Original Article

Access this article online

Quick Response Code:

Website:
www.jorthodsci.org

DOI:
10.4103/jos.jos_161_21

Pharyngeal airway dimensions in Iranian female young adults with different skeletal patterns using cone-beam computed tomography

Amin Golshah, Tanaz Hosseini Jalilian[1] and Nafiseh Nikkerdar[2]

Abstract

OBJECTIVES: To assess the oropharyngeal airway in Iranian female young adults with different skeletal patterns using cone-beam computed tomography (CBCT).

MATERIALS AND METHODS: This descriptive, cross-sectional study evaluated 105 CBCT scans of female patients between 18 and 35 years retrieved from the archives of a radiology clinic. The images were evaluated in axial, sagittal, and frontal sections. In the axial plane, the maximum and minimum cross-sectional area (CSA) of the airways at the oropharynx, minimum width (anteroposteriorly), and minimum depth (laterally) were measured using Mimics Medical software. The oropharyngeal volume was measured by NemoFAB software. The values were compared among the groups with different sagittal, vertical, and transverse patterns. The correlation of indices with airway measurements was analyzed using Monte Carlo Chi-square and Pearson's correlation coefficient.

RESULTS: No significant difference was noted in oropharyngeal airway dimensions and volume among cases with different skeletal sagittal, vertical, and transverse patterns ($P > 0.05$) except for class III patients with normal transverse pattern in whom maximum CSA in low-angle group was larger than that in normal-angle group ($P < 0.05$) and class I normal-angle patients in whom maximum CSA in transverse normal group was smaller than that in constriction group ($P < 0.05$).

CONCLUSIONS: Oropharyngeal dimensions were not significantly different in Iranian female young adults with different skeletal patterns.

Keywords:

Conebeam computed tomography, facial skeletal pattern, oropharyngeal airway, sagittal, vertical

Departments of Orthodontic, School of Dentistry, Kermanshah University of Medical Sciences, Kermanshah, Iran [1]Student Research Committee, School of Dentistry, Kermanshah University of Medical Sciences, Kermanshah, Iran and [2]Oral and Maxillofacial Radiology, School of Dentistry, Kermanshah University of Medical Sciences, Kermanshah, Iran

Address for correspondence:
Dr. Tanaz Hosseini Jalilian, School of Dentistry, Kermanshah University of Medical Sciences, Kermanshah, Iran. E-mail: t_jalilian1992@yahoo.com

Submitted: 13-Jul-2021
Revised: 03-Jun-2022
Accepted: 08-Aug-2022
Published: 18-Mar-2023

Introduction

Patients' respiratory function is an important factor to consider in orthodontic diagnosis and treatment planning. Upper airway dimensions play a fundamental role in respiratory function.[1] The pharyngeal airway space is involved in both respiration and deglutition. The position of the head, tongue, and jaws may be influenced by the airway dimensions.[2] Abnormal growth and development of the upper airways may cause airway constriction. Decreased respiratory function by craniofacial abnormalities has been a topic of interest for many orthodontists.[3-6] There seems to be a relationship between the size of the upper airways (especially pharyngeal dimensions) and position of the craniofacial structures, and the airway space is believed to affect the anteroposterior jaw relationship and vertical growth pattern.[6-13] For instance, downward and backward rotation of the mandible occurs in patients with nasal airway obstruction.[11] Mandibular retrognathism and vertical excess are among

How to cite this article: Golshah A, Jalilian TH, Nikkerdar N. Pharyngeal airway dimensions in Iranian female young adults with different skeletal patterns using cone-beam computed tomography. J Orthodont Sci 2023;12:4.

the conditions correlated with airway problems. For example, patients with obstructive sleep apnea (OSA) have a smaller pharyngeal airway because of abnormal skeletal and soft tissue patterns.[14] Many authors believe that morphological characteristics of the airways are variable in individuals with different skeletal patterns. Decreased airway dimensions have been reported in class II malocclusion patients because of backward and downward rotation of the mandible.[15-17] Also, it has been shown that airway cross-section and width in class III malocclusion patients are larger than the corresponding values in class I malocclusion cases.[3-5] Furthermore, it has been demonstrated that airway volume in high-angle patients is smaller than that in low- and normal-angle cases.[9-17] However, some studies did not find any significant correlation between dimensions and morphology of the upper airways with skeletal vertical and sagittal patterns.[1,4,6,10,11,13,15,18-20] Cephalometry, magnetic resonance imaging, computed tomography (CT), acoustic pharyngometry, nasopharyngoscopy, polysomnography, and recently cone-beam computed tomography (CBCT) have been used for evaluation of the upper airways structurally and physiologically.[21] Cephalometry is a commonly used modality to study the upper airways. However, this imaging modality has inherent shortcomings such as image distortion, poor reproducibility, magnification error, superimposition of bilateral craniofacial structures, and more importantly, two-dimensional nature of cephalograms.[9-16] Furthermore, many of the defects and changes in the airways occur in mediolateral dimension. Thus, the application of cephalometry for airway assessment is limited.

