ORIGINAL RESEARCH

Evaluation of the Upper Airway Morphology in Patients with Class II Malocclusion Using 3-Dimentional Computed Tomography

Ali Alkhayer[1]
Fadi Khalil[2]
Hazem Hasan[3]

[1]MSc Student, Department of Orthodontics, Faculty of Dentistry, Tishreen University, Lattakia, Syria
[2]Ass. Professor at Orthodontics and Dentofacial Orthopedic Department, Dental School, Tishreen University, Lattakia, Syria
[3]Professor at Orthodontics and Dentofacial Orthopedic Department, Dean of the Faculty of Dentistry, Tishreen University.

Corresponding Author:
E-mail: ali.alkhayer@hotmail.com.

Access this Article Online

Quick Response Code	www.idjsr.com
	Use the QR Code scanner to access this article online in our database
	Article Code: IDJSR 0192

Abstract

Introduction: It is common nowadays that respiratory functions are highly relevant to the orthodontic diagnosis and the treatment plan, besides their effects on the stability of the treatment results. So it is important to have a better and more deeply analysis of the upper airway morphology in our patients, especially, in class II patients where the upper airway could be affected by the pressures against the dentition, dental arch form, and the possibly direction of mandibular and maxillary growth.
Objective: The aim of this study was to evaluate the size and areas of the upper airways in adults with skeletal Class II malocclusion, using three dimensional computed tomography (3DCT) and to compare the cross-sectional measurements and cephalometric variables with skeletal class I group, to investigate possible relationships between the upper airway and anteroposterior growth type.
Materials and methods: Our Sample's consisted of 36 adults (15males, 21 females) who were selected from patients who were ordinary undergoing 3DCT for non-orthodontic nor otolaryngology purpose and didn't have orthodontic treatment. The anteroposterior positions of both the maxilla and the mandible were evaluated with the ANB angle, AF-BF distance, Wits appraisal to divide our subjects into 2 groups: (1) skeletal Class I patient's with2 >ANB<5, and (2) skeletal Class II patients with ANB >5. Then we calculated Pearson's Correlation to investigate the possible relationship between the upper airway measurements and the Cephalometric measurements determining anteroposterior growth patterns.
Results: we found statistically significant correlation between nasopharyngeal airway measurements and the cephalometric measurements determining anteroposterior growth patterns. The depth and area of NA showed negative correlation with ANB, WITS, AF-BF ($p < 0.05$). We also found that this depth and area were smaller in class II. We didn't see significant differences between males and females in airway measurements.
Conclusions: The skeletal Class II malocclusion had a narrower nasopharyngeal airway than the Class I group, there is a statistically significant correlation between nasopharyngeal airway measurements and the cephalometric measurements determining anteroposterior growth patterns.

Key words: Upper airway Morphology, 3DCT, Class II malocclusion, Anteroposterior growth type.

Introduction

Several lines of evidence from cephalometric studies support a link between presumed respiratory mode and facial morphology[1]. For that, the effects of respiratory function on craniofacial growth have been studied for decades, and most clinicians now understand that respiratory functions is highly relevant to the orthodontic diagnosis and to the treatment plan. Accordingly, much attention has been paid to the relationship between respiratory function and facial morphology in orthodontics[2]. In 1907, Angle [3] showed that his Class II Division 1 malocclusion is associated with obstruction of the upper pharyngeal airway and mouth breathing.
A common cause of mouth breathing arises from the adenoids, which are a conglomerate of lymphatic tissues located in the posterior pharyngeal airway. Infection and

inflammation of the adenoids leads to upper airway obstruction, and the term ‘‘adenoid facies’’ is often used to describe a possible aberrant craniofacial growth pattern, which is related to mouth breathing and characterized by lip incompetency, underdeveloped nose, increased anterior facial height, constricted dental arches, and proclined maxillary incisors with a Class II occlusal relationship [4-6]. This reasonable link between respiratory mode and the development of malocclusion could be soft-tissue pressures against the dentition that might affect tooth eruption, dental arch form, and possibly the direction of mandibular and maxillary growth [1]. Rosen CL (2004) found that Class II patients have a narrower anteroposterior pharyngeal dimension, and this narrowing is specifically noted in the nasopharynx at the level of the hard palate and in the oropharynx at the level of the tip of the soft palate and the mandible [7]. Class II Division 1 malocclusion is associated with a narrower upper airway even without retrognathia [8].

