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Evaluation of Pharyngeal Airway Volume in Individuals with Different Skeletal Patterns

Farklı İskelet Yapısına Sahip Bireylerde Faringeal Havayolu Hacminin Değerlendirilmesi

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Abstract

Objective: This retrospective study aimed to evaluate and compare the airway shape and volume using cone-beam computed tomography (CBCT), which allows three-dimensional examination of the airway in individuals with different skeletal patterns.

Materials and Methods: For this retrospective study, a total of 235 CBCT images were selected from the archives of Dicle University Faculty of Dentistry Department of Oral Diagnosis and Radiology. Selected CBCTs were first divided into three groups according to their ANB angles: Class I (0<ANB<4), Class II (ANB>4) and Class III (ANB<0). Each group was further divided into three subgroups: low angle [SNGoGn<28, sum of posterior angles (SPA)<393], normal angle (28<SNGoGn<36, 393<SPA<399) and high angle (SNGoGn>36, SPA>399) according to SNGoGn and SPA. The total airway volume, oropharyngeal airway volume, nasopharyngeal airway volume, axial area at C2 and C3 vertebra levels, minimum axial area, axial area at the border of the oropharynx and nasopharynx and the transverse and anteroposterior lengths of each area were measured. Kruskal-Wallis variance analysis was used in between-group comparisons. Correlations between variables were tested with the Pearson correlation coefficient.

Results: Statistically significant differences in the oropharyngeal airway and total airway were found between Class I and Class II and between Class II and Class III ($p<0.01$). A statistically significant difference in the total airway volume was noted between the low angle and high angle subgroups of Class I, Class II and Class III ($p<0.05$).

Conclusion: The oropharyngeal, nasopharyngeal and total airway volumes of patients with Class II were smaller than those with Class I and Class III. Individuals with high angle vertical skeletal pattern were found to have smaller total airway volume than those with a low angle vertical skeletal pattern.

Keywords
Oropharyngeal airway, nasopharyngeal airway, cone-beam computed tomography, skeletal pattern

Anahtar Kelimeler
Orofaringeal havayolu, nazofaringeal havayolu, konik ışınlı bilgisayarlı tomografi, iskelet yapısı

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Öz

Amaç: Bu retrospektif çalışmanın amacı, farklı iskelet yapısına sahip bireylerde havayolunun 3-boyutlu incelenmesine olanak veren konik ışınlı bilgisayarlı tomografi (KIBT) yardımıyla havayolu şeklini ve hacmini değerlendirmek ve karşılaştırmaktır.

Gereç ve Yöntemler: Bu retrospektif çalışmada Dicle Üniversitesi Diş Hekimliği Fakültesi Ağız Diş ve Çene Radyolojisi Anabilim Dalı arşivinden toplam 235 KIBT görüntüsü seçildi. Seçilen KIBT'ler ilk olarak ANB açılarına göre Sınıf I ($0<ANB<4$), Sınıf II ($ANB>4$) ve Sınıf III ($ANB<0$) olmak üzere üç gruba ayrıldı. Her grup SNGoGn açısı ve posterior açılar toplamına (PAT) göre üç alt gruba ayrıldı: Kısa ($SNGoGn<28$, $PAT<393$), normal ($28<SNGoGn<36$, $393<PAT<399$) ve uzun ($SNGoGn>36$, $PAT>399$). Toplam havayolu hacmi, orofaringeal hava yolu hacmi, orofaringeal havayolu hacmi, nazofaringeal havayolu hacmi, C2 ve C3 vertebra seviyelerinde aksiyal alan, minimum aksiyal alan, orofarinks ve nazofarinks sınırında aksiyal alan ve her alanın transversal ve anteroposterior uzunluğu ölçüldü. Gruplar arası karşılaştırmalarda Kruskal-Wallis varyans analizi kullanıldı. Değişkenler arasındaki korelasyonlar Pearson korelasyon katsayısı ile test edildi.

Bulgular: Orofaringeal havayolu ve toplam havayolunda Sınıf I ve Sınıf II grupları ile Sınıf II ve Sınıf III grupları arasında $p<0,01$ düzeyinde istatistiksel olarak anlamlı farklılıklar bulundu. Sınıf I, Sınıf II ve Sınıf III gruplarının kısa ve uzun alt grupları arasında toplam havayolu hacminde $p<0,05$ düzeyinde istatistiksel olarak anlamlı farklılık vardı.

Sonuç: Sınıf II hastaların orofaringeal, nazofaringeal ve toplam havayolu hacimleri, Sınıf I ve Sınıf III hastalardan daha küçüktü. Uzun yüz yapısına sahip bireylerin, kısa yüz yapısına sahip olanlara göre daha küçük toplam havayolu hacmine sahip oldukları bulundu.

Introduction

Obstructive sleep apnea (OSA) is a form of sleep-disordered breathing that has a high prevalence rate and is often underdiagnosed. Although it has been known for years, its importance for individuals and society has recently come to the fore. Upper airway narrowing is also considered a risk factor for OSA (1). Due to close relationship between pharyngeal structures and both craniofacial structures, a mutual interaction between pharyngeal structures and dentofacial pattern is expected. Therefore, the relationship between airway volume and facial morphology has long been a subject of debate, and there is a general view that oropharyngeal and nasopharyngeal structures play a role in the development of the dentofacial complex (2-7).