CBCT enables accurate two-dimensional (2D) and three-dimensional (3D) assessment of the hard and soft tissues with a wide range of contrast. Because of high resolution, lower patient radiation dose, and fast image acquisition compared to CT, CBCT has higher value for airway studies.[5,9,12,17,19,22,23] No previous study has evaluated the association of transverse patterns of the jaws and airway dimensions. Considering the gap of information in this respect and the existing controversies regarding the relationship of skeletal sagittal and vertical patterns and airway dimensions,[3,5,7,9-11,15-18,23] this study aimed to assess oropharyngeal dimensions in Iranian female young adults with different skeletal patterns using CBCT.

Materials and Methods

In this descriptive, cross-sectional study, CBCT scans of Iranian young adults between 18 and 35 years were retrieved from the archives of a radiology clinic in Kermanshah, Iran. The CBCT scans had been taken for orthodontic treatment or other purposes not related to this study. The study was approved in the ethics committee of Kermanshah University of Medical sciences (Ir.kums.rec. 1395.267). Minimum sample size was calculated to be 51 records according to a previous study by Iwasaki *et al*.,[5] assuming the effect size of 0.602, alpha = 0.05, and power of 90%.

The inclusion criteria were high-quality CBCT scans of patients between 18 and 35 years taken with 15 × 15 cm field of view. CBCT scans of patients with a history of orthodontic treatment or orthognathic surgery, craniofacial syndromes, such as cleft lip and palate, pathologies involving the upper airways, upper airway infection, chronic mouth breathing, permanent snoring, history of trauma, missing more than four teeth in each jaw, tonsillar or adenoid hypertrophy, history of adenoidectomy, and respiratory problems were excluded. The exclusion criteria were evaluated based on CBCT scans and a previously filled-out questionnaire.

All CBCT scans had been obtained using the same CBCT system (VGI NewTom, QR s.r.l, Verona, Italy) with spatial resolution of 250 μm (0.25 mm voxel size), 110 kV, 7.31 mAs, 0.25 mm slice thickness, and exposure time of 3.6 s. The images had been taken in natural head position and in maximum intercuspation. CBCT data were analyzed using NNT Viewer software version 8 (QR s.r.l, Verona, Italy). Data were exported in DICOM format. Mimics Medical software (version 19; Materialise, Leuven, Belgium) was used to reconstruct lateral and posteroanterior cephalometric images. Also, NemoFAB software (Nemotec, Madrid, Spain) was used to calculate the volume of the oropharyngeal airways.

The images were evaluated in axial, sagittal, and frontal planes. The axial sections were used to assess the cross-section, width, depth, and shape of the airways. The frontal sections were used to assess the transverse jaw patterns and the sagittal sections were used to evaluate the anteroposterior position of the jaws relative to each other and the vertical jaw patterns.

To standardize the images and minimize errors in measurements by NNT Viewer software, image reorientation was performed according to the line that passed through the anterior nasal spine (ANS) and dens such that the axial plane matched the occlusal plane (a line passing through the cusp tips of the maxillary posterior teeth and the incisal edges of the maxillary central incisors).[24] The midsagittal plane passed through ANS and was perpendicular to the occlusal plane, and the coronal plane passed through the dens point and was perpendicular to both the sagittal and occlusal planes.

A total of 525 CBCT records were evaluated and after applying the exclusion criteria, eventually, 105 records remained in the study. Tables 1 and 2 demonstrate the cephalometric indices and measurements that we used.

The selected CBCT scans were evaluated in terms of sagittal pattern (class I, II, and III) according to ANB and Wits appraisal, vertical pattern (low angle, normal angle, and high angle) according to maxillary–mandibular plane angle (MMA) and facial height index (FHI), and transverse pattern (normal, constriction, and others) according to the distance between jugal processes of the right and left sides (JR–JL)/the distance between gonion points in the right and left sides (Gor–Gol).