Park et al noticed that the Inclination of the oropharyngeal airway might be a key factor in determining the form of the entire pharyngeal airway, and found that Children with Class II malocclusion have more backward orientation and smaller volume of the pharyngeal airway than do children with Class I and III malocclusion [9]. Hwang et al reported that a constricted nasopharyngeal airway is associated with detruded mandible and maxilla [10]. Grauer et al found in their recent CBCT study a potential influences of the anteroposterior growth type on the airway dimensions and shape, and they noticed that the inferior compartment airway volume was smaller in skeletal Class II than in Class I and Class III patients. They also found that Subjects with Class II skeletal pattern was associated with a more forward orientation of the airway compared with the other groups [1].

In addition to studies that affirm nasal obstruction as the major factor responsible for dentofacial anomalies, other studies refute a significant relationship between airway obstruction and the frequency of malocclusion. In a study of 500 patients with upper airway problems, Leech [11] discovered that 60% of the mouth-breathing patients were Class I and concluded that mouth breathing has no influence on craniofacial growth. Similarly, Gwynne-Evans [12] determined that facial growth is constant regardless of the mode of breathing.

Morphometric evaluation of the pharyngeal airway has been mostly performed on lateral cephalometric head films, by identifying specific landmarks and measuring various lengths and areas in the pharyngeal region [3-5,11,12]. Despite the vast amount of researches concerning airway anatomy and its influence on craniofacial growth and development, this technique has been concerned limited, because it provides 2-dimensional (2D) images of complex 3-dimensional (3D) anatomic structures[13]. New 3-dimensional (3D) technology of computed tomography (CT) has expanded diagnostic capacities, making volumetric analysis and accurate visualization of the airway possible, and has the advantage of high-quality images to discern hard- and soft-tissue anatomies. Cross-sectional and volumetric investigations of the pharyngeal airway have been possible by using 3DCT scans to analyze the complex airway anatomy, and previous studies have confirmed that volumetric measurements of airways with 3DCT are accurate with minimal error [14].

Accordingly, the purpose of this study was to carry out an evaluation of the oropharyngeal airway (OA) and nasopharyngeal airway (NA) in Adults with a skeletal Class II malocclusion by using 3-Dimentional computed tomography (3DCT) and 3-dimensional (3D) image reconstruction software, (ie, cross-sectional area [CSA]), depth, and width in the horizontal plane of adults with class II malocclusion were measured and compared with adults with Class I. The null hypothesis was that Class II and Class I patients do not differ in airway dimensions.

Material and Methods

-subjects

Sample's subjects were selected from patients who were ordinary undergoing 3DCT scan neither for orthodontic nor for otolaryngology purpose and they didn’t get an orthodontic treatment. The criteria for selecting the subjects were taken as follows:

1. No visual, hearing, or swallowing disorders and no history of speech-language pathology
2. No history of hyperplasia of tonsils and adenoids, tonsillectomy or adenoidectomy and those with OSA, nasal respiratory complex surgery for the control group.
3. No history of trauma to the dento-facial structures.
4. Each subject must have fully erupted permanent dentition up to second molar.

Exclusion criteria were subjects with congenital anomalies/ evident signs of neurological impairment and/or syndromes or dentoskeletal asymmetries and craniofacial malformation.

Sample estimation

To determine the minimum sample size to be statistically significant, a similar previous study was realized on 45 subject (who were selected according to the criteria of selecting this study`s sample). It has been found that descriptive statistics results follow the normal distribution; therefore, determining the minimum sample size to be statistically significant was according to the following formula:

$$n = \frac{Z^2 . \sigma^2}{(e)^2}$$

(N): is the sample size; (z): is the value corresponding to a confidence level, estimated at 99% (Z = 2.58) (i.e. significance level is 0.019), (σ): highest Standard

Deviation value within the all linear and angular variables at the pilot study (σ = 7.92)
(e): Margin of error (maximum acceptable error in mean estimate) (e=5). Thus:

$$n = \frac{(2.58)^2(7.92)^2}{5^2} \approx 16.7$$

According to that previous study, the sample size (n) must be as minimum of 16.7 patients, whereas sample size of this study was n=36.
A total of 36 patients (15 males, 21 females, mean age 31 years), who came for non-orthodontic nor otolaryngology purpose were participated in this study.