Most of the previous researchers (2-6,8-11) analyzed the relationship between facial morphology and pharyngeal airway shape on 2-dimensional (2D) cephalometric radiographs. However, the problem with 2D radiographs is that they do not allow assessment of pharyngeal volumes. The human airway is 3-dimensional (3D) and therefore lateral films represent 3D structure in 2D. Therefore, previous studies were limited due to analyzing a 3D structure in 2D (12). Lateral cephalometric radiographs also have severe limitations in distortion, magnification, superimposition, and low reproducibility (13).

The diagnostic capacity of the airway has expanded with the development of computed tomography (CT) 3D technology; however, there is an important limitation in the routine use of CT devices due to the high radiation dose they generate. The radiation dose has been reduced thanks to the development of cone-beam computed tomography (CBCT). CBCT has become an accepted craniofacial imaging technique, especially known for its low radiation dose and faster image acquisition times compared to conventional CT (14).

The aim of this retrospective study is to evaluate and compare airway shape and volume with the help of CBCT, which allows the 3D examination of the airway in individuals with different skeletal pattern. Most or the previous studies were based on the sagittal craniofacial pattern and upper pharyngeal airway. This study focused on both sagittal and vertical skeletal pattern with extended sample size.

Materials and Methods

This retrospective study protocol was approved by the Local Ethics Committee in Dicle University Faculty of Dentistry (decision no: 5, date: 01.12.2014). Patients were not given additional radiation for the purpose of this study. CBCT scans were performed for better diagnosis of dental problems, and all patients or parents signed an informed consent form allowing the use of these records. One thousand and three hundred CBCT scans in the archives of Dicle University Faculty of Dentistry Department of Oral Diagnosis and Radiology were evaluated and CBCT scans of 235 individuals (114 girls, 121 boys) who met the inclusion criteria were selected. Our exclusion criteria for research were: detectable pathology along the upper airway, missing teeth except third molars, previous orthodontic treatment or orthognathic surgery, craniofacial syndrome and cleft lip and palate, adenoidectomy or tonsillectomy, CBCT scan age less than 16, nasal obstruction and scans showing incomplete view of the upper airway.

Selected CBCTs were first divided into three groups according to their ANB angles, Class I (0<ANB<4), Class II (ANB>4) and Class III (ANB<0). Each group is divided into three subgroups, low angle (SNGoGn<28, sum of posterior angles (SPA)<393), normal angle (28<SNGoGn<36, 393<SPA<399) and high angle (SNGoGn>36, SPA>399) according to SNGoGn and SPA. The male-female composition of the individuals included in this study by groups and subgroups are shown in Table 1.

All selected CBCT images were acquired with an i-CAT (Imaging Sciences International, Hatfield, Pa) device with 5.0 mA, 120kV, 0.3 mm voxel thickness, a single 360° rotation and 9.6 seconds setting. All data were collected and measured by the same researcher (Y.A.U). All skeletal and airway measurements were done with Dolphin 3D (version 11, Dolphin imaging & Management Solutions, Chatsworth, Calif), a third-party software program.

Total airway volume (TAV), oropharyngeal airway volume (OAV), nasopharyngeal airway volume (NAV), axial area at C2 and C3 vertebra levels, minimum (min) axial area, axial area at the border of the oropharynx and nasopharynx, and the transverse and anteroposterior (AP) length of each area were measured for 3D airway analysis on the CBCT data. The posterior border of the TAV is the posterior pharyngeal wall, the anterior border is the anterior pharyngeal wall, the lower border is the line passing through the lowest and the furthest level of vertebra C3 and parallel to the Frankfurt horizontal plane. When viewed from the sagittal aspect, the upper border is determined as the line that will contain the radiolucent region remaining posteriorly in the section where the dorsal region of the vomer meets the palate (Figure 1). The upper boundary of the OAV is defined as the line that passes through the lowest and foremost end of the Atlas and runs parallel to the Frankfurt Horizontal plane. The lower border is the line passing through the lowest and foremost level of vertebrae C3 and parallel to the Frankfurt Horizontal plane, the posterior border is the posterior pharyngeal wall and the anterior border is the anterior pharyngeal wall (Figure 2). NAV was calculated as the volume obtained by subtracting the OAV from the TAV.

Statistical Analysis

SPSS 15.0 (SPSS Inc., Chicago, IL, USA) statistical package program was used to analyze the data obtained in our study. Statistical significance was set at 0.05. Chi-square test was used to check the distribution of gender in balance between groups. Kolmogorov-Smirnov test was used to determine whether the data were normally distributed. One-Way ANOVA analysis was used to comparisons between groups with normally distributed parameters. Kruskal-Wallis variance analysis was used as a statistical method for comparing the groups for parameters that did not show normal distribution. The Mann-Whitney U test with Bonferroni correction was used for parameters that showed statistically significant differences according to the analysis results. Correlations between variables were tested with the Pearson correlation coefficient.

