

PHARYNGEAL AIRWAY VOLUME AMONG DIFFERENT VERTICAL SKELETAL PATTERNS USING CONE-BEAM COMPUTED TOMOGRAPHY

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ABSTRACT

Introduction: Pharynx morphology affects airway volume, facial growth pattern, risk of obstructive sleep apnea, and chewing pattern.

Objectives: This study aimed to compare the pharyngeal airway volume among vertical skeletal patterns using cone-beam computed tomography (CBCT).

Material and methods: In this cross-sectional study, 100 CBCT images were selected from the archive of Department of Orthodontic of Hamadan Dental School, Iran. Among reviewed images, 60 cases met inclusion criteria. They were divided into three groups of long, normal, and short faces based on the posterior facial height to anterior facial height (PFH/AFH) ratio. Airway volume, minimum axial cross-section, airway length, midline area, and airway morphology were measured using ITK-SNAP software. Obtained data were transferred into SPSS 16 software and analyzed using ANOVA test.

Results: Volume, minimum axial cross-section, and other variables of the pharyngeal airway had no significant relation with skeletal vertical patterns. The average airway volume in men was 1712.348 mm^3, which was more than that in women, and this value decreased by 67.175 mm^3 with age increasing. The average airway volume also decreased by 46.346 mm^3, with each unit increasing in PFH/AFH ratio.

Conclusions: In the present study, different vertical skeletal patterns and airway variables were not significantly correlated with each other. Airway volume decreased with increasing age, and it was observed larger in men than in women.

Key words: facial vertical pattern, cone-beam computed tomography, airway.

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INTRODUCTION

The pharynx morphology affects the airway volume, facial growth pattern, risk of obstructive sleep apnea (OSA), and chewing pattern [1]. Growth and function of the nasal cavities, nasopharynx, and oropharynx are associated with normal cranial growth, and respiratory tract function has a direct correlation with orthodontic diagnosis and treatment planning [2].

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Understanding effective anatomical factors in maintaining the airway open can help recognizing risk factors for airway obstruction and even prevent it using various therapeutic methods.

Additionally, if skeletal problems in the vertical dimension are a cause of the airway collapse, respiratory difficulties, such as OSA, can be treated with an appropriate orthodontic treatment plan, in addition to dento-skeleton problems [3,4].

The relationship between pharyngeal airway and craniofacial complex has been examined in cephalometric images by most of previous studies. Even though, cephalometry provides valuable information, their limitation is showing three-dimensional structures in a two-dimensional path. Alternatively, cone-beam computed tomography (CBCT) provides images of 3D structures at different sections with appropriate quality [5].

OBJECTIVES

The aim of the present study was to determine the relationship between craniofacial morphology and upper airway volume and morphology, using CBCT images from ITK-SNAP software.

MATERIAL AND METHODS

This cross-sectional study was approved by an ethics committee of Hamadan University of Medical Sciences (IR.UMSHA.REC.1396.582). Patients were identified by reviewing the archive records of Department of Orthodontic at Hamadan Dental School. Of 100 examined CBCT images, 60 met inclusion criteria. CBCTs of the patients were obtained using NewTom3G scanner (Newtom, Verona, Italy), with 110 kvp, 3.2 mA, and 1.1 s exposure settings. Inclusion criteria were: 1) people aged 18 years and more (those who completed the developmental age); 2) CBCT images with a 12-inch field of view (FOV) and closed mouth in maximum intercuspation; 3) patients with no respiratory disorders; 4) clarity of the fourth cervical vertebra in CBCT images.

Exclusion criteria were edentulous patients, those having any pharyngeal pathology, and individuals with a history of orthognathic surgery.

Facial skeletal patterns were extracted from records of the patients. In case of unclear skeletal patterns, these patterns were obtained through the existing CBCT and orthodontic analyses. As CBCT images were captured in large FOV and closed mouth (maximum intercuspation), lateral cephalometric view of CBCT images were reconstructed in Ray Sum format. In the next step, a ratio of posterior facial height (PFH) to anterior facial height (AFH) was measured. Based on this ratio, the patients were divided into three groups such as: group 1 – short face, with a PFH/AFH ratio of > 65%; group 2 – normal face, with a PFH/AFH ratio of 62-65%; group 3 – long face, with a PFH/AFH ratio of < 62%. There were 20 patients in each group.

All the images were converted into DICOM format and saved on semi-automatic ITK-SNAP 3.60-beta segmenting software. This free software is a useful tool to separate anatomic structures manually or automatically on medical 3D images as well as accurately determining volume of certain structures (www.ITK-SNAP.org).