Table 1: Definitions of cephalometric landmarks

Landmark	Definition
Points-Lateral cephalometric view	
ANS	Tip of anterior nasal spine
PNS	The most posterior point on the bony hard palate
A point	Most posterior (deepest) point on the concavity on anterior profile of the maxilla.
B point	Most posterior (deepest) point on the anterior contour of the lower alveolar process
Go (Gonion)	A point midway between the points representing the middle of the curvature at right angle of the mandible
Me (Menton)	the lowest point on the symphysis of the mandible
Gn (Gnathion)	The mid-point on the anterior margin of the lower jaw in the midsaggital plane
Or (Orbitale)	The most inferior-anterior point on right orbit's margin
PO (Porion)	The midpoint of the upper contour of the right external auditory canal
Pog'	most prominent point of the soft tissue of the chin
lines-Lateral cephalometric view	
U1 (Upper Incisor)	A line connecting the incisal edge and the root apex of the most prominent maxillary incisor
L1 (Lower Incisor)	A line connecting the incisal edge and the root apex of the most prominent lower incisor
FH plane (Frankfort Horizontal plane)	A line connecting right Po toright Or
PP (Palatal plane)	ANS-PNS: Distance between the anterior and posterior nasal spine in the sagittal plane in millimeters
MP (mandibular plane)	a line connecting Go to Gn
S-line	Line from Pog' () to the mid-point of the S-shaped curvature of the nose in sagittal plane
Occlusal plane	a line passing through the cusp tips of the maxillary posterior teeth and the incisal edges of the maxillary central incisors
Points- Frontal view	
J (jugal point)	point on Jugular process at intersection of the outline of the tuberosity the maxilla and the zygomatic buttress
JR	right Jugal processes
JL	left Jugal processes
Go (Gonion)	Midpoint on the curvature at the angle of the mandible
Gor	right gonion
Gol	left gonion

Tables 3 and 4 show cephalometric indices for assessment of sagittal and vertical pattern. The high angle group was not included in statistical analyses because of small sample size.

To assess the records in transverse dimension on frontal view, two cephalometric indices were used. To determine the width of the maxilla, the JR–JL was measured. To determine the width of the mandible, the Gor–Gol was measured. Next, the maxillary width to mandibular width index was calculated using the formula below:

JR–JL/Gor–Gol × 100 = 66% ± 5% (female). The transverse dimension was divided into three

Table 2: Definitions of measurements

Measurements	Definition
Lateral cephalometric view	
ANB	The angle formed by the intersection of the A-N to N-B, and defines the relationship of the maxillary and mandibular bases to each other in the sagittal plane.
Wits (AO-BO)	The linear distance between the perpendicular lines from point A and B on the maxilla and mandible, respectively, onto the occlusal plane, which is drawn through the region of maximum cuspal interdigitation.
AFH	Perpendicular linear distance between PP and Me, measured in Me-PP line.
PFH	Linear distance between Articular and the mandibular plane (Go-Me), tangent to the mandibular ramus.
FHI	Ratio of PFH and AFH, multiplied by 100 (FHI=PFH/AFH×100)
MMA	The angle formed between the PP and MP
Mandibular body length	Go-Gn: Distance between gonion and gnathion in the sagittal plane in millimeters
Nasolabial angle	Angle between the line tangent to the nasal base and the line tangent to the upper lip
U1-PP	Angle between the longitudinal axis of upper 1 (U1) and PP in sagittal plane
L1-MP	Angle between the longitudinal axis of lower 1 (L1) and MP in the sagittal plane
S-line to lips	upper lip prominence such that if the upper lip is tangent to this line, it is considered normal, if it is posterior to this line, it is considered flat and if it is anterior to this line, it is considered prominent.
Frontal view	
maxillary width	JR-JL
Nasal width	Calculated based on the width of the widest part of the nasal cavity according to Rickets analysis

ANS=anterior nasal spine, AFH=anterior facial height, PFH=posterior facial height, FHI=facial height index, U1-PP=upper 1 to PP, L1-MP=lower 1 to MP, Me=menton, PP=palatal plane, MP=mandibular plane, JR=right jugal processes, JL=left jugal processes Ar = Articular

Table 3: Cephalometric indices for assessment of sagittal pattern

Sagittal pattern	ANB	Wits
Class I	1-4°	0-1 mm
Class II	>4°	>0
Class III	<1°	<-1

Table 4: Cephalometric indices for assessment of vertical pattern

Vertical pattern	MMA	FHI
Low angle	<23°	<65%
Normal angle	27±4°	65-75%
High angle	>31°	>75%

MMA=maxillary-mandibular plane angle, FHI=facial height index

groups constriction (JR–JL/Gor–Gol × 100 <61%), normal (JR–JL/Gor–Gol × 100 = 66% ± 5%), and others (JR–JL/Gor–Gol × 100 >71%).

The radiographs were analyzed and the relationship of airway dimensions with the classifications in each dimension was evaluated irrespective of the other two dimensions.

Airway indices assessed in this study were minimum and maximum cross-sectional area (CSA) of the airways in oropharynx, airway width (laterally), airway depth (anteroposteriorly), and oropharyngeal airway volume, which were measured at different points along the oropharyngeal airway. The maximum and minimum airway CSA, minimum width, minimum depth, minimum volume and location of maximum and minimum CSA, minimum depth, and minimum width relative to the second and third cervical vertebrae were all determined at the oropharynx separately on each section. The oropharynx boundaries to detect these airway measurements were the line extending from PNS – tip of the odontoid process in superior and the line extending from the posterior-superior border of C4 – the base of the epiglottis symphysis of the mandible in inferior.[13] The airway shape at the oropharynx was also determined according to the afore-mentioned measurements (airway width and depth) along the C3 such that if width > depth, the airway shape was determined to be wide; if width < depth, it was determined to be long; and if width = depth, it was determined to be square shaped.[5] Airway measurements were then compared in groups with different skeletal sagittal, vertical, and transverse patterns. Also, the correlation of indices with airway measurements was analyzed and reported.