Images were re-measured 3 weeks after the first measurements for reliability purposes. Dahlberg's

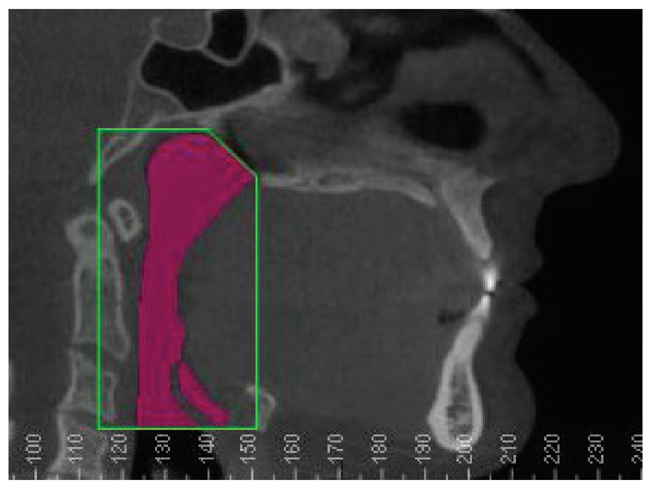

Figure 1. Total airway volume borders

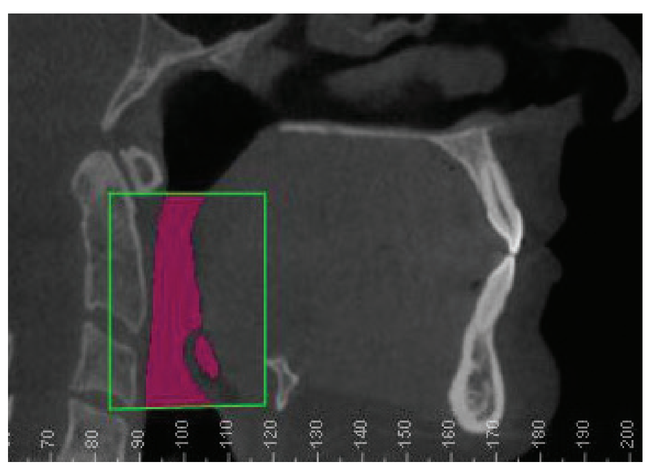

Figure 2. Oropharyngeal airway volume borders

formula ($\sqrt{\sum d^2/2n}$) for linear, areal and angular measurements and the intra-class correlation coefficient (ICC) for volumetric measurements were used to test reliability (15).

Results

In the evaluation of operator calibration, it was confirmed that the ICC results were between 0.928-0.941, and the results of Dalhberg's formula were between 0.354 and 0.802 for all variables evaluated.

The gender distributions of the groups are given in Table 1. The chi-square test was used to check the balanced distribution of gender among the groups. In the groups of this study, we could not find any differences between the groups due to the similar male-female composition and the data were combined because there was no significant difference. As we used ANB, SnGoGn and SPA to form the groups, it was expected to have statistically significant differences on skeletal variables between the groups ($p<0.001$).

Descriptive statistics showing means, standard deviations, min and maximum values for different groups and the results of their comparison are shown in Table 2 ($p<0.05$). There were statistically significant differences between Class I and Class II groups, Class II and Class III groups in terms of OAV, NAV, TAV, cross-sectional area at the C3 level, and min axial area. C3 T and C3 AP lengths differ significantly between Class II and Class III groups ($p<0.05$); min axial AP length between Class I and Class II groups ($p<0.05$); however, no difference was found in other length parameters.

Statistically significant differences were found between the low angle and high angle subgroups of Class I group in terms of OAV and TAV ($p<0.05$). Statistically significant differences at $p<0.05$ level were found between the low angle and high angle subgroups of the Class I group and the normal angle and high angle subgroups in the cross-sectional area at C2 level. There were statistically significant differences at $p<0.01$ level in terms of C2 AP length between the low angle and high angle, normal angle and high angle subgroups of the Class I group (Table 3). There was a statistically significant difference at the level of $p<0.05$ in TAV between the low angle and high angle subgroups of Class II and Class III groups (Tables 4, 5).

Bivariate correlations are given in Table 6. Negative correlations were found between volumetric measurements and ANB, SNGoGn and SPA. In addition, negative correlations were found between C2, min and O-N border AP length measurements, SNGoGn and SPA. A high correlation was found between the min axial cross-sectional area and volumetric measurements. A positive correlation was found between OAV and NAV.

Discussion

There are few studies examining the pharyngeal airway with 3D techniques in Class I, Class II and Class III skeletal malocclusions with different vertical skeletal pattern. Whereas, understanding the anatomy of individuals with different craniofacial growth patterns and the nature of this region may create new opportunities for the development of treatment plans and treatment methods.

Table 1. Male-female composition of Class I, Class II and Class III groups and their subgroups

Group	Female	Male	Sum	Subgroup	Female	Male	Sum	p
Class I	42	40	82	High angle	14	14	28	>0.10
				Normal angle	14	14	28	
				Low angle	14	12	26	
Class II	40	43	83	High angle	12	14	26	
				Normal angle	14	15	29	
				Low angle	14	14	28	
Class III	32	38	70	High angle	11	13	24	
				Normal angle	10	12	22	
				Low angle	11	13	24	
Sum	114	121	235		114	121	235	

Table 2. Descriptive statistics showing the means, standard deviations, minimum and maximum values of the Class I, Class II and Class III groups and results of intergroup comparisons using Kruskal-Wallis test