In this study, the pharyngeal airway was evaluated by assessing variables of the upper airway volume size, minimum upper airway axial cross-section, upper airway length, and midline airway area in the sagittal section.

The minimum area location of the axial section in the lower pharyngeal region was determined by the following equation, derived from Holsbeke [6].

Location described as the upper airway length/total airway length upper airway length as an important parameter for the assessment of airway and airflow in the pharynx, referred to the airway length in the upper part of minimum axial section. Three sections, including velopharynx, oropharynx, and hypopharynx were examined in the lower airway. After determining minimum area of the axial section and length of the lower pharyngeal airway section with ITK-SNAP software, the mean area and morphology of each section were calculated as follows: mean area = volume/total airway length, and morphology = minimum axial area/mean area.

These ratios indicated that the airway cross-section was distributed uniformly and regularly or irregularly along the pharynx. The volume and shape of the airway in different parts of the pharynx were also compared using a calculation and statistical analyzing of these variables.

The pharyngeal airway was easily identified due to large differences of surrounding tissues in X-ray attenuation between the air in the pharynx and waterlogged components of surrounding tissues, making it easy to distinguish the airway. Before measuring the airway volume, the desired range of the pharynx was determined with anatomical landmarks to calculate the airway volume, as described as follow (Figure 1A): 1) the junction of the nasal septum (vomer), and the body of the sphenoid bone (the uppermost limit of pharyngeal airway), 2) posterior nasal spine; 3) the lowest point of the cranial base (basion); 4) the line, which passes through the uppermost anterior point of the fourth cervical vertebra and the posterior wall of the pharynx, parallel to Frankfurt line. Then, the active contour of segmentation mode method was selected from main toolbar. Rectangular box of the software was adjusted to include a range specified in the above-mentioned figure. Then, segment 3D was connected to display rectangular box separately. From the main toolbar menu, paintbrush mode method was selected, and a font shape was established for the circle. Next, a classification method was chosen from pre-segmentation mode menu in actions' section. First, red color was chosen and different parts of the airway were marked with a few spheres. As shown in Figure 1B, this was done in green and blue col-

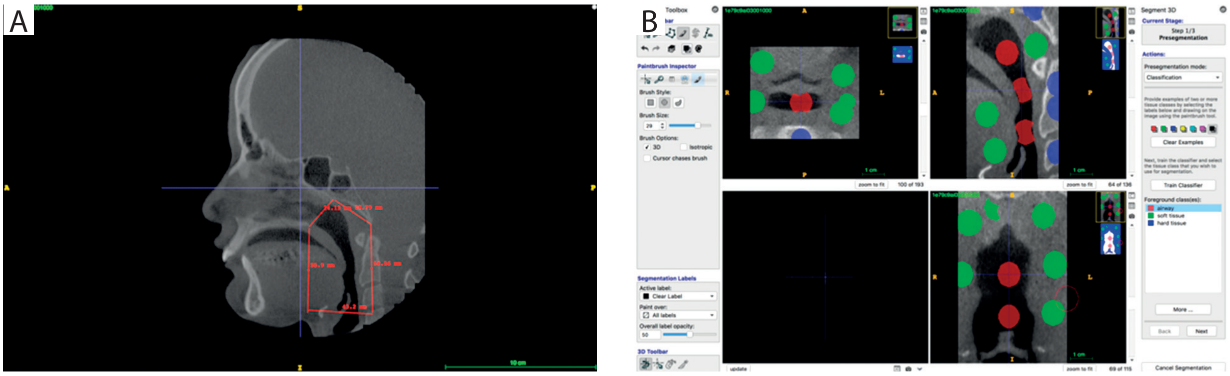

FIGURE 1. A) Bony range of the airway. **B)** Definition of different tissues in the software

