RESEARCH

Cone-Beam Computed Tomography Analysis of Pharyngeal Airway Among Different Skeletal Facial Types

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Abstract: Craniofacial anomalies may cause alteration of pharyngeal airway due to compensation mechanisms occur as a result of physiological progresses. It's been always a subject of interest for orthodontics if there is a correlation between face morphology and airway. The aim of our study is to evaluate the relationship between pharyngeal airway and craniofacial structures according to facial growth patterns by 3-D imaging methods in individuals with different skeletal anomalies. For this purpose, archieved Cone Beam Computed Tomography (CBCT) images are used. Total number of 180 CBCT data were divided into to 3 groups in sagittal direction according to ANB as Class 1, Class 2 and Class 3. Then, each group were divided into 3 subgroups in vertical direction as horizontal, normal and vertical face types according to the SN-GoGn and sum of Posterior angles. The volumetric, areal and linear measurements of the airway were performed on the CBCT images by the MIMICS program and the results were analyzed by statistical methods. There was no statistically significant difference in volumetric measurements between Class 1, Class 2 and Class 3 groups. Significant differences in areal measurements in axial area at C2 level, in the transversal area at O-N border and in linear measurements, a-p at C2 levels and a-p at O-N margin were found. In Class 3 patients, there was a statistically significant difference between horizontal and normal face types at the level of a-p at C2. There was a statistically significant difference in a-p measurements at C2 level of horizontal face type group between Class 1-Class 3 and between Class 2-Class 3 groups. Malformations in the sagittal direction and different facial types in the vertical dimension may be related to pharyngeal airway volume and dimension.

INTRODUCTION

Morphological, physiological or pathological features such as adenoid and tonsillar hypertrophy, chronic and allergic rhinitis, infections, congenital nasal deformities, nasal trauma, polyps and tumors are predisposing factors that may cause pharyngeal airway obstruction which results in oral respiration and functional imbalance[1].

Several studies on pharyngeal airway and face types have been done[1,3]. However, many have been evaluated by means of two-dimensional lateral cephalometric radiographs[2, 3]. Since the human airway is a three-dimensional dynamic structure, two-dimensional static examination is not sufficient.

Craniofacial anomalies such as mandibular or maxillary retrognathism, short mandibular body, and clockwise rotation of the mandible may cause narrowing of the pharyngeal airway[4]. In addition, different anatomical features in the maxilla and mandible may change the hyoid and soft palate position and cause a reduction in posterior airway dimension[5].

Tongue and hyoid bone do not alter in sagittal direction by this clockwise rotation of the developing mandible in order to prevent narrowing of the oropharyngeal and laryngeal spaces. Consequently, hyoid is displaced downward while the tongue is placed lower and farther in the oral cavity[6]. When adenoids grow, they cause partial or total nasopharyngeal airway obstruction, resulting in nasal respiratory deficiencies[7]. The conflict between adenoid size and nasopharyngeal airway volume may arise from the fact that the skeletal structure of the nasopharynx and tonsillar tissue follow different growth patterns[8].

It is argued that if there is a relationship between airway and face morphology[9]. Airway volume can be affected by anterior displacement of maxilla, head posture and sagittal skeletal relationship[10]. Statistically significant findings were obtained on the relationship between pharyngeal airway dimensions and craniofacial anomalies[11].

While some authors argue whether there is a relationship between oral respiration and Class II malocclusion, it is also discussed that there are significant correlations between pharyngeal airway obstruction with vertical growth and oral respiration[3].

Grauer et al[2]. studied the relationship between pharyngeal volume and shape and facial morphology in 62 adult subjects aged 17-46 years on Cone Beam Computed Tomography (CBCT). Statistically significant differences were reported between the sagittal relationship of the jaws and the

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lower airway volume[2]. Also, a significant relationship was found between airway volume and facial dimensions and gender. However, there was no significant difference between the vertical face ratios and the airway volume.

The purpose of this study is to evaluate craniofacial structure relations with pharyngeal airway according to horizontal and vertical direction growth patterns in Class 1, Class 2, Class 3 skeletal anomalies by 3D imaging methods and to reveal possible differences.

MATERIALS and METHODS

In this research, CBCT images, which was previously recorded for diagnostic and therapeutic purposes, was used from the archives of İzmir Katip Çelebi University Faculty of Dentistry Department of Radiology. In order to carry out the study, a report of ethics committee numbered 194 dated 13.09.2017 was obtained from the local ethics committee of the İzmir Katip Çelebi University Faculty of Medicine.

In our study, among 600 CBCT images from the archives of the Radiology Department of Izmir Katip Çelebi University Faculty of Dentistry were scanned and CBCT images of 180 individuals which met inclusion criteria were included. The CBCT data selected in accordance with the inclusion criteria were divided into 3 main groups according to ANB angle. Then, each group was divided into 3 subgroups as according to SN-GoGn and sum of Posterior angles (SUM). We included CBCT images of Class 1 vertical (n: 20), Class 1 horizontal (n: 20), Class 1 normal (n: 20), Class 2 vertical (n: 20), Class 2 horizontal (n: 20), Class 2 normal (n: 20), Class 3 vertical (n: 20), Class 3 horizontal (n: 20) and Class 3 normal (n: 20) individuals with the total number of 180.