	Class I				Class II				Class III				I-II	I-III	II-III
	n	Mean ± SD	Min	Max	n	Mean ± SD	Min	Max	n	Mean ± SD	Min	Max		p	p
Volumetric (mm³)															
OAV	82	11296.51±4475.99	4483.90	21374.80	83	9240.28±2489.81	2929.7	23110.2	70	11427.97±2887.77	3159.70	31943	**	NS	**
NAV	82	11192.44±3737.70	3771	22051	83	9423.65±3767.87	1297.3	21806.1	70	10693.53±3509.48	2385	24239.70	**	NS	*
TAV	82	22488.94±7407.03	10655.20	41025.90	83	18663.93±5232.03	6998	44916.3	70	22121.50±5997.42	6635.10	44749.3	**	NS	**
Cross-sectional (mm²)															
C2	82	247.76±118.90	54.70	563.50	83	219.64±119.11	40.70	620.2	70	240.35±106.38	60.30	506.70	NS	NS	NS
C3	82	268.64±117.56	75.60	589.60	83	222.98±108.49	54.60	641.10	70	269.32±131.21	66.40	707.10	*	NS	*
MinAx	82	202.59±94.71	50	441.7	83	157.68±82.04	33.1	421.9	70	175.48±78.69	57.40	407.20	**	NS	*
OP-NP border	82	303.26±110.8	86.7	565.8	83	278.08±118.91	46.5	569.2	70	293.99±120.14	59.20	735.90	NS	NS	NS
Length (mm)															
C2 T	82	25.19±6.59	10.59	38.28	83	24.41±7.02	10.30	40.30	70	26.8±7.16	10.41	50	NS	NS	NS
C2 AP	82	10.94±3.58	3.57	20	83	10.21±3.07	3.49	19.43	70	11.23±3.72	4.31	19.67	NS	NS	NS
C3 T	82	29.38±5.2	14.44	40.54	83	28.39±5.61	14.14	40.42	70	30.67±6.19	16.33	51	NS	NS	*
C3 AP	82	11.73±4.36	3.90	22.12	83	10.33±3.83	3.08	21.67	70	12.03±4.47	4.35	26.88	NS	NS	*
MinAx T	82	23.22±6.03	10.54	39.94	83	23.38±6.30	10.59	30.54	70	23.56±6.08	7.14	36.56	NS	NS	NS
MinAx AP	82	9.43±3.01	3.20	15.11	83	8.05±2.99	2.65	17.58	70	8.33±3.03	2.59	15.71	*	NS	NS
OP-NP border T	82	29.2±6.61	14.86	44.44	83	27.18±7.46	10.70	50.88	70	28.79±6.42	13.96	42.5	NS	NS	NS
OP-NP border AP	82	12.08±3.47	6.46	22.96	83	11.26±3.38	4.23	20.5	70	12.30±4.03	4.79	30	NS	NS	NS

NAV: Nasopharyngeal airway volume, OAV: Oropharyngeal airway volume, TAV: Total airway volume, OP: Oropharynx, NP: Nasopharynx, minAx: Minimum area of the oropharynx on the axial slice, T: Transversal, AP: Anteroposterior, I: Class I, II: Class II, III: Class III, SD: Standard deviation; min: Minimum, max: Maximum, NS: Not significant, *p<0.05, **p<0.01, ***p<0.001

Table 3. Descriptive statistics of Class I subgroups showing means and standard deviations of volumetric, cross-sectional, and length variables, and comparison of these measurements according to vertical skeletal pattern

Class I									
	Low angle		Normal angle		High angle		L-N	L-H	N-H
Volumetric (mm³)	n	Mean ± SD	n	Mean ± SD	n	Mean ± SD	p	p	p
OAV	28	12386.62±4640.58	29	11766.08±5855.47	26	9736.83±3570.29	NS	*	NS
NAV	28	11646.36±3426.18	29	11640.37±3958.44	26	10290.59±3752.73	NS	NS	NS
TAV	28	24032.98±7308.16	29	23406.45±8111.74	26	20027.39±6311.91	NS	*	NS
Cross sectional (mm²)									
C2	28	279.29±134.83	29	261.67±109.52	26	202.32±102.59	NS	*	*
C3	28	286.89±143.75	29	272.34±93.74	26	246.69±109.29	NS	NS	NS
MinAx	28	204.21±100.21	29	198.10±98.29	26	205.46±82.41	NS	NS	NS
OP-NP border	28	301.91±118.99	29	294.52±96.19	26	313.35±113.94	NS	NS	NS
Length (mm)									
C2 T	28	25.55±6.49	29	25.89±6.72	26	24.13±6.64	NS	NS	NS
C2 AP	28	12.19±3.88	29	11.45±3.66	26	9.18±2.51	NS	* *	* *
C3 T	28	30.32±5.53	29	29.15±4.11	26	28.67±5.93	NS	NS	NS
C3 AP	28	11.94±5.19	29	12.42±3.85	26	10.83±4.01	NS	NS	NS
MinAx T	28	22.77±4.33	29	24.08±5.75	26	22.81±7.59	NS	NS	NS
MinAx AP	28	8.78±3.29	29	8.76±3.18	26	10.75±2.53	NS	NS	NS
OP-NP border T	28	30.45±6.67	29	28.85±6.27	26	28.3±6.98	NS	NS	NS
OP-NP border AP	28	13.12±4.04	29	11.96±2.40	26	11.16±3.69	N.S.	N.S.	N.S.