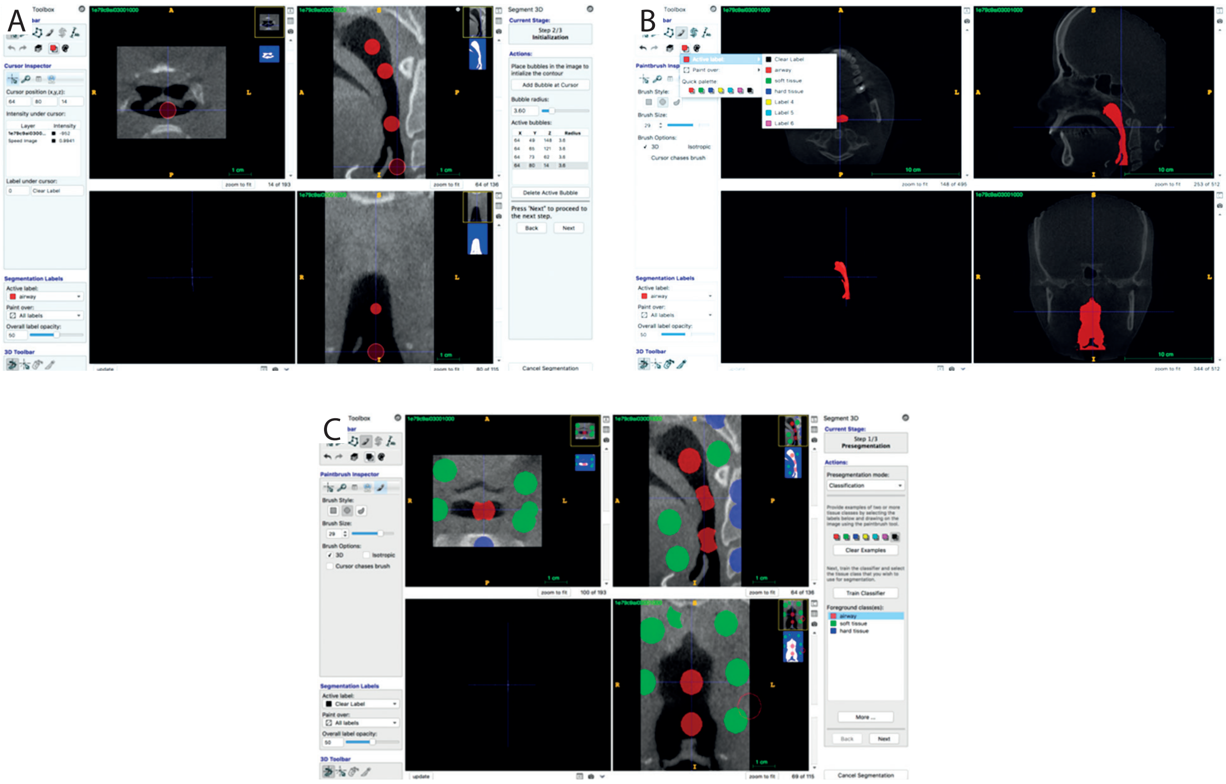

FIGURE 2. A) Determination of the points to start measuring the volume. **B)** Measured range and selection of the clear label. **C)** Location of receiving the volume information

ors for soft and hard tissues, respectively. This procedure was finalized by clicking "train" classifier.

In this way, our specified space was defined for the software. The area measured by the software was shown in white, and the rest of background was marked in blue. In the next stage, the software asked to place a few bubbles in the image to start the measurement from the bubbles (Figure 2A). Then, the software returned to original image size, and determined area was displayed separately by selecting the update button at the bottom of third image. Additional areas recorded in the measurement, such as the end of oral cavity, were removed by re-selecting the paintbrush mode and selecting a clear label (Figure 2B). From the segmentation menu, an option "volumes and statistics" was selected to receive volume of a specified area as the software output (Figure 2C). Data were analyzed using SPSS version 21 (SPSS Inc., Chicago, IL, USA), with a 0.05 level of significance. Different variables in the three vertical skeletal patterns were compared using one-way analysis of variance (ANOVA).

RESULTS

In this study, 60 selected patients (34 females and 26 males) were divided into three skeletal cohorts, in-

TABLE 1. Mean area in different vertical skeletal patterns using ANOVA test

Parameter	*n*	Mean	Std. deviation	Std. error	Confidence interval for 95% mean		Sig .
					Lower bound	Upper bound	
Long face	20	276.08	93.01	20.79	232.55	319.61	0.623
Normal face	20	261.16	71.50	15.98	227.70	294.63	
Short face	20	253.34	12.28	43.50	227.63	279.05	
Total	60	263.53	9.57	23.50	244.38	282.68	

TABLE 2. Midline area in different vertical skeletal patterns using ANOVA test

Parameter	*n*	Mean	Std. deviation	Std. error	Confidence interval for 95% mean		Sig .
					Lower bound	Upper bound	
Long face	20	855.74	185.27	41.42	769.03	942.45	0.778
Normal face	20	819.68	172.78	38.63	738.81	900.54	
Short face	20	855.42	194.53	43.50	764.38	946.47	
Total	60	843.61	182.06	23.50	796.58	890.64	