Reliability test: The values obtained by analysis of 20 CBCT scans by two examiners (a trained dental student and an oral and maxillofacial radiologist) were evaluated and compared to calculate intraclass correlation coefficient (ICC) and assess inter-examiner reliability. To assess intra-examiner reliability, each examiner analyzed the 20 CBCT scans again after 2 weeks and the results were compared with those of first-time assessment and inter-class correlation coefficient was calculated. The collected data were analyzed using SPSS version 18 (SPSS Inc., IL, USA). Normal distribution of data was evaluated using the Kolmogorov–Smirnov test. ANOVA was used for multiple comparisons, and independent samples *t*-test was used for pairwise comparisons. Monte Carlo Chi-square test was applied to assess the correlation between qualitative variables, whereas Pearson's correlation coefficient was applied to assess the correlation between quantitative variables. Level of significance was set at 0.05.

Results

Of a total of 525 CBCT scans of females, 105 were eligible and remained in the study. The male patients were not evaluated because records of male patients were not many in the archives.

For analysis of the results, we classified records using two different classifications. First, airway dimensions in different skeletal patterns were compared separately, irrespective of other patterns [Table 5].

To assess inter- and intra-examiner reliability for Go–Go, J–J, and MMA measurements, inter-class correlation coefficient and the ICC were calculated. The lowest inter-class correlation coefficient was 0.989, which indicated very high agreement between the two examiners. The lowest ICC was 0.969, which was optimal.

A significant correlation existed between maximum CSA and minimum width of the upper airways ($P < 0.001$, $r = 0.47$). A significant correlation also existed between minimum CSA and minimum depth ($P < 0.001$, $r = 0.511$). Minimum CSA was significantly correlated with minimum width of the upper airways as well ($P < 0.001$, $r = 0.583$).

The shape of the upper airways was wide in 93.3% and square in 6.7% of patients. No patient had long airways.

According to the independent samples *t*-test, minimum width of the upper airway was significantly different among airways with different shapes ($P = 0.002$).

In general, patients with different skeletal patterns were not significantly different in terms of airway volume.

Our results regarding the location of maximum CSA, minimum CSA, minimum depth, and minimum width showed that in the majority of records, maximum CSA

Table 5: Overall comparison of oropharyngeal dimensions among patients with different skeletal sagittal, vertical and transverse patterns

		Maximum CSA*		Minimum CSA		Minimum width		minimum depth		volume	
	Count	Mean	SD†	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Sagittal											
Class I	53	343.3893	103.6519	113.9736	65.4450	17.1515	5.1402	4.0926	1.8299	3727.16	1391.73
Class II	26	322.7843	88.6589	113.9610	45.7472	18.5892	4.8701	3.8092	2.0112	4029.39	1670.64
Class III	26	351.8415	84.2045	115.8315	49.5083	17.6846	4.0856	4.1215	2.0568	3970.58	1549.66
P		0.522		0.990		0.464		0.798		0.644	
Vertical											
Normal angle	53	338.8909	95.1571	110.8454	51.9993	17.6936	5.1711	4.2108	1.9736	3626.35	1504.05
Low angle	44	352.4683	90.1466	118.7293	61.9823	17.7130	4.6516	3.8070	1.8231	4133.68	1466.33
High angle	8	283.7603	114.5834	114.5389	64.4617	16.8775	3.6725	4.0538	2.1811	3932.52	1521.78
P		0.171		0.797		0.899		0.591		0.250	
Frontal											
Normal	79	335.7810	87.1684	112.2955	52.1351	17.5099	4.5493	4.0985	1.9910	3907.09	1510.86
Constriction	18	358.7236	126.9296	112.7841	65.0200	18.7144	6.3561	3.8639	1.5545	3679.34	1565.59
Wide	8	344.5225	99.9744	139.2186	82.0978	16.5013	3.5202	3.7225	2.0977	3831.30	1311.71
P		0.653		0.443		0.502		0.805		0.845	

*CSA=cross-sectional area. †SD=Standard deviation

in all three skeletal patterns of sagittal, vertical, and transverse was at the level of the upper third of the second cervical vertebra, followed by lower third of the third cervical vertebra. However, these differences were not significant ($P > 0.05$). Minimum CSA, minimum width, and minimum depth in all three skeletal groups were recorded at the middle third of the second cervical vertebra, followed by lower third of the second cervical vertebra. These differences were not significant ($P > 0.05$) except for the minimum depth that was significantly different in different sagittal patterns ($P = 0.025$).