NAV: Nasopharyngeal airway volume, OAV: Oropharyngeal airway volume, TAV: Total airway volume, OP: Oropharynx, NP: Nasopharynx, MinAx: Minimum area of the oropharynx on the axial slice, T: Transversal, AP: Anteroposterior, L: Low angle group, N: Normal angle group, H: High angle group, SD: Standard deviation, NS: Not significant, *p<0.05, **p<0.01, ***p<0.001

Although there are 2D studies in the literature in which airway analyzes of individuals are performed, the number of 3D studies has not yet reached a sufficient level yet (3-6,10). The advantage of this method is that the lateral cephalometric radiography is more common and cheaper than CBCT, and the radiation level is lower. Since the human airway is a 3D dynamic structure, it is not sufficient to examine it statically in 2D. However, there are some disadvantages, such as magnification of the 2D image, distortion, and superimposing of anatomical structures (16). Aboudara et al. (12) reported that CBCT was a simple and effective data for accurate airway analysis in their study comparing the airway measurements obtained with lateral cephalometric radiography and CBCT. In addition, 2D measurements of nasopharyngeal airway area; they found that due to the compression of the 3D structure into the 2D structure, most of the structural information was insufficient. Airway measurements of this study are consistent with the study of Haskell et al. (17).

As is known, the airway is a mobile structure and can exhibit mobility during inhalation. Lowe et al. (13) reported that airway size is related to the respiratory phase. People are routinely instructed to hold their breath during the CBCT scan with the i-CAT device. It is suitable for not breathing due to its short 9.6 seconds scanning time. Thus, the respiratory phase was controlled, a standardization of the images was obtained and at the same time, the airway was kept stable during the scan.

El and Palomo (18) performed 3D measurements of the pharyngeal airway using different software programs and compared the accuracy and reliability

Table 4. Descriptive statistics of Class II subgroups showing means and standard deviations of volumetric, cross-sectional, and length variables, and comparison of these measurements according to vertical skeletal pattern

Class II									
	Low angle		Normal angle		High angle		L-N	L-H	N-H
Volumetric (mm³)	**n**	**Mean ± SD**	**n**	**Mean ± SD**	**n**	**Mean ± SD**	**p**	**p**	**p**
OAV	24	9838.04±4488.03	22	9475.61±4875.09	24	8407.19±4185.27	NS	NS	NS
NAV	24	10433.59±3254.85	22	9047.91±4962.34	24	8789.45±3939.99	NS	NS	NS
TAV	24	20271.63±6678.80	22	18523.52±8010.50	24	17196.64±6979.50	NS	*	NS
Cross sectional (mm²)									
C2	24	227.64±122.49	22	239.00±108.11	24	192.28±101.20	NS	NS	NS
C3	24	230.05±124.32	22	233.24±89.32	24	205.65±110.07	NS	NS	NS
MinAx	24	161.98±82.81	22	170.63±91.12	24	140.43±72.81	NS	NS	NS
OP-NP border	24	269.79±87.52	22	281.87±135.34	24	282.58±133.88	NS	NS	NS
Length (mm)									
C2 T	24	23.56±5.27	22	26.44±8.76	24	23.23±6.65	NS	NS	NS
C2 AP	24	10.35±3.55	22	10.91±2.49	24	9.37±2.97	NS	NS	NS
C3 T	24	28.67±5.59	22	29.03±5.51	24	27.47±6.12	NS	NS	NS
C3 AP	24	10.89±4.13	22	10.64±3.20	24	9.46±4.05	NS	NS	NS
MinAx T	24	23.82±6.51	22	23.13±6.89	24	23.19±5.75	NS	NS	NS
MinAx AP	24	8.30±3.33	22	8.30±2.83	24	7.55±2.84	NS	NS	NS
OP-NP border T	24	26.91±7.09	22	27.83±8.95	24	26.8±6.56	N.S.	N.S.	N.S.
OP-NP border AP	24	10.89±2.22	22	11.50±3.34	24	11.39±4.35	N.S.	N.S.	N.S.

NAV: Nasopharyngeal airway volume, OAV: Oropharyngeal airway volume, TAV: Total airway volume, OP: Oropharynx, NP: Nasopharynx, MinAx: Minumum area of the oropharynx on the axial slice, T: Transversal, AP: Anteroposterior, L: Low angle group, N: Normal angle group, H: High angle group, SD: Standard deviation, NS: Not significant, *p<0.05, **p<0.01, ***p<0.001

of these programs. One of the software programs they use is the Dolphin 3D program, and they have reported that it is reliable. In our study, we performed 3D airway analysis using Dolphin 3D software.

In the literature, malocclusion type has no effect on pharyngeal airway width (5,6). When the skeletal classification is examined, it is seen that Class I and Class III individuals have a larger airway volume than Class II individuals. Kim et al. (19) stated that retrognathic individuals tend to have a smaller airway volume in normal anteroposterior relationship compared to those with retrognathic jaws. In our study, we found that the smaller airway volume in Class II skeletal individuals emerged as a result of the retrognathic skeletal structure. Grauer et al. (20) also found similar findings. In the Class II group, the shorter and backward mandible can push the tongue and soft palate into the pharyngeal cavity, resulting in a decrease in the volume of the oropharynx. Kikuchi (21) reported in a 3D airway study that the airway is affected by the skeletal structure of the oropharyngeal region. He stated that the pharyngeal morphology other than the airway size was affected by the anteroposterior relationship of the mandible.