TABLE 3. Minimum axial area in different vertical skeletal patterns using Kruskal-Wallis test

Parameter	*n*	Mean	Std. deviation	Std. error	95% Confidence interval for mean		Sig .
					Lower bound	Upper bound	
Long face	20	174.29	95.67	21.39	129.52	219.07	0.947
Normal face	20	164.70	82.02	18.34	126.31	203.08	
Short face	20	161.12	61.06	13.65	132.54	189.70	
Total	60	166.70	79.66	10.28	146.12	187.28	

TABLE 4. Location in different vertical skeletal patterns using ANOVA test

Parameter	*n*	Mean	Std. deviation	Std. error	95% Confidence interval for mean		Sig .
					Lower bound	Upper bound	
Long face	20	0.49	0.05	0.01	0.46	0.51	0.745
Normal face	20	0.49	0.06	0.01	0.46	0.52	
Short face	20	0.50	0.05	0.01	0.47	0.53	
Total	60	0.49	0.057	0.00	0.48	0.51	

cluding the long face group, the normal face group, and the short face group, with 20 patients in each group. Two oral and maxillofacial radiologists, who were specialist in ITK-SNAP software, examined the images and calculated the measurements of every patient. Having computed the correlation between the two observer measurements, their agreement was high (more than 87%). Therefore, the data of only one observer were used for analysis.

Kolmogorov-Smirnov test was performed to assess homogeneity of the data. The mean area, midline area, and location variables presented a normal distribution. Therefore, these data were subjected to ANOVA test. Data of the minimum axial area variable was not hemogenic; therefore, the Kruskal-Wallis test was performed to compare significance of differences between the three investigated groups of patients. Descriptive analysis of mean area in vertical skeletal patterns and comparison of significant differences between the three different groups using ANOVA test are presented in Table 1. As seen in that table, the mean area was not significantly different within the three groups ($p = 0.623$). Descriptive analysis of midline area in vertical skeletal patterns and comparison of statistical significance between the three investigated groups based on ANOVA are shown in Table 2. According to that table, the midline area was

TABLE 5. Morphology in different vertical skeletal patterns using ANOVA test

Parameter	*n*	Mean	Std. deviation	Std. error	95% Confidence interval for mean		Sig.
					Lower bound	Upper bound	
Long face	20	0.60	0.14	0.03	0.53	0.67	0.898
Normal	20	0.61	0.16	0.03	0.53	0.68	
Short face	20	0.62	0.16	0.03	0.54	0.69	
Total	60	0.61	0.15	0.01	0.57	0.65	

TABLE 6. Relation between airway volume and age, sex, and PFH/ AFH ratio

Model		Unstandardized coefficients		Standardized coefficients	*t*	Sig.
		B	Std. error	Beta		
1	(Constant)	22583.343	10231.936	–	2.207	0.032
	Age	–67.175	63.025	–0.151	–1.066	0.292
	Sex	1712.348	1771.870	0.142	0.966	0.339
	p.f.h/a.f.h	–46.346	160.847	–0.043	–0.288	0.774

not significantly different in the three studied groups ($p = 0.778$).

Table 3 illustrates descriptive analysis of minimum axial area in vertical skeletal patterns, and comparison of statistical significance between the three different groups based on Kruskal-Wallis test. As can be seen, there was no statistically significant difference between the three groups in the minimum axial area ($p = 0.947$). Descriptive analysis of location in skeletal vertical patterns and comparison of statistical significance between the three different groups based on ANOVA are presented in Table 4. According to Table 4, no statistically significant difference was observed in the location between the three groups ($p = 0.745$). Table 5 shows descriptive analysis of morphology in vertical skeletal patterns as well as comparison of statistical significance between the three different groups based on ANOVA test. In the three analyzed groups, no significant difference in terms of airway volume was observed, with *p*-value = 0.898.

INTERPRETATION OF REGRESSION MODEL COEFFICIENTS

The average airway volume in men was 1712.348 units, which was more than that of women, and this value decreased by 67.175 units in each year while age increasing. Also, the average airway volume decreased by 46.346 units, with each unit increasing in PFH/AFH ratio (Table 6).

Taking into account the values of PFH/AFH and age, and assigning 1 and 2 to females and males, respectively, the regression equation model for the prediction was as follows:

(total volume) = 21942.053 + 1406.386 (sex) – 78.153 (age) – 31.012 (PFH/AFH).