Discussion

The upper airways are a complex structure of bone, cartilage, and soft tissue. The effect of mode of breathing on facial growth has always been an interesting topic for orthodontists, and the correlation of the two has been previously confirmed.[10-25] This study assessed upper airway characteristics, including minimum and maximum CSA, airway width (laterally), and airway depth (anteroposteriorly), in patients with different skeletal sagittal, vertical, and transverse patterns using CBCT.

CBCT is a reliable imaging modality for detection of maxillofacial problems. It enables accurate volumetric analyses and clearly visualizes the airways.[26] CBCT allows better calculation of CSA of the airways compared to 2D radiography. Ghoneima and Kula[26] showed that 3D measurements of the volume and minimum width of the airways by CBCT were more accurate and more reliable compared to other modalities. Computerized calculations of the airway CSA, width, and depth are highly accurate and decrease bias.[5] More comprehensive 3D visualization by CBCT allows more accurate assessment of the airways on CBCT scans compared to lateral cephalograms.[19] Tourné[27] stated that nasopharyngeal structure has the least effect on anteroposterior facial dimensions in apparently healthy individuals; thus, we only evaluated the oropharyngeal airway in this study.

Previous studies showed that different head posture, patient position (supine or upright), and respiratory phase changed the upper air way dimensions.[10,23,28-30] In our study, CBCT scans were obtained in upright position and natural head position but respiratory phase was not evaluated.

In the current study, we evaluated all sections and manually sectioned the airways to determine the airway dimensions. Although the manual technique requires more time and may have some errors, it has higher reproducibility than the automated technique. Di Carlo *et al*.[10] and El and Palomo[28] also confirmed higher reliability and accuracy of the manual technique. The inter-class correlation coefficient was very high in our study. Furthermore, the current study was performed on female young adults between 18 and 35 years because the possibility of changes in airway dimensions and volume is minimal in this age range.[31] Many studies have evaluated the correlation of pharyngeal dimensions with craniofacial morphology.[1,3,5,7,8,11,15,23,28,32,33]

In our study, the mean of minimum airway width in normal-angle patients with normal transverse pattern was higher in class II and lower in class III malocclusion patients compared to class I patients. The results of Kim *et al*.,[6] regarding airway CSA, were in line with our findings because they found no significant correlation between airway CSA and the skeletal sagittal pattern.

Alves *et al*.[7] compared minimum CSA of the oropharyngeal airway in patients with different sagittal patterns and reported results different from ours such that the minimum CSA in class II patients was significantly smaller than that in class I patients. Difference in the results of the two studies may be explained by different method of airway assessment and different age range of patients because patients were aged between 8 and 10 years in their study. Zhong *et al*.[33] evaluated lateral cephalograms of normodivergent patients and demonstrated that class II patients had the greatest and class III patients had the smallest airway dimensions. Their findings were close to ours, although they found significant differences between groups, whereas the differences in our study did not reach statistical significance. This may be because of their much larger sample size. Similar to our study, Kula *et al*.[13] found no significant difference among different skeletal groups in terms of the narrowest part of the airway, airway volume, and size. Hong *et al*.[3] discussed that CSA at the epiglottis of class III patients was significantly larger than that in class I patients.

Iwasaki *et al*.[5] also showed that CSA of class III patients was significantly larger than that of class I patients. According to their study, airway CSA had a moderate correlation with the Wits appraisal, whereas no such correlation was found in our study. The results of the two afore-mentioned studies were different from ours.

Indriksone and Jakobsone[19] concluded that craniofacial morphology has a weak effect on oropharyngeal airway dimensions. A systematic review by Indriksone and Jakobsone[18] on the upper airway dimensions in different sagittal craniofacial patterns reported that 75% of the reviewed studies found no significant difference in nasopharyngeal airway dimensions among patients with different sagittal patterns. Also, 50% of the reviewed articles found no significant association between the oropharyngeal airway volume or linear dimensions of the airways and different sagittal patterns.

With regard to airway characteristics in transverse pattern groups, the maximum CSA was significantly smaller in normal transverse group compared to maxillary constriction group, which was opposite to our expectations, which may be because of the fact that we evaluated oropharynx and not nasopharynx. Also, minimum CSA had a significant correlation with maxillary width (J–J). No previous study is available on the correlation of transverse pattern with airway characteristics to compare our results with.

The size and shape of the airways are affected by the growth and development of craniofacial structures.[34] The size and shape of the airways were also evaluated in our study and compared in different skeletal patterns. The results showed that wide shape of the airways had the highest frequency in all three skeletal patterns (sagittal, vertical, and transverse), and the long shape was not found in any case. In the study by Iwasaki *et al*.,[5] the square shape had the highest frequency in class I group, whereas wide shape of the airways was the most frequent in class III group. These differences in the results of the two studies may be because of racial differences.