In our study, CBCT data were selected in accordance with the following inclusion criteria:

- Without any disease or syndrome of the skeletal system,
- Adequate quality of CBCT image so that the reference landmarks can be clearly defined,
- No previous orthodontic or orthognathic treatment history,
- Not younger than 16 years,
- Patients who haven't lost excessive amount of tooth that can lead to changes in vertical dimention (n> 4),
- Patients without hard or soft tissue operation history at head and neck region.

In our study, we used Nasion (N), Sella (S), Artikulare (Ar), Gonion (Go), Menton (Me), Pogonion (Pg), Gnathion (Gn), Point A (A), Point B (B) skeletal landmarks. Sella-Nasion Plane (SN), Mandibular plane (MD), Ramus Plane (RD), NA plane (NA), NB plane (NB) were selected as planes. And for angular measurements, we used SNA, SNB, ANB, Saddle angle, Articulare angle, Gonial angle, Sum of Posterior Angles (SUM) and SN-GoGn angles.

SNA, SNB, ANB, SUM and SN-GoGn angle measurements were evaluated with Vistadent OC software (DENTSPLY GAC, Birmingham, Alabama, USA) for the seperation of groups. CBCT data was selected via scanning of the images taken using the Newtom 5G CBCT device at the Radiology Department of institution. The 18x16 FOV area is preferred. In the routine tomographic imaging protocol, after the patients are placed in the CBCT device in lying position, the patient's head is positioned in the natural head position, the images are taken with the jaws in centric relationship and lips in the resting position. The CBCT data was recorded in DICOM (Digital Imaging and Communications in Medicine) format using an external hard disk. DICOM data containing individual CBCT images was transferred to the software program MIMICS 17.0® (Materialize Europe, World Headquarters, Leuven, Belgium).

Measurements used in airway evaluation (Figure 1, Figure2)

Volumetric measurements including:

- Total Airway Volume
- Oropharyngeal Airway Volume
- Nasopharyngeal Airway Volume

Areal measurements including

- Axial area at the border of oropharynx and nasopharynx
- Axial area at C2 level
- Axial area at C3 level

Six linear measurements including

- Transversal and Anteroposterior Length Between Oropharynx and Nasopharynx
- Transversal and Anteroposterior Length at C2 level
- Transverse and Anteroposterior at C3 level.

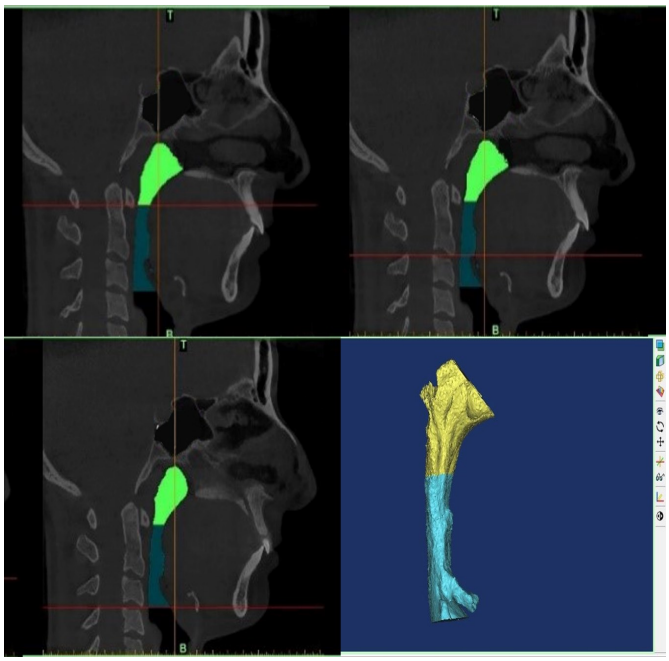

Figure 1. Volumetric evaluation of the oropharyngeal and nasopharyngeal airways in sagital view.

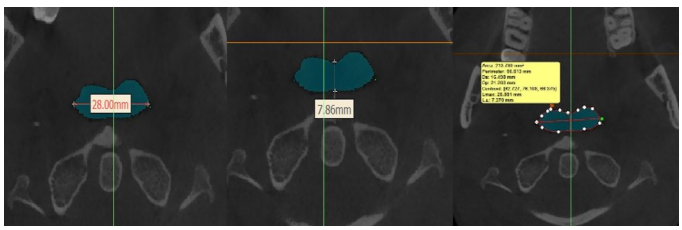

Figure 2. Measuring the boundaries of the area of the axial section.

The MIMICS program airway measurements were performed on CBCT images and the difference between the groups was evaluated statistically using the SPSS 22.0 package program. Parametric tests were applied to the groups with normal distribution and Tukey-HSD tests were used for multiple comparisons when there was a significant difference between the groups by one way ANOVA. In nonparametric parameters, nonparametric tests were applied between groups and Kruskal Wallis Variance Analysis was used. In case of significant difference between the groups, binary comparison was made with the Mann Whitney-U test to determine the group in which the difference was caused.

RESULTS

Statistical analysis of the descriptive data of orthodontic parameters used in evaluation of the Class 1, Class 2 and Class 3 groups revealed no statistically significant difference between the groups when the volumetric airway measurements Oropharyngeal volume, Nasopharyngeal volume and Total Airway volume were evaluated. (Table 1).