- 3DCT – Study
The CT images were made with a multislice CT at Al-Assad University Hospital (Toshiba, Aquilion 64 slices, 2008) with a high-resolution bone algorithm, 512 _ 512 matrix, 120 KV, and 300 mA. The thickness of the axial images 0.5 mm and exposure time of 9.6 seconds.
The subjects were positioned with the Frankfort horizontal (FH) line perpendicular to the floor and the facial midline coinciding with the long axis of the CT machine. The image covered the area from the vertex to the inferior border of the mandibular body.
The patients were instructed not to breathe deeply, not to swallow, to maintain the teeth in maximum intercuspation, and not to move the head and tongue during scanning. The axial images were transformed to the DICOM (Digital Imaging and Communications in Medicine) format and reconstructed into a 3D model by using Ondemand 3d app version 1.0 (CyberMed).

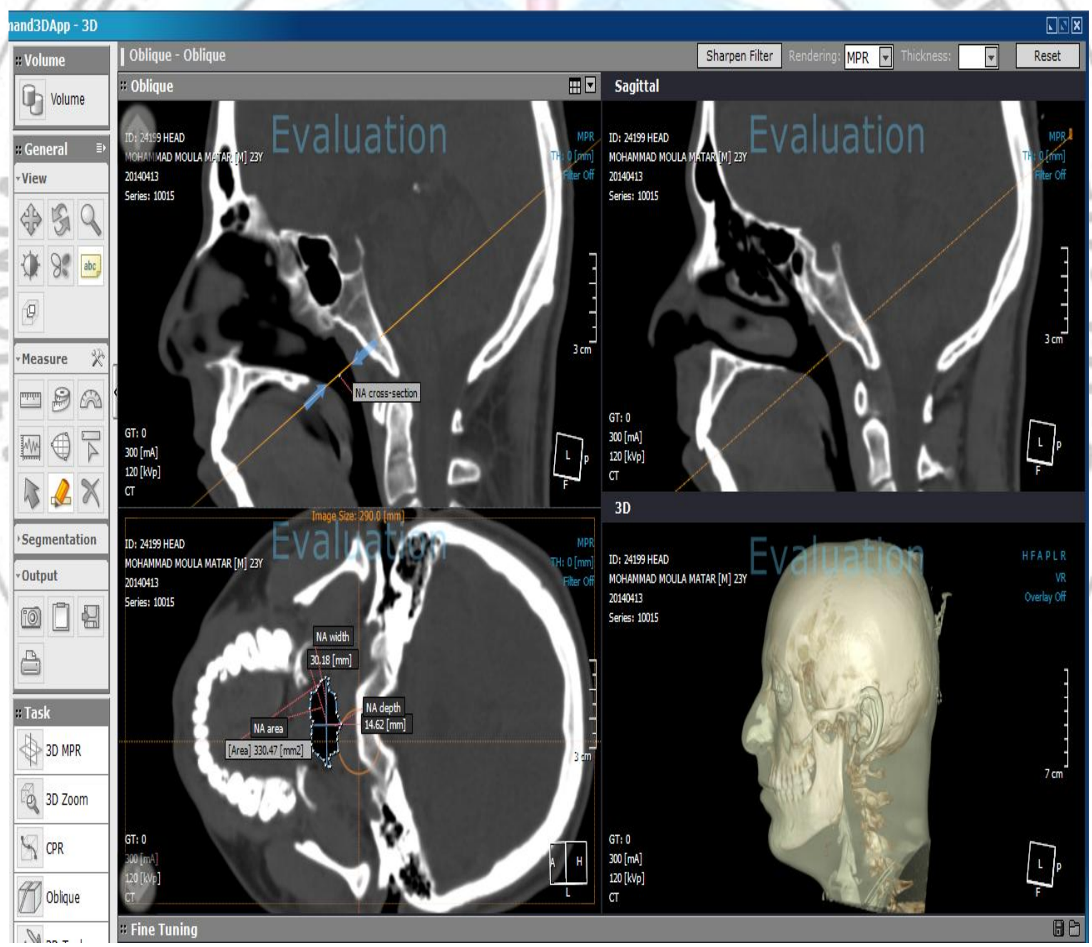


Fig. 1: program was used to measure the 3D models

Then, on multiple planar reconstruction (MPR) images, The head 3D reconstructions of each patient were re-oriented using the Frankfurt (FH) plane as the horizontal reference plane [15,16]
The origin of the 3D coordinate system was the midpoint between the left and right porions. This origin and left and right orbitale defined the standard horizontal plane. A frontal plane was constructed through both orbitale points and perpendicular to the horizontal plane. The sagittal plane was constructed through both orbitale midpoints and perpendicular to the horizontal and frontal planes [17].

3DCT measurements

Airway cross-sectional measurements included CSA, depth (anteroposterior direction), and width (left-right direction). The CSAs of the nasopharyngeal and oropharyngeal airways were defined as shown in Figure 2. Three parameters for the size of the nasopharyngeal and oropharyngeal airways were determined based on previous reports [18,19]. The nasopharyngeal airway cross-section was measured along a horizontal plane at the airway's narrowest part on the cephalometric image. The OA cross-section was measured along a horizontal plane passing through the midpoint of bilateral gonion. A Hounsfield unit range of 300 to 1024– was interpreted to be air [17].