El and Palomo (7), in a study examining the airway in 3D, found that the NAV of Class I individuals was larger than Class II individuals. Kerr (9) stated that individuals with Class II malocclusion have smaller nasopharyngeal and adenoid tissue areas. Researchers have shown that there is a relationship between the upper airway and the type of malocclusion and that the nasopharynx is narrower in individuals

Table 5. Descriptive statistics of Class III subgroups showing means and standard deviations of volumetric, cross-sectional, and length variables, and comparison of these measurements according to vertical skeletal pattern

Class III									
	Low angle		Normal angle		High angle		L-N	L-H	N-H
Volumetric (mm³)	**n**	**Mean ± SD**	**n**	**Mean ± SD**	**n**	**Mean ± SD**	**p**	**p**	**p**
OAV	28	12088.98±4549.18	28	11711.97±5564.04	26	10482.96±4467.88	NS	NS	NS
NAV	28	11808.89±3548.90	28	10663.86±3508.07	26	9607.84±3193.09	NS	NS	NS
TAV	28	23897.87±7534.68	28	22375.83±6241.54	26	20090.8±6832.01	NS	*	NS
Cross sectional (mm²)									
C2	28	250.14±110.87	28	239.74±106.80	26	231.17±104.21	NS	NS	NS
C3	28	282.60±134.80	28	280.82±137.96	26	244.54±120.67	NS	NS	NS
MinAx	28	178.66±76.45	28	179.68±84.94	26	168.1±70.80	NS	NS	NS
OP-NP border	28	314.68±144.16	28	295.56±91.29	26	271.73±119.33	NS	NS	NS
Length (mm)									
C2 T	28	26.67±7.42	28	27.05±6.42	26	26.68±7.69	NS	NS	NS
C2 AP	28	11.60±3.74	28	11.43±3.59	26	10.66±3.90	NS	NS	NS
C3 T	28	31.29±7.08	28	30.98±6.43	26	29.74±4.87	NS	NS	NS
C3 AP	28	12.11±4.23	28	13.45±4.43	26	10.53±4.41	NS	NS	Ns
MinAx T	28	23.84±6.17	28	23.84±5.17	26	23±7.03	NS	NS	NS
MinAx AP	28	8.29±3.21	28	8.67±3.01	26	8.03±2.95	NS	NS	NS
OP-NP border T	28	29.85±7.30	28	28.63±4.91	26	27.89±6.89	NS	NS	NS
OP-NP border AP	28	13.54±5.38	28	12.24±2.66	26	11.12±3.21	NS	NS	NS

NAV: Nasopharyngeal airway volume, OAV: Oropharyngeal airway volume, TAV: Total airway volume, OP: Oropharynx, NP: Nasopharynx, MinAx: Minumum area of the oropharynx on the axial slice, T: Transversal, AP: Anteroposterior, L: Low angle group, N: Normal angle group, H: High angle group, SD: Standard deviation, NS: Not significant, *p<0.05, **p<0.01, ***p<0.001

with Class II malocclusion (22,23). Hwang et al. (24) reported that the narrowed nasopharyngeal airway is associated with the retrusive mandible and maxilla. Paul and Nanda (23) found a high prevalence of mouth breathing and nasopharyngeal airway obstruction in individuals with Class II malocclusion. These studies are compatible with our study.

In some studies (5,6,8), no significant difference was found when comparing the upper airways of various individuals. We concluded that these results are due to the small number of cases, the classification being performed as dental instead of skeletal, or 2D studies.

In this study, statistically significant differences were found between the Class I and Class II groups and between the Class II and Class III groups in C3 and min axial cross-sectional areas. There was no difference in other area parameters. In linear measurements, no statistically significant difference was observed in most parameters. The statistically significant differences observed in the volumetric parameters were not similar in all area and linear parameters. We concluded that not every subdivision of the airway represents the entire airway capacity of the individual. The findings of Kim et al. (19) are consistent with this result.

In this study, it was observed that individuals with the high angle vertical skeletal type had a smaller TAV than the low angle type. There was no significant difference in NAV in all three groups and subgroups. Kerr (9), Handelman and Osborne (25) found a weak relationship between facial morphology and the nasopharyngeal airway. These studies are consistent with our findings. de Freitas et al. (6) found that

Table 6. Pearson correlation coefficients for oropharyngeal airway volume, nasopharyngeal airway volume, total airway volume, and MinAx area compared with the variables used for this study

		OAV	NAV	TAV	Minimum axial area
ANB	R	-0.176**	-0.207**	-0.173**	-0.178**
SN-GoGn	R	-0.175**	-0.196**	-0.211**	-0.140*
SIA	R	-0.180**	-0.192**	-0.213**	-0.144*
Age	R	0.047	0.027	0.036	0.007
OAV	R	1	0.513**	0.899**	0.860**
NAV	R	0.513**	1	0.838**	0.523**
TAV	R	0.899**	0.838**	1	0.815**
C2 Area	R	0.895**	0.476**	0.813**	0.843**
C3 Area	R	0.231**	0.316**	0.626**	0.690**
MinAx	R	0.860**	0.523**	0.815**	1
O-N Area	R	0.681**	0.528**	0.703**	0.640**
C2 T	R	0.713 **	0.408**	0.662**	0.632**
C2 AP	R	0.701**	0.311**	0.605**	0.697**
C3 T	R	0.561**	0.244**	0.482**	0.496**
C3 AP	R	0.606**	0.263**	0.520**	0.600**
MinAx T	R	0.712**	0.422**	0.699**	0.693**
MinAx AP	R	0.631**	0.361**	0.586**	0.712**
O-N T	R	0.630**	0.541**	0.678**	0.614**
O-N AP	R	0.436**	0.284**	0.423**	0.377**