Table 1. ANOVA and multiple comparison test results of groups according to orthodontic parameters.

	Parameters	Mean ± SD			p	Post-Hoc Comparisons		
		Class 1	Class 2	Class 3		1 - 2	1 - 3	2- 3
Sagittal Skeletal Measurements (°)	*SNA	79,12 ±3,52	81,85 ±4,13	77,07 ±4	p<0,001**	0,001**	0,012*	0,001**
	*SNB	77,26 ±3,42	75,77 ±4,58	81,25 ±4,82	p<0,001**	0,144	0,001**	0,001**
	†ANB	1,87 ±0,97	6 ±1,49	4,18 ±2,91	p<0,001**	0,001**	0,001**	0,001**
Vertical Skeletal Measurements (°)	†Sum of Internal Angles	394,52 ±7,76	394,75 ±8,64	394,58 ±7,68	P=0,948	-	-	-
	SN-GOGN	33,53±7,24	33,97 ±8,15	33,15 ±7,32	P=0,902	-	-	-
Volumetric Airway Measurements (mm^3)	†Oropharyngeal Volume (OV)	8044,3 ±2968,32	6979,53 ±2590,41	8872 ±4698,37	P=0,089	-	-	-
	†Nasopharyngeal Volume (NV)	6609,07 ±2554,18	5991,33 ±2580,38	6236,83 ±2801,7	P=0,315	-	-	-
	Total Volume (TV)	14653,37 ±5018,75	12970,86 ±4567,79	15108,83 ±6772,64	P=0,153	-	-	-
Areal Airway Measurements (mm^2)	†O-N Border	202,24 ±90,98	170,19 ±90,99	205,59 ±96,48	P=0,067	-	-	-
	†C2 Level	202,36 ±89,96	175,22 ±75,05	235,67 ±131,83	p<0,050*	0,497	0,874	0,044*
	†C3 Level	229,37 ±91,22	231,46 ±97,76	237,02 ±117,26	P=0,999	-	-	-
Linear Airway Measurements (mm)	*O-N Border Transversal	22,18 ±5,84	19,29 ±5,83	20,95 ±5,8	p<0,027*	0,020*	0,484	0,001**
	*O-N Border Antero- posterior	9,4 ±2,94	8,71 ±3,95	10,35 ±3,62	p<0,040*	0,531	0,305	0,031*
	*C2 Level Transversal (C2T)	22,85 ±5,36	21,89 ±5,73	22,83 ±7,1	P=0,616	-	-	-
	†C2 Level Antero-posterior (C2AP)	10,13 ±3,93	9,57 ±3,71	11,42 ±4,03	p<0,035*	1,0	0,139	0,046*
	†C3 Level Transversal (C3T)	26,69 ±6,74	26,69 ±6,74	27,85 ±6,94	P=0,406	-	-	-
	* C3 Level Antero-posterior (C3AP)	11,16 ±3,34	11,5 ±3,15	10,93 ±4,09	P=0,669	-		

* One-way Analysis of Variance (ANOVA), † Kruskal Wallis Test; ns (non significant) - p>0,05; *p<0,05; **p<0,001

Axial area measurements at C2 level and C3 level were statistically significant (p <0,05) between the groups when the axial area of the Oropharynx and Nasopharyngeal axis (O-N boundary), the axial area at C2 level and the axial area at C3 level were evaluated. There was statistically significant difference (p <0,05) between Class 2 and Class 3 in the C2 level subgroups, but no significant difference was found between Class 1 and Class 2, Class 1 and Class 3 groups. There was no statistically significant difference between the axial area at O-N and the axial area at C3. When the linear airway measurements were evaluated, measurements of transversal and anteroposterior (a-p) length and C2 level antero-posterior length measurements on the O-N border showed statistically significant difference between the groups (p <0.05). There was no statistically significant difference between Groups Class 1 – Class 2 and Class 1 - Class 3 groups (p <0.05), while O-N border transversal and a-p length and a-p length at C2 level showed statistically significant difference only between Class 2 and Class 3 groups (p <0,05). C2 level transversal and C3 level transversal and a-p lengths did not differ statistically between the groups. (Table 2, Table 3).

When the results of statistical evaluation according to orthodontic parameters of patients examined, there was no statistically significant difference between the groups when the volumetric airway measurements Oropharyngeal volume, Nasopharyngeal volume and Total airway volume were evaluated. No statistically significant difference was found when the axial area at the O-N border, the axial area of the C2 level, and the axial area of the C3 level were evaluated. There was a statistically significant difference only in the Class 3 patient group in C2 a-p length in linear airway measurements. While there was a statistically significant difference (p <0,05) between Horizontal and Normal groups in C2 a-p length, no significant difference was found between Horizontal-Vertical and Normal-Vertical groups. No statistically significant result was found in the other linear measures. (Table 4).