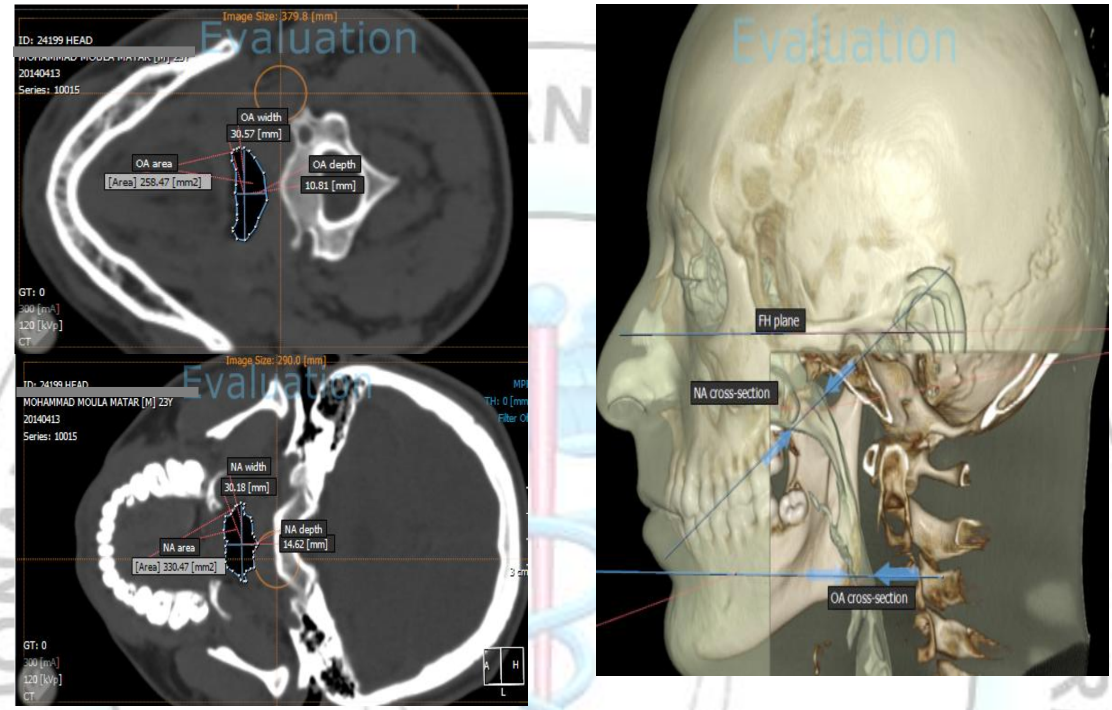


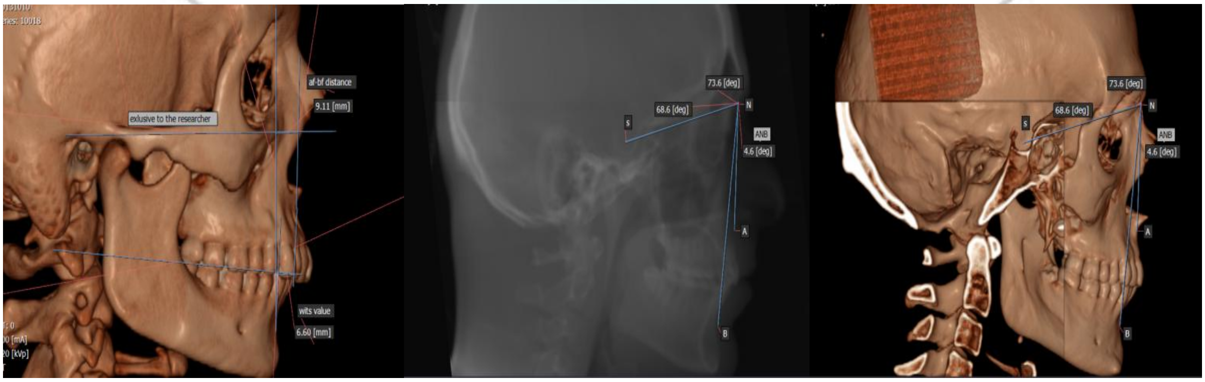
Fig. 2: Measurements of the nasopharyngeal airway (NA) and the oropharyngeal (OA

-lateral cephalometric analysis:

Since 2-dimensional (2D) images produced from three dimensional computed tomography (3DCT) images could substitute for traditional cephalograms [17], in this study, lateral cephalometric analysis was obtained by Kumar method (2008) using 2-dimensional images produced from 3-dimentional computed tomography, which were achieved in centric occlusion [20].

From this cephalometric image, the anteroposterior positions of both the maxilla and the mandible were evaluated with the ANB angle [21], AF-BF (the distance between perpendiculars drawn from A-point and B-point onto the Frankfort horizontal plane) [22], Wits appraisal [23].

We divided our subjects into 2 groups according to the occlusion: (1) skeletal Class I patients(12 female and 7 male)with2 >ANB<5,and (2) skeletal Class II patients(9 female and 8 male)with ANB >5.



Statistical analysis

T tests were used to compare (1) the anteroposterior position of the maxilla and the mandible; (2) the size of the upper airway (CSA, width, depth). The Pearson product-moment correlation coefficients were calculated to evaluate the relationships among CSA, depth, and width of the OA and the NA, and correlations between the measurements of the OA, NA and the anteroposterior position of the maxilla and the mandible in the Class II group. Then Mann-Whitney analysis for small samples was used to evaluate the correlation between the upper airway measurements and gender in class I and class II groups, and to investigate the differences between males and females in these measurements.

- Error of method:

All cephalometric and 3DCT measurements were repeated twice with a month interval, by the same calibrated investigator using the same workstation, the initial measurements and the repeated measurements were compared by using a paired t-test at α= 0.05 to check any systematic error. The t-test did not show any statistical significance.

Results

Descriptive statistics for anteroposterior measurements of the maxilla and the mandible are presented in table 1.

Table 1: Cephalometric measurements of the anteroposterior position of the maxilla and the mandible