DISCUSSION

The respiratory function and morphology of the pharynx upper airway are associated with orthodontic diagnosis and treatment planning. Therefore, changes in the respiratory pattern can affect facial morphology and growth [7]. This study mainly aimed to compare the variables of volume, average, and minimum airway cross-section in the axial section, location, and morphology in different vertical skeletal patterns, using ITK-SNAP software. The results showed no significant differences in the airway volume in the vertical skeletal patterns. The mean airway surface and minimum axial airway cross-section did not differ significantly in the patients with different skeletal patterns. Grauer *et al.* studied premature cases, who were classified according to anterior-posterior relation of the jaws and vertical skeletal patterns. They reported a significant relationship between lower airway volume and anterior-posterior jaw relation, but no correlation was found between different facial skeletal patterns and airway volume [1]. These results are consistent with those of our study concerning different skeletal patterns.

In a study, Celikoglu *et al.* observed significant differences in total airway volume, SN_MP (angle between Sella-Nasion line and mandibular plane) as well as distance between the zygomas, nasopharynx, and oropharynx among different groups of vertical malocclusions, and measured maximum distance between two zygomas in a low-angle patients group. A possible reason explaining a larger airway in low-angle patients than in the other two groups was a long distance between two zygomas. A retruded mandible was another explanation for different airways in high-angle patients [8].

The relation between different types of malocclusion with airway volume and airway cross-section have been mentioned in most previous studies [7, 9]. There are a few studies on the classification of vertical skeletal patterns, with most studies investigating anterior-posterior dimension. The effect of anterior-posterior dimension on the airway seems to be greater than that of vertical dimension. Jayaratne *et al.* studied three-dimensional airway characteristics in young adults with class II and class III skeletal malocclusions. They found that airway volume was significantly higher in class III patients, who presented a highest airway area [10].

The limitation of cephalometric imaging technique is a factor limiting most orthodontic research in the field of airway health. Due to unknown mediolateral width using 2D radiographs, no reliable results can be obtained regarding orthodontic effects on the airway volume. An advantage of the present study and other research on the airway based on CBCT technology is that it allows a measurement of these dimensions, including area and volume [11].

Despite clinical significance of OSA, it is not possible to generalize these findings to OSA, since CBCT images were taken while the patients were awake, which did not allow to identify whether or not their tongues were in a standard position.

Although in this study the patients were imaged in a prone position, a difference in airway volume was reported in prone, sitting, or standing position. It should be noted that a slightly higher airway was reported in studies using standing mode imaging than in those, where patients were imaged in a prone position. Therefore, necessary precautions should be taken in interpretation of airway analysis in 3D images because head posture affects airway volume [12, 13].

In future studies on the airway, it is recommended to perform imaging in a prone position simultaneously with sleep studies. This information can be combined with nasopharyngeal airway measurements to better understand OSA.

Methods used to divide the pharynx into different parts require a combination of hard and soft tissue landmarks to evaluate the airway morphology more accurately. Therefore, it is recommended to compare hard and soft tissue landmarks to discover those more reliable. Although some studies have reported that landmarks such as cervical vertebrae and hyoid bones are not decisive enough due to different locations in patients. Therefore, it cannot be definitely concluded that soft tissue landmarks are more reliable.

Due to lack of research on respiratory health, it is impossible to distinguish effects of tonsillectomy on outcomes. Tonsillar hypertrophy is a result of enlargement in the posterior wall of pharyngeal airway, which is classified into different stages in terms of size. According to Rowe, bulk of the tonsils and presence of the third tonsil are the main causes of upper airway obstruction in young patients [14]. Therefore, more knowledge on the respiratory history of patients would be beneficial. In the present study, however, patients with very large tonsils (more than 4 mm [15]) were excluded, as they cause airway obstruction.

Future studies are recommended to focus on the history of respiratory diseases and to examine the size of tonsils before a study. Also, sleep studies can be performed simultaneously to determine the risk of obstructive sleep disorders more accurately.

CONCLUSIONS

This study showed that the cross-section of the airway in the mid-sagittal section, the minimum cross-section of the airway axial dimension, and the position and morphology of the minimum airway cross-section did not differ in the vertical facial patterns. The average airway volume was higher in males than that of females, which reduced with age improving. Furthermore, the airway volume decreased in growing PFH/AFH ratio.

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CONFLICT OF INTEREST

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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