When the results of statistical evaluation of patients with different skeletal facial types according to orthodontic parameters in vertical class were examined, there was no statistically significant difference between the groups when the volumetric airway measurements Oropharyngeal volume, Nasopharyngeal volume and Total airway volume were evaluated. No statistically significant difference was found when the axial area at the O-N border, the axial area at the C2 level, and the axial area at the C3 level were evaluated. When linear airway measurements of horizontal face type individuals were evaluated, there was a statistically significant difference in the C2 level antero-posterior length measurements (p <0.05). The a-p length at C2 level showed a statistically significant difference (p <0,05) between Class 1-Class 3 and Class 2-Class 3 groups, but no significant difference was observed between Class 1-Class 2 groups. No statistically significant difference was observed between the other linear measurements of the horizontal face type. (Table 5, Table 6, Table 7).

DISCUSSION

Various studies have been carried out in the literature with three dimensional techniques considering that skeletal malpositions and different face types[2, 12, 13] might cause difference in pharyngeal airway dimensions. Therefore, the aim of our study is to investigate craniofacial structure relations with pharyngeal airway according to facial growth pattern in Class 1, Class 2, Class 3 skeletal anomalies by 3D imaging methods.

Table 2. ANOVA and multiple comparison test results of groups according to orthodontic parameters.

	Parameters	Mean±SD			p	Post-Hoc Comparisons		
		Horizontal	Normal	Vertical		h - n	h - v	n- v
Sagittal Skeletal Measurements (°)	*SNA	81,4 ±2,91	78,85 ±2,39	77,1 ±3,81	p<0,001	0,031	<0,001	0,182
	*SNB	79,29 ±2,98	76,93 ±2,69	75,56 ±3,56	p=0,001	0,049	0,001	0,351
	*ANB	2,11 ±0,85	1,97 ±0,91	1,54 ±1,09	p=0,156	-	-	-
Vertical Skeletal Measurements (°)	*Sum of Internal Angles	386,05 ±4,1	394,65 ±2,32	402,85 ±4,02	p<0,001	<0,001	<0,001	<0,001
	†SN-GOGN	25,36 ±3,05	33,9 ±1,82	41,34 ±3,96	p<0,001	<0,001	<0,001	<0,001
Volumetric Airway Measurements (mm^3)	†Oropharyngeal Volume (OV)	8064,48 ±3046,4	7980,79 ±2957,57	8087,62 ±3053,81	p=0,982	-	-	-
	*Nasopharyngeal Volume (NV)	7167,89 ±2732,86	6935,75 ±2665,67	5723,57 ±2101,78	p=0,159	-	-	-
	*Total Volume (TV)	15232,37 ±5096,46	14916,55 ±5369,37	13811,19 ±4715,76	p=0,650	-	-	-
Areal Airway Measurements (mm^2)	†O-N Border	217,63 ±92,61	210,37 ±85,66	178,72 ±94,29	p=0,152	-	-	-
	†C2 Level	206,93 ±96,32	200,32 ±88,51	199,82 ±89,38	p=0,984	-	-	-
	*C3 Level	232,43 ±82,31	239,24 ±97,04	216,44 ±96,75	p=0,726	-	-	-
Linear Airway Measurements (mm)	*O-N Border Transversal	22,01 ±5,45	23,3 ±5,45	21,23 ±6,65	p=0,534	-	-	-
	*O-N Border Antero- posterior	10,41 ±3,13	9,39 ±3,16	8,41 ±2,24	p=0,098	-	-	-
	*C2 Level Transversal (C2T)	23,05 ±3,85	22,94 ±5,15	22,54 ±6,91	p=0,952	-	-	-
	†C2 Level Antero-posterior (C2AP)	9,77 ±3,65	10,65 ±3,55	9,99 ±4,64	p=0,651	-	-	-
	†C3 Level Transversal (C3T)	26,53 ±6,46	25,48 ±9,36	25,5 ±7,4	p=0,882	-	-	-
	* C3 Level Antero-posterior (C3AP)	12,1 ±3,41	11,44 ±3,07	9,96 ±3,31	p=0,115	-	-	-

* One-way Analysis of Variance (ANOVA), † Kruskal Wallis Test; ns (non significant) - p>0,05; *p<0,05; **p<0,001

Table 3. Results of class 2 different vertical facial types (horizontal, normal, vertical) ANOVA and multiple comparison test.