In line with our findings, Kula *et al*.[13] stated that the location of the narrowest part of the airways was not significantly different among patients with different skeletal classes. They showed that the location of the most constricted area was different but it was mainly in the superior part of the oropharynx and had a much lower prevalence in nasopharynx. A 3D study reported that the narrowest part of the airways was posterior in the dorsal surface of the tongue.[35] Their findings were relatively similar to ours.

Evaluation of the correlation of airway characteristics with the measured indices revealed no significant correlation except for the minimum CSA of the upper airways with minimum depth and minimum width, maximum CSA and minimum width of the upper airways, and minimum CSA and maxillary width. Iwasaki *et al*.[5] showed a stronger correlation between airway CSA and airway width rather than depth and indicated that airway width was a more important predictor of the airway CSA than airway depth. No such a correlation was found in our study. Alves *et al*.[8] found that nasal width in class III patients was significantly greater than that in class II patients. However, our study did not find a significant sagittal correlation between nasal width and airway dimensions.

Our study did not find a significant difference in volume of the airways among patients with different skeletal patterns. The results of studies on the correlation of airway volume and skeletal pattern have been controversial.[3,5,6,8-11,13,17,19,23,34,36] Some studies reported that the upper airway volume was the same in different sagittal and vertical patterns.[5,6,10,11,13,17,23,34] However, Celikoglu *et al*.[9] indicated that the oropharyngeal volume was the largest in low-angle patients, whereas Grauer *et al*.[11] reported airway volume is minimum in short face patients. With regard to sagittal pattern, some authors reported that the pharyngeal volume in class III patients was larger than that in class II patients,[3-19] whereas in the study by Alves *et al*.,[8] airway volume in class II patients was larger than that in class III patients. Kim *et al*.[6] reported that airway volume in class I patients was significantly larger than that in class III patients. Grauer *et al*.[11] found airway volume was maximum in class I and minimum in class II cases with no significant difference.

Nejaim *et al*.[35] found a significant correlation between pharyngeal airway volume and hyoid bone and mandibular dimensions such that the smallest pharyngeal width was noted in class II mesofacial and dolichofacial patients. However, they explained that these differences between studies were probably because of different methodologies, sample size, races, assessment modalities, and software programs.

Ogawa *et al*.[16] compared airway volume and minimum CSA of the oropharyngeal airway in OSA and non-OSA patients. Airway volume was the same in both groups but minimum CSA was significantly different. Thus, it seems that difference in oropharyngeal airway dimensions relative to its volume is more prominent in OSA patients than healthy subjects. Airway resistance depends on the size and morphology of the airways. A stenotic area in an airway with large volume would cause resistance.[3] Thus, it seems that airway volume does not have a significant correlation with inhaled air volume, and it appears that the narrowest cross-section of the airway is more important than the airway volume. Airflow is also correlated with nasal airway resistance.[35] Evidence shows that the nasal airway cross-section is an important factor determining the amount of inhaled air.[27,35] Thus, it is a possibility that the volume and cross-sectional area of the oropharyngeal airway do not determine the amount of inhaled air or the respiratory pattern and explain lack of correlation with jaw relations and controversial results of studies in this respect.

Another theory explaining the absence of a significant correlation between pharyngeal airway and different skeletal patterns is the head compensation by changing the head posture. Head posture, defined by the craniocervical angle, is an important factor in pharyngeal airway status and is correlated with sagittal skeletal pattern.[1,23,37] Solow *et al*.[37] stated that the craniofacial angle is smaller in patients with mandibular prognathism and larger in patients with mandibular retrognathism. They showed that postural changes of the head such as its extension caused backward and downward rotation of the mandible. Such postural changes also changed the muscular status and subsequently the airways. Oh *et al*.[23] showed that the anteroposterior skeletal pattern is also correlated with head posture. However, it has been shown that by a change in anteroposterior skeletal pattern, pharyngeal structures experience a postural change but the airway dimensions eventually remain unchanged.[1] According to the afore-mentioned studies, there is a possibility that by changing the head posture, some sort of muscular adaptation occurs and compensates the different skeletal patterns. However, in cases where muscular adaptation does not occur, as in OSA patients, this compensation does not occur and, therefore, head posture affects the position of the jaw and upper airway dimensions. In the current study, the head posture was not evaluated, which is a limitation of this study and further studies are required to take into account the effect of head posture on the results.