NAV: Nasopharyngeal airway volume, OAV: Oropharyngeal airway volume, TAV: Total airway volume, minAx: Minimum area of the oropharynx on the axial slice, SIA: Sum of the inner angles, T: Transversal, AP: Anteroposterior *Correlation is significant at the 0.05 level (2-tailed) **Correlation is significant at the 0.01 level (2-tailed)

individuals with vertical skeletal pattern of Class I and Class II malocclusion had a narrower upper airway than vertically normal Class I and Class II malocclusion individuals. Other 2D studies (26-28) are not in line with our results. These studies were performed to evaluate pharyngeal airway widths on 2D lateral cephalometric films. Airway volume requires complex and dynamic 3D evaluation. There may be different findings due to this situation.

A negative correlation was found between volumetric measurements and ANB angle in the current study. This supports the results of the comparison of different anteroposterior skeletal types between the groups. This negative correlation between ANB angle and volumetric measurements can be explained by the fact that Class I and Class III groups have larger airway volume than Class II group. El and Palomo (7) observed that the oropharyngeal volume is inversely correlated with the ANB angle. Ceylan and Oktay's (5) study is also compatible with our study. Kim et al. (19) showed a negative correlation between the ANB angle and the TAV in their study.

A negative correlation was found between the volumetric measurements and SNGoGn and SPA angles. In addition, a negative correlation was found between C2, minimum and O-N boundary anteroposterior length measurements and SNGoGn and SPA angles. Joseph et al. (2) reported that the hyperdivergetic patients showed narrow pharyngeal dimensions, especially in the nasopharynx at the level of the hard palate, in the anteroposterior direction, and at the level of the soft palate and mandible in the anteroposterior direction. Our results are consistent with studies reporting an inverse relationship between pharyngeal volume and vertical skeletal type (6,29,30). El and Palomo (7) could not find a significant correlation between mandibular plane angle and OAV and NAV. The reason for this different result may be that El and Palomo (7) excluded severe hypodivergent and hyperdivergent individuals from their work. Contrary to our findings, Kim et al. (19) found a positive correlation between vertical skeletal pattern and values analyzing airway volume. The reason for this discrepancy may be due to the values used to evaluate the vertical skeletal type being less comparable to the different values used.

A high correlation was found between the min axial cross-sectional area and volumetric measurements. Tso et al. (31) also mentioned the high correlation between the narrowest cross-sectional area of the airway and TAV. El and Palomo (7) found a high correlation between OAV and min axial cross-sectional area. Considering the results of our study, we think that the determining the areas with upper airway constriction and understanding the size and volume of the pharyngeal airway are clinically important in treatment planning.

A positive correlation was found between OAV and NAV. Kim et al. (19) found a positive correlation between the nasal airway and the upper pharyngeal airway. El and Palomo (7) also found a positive correlation between NAV and OAV. We think that the positive correlation between the OAV and NAV is due to the use of healthy individuals without airway pathology. Individuals with nasal allergy, craniofacial anomalies, hypertrophic adenoids, and narrowed nasopharyngeal airway space will have pharyngeal contraction inevitable and a negative correlation will be observed (32). Structurally, OAV and NAV are not only anatomically contiguous structures, but also directly related in volume. Therefore, the positive and negative factors that may occur will contribute positively and negatively to the correlation relationship.

Conclusion

Class II individuals have smaller OAV, NAV, TAV and min axial area than Class I and Class III groups. Individuals with high angle vertical skeletal pattern were found to have smaller TAV than those with a low angle vertical skeletal pattern.

Volumetric studies about pharyngeal airway add a new perspective to orthodontic practice. Detailed analysis of airway shape and volume can be an important tool in orthodontic diagnosis and treatment plan. Caution should be taken in this regard, especially in patients with mandibular retrusion, with a tendency to have a smaller oropharyngeal area and volume, and patients with hyperdivergent growth patterns.

Ethics

Ethics Committee Approval: This retrospective study protocol was approved by the Local Ethics Committee in Dicle University Faculty of Dentistry (decision no: 5, date: 01.12.2014).

Informed Consent: All patients or parents signed an informed consent form allowing the use of these records.

Peer-review: Externally peer-reviewed.

Authorship Contributions

Concept: M.İ.K., Y.A.Ü., Design: M.İ.K., Y.A.Ü., Supervision: M.İ.K., Data Collection or Processing: Y.A.Ü., Analysis or Interpretation: İ.Y., Literature Search: M.İ.K., Critical Review: M.İ.K., Writing: Y.A.Ü.