	Parameters	Mean±SD			p	Post-Hoc Comparisons		
		Horizontal	Normal	Vertical		h - n	h - v	n- v
Sagittal Skeletal Measurements (°)	*SNA	84,85 ±2,92	82,1 ±3,95	78,6 ±2,85	p<0,001	0,028	<0,001	0,004
	*SNB	79,01 ±3,64	76,52 ±3,45	71,79 ±3,41	p<0,001	0,072	<0,001	<0,001
	†ANB	5,85 ±1,38	5,59 ±1,1	6,57 ±1,81	p=0,199	-	-	-
Vertical Skeletal Measurements (°)	*Sum of Internal Angles	386,05 ±2,48	393,1 ±2	405,1 ±5,12	p<0,001	<0,001	<0,001	<0,001
	*SN-GOGN	25,61 ±1,99	32,48 ±1,77	43,82 ±4,61	p<0,001	<0,001	<0,001	<0,001
Volumetric Airway Measurements (mm^3)	†Oropharyngeal Volume (OV)	7369,44 ±2839,32	7066,48 ±2770,11	6502,67 ±2166,66	p=0,701	-	-	-
	*Nasopharyngeal Volume (NV)	5845,28 ±2443,77	6054,6 ±2700,76	6074,13 ±2715,86	p=0,954	-	-	-
	†Total Volume (TV)	13214,72 ±4826,43	13121,08 ±4938,62	12576,79 ±4105,62	p=0,965	-	-	-
Areal Airway Measurements (mm^2)	†O-N Border	161,99 ±75,05	177,48 ±99,17	171,1 ±100,57	p=0,995	-	-	-
	*C2 Level	185,91 ±74,37	175,28 ±61,79	164,48 ±88,88	p=0,673	-	-	-
	†C3 Level	218,33 ±119,53	235,86 ±92,13	240,18 ±81,35	p=0,459	-	-	-
Linear Airway Measurements (mm)	*O-N Border Transversal	17,78 ±5,15	20,1 ±5,66	20,01 ±6,59	p=0,368	-	-	-
	†O-N Border Antero- posterior	9,03 ±3,8	8,96 ±3,88	8,13 ±4,3	p=0,681	-	-	-
	*C2 Level Transversal (C2T)	21,71 ±5,82	22,13 ±5,48	21,82 ±6,16	p=0,973	-	-	-
	*C2 Level Antero-posterior (C2AP)	10,38 ±3,89	9,47 ±3,37	8,87 ±3,86	p=0,437	-	-	-
	†C3 Level Transversal (C3T)	24,65 ±8,43	27,55 ±4,73	27,88 ±6,41	p=0,295	-	-	-
	* C3 Level Antero-posterior (C3AP)	11,69 ±3,82	11,35 ±2,87	11,48 ±2,83	p=0,945	-	-	-

* One-way analysis of variance (ANOVA), † Kruskal Wallis Test; ns (non significant) - p>0,05; *p<0,05; **p<0,001

Table 4. Results of class 3 different vertical facial types (horizontal, normal, vertical) ANOVA and multiple comparison test .

	Parameters	Mean±SD			p	Post-Hoc Comparisons		
		Horizontal	Normal	Vertical		h - n	h - v	n- v
Sagittal Skeletal Measurements (°)	†SNA	78,45 ±3,66	77,45 ±3,2	75,3 ±4,54	p=0,148	-	-	-
	†SNB	82,6 ±4,65	82,03 ±4,03	79,11 ±5,19	p=0,149	-	-	-
	†ANB	-4,15 ±3,21	-4,58 ±3,19	-3,81 ±2,34	p=0,898	-	-	-
Vertical Skeletal Measurements (°)	†Sum of Internal Angles	386,55 ±3,75	394,2 ±2,73	403 ±4,35	p<0,001	0,001	<0,001	0,001
	†SN-GOGN	25,46 ±2,95	32,41 ±2,04	41,59 ±3,96	p<0,001	0,001	<0,001	0,001
Volumetric Airway Measurements (mm^3)	†Oropharyngeal Volume (OV)	9282,21 ±5113,42	8704,03 ±4405,68	8629,75 ±4766,77	p=0,879	-	-	-
	†Nasopharyngeal Volume (NV)	5605,3 ±2482,1	6885,99 ±2899,38	6219,21 ±2990,63	p=0,253	-	-	-
	†Total Volume (TV)	14887,5 ±7068,23	15590,02 ±6915,51	14848,96 ±6654,6	p=0,901	-	-	-
Areal Airway Measurements (mm^2)	†O-N Border	204,22 ±106,52	225,89 ±98,99	186,65 ±83,36	p=0,464	-	-	-
	†C2 Level	270,62 ±150,66	206,76 ±104,33	229,64 ±134,83	p=0,406	-	-	-
	*C3 Level	244,15 ±112,77	214,02 ±109,21	252,87 ±131,06	p=0,554	-	-	-
Linear Airway Measurements (mm)	*O-N Border Transversal	19,36 ±6,26	22,81 ±5,52	20,69 ±5,34	p=0,167	-	-	-
	*O-N Border Antero- posterior	11,09 ±3,62	10,52 ±3,96	9,45 ±3,23	p=0,353	-	-	-
	*C2 Level Transversal (C2T)	22,75 ±6,85	22,86 ±7	22,88 ±7,79	p=0,998	-	-	-
	*C2 Level Antero-posterior (C2AP)	13,34 ±4,11	9,51 ±3,47	11,4 ±3,72	p=0,009	0,006	0,243	0,262
	*C3 Level Transversal (C3T)	26,57 ±6,14	29,62 ±7,65	27,36 ±6,93	p=0,360	-	-	-
	* C3 Level Antero-posterior (C3AP)	11,52 ±4,05	9,24 ±3,99	12,01 ±3,86	p=0,071	-	-	-

* One-way analysis of variance (ANOVA), † Kruskal Wallis Test; ns (non significant) - p>0,05; *p<0,05; **p<0,001

Table 5. Results of ANOVA and multiple comparison test of the horizontal individuals according to sagittal classes.