Most previous studies that found a significant correlation between airway characteristics and skeletal patterns had a small sample size and did not take into account the effect of confounders, such as weight, size of the face, smoking status, neck circumference, respiratory status, and head posture.[3,5,7,9,11,15,17,19,31-34,38] Thus, the significance of the correlations that were found to be weakly significant in such studies must be tested in clinical conditions. For this purpose, more accurate long-term investigations on a larger sample size with excellent control of the confounders are required. Last but not least, controversies in the results of previous studies may be because of racial differences of study populations. Racial differences can affect cephalometric and anthropometric indices[39] and consequently the results. The studies discussed earlier had been conducted on north American,[11,13] Japanese,[5,33] Turkish,[9] Chinese,[17] Korean,[3,6,23] Pakistani,[15] and Brazilian[7,8,35] populations, whereas our study was performed on an Iranian population, which may explain the controversy in the results.

Our study had some limitations. Because of small number of male patients, our analysis was only performed on females. Also, because of small sample size in high-angle group, the results of this group could not be analyzed. Small CBCT field of view (15 × 15 cm) was another limitation that resulted in elimination of some anatomical points and exclusion of cases. Not evaluating the respiratory phase, neck circumference, weight, and facial size was also a limitation of this study.

Considering the existing ambiguities regarding the correlation of upper airway characteristics and craniofacial morphology, future studies with a larger sample size are required to assess both pharyngeal and nasal airways simultaneously in different facial patterns using nasal flow measurement, 3D radiography, endoscopy, and magnetic resonance imaging.

Conclusion

Within the limitations of this study, the results showed no significant difference in airway dimensions among different skeletal sagittal patterns. Wide airway shape was the most common in all skeletal patterns and long shape was not found in any case.

Financial support and sponsorship

This study was derived from a thesis, submitted to Kermanshah University of Medical Sciences, School of Dentistry and was financially supported from the Kermanshah University of Medical Sciences, Kermanshah, Iran.

Conflicts of interest

Amin Golshah, Tanaz Hosseini Jalilian, Nafiseh Nikkerdar declare that they have no conflict of interest.