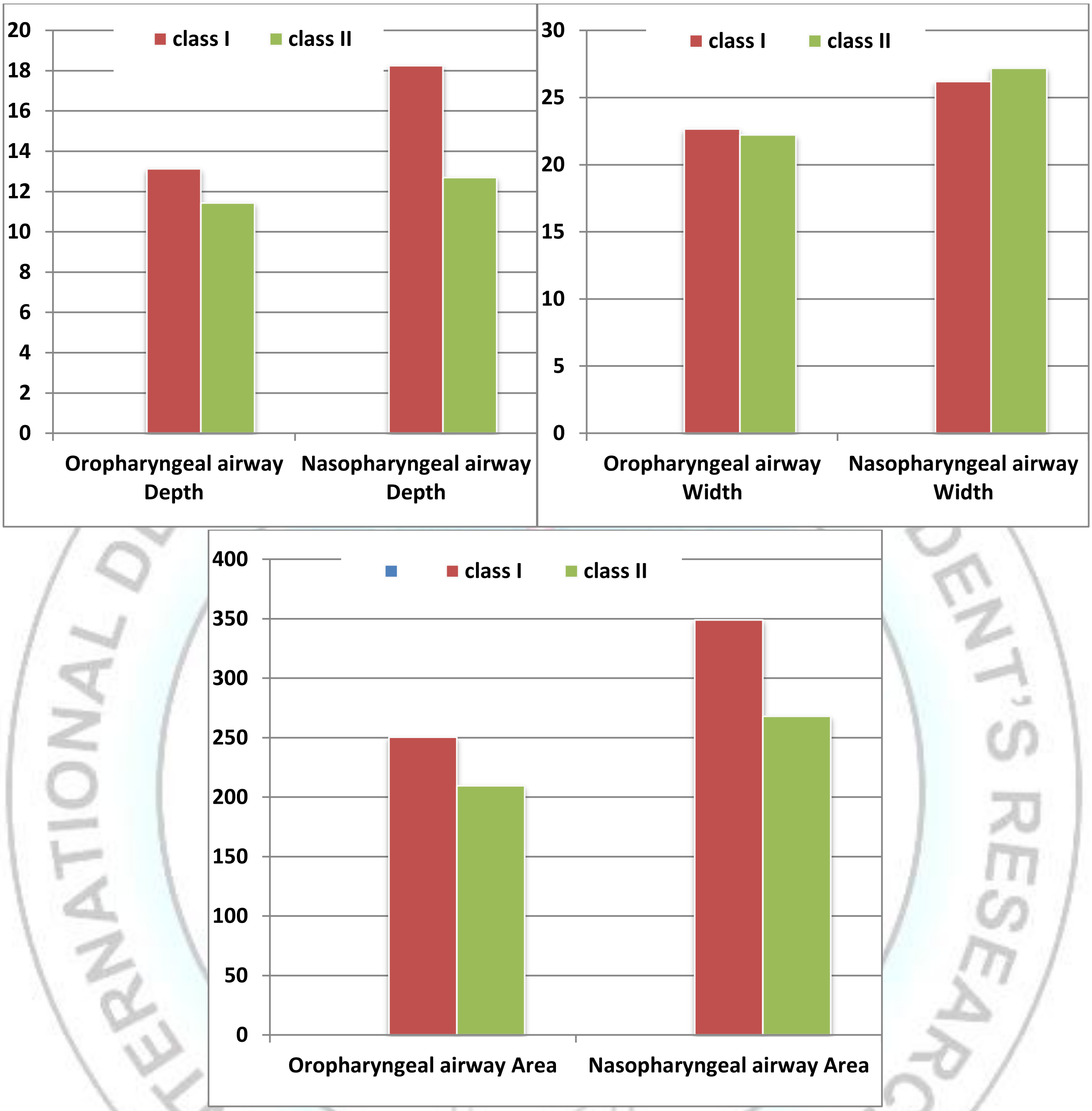
	CLASS I		CLASS II			
	SD	Mean	SD	Mean	t	Sig
SNA(°)	3.43904	82.3579	3.59582	80.4353	1.639	.110
SNB(°)	3.04363	79.1421	3.47543	74.3118	1.635	**.000
ANB(°)	1.03562	3.2158	1.49228	6.6235	4.446	**.000
Wits(mm)	2.17993	.5837	1.77653	5.5029	-7.367-	**.000
AF-BF(mm)	1.60684	4.0663	1.83882	8.6806	-8.036-	**.000
** Statistically significant at P< 0.01.						

Descriptive statistics for OA and NA measurements in class I and class II are presented in table 2.