	Parameters	Mean±SD			p	Post-Hoc Comparisons		
		Class 1	Class 2	Class 3		1 - 2	1 - 3	2 - 3
Sagittal Skeletal Measurements (°)	†SNA	81,4 ±2,91	84,85 ±2,92	78,45 ±3,66	p<0,001	0,025	0,032	<0,001
	†SNB	79,29 ±2,98	79,01 ±3,64	82,6 ±4,65	p=0,021	1,000	0,047	0,048
	†ANB	2,11 ±0,85	5,85 ±1,38	-4,15 ±3,21	p<0,001	0,001	0,001	<0,001
Vertical Skeletal Measurements (°)	*Sum of Internal Angles	386,05 ±4,1	386,05 ±2,48	386,55 ±3,75	p=0,874	-	-	-
	†SN-GOGN	25,36 ±3,05	25,61 ±1,99	25,46 ±2,95	p=0,968	-	-	-
Volumetric Airway Measurements (mm^3)	†Oropharyngeal Volume (OV)	8064,48 ±3046,4	7369,44 ±2839,32	9282,21 ±5113,42	p=0,718	-	-	-
	†Nasopharyngeal Volume (NV)	7167,89 ±2732,86	5845,28 ±2443,77	5605,3 ±2482,1	p=0,116	-	-	-
	†Total Volume (TV)	15232,37 ±5096,46	13214,72 ±4826,43	14887,5 ±7068,23	p=0,366	-	-	-
Areal Airway Measurements (mm^2)	†O-N Border	217,63 ±92,61	161,99 ±75,05	204,22 ±106,52	p=0,161	-	-	-
	†C2 Level	206,93 ±96,32	185,91 ±74,37	270,62 ±150,66	p=0,164	-	-	-
	†C3 Level	232,43 ±82,31	232,43 ±82,31	244,15 ±112,77	p=0,574	-	-	-
Linear Airway Measurements (mm)	*O-N Border Transversal	22,01 ±5,45	17,78 ±5,15	19,36 ±6,26	p=0,06	-	-	-
	*O-N Border Antero- posterior	10,41 ±3,13	9,03 ±3,8	11,09 ±3,62	p=0,180	-	-	-
	*C2 Level Transversal (C2T)	23,05 ±3,85	21,71 ±5,82	22,75 ±6,85	p=0,734	-	-	-
	†C2 Level Antero-posterior (C2AP)	9,77 ±3,65	10,38 ±3,89	13,34 ±4,11	p=0,017	1,000	0,019	0,118
	†C3 Level Transversal (C3T)	26,53 ±6,46	24,65 ±8,43	26,57 ±6,14	p=0,712	-	-	-
	* C3 Level Antero-posterior (C3AP)	12,1 ±3,41	11,69 ±3,82	11,52 ±4,05	p=0,841	-	-	-

* One-way analysis of variance (ANOVA), † Kruskal Wallis Test; ns (non significant) - p>0,05; *p<0,05; **p<0,001

Table 6. Results of ANOVA and multiple comparison test of the normal individuals according to sagittal classes.

	Parameters	Mean±SD			p	Post-Hoc Comparisons		
		Class 1	Class 2	Class 3		1 - 2	1 - 3	2 - 3
Sagittal Skeletal Measurements (°)	*SNA	78,85 ±2,39	82,1 ±3,95	77,45 ±3,2	p<0,001	0,007	0,366	<0,001
	*SNB	76,93 ±2,69	76,52 ±3,45	82,03 ±4,03	p<0,001	0,924	<0,001	<0,001
	†ANB	1,97 ±0,91	5,59 ±1,1	-4,58 ±3,19	p<0,001	0,001	0,001	<0,001
Vertical Skeletal Measurements (°)	*Sum of Internal Angles	394,65 ±2,32	393,1 ±2	394,2 ±2,73	p=0,113	-	-	-
	*SN-GOGN	33,9 ±1,82	32,48 ±1,77	32,41 ±2,04	p=0,024	0,053	0,040	0,992
Volumetric Airway Measurements (mm^3)	†Oropharyngeal Volume (OV)	7980,79 ±2957,57	7066,48 ±2770,11	8704,03 ±4405,68	p=0,414	-	-	-
	*Nasopharyngeal Volume (NV)	6935,75 ±2665,67	6054,6 ±2700,76	6885,99 ±2899,38	p=0,529	-	-	-
	†Total Volume (TV)	14916,55 ±5369,37	13121,08 ±4938,62	15590,02 ±6915,51	p=0,386	-	-	-
Areal Airway Measurements (mm^2)	†O-N Border	210,37 ±85,66	177,48 ±99,17	225,89 ±98,99	p=0,168	-	-	-
	*C2 Level	200,32 ±88,51	175,28 ±61,79	206,76 ±104,33	p=0,483	-	-	-
	*C3 Level	239,24 ±97,04	235,86 ±92,13	214,02 ±109,21	p=0,688	-	-	-
Linear Airway Measurements (mm)	*O-N Border Transversal	23,3 ±5,45	20,1 ±5,66	22,81 ±5,52	p=0,154	-	-	-
	†O-N Border Antero- posterior	9,39 ±3,16	8,96 ±3,88	10,52 ±3,96	p=0,225	-	-	-
	*C2 Level Transversal (C2T)	22,94 ±5,15	22,13 ±5,48	22,86 ±7	p=0,892	-	-	-
	†C2 Level Antero-posterior (C2AP)	10,65 ±3,55	9,47 ±3,37	9,51 ±3,47	p=0,478	-	-	-
	*C3 Level Transversal (C3T)	25,48 ±9,36	27,55 ±4,73	29,62 ±7,65	p=0,227	-	-	-
	* C3 Level Antero-posterior (C3AP)	11,44 ±3,07	11,35 ±2,87	9,24 ±3,99	p=0,072	-	-	-

* One-way analysis of variance (ANOVA), † Kruskal Wallis Test; ns (non significant) - p>0,05; *p<0,05; **p<0,001

Table 7. Results of ANOVA and multiple comparison test of the vertical individuals according to sagittal classes.