References

1. Ceylan I, Oktay H. A study on the pharyngeal size in different skeletal patterns. Am J Orthod Dentofacial Orthop 1995;108:69-75.
2. Shelton RL Jr, Bosma JF. Maintenance of the pharyngeal airway. J Appl Physiol 1962;17:209-14.
3. Hong JS, Oh KM, Kim BR, Kim YJ, Park YH. Three-dimensional analysis of pharyngeal airway volume in adults with anterior position of the mandible. Am J Orthod Dentofacial Orthop 2011;140:e161-9.
4. Hwang YI, Lee KH, Lee KJ, Kim SC, Cho HJ, Cheon SH, *et al*. Effect of airway and tongue in facial morphology of prepubertal Class I, II children. Korean J Orthod 2008;38:74-82.
5. Iwasaki T, Hayasaki H, Takemoto Y, Kanomi R, Yamasaki Y. Oropharyngeal airway in children with Class III malocclusion evaluated by cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2009;136:318.e1-9.
6. Kim YJ, Hong JS, Hwang YI, Park YH. Three-dimensional analysis of pharyngeal airway in preadolescent children with different anteroposterior skeletal patterns. Am J Orthod Dentofacial Orthop 2010;137:306.e1-11.
7. Alves M Jr, Franzotti ES, Baratieri C, Nunes LK, Nojima LI, Ruellas AC. Evaluation of pharyngeal airway space amongst different skeletal patterns. Int J Oral Maxillofac Surg 2012;41:814-9.
8. Alves PV, Zhao L, O'Gara M, Patel PK, Bolognese AM. Three-dimensional cephalometric study of upper airway space in skeletal class II and III healthy patients. J Craniofac Surg 2008;19:1497-507.
9. Celikoglu M, Bayram M, Sekerci AE, Buyuk SK, Toy E. Comparison of pharyngeal airway volume among different vertical skeletal patterns: Acone-beam computed tomography study. Angle Orthod 2014;84:782-7.
10. Di Carlo G, Polimeni A, Melsen B, Cattaneo PM. The relationship between upper airways and craniofacial morphology studied in 3D. A CBCT study. Orthod Craniofac Res 2015;18:1-11.
11. Grauer D, Cevidanes LS, Styner MA, Ackerman JL, Proffit WR. Pharyngeal airway volume and shape from cone-beam computed tomography: Relationship to facial morphology. Am J Orthod Dentofacial Orthop 2009;136:805-14.
12. Haskell JA, Haskell BS, Spoon ME, Feng C. The relationship of vertical skeletofacial morphology to oropharyngeal airway shape using cone beam computed tomography: Possible implications for airway restriction. Angle Orthod 2014;84:548-54.
13. Kula K, Jeong AE, Stacey H, Kendall D, Ghoneima A. Three dimensional evaluation of upper airway volume in children with different dental and skeletal malocclusions. J Biomed Graph Comput 2013;3:116.
14. Bacon WH, Turlot JC, Krieger J, Stierle JL. Cephalometric evaluation of pharyngeal obstructive factors in patients with sleep apneas syndrome. Angle Orthod 1990;60:115-22.
15. Memon S, Fida M, Shaikh A. Comparison of different craniofacial patterns with pharyngeal widths. J Coll Physicians Surg Pak 2012;22:302-6.
16. Ogawa T, Enciso R, Shintaku WH, Clark GT. Evaluation of cross-section airway configuration of obstructive sleep apnea. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;103:102-8.
17. Wang T, Yang Z, Yang F, Zhang M, Zhao J, Chen J, *et al*. A three dimensional study of upper airway in adult skeletal Class II patients with different vertical growth patterns. PLoS One 2014;9:e95544.
18. Indriksone I, Jakobsone G. The upper airway dimensions in different sagittal craniofacial patterns: Asystematic review. Stomatologija 2014;16:109-17.
19. Indriksone I, Jakobsone G. The influence of craniofacial morphology on the upper airway dimensions. Angle Orthod 2015;85:874-80.
20. Oz U, Orhan K, Rubenduz M. Two-dimensional lateral cephalometric evaluation of varying types of Class II subgroups on posterior airway space in postadolescent girls: Apilot study. J Orofac Orthop 2013;74:18-27.
21. Halazonetis DJ. Morphometric evaluation of soft-tissue profile shape. Am J Orthod Dentofacial Orthop 2007;131:481-9.
22. De Vos W, Casselman J, Swennen GR. Cone-beam computerized tomography (CBCT) imaging of the oral and maxillofacial region: Asystematic review of the literature. Int J Oral Maxillofac Surg 2009;38:609-25.
23. Oh KM, Hong JS, Kim YJ, Cevidanes LS, Park YH. Three-dimensional analysis of pharyngeal airway form in children with anteroposterior facial patterns. Angle Orthod 2011;81:1075-82.
24. Babbush CA, Zwemer TJ, Fehrenbach MJ, Emmons M, Nunez DW. Mosby's dental dictionary Mosby Inc; 2007.
25. Linder-Aronson S. Adenoids. Their effect on mode of breathing and nasal airflow and their relationship to characteristics of the facial skeleton and the denition. A biometric, rhino-manometric and cephalometro-radiographic study on children with and without adenoids. Acta Otolaryngol Suppl 1970;265:1-132.
26. Ghoneima A, Kula K. Accuracy and reliability of cone-beam computed tomography for airway volume analysis. Eur J Orthod 2013;35:256-61.
27. Tourné LP. Growth of the pharynx and its physiologic implications. Am J Orthod Dentofacial Orthop 1991;99:129-39.
28. El H, Palomo JM. Measuring the airway in 3 dimensions: Areliability and accuracy study. Am J Orthod Dentofacial Orthop 2010;137:S50.e1-9.
29. Pae EK, Lowe AA, Sasaki K, Price C, Tsuchiya M, Fleetham JA. A cephalometric and electromyographic study of upper airway structures in the upright and supine positions. Am J Orthod Dentofacial Orthop 1994;106:52-9.
30. Solow B, Siersbaek-Nielsen S, Greve E. Airway adequacy, head posture, and craniofacial morphology. Am J Orthod 1984;86:214-23.
31. Johnston CD, Richardson A. Cephalometric changes in adult pharyngeal morphology. Eur J Orthod 1999;21:357-62.
32. Muto T, Yamazaki A, Takeda S. A cephalometric evaluation of the pharyngeal airway space in patients with mandibular retrognathia and prognathia, and normal subjects. Int J Oral Maxillofac Surg 2008;37:228-31.
33. Zhong Z, Tang Z, Gao X, Zeng XL. A comparison study of upper airway among different skeletal craniofacial patterns in nonsnoring Chinese children. Angle Orthod 2010;80:267-74.
34. Dalmau E, Zamora N, Tarazona B, Gandia JL, Paredes V. A comparative study of the pharyngeal airway space, measured with cone beam computed tomography, between patients with different craniofacial morphologies. J Craniomaxillofac Surg 2015;43:1438-46.
35. Nejaim Y, Aps JKM, Groppo FC, Haiter Neto F. Evaluation of pharyngeal space and its correlation with mandible and hyoid bone in patients with different skeletal classes and facial types. Am J Orthod Dentofacial Orthop 2018;153:825-33.

36. Tso HH, Lee JS, Huang JC, Maki K, Hatcher D, Miller AJ. Evaluation of the human airway using cone-beam computerized tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;108:768-76.
37. Solow B, Sandham A. Cranio-cervical posture: Afactor in the development and function of the dentofacial structures. Eur J Orthod 2002;24:447-56.
38. Kikuchi Y. Three-dimensional relationship between pharyngeal airway and maxillo-facial morphology. Bull Tokyo Dent Coll 2008;49:65-75.
39. Farkas LG, Katic MJ, Forrest CR, Alt KW, Bagic I, Baltadjiev G, *et al*. International anthropometric study of facial morphology in various ethnic groups/races. J Craniofac Surg 2005;16:615-46.