class II was only two-thirds of the airway volume of those in skeletal class III. The airway volumes obtained in this study could serve as a reference for the assignment of patients to skeletal patterns in clinical settings. This can be listed as an indicator for respiratory problems when formulating treatment plans.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

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References

1. Hiatt JL, Gartner LP. *Textbook of head and heck anatomy*. New York, NY: Appleton-Century-Crofts, 1982:48–56.
2. Nanci Antonio. *Ten cate's oral histology: development, structure, and function*, 8th ed. Mosby company, 2012.
3. Chen Y, Hong L, Wang CL, et al. Effect of large incisor retraction on upper airway morphology in adult bimaxillary protrusion patients. *Angle Orthod* 2012;82:964–70.
4. Keum BT, Choi SH, Choi YJ, Baik HS, Lee KJ. Effects of bodily retraction of mandibular incisors versus mandibular setback surgery on pharyngeal airway space: a comparative study. *Korean J Orthod* 2017;47:344–52.
5. Burstone CJ, James RB, Legan H, Murphy GA, Norton LA. Cephalometrics for orthognathic surgery. *J Oral Surg* 1978;36: 269–77.
6. Schwab RJ, Goldberg AN. Upper airway assessment: radiographic and other imaging techniques. *Otolaryngol Clin* 1998; 31:931–68.
7. Jakobsone G, Stenvik A, Espeland L. The effect of maxillary advancement and impaction on the upper airway after bimaxillary surgery to correct Class III malocclusion. *Am J Orthod Dentofacial Orthop* 2011;139:e369–76.
8. Davies RJO, Stradling JR. The relationship between neck circumference, radiographic pharyngeal anatomy, and the obstructive sleep apnea syndrome. *Eur Respir J* 1990;3: 509–14.
9. Huntley C, Steffen A, Doghramji K, Hofauer B, Heiser C, Boon M. Upper airway stimulation in patients with obstructive sleep apnea and an elevated body mass index: a multi-institutional review. *Laryngoscope* 2018;128:2425–8.
10. Kawamata A, Fujishita M, Ariji Y, Ariji E. Three dimensional computed tomographic evaluation of morphologic airway changes after mandibular setback osteotomy for prognathism. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2009;89: 278–87.
11. Yamaoka M, Furusawa K, Uematsu T, Okafuji N, Kayamoto D, Kurihara S. Relationship of the hyoid bone and posterior surface of the tongue in prognathism and micrognathia. *J Oral Rehabil* 2003;30:914–20.
12. Battagel JM, Johal A, L'Estrange PR, Croft CB, Kotecha B. Changes in airway and hyoid position in response to mandibular protrusion in subjects with obstructive sleep apnea (OSA). *Eur J Orthod* 1999;21:363–76.
13. Abu Allhaija ES, Al-Khateeb SN. Uvulo-glosso-pharyngeal dimensions in different anteroposterior skeletal patterns. *Angle Orthod* 2005;75:1012–8.
14. Opdebeeck H, Bell WH, Eisenfeld J, Mishelevich D. Comparative study between the SFS and LFS rotation as a possible morphogenic mechanism. *Am J Orthod* 1978;74:509–21.
15. El H, Palomo JM. Airway volume for different dentofacial skeletal patterns. *Am J Orthod Dentofacial Orthop* 2011;139: e511–21.