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References

1. Banno K, Kryger MH. Sleep apnea: clinical investigations in humans. Sleep med 2007; 8: 400-26.
2. Joseph AA, Elbaum J, Cisneros GJ, Eisig SB. A cephalometric comparative study of the soft tissue airway dimensions in persons with hyperdivergent and normodivergent facial patterns. J Oral Maxillofac Surg 1998; 56: 135-9.
3. Alves M, Franzotti E, Baratieri C, Nunes L, Nojima L, Ruellas A. Evaluation of pharyngeal airway space amongst different skeletal patterns. Int J Oral Maxillofac Surg 2012; 41: 814-9.
4. 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: a pilot study. J Orofac Orthop 2013; 74: 18-27.
5. Ceylan I, Oktay H. A study on the pharyngeal size in different skeletal patterns. Am J Orthod Dentofacial Orthop 1995; 108: 69-75.
6. de Freitas MR, Alcazar NM, Janson G, de Freitas KM, Henriques JF. Upper and lower pharyngeal airways in subjects with Class I and Class II malocclusions and different growth patterns. Am J Orthod Dentofacial Orthop 2006; 130: 742-5.
7. El H, Palomo JM. Airway volume for different dentofacial skeletal patterns. Am J Orthod Dentofacial Orthop 2011; 139: e511-21.
8. McNamara Jr JA. Influence of respiratory pattern on craniofacial growth. Angle Orthod 1981; 51: 269-300.
9. Kerr WJS. The nasopharynx, face height, and overbite. Angle Orthod 1985; 55: 31-6.
10. Uçar Fİ, Uysal T. Orofacial airway dimensions in subjects with Class I malocclusion and different growth patterns. Angle Orthod 2011; 8: 460-8.

11. Martin O, Muelas L, Vinas MJ. Nasopharyngeal cephalometric study of ideal occlusions. Am J Orthod Dentofacial Orthop 2006; 130: 436 e1-9.
12. Aboudara C, Nielsen I, Huang JC, Maki K, Miller AJ, Hatcher D. Comparison of airway space with conventional lateral headfilms and 3-dimensional reconstruction from cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2009; 135: 468-79.
13. Lowe AA, Fleetham JA, Adachi S, Ryan CF. Cephalometric and computed tomographic predictors of obstructive sleep apnea severity. Am J Orthod Dentofacial Orthop 1995; 107: 589-95.
14. Palomo JM, Rao PS, Hans MG. Influence of CBCT exposure conditions on radiation dose. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008; 105: 773-82.
15. Dahlberg G. Statistical methods for medical and biological students. Statistical Methods for Medical and Biological Students. Br Med J 1940; 2: 358-9.
16. Farman AG, Scarfe WC. The basics of maxillofacial cone beam computed tomography. Semin Orthod 2009; 15: 2-13.
17. Haskell JA, McCrillis J, Haskell BS, Scheetz JP, Scarfe WC, Farman AG. Effects of mandibular advancement device (MAD) on airway dimensions assessed with cone-beam computed tomography. Semin Orthod 2009; 15: 132-58.
18. El H, Palomo JM. Measuring the airway in 3 dimensions: a reliability and accuracy study. Am J Orthod Dentofacial Orthop 2010; 137: S50 e1-9; discussion S-2.
19. 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.
20. 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.
21. Kikuchi Y. Three-dimensional relationship between pharyngeal airway and maxillo-facial morphology. Bull Tokyo Dent Coll 2008; 49: 65-75.
22. Mergen DC, Jacobs RM. The size of nasopharynx associated with normal occlusion and Class II malocclusion. Angle Orthod 1970; 40: 342-6.
23. Paul J, Nanda RS. Effect of mouth breathing on dental occlusion. Angle Orthod 1973; 43: 201-6.
24. Hwang YI, Lee KH, Lee KJ, Kim SC, Cho Hj, Chean Sh et al. Effect of airway and tongue in facial morphology of prepubertal Class I, II children. Korean J Orthod 2008; 38: 74-82.
25. Handelman CS, Osborne G. Growth of the nasopharynx and adenoid development from one to eighteen years. Angle Orthod 1976; 46: 243-59.
26. Ackerman R, Klapper L. Tongue position and open-bite: the key roles of growth and the nasopharyngeal airway. ASDC J Dent Child 1981; 48: 339-45.
27. Linder-Aronson S, Backstrom A. A comparison between mouth and nose breathers with respect to occlusion and facial dimensions. Odontol Revy 1960; 2: 343-76.
28. Faye Dunn G, Green LJ, Cunat JJ. Relationships between variation of mandibular morphology and variation of nasopharyngeal airway size in monozygotic twins. Angle Orthod 1973; 43: 129-35.
29. Linder-Aronson S. Adenoids: Their effect on mode of breathing and nasal airflow and their relationship to characteristics of the facial skeleton and the dentition. A biometric, rhino-manometric and cephalometro-radiographic study on children with and without adenoids. Acta Otolaryngol Suppl 1970; 265: 1-132.
30. Behlfelt K, Linder-Aronson S, McWilliam J, Neander P, Laage-Hellman J. Cranio-facial morphology in children with and without enlarged tonsils. Eur J Orthod 1990; 12: 233-43.
31. 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.
32. Fairburn SC, Waite PD, Vilos G, Hording SM, Bernreuter W, Cure J et al. Three-dimensional changes in upper airways of patients with obstructive sleep apnea following maxillomandibular advancement. J Oral Maxillofac Surg 2007; 65: 6-12.