	Parameters	Mean±SD			p	Post-Hoc Comparisons		
		Class 1	Class 2	Class 3		1 - 2	1 - 3	2 - 3
Sagittal Skeletal Measurements (°)	*SNA	77,1 ±3,81	78,6 ±2,85	75,3 ±4,54	p=0,029	0,430	0,299	0,022
	*SNB	75,56 ±3,56	71,79 ±3,41	79,11 ±5,19	p<0,001	0,015	0,023	<0,001
	†ANB	1,54 ±1,09	6,57 ±1,81	-3,81 ±2,34	p<0,001	0,001	0,001	<0,001
Vertical Skeletal Measurements (°)	†Sum of Internal Angles	402,85 ±4,02	405,1 ±5,12	403 ±4,35	p=0,297	-	-	-
	†SN-GOGN	41,34 ±3,96	43,82 ±4,61	41,59 ±3,96	p=0,166	-	-	-
Volumetric Airway Measurements (mm^3)	†Oropharyngeal Volume (OV)	8087,62 ±3053,81	6502,67 ±2166,66	8629,75 ±4766,77	p=0,276	-	-	-
	*Nasopharyngeal Volume (NV)	5723,57 ±2101,78	6074,13 ±2715,86	6219,21 ±2990,63	p=0,829	-	-	-
	*Total Volume (TV)	13811,19 ±4715,76	12576,79 ±4105,62	14848,96 ±6654,6	p=0,400	-	-	-
Areal Airway Measurements (mm^2)	†O-N Border	178,72 ±94,29	171,1 ±100,57	186,65 ±83,36	p=0,800	-	-	-
	*C2 Level	199,82 ±89,38	164,48 ±88,88	229,64 ±134,83	p=0,163	-	-	-
	*C3 Level	216,44 ±96,75	240,18 ±81,35	252,87 ±131,06	p=0,542	-	-	-
Linear Airway Measurements (mm)	*O-N Border Transversal	21,23 ±6,65	20,01 ±6,59	20,69 ±5,34	p=0,825	-	-	-
	†O-N Border Antero- posterior	8,41 ±2,24	8,13 ±4,3	9,45 ±3,23	p=0,476	-	-	-
	*C2 Level Transversal (C2T)	22,54 ±6,91	21,82 ±6,16	22,88 ±7,79	p=0,887	-	-	-
	†C2 Level Antero-posterior (C2AP)	9,99 ±4,64	8,87 ±3,86	11,4 ±3,72	p=0,080	-	-	-
	†C3 Level Transversal (C3T)	25,5 ±7,4	27,88 ±6,41	27,36 ±6,93	p=0,499	-	-	-
	* C3 Level Antero-posterior (C3AP)	9,96 ±3,31	11,48 ±2,83	11,48 ±2,83	p=0,144	-	-	-

* One-way Analysis of Variance (ANOVA), † Kruskal Wallis Test; ns (non significant) - p>0,05; *p<0,05; **p<0,001

Our study included CBCT data for individuals over 16 years. In a previous 2-D study, in hundred and one people between 14-18 years, the oropharnygeal airway volume differed significantly especially between Classs III mandibular prognaty and Class II mandibular retrognaty groups, with the former showing a larger volume[14]. Taylor et al.[15] reported that the oropharyngeal and nasopharyngeal area can be measured between 14-18 years. In literature, adult individuals were selected for airway evaluations frequently for similar studies[15, 16]. As we selected our subjects between individuals that completed growth and development phase, mentioned changes had no effect on our study.

Gravity is an another factor in airway evaluation as oropharyngeal structures are affected[17]. As CBCT scan differs depending on the type of device used, more research is needed in airway soft tissue evaluation for different postures[18]. Pracharktam et al.[19] evaluated the upper airway volume as patient both standing and lying down and concluded that the 2D cephalometric evaluation gave the same results in both positions[19]. Thus, the CBCT device NewTom 5G, which functions while the patient is in the lying position is used. In our study, all the scans were performed using craniofacial landmarks procedure.

Because of the low dose exposure, three-dimensional methods are used safely and frequently as we preferred in our study. The CBCT device (NewTom 5G) used in our study is advantageous as the patients are exposed to less radiation compared to other devices (I-CAT, MercuRay) that are frequently used[20].

Since the airway has a dynamic morphology, structures are mobile during respiration. In their study Lowe et al.[21] concluded that airway dimensions are related to the respiratory phase. In our study, CBCT images were taken with 360-degree rotation and within 3,6 s duration with 0.25 mm a voxel thickness with The NewTom 5G device while individuals hold their breath. In that way, respiratory phase was taken under control and the images were standardized and the airway remained still during the scan.

Moshiri et al.[22] studied on lateral cephalometric graphs obtained from CBCT data and compared them with conventional cephalometric radiographs and direct measurements performed on human skulls. Most of the linear measurements in the sagittal plane were found to be more reliable on radiographs obtained from CBCT data than conventional cephalometric radiographs[22]. In our study, the evaluation of lateral cephalometric images obtained with CBCT instead of conventional cephalometric radiographs gave us the advantage of greater accuracy and is compatible with the previous studies.

ANB angle is a frequently used angle in defining the dentofacial anomalies in the anteroposterior direction of the maxilla and mandible[6]. Ishikawa et al.[23] reported that ANB was one of the most reliable and accurate value in evaluating the jaw relationship. SNA and SNB angles are also commonly used to assess the position of the maxillary and mandibular relation to the cranial base[6]. In our study, we aided SNA, SNB and ANB angles.

In our study, no statistically significant difference was found between the groups when the volumetric airway measurements Oropharyngeal volume, Nasopharyngeal volume and Total Airway volume were evaluated. This can be result of Class 1 individuals presenting normal positioning maxilla and mandible whereas Class 3 individuals has retrognathic maxilla and prognathic mandible. In the literature, there are studies that show malocclusion and malposition type have no effect on the pharyngeal airway width[4, 11, 13].

Çoban and Karadede[24] found a statistically significant difference only between Class I and Class II groups' airway volumes in their 3D study in which nasopharyngeal volume parameters were evaluated. In the same study, while total and oropharyngeal airway volume of the Class II group found to be statistically significantly lower than the Class I and Class III groups, a statistically significant difference was not found a between the airway volumes of Class I and Class III groups. In our study, there was no statistically significant difference in volumetric measurements between Class 1, Class 2 and Class 3 groups.

Ceylan and Oktay[11] conducted two dimensional studies on airway and found that there was no statistically significant difference between ANB angle and parameters other than at oropharyngeal area and the pharyngeal airway size did not change after the sagittal changes of the jaws. De Freitas et al.[13] concluded that malocclusion type does not affect the upper airway width in the airway evaluation of patients with different growth patterns with Class I and Class II malocclusion. Sosa et al.[25] reported that there was no statistically significant association between ANB angle and pharyngeal structures in subjects with Class I and Class II malocclusions. Consistent with these studies, Solow et al.[26] and Wenzel et al.[27] concluded that there was no relationship between the pharyngeal airway and the sagittal relationship of the jaws.

When we evaluate subgroups according to Horizontal, Normal and Vertical face types in Class 1, Class 2 and Class 3 groups, no statistically significant result was found in any of the volumetric and areal airway findings. There was a statistically significant difference in Linear measures C2 a-p length only in Class 3 group. C2 a-p length was statistically significant between the groups between the Horizontal and Normal groups. No significant difference was found between Horizontal-Vertical and Normal-Vertical groups. No statistically significant result was found among the other linear measures.

Fernandez et al.[12] evaluated the relationship between different vertical facial biotypes and pharyngeal airway volume in patients with skeletal Class 2 malposition in three-dimensional CBCT studies. None of the spatial and volumetric pharyngeal airway measurements showed a significant difference for the facial types[12]. These findings are consistent with our study.

Grauer et al.[2] found no statistically significant difference between vertical, normal and horizontal facial types and airway in their studies evaluating the relationship between pharyngeal volume and shape, sagittal jaw relations and different facial types in the vertical direction in three dimensional CBCT studies. Changes in vertical jaw relationships have shown that the final airway volume does not change but only the shape changes. These findings are consistent with our study.

In our study, no statistically significant results were found in the horizontal, normal, and vertical groups in terms of Class 1, Class 2, and Class 3 individuals for both areal and volumetric airway findings. There was a statistically significant difference in C2 a-p length only for the linear measurements of the horizontal group. For the C2 a-p length, Class 1 and Class 2 groups were similar, whereas Class 3 was significantly higher than Class 1 and Class 2 groups. No statistically significant result was found among the other linear measures.

Claudino et al.[1] used the FMA angle as a parameter in the vertical direction in three-dimensional studies evaluating the volume and morphology of the pharyngeal airway in adolescents with CBCT and assessed their association with the facial skeletal pattern and found no correlation with airway volume. Although we do not use different angles for our subgroups in the vertical direction, the findings are consistent with our study.

In their CBCT study on adolescent individuals, Wanzeler et al.[28] have found that there is no statistically significant difference between vertical face types and airway volume and anatomical relationship between nasopharyngeal space volume and face type. These findings are consistent with our study.

In their 3-D CBCT study on adolescents aged between 11-17 Fields et al. used respirometric techniques to compare breathing behaviors[29] and have found that subjects that present vertical growth

pattern have significantly shown lower nasal respiration than normal growing subjects. Even though it's not statically significant, in our study, the volumetric measurements in the vertical group are found to be lower than the normal group.

Conclusion

In individuals with prognathic mandible, hyoid bone and tongue is located more anteriorly and by the stretch effect created on the posterior soft tissues, an increase occurs in the antero-posterior length, especially in Class 3 individuals at the C2 level. Oral breathing of patients presenting vertical direction growth excess (statistically insignificant) also negatively affected nasopharyngeal airway volume. Different sagittal and vertical facial types affect the pharyngeal airway.

Conflict of interest

The authors declare that they have no conflict of interest.

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