Table 2: Mean measurements of OA and NA measurements in class I and class II

		CLASS I		CLASS II			
		SD	**Mean**	**SD**	**Mean**	**Sig**	**t**
Oropharyngeal Airway	Depth(mm)	4.72964	13.1321	2.60916	11.4347	.199	1.311
	Width(mm)	5.54768	22.6637	4.80545	22.2282	.804	.250
	Area(mm²)	130.06426	250.4763	85.76856	209.4547	.278	1.103
Nasopharyngeal Airway	Depth(mm)	2.89749	18.2437	2.09679	12.6959	.000**	6.511
	Width(mm)	3.59775	26.1884	3.94701	27.1806	.436	.789-
	Area(mm²)	66.32639	348.9889	69.87441	267.8994	.001**	3.571
**.Statistically significant at P< 0.01.							

Graphical diagrammatic for OA and NA measurements and areas in class I and class II subjects are presented in graph 1.



Graph 1: Graphical diagrammatic for OA and NA measurements in class I and class II.

Results of Pearson's Correlation test between the measurements of OA and NA of the Class I and Class II groups are presented in table 3.

Table 3: Correlations among the OA and NA measurements of the Class I and Class II groups

			Depth	Width
Class I group	Oropharyngeal airway	CSA	.889**(.000)	.671**(.002)
		Depth	-	.380 (.109)
	nasopharyngeal airway	CSA	.401(.088)	.691**(.001)
		Depth	-	-.153-(.531)
Class II group	Oropharyngeal airway	CSA	.883**(.000)	.787**(.000)
		Depth	-	.536*(.027)
	nasopharyngeal airway	CSA	.736**(.001)	.653**(0.05)
		Depth	-	.237 (.360)
*Statistically significant at P <0.05; **Statistically significant at P<0.01.				

Results of Pearson's Correlation test between OA and NA measurements and all cephalometric measurements determining anteroposterior growth patterns within all subjects of the sample (regardless of gender) are presented in table 4.

Table 4: Correlations between the anteroposterior position of the maxilla and the mandible and the OA, NA measurements

	Oropharyngeal airway			nasopharyngeal airway		
	Depth	Width	CSA	Depth	Width	CSA
SNA (P)	-.004-	.021	.009	.159	.053	.266
	.982	.901	.956	.353	.761	.117
SNB (P)	.086	.063	.125	.346*	-.114-	.320
	.619	.716	.468	.039	.507	.057
ANB (P)	-.130-	-.065-	-.139-	-.551-**	.118	-.313-*
	.451	.705	.420	.000	.492	.050
Wits(p)	-.193-	-.178-	-.193-	-.541-**	.260	-.233-
	.260	.300	.258	.001	.125	.172
AF-BF(p)	-.004-	-.097-	-.045-	-.467-**	.006	-.356-*
	.982	.575	.795	.004	.971	.048
*Statistically significant at P <0.05; **Statistically significant at P<0.01.						

Table 5: Correlations between the anteroposterior position of the maxilla and the mandible and the OA, NA measurements of the Class II group

Class II	nasopharyngeal airway			Oropharyngeal airway		
	Depth	Width	CSA	Depth	Width	CSA
ANB (P)	.259	.082	.218	.024	.148	-.054-
	.315	.756	.400	.927	.570	.836
Witz(p)	.479	.362	.278	-.453-	-.389-	-.534-*
	.052	.012	.021	.068	.123	.027
AF-BF(p)	.245	-.150-	.212	-.019-	-.216-	-.126-
	.343	.566	.414	.942	.405	.630
***Statistically significant at P <0.05; **Statistically significant at P<0.01.**						

Descriptive statistics for OA and NA measurements in class I and class II (both genders, male, female) are presented in table 6.

Table 6: Mean measurements of the upper airway in males and females in each group.

Class	Gender		Oropharyngeal airway			nasopharyngeal airway		
			Depth (mm)	Width (mm)	Area (mm²)	Depth (mm)	Width (mm)	Area (mm²)
Class I	**Male**	Mean	17.02	23.23	339.44	17.31	26.60	362.58
		Std. D	4.41	6.17	160.50	2.85	3.62	69.69
	Female	Mean	10.86	22.32	198.58	18.78	25.94	341.06
		Std. D	3.27	5.40	75.20	2.90	3.72	66.05
Class II	**Male**	Mean	11.97	21.86	206.63	12.51	26.57	254.19
		Std. D	3.15	5.77	96.06	2.18	3.68	56.92
	Female	Mean	10.95	22.55	211.96	12.85	27.71	280.08
		Std. D	2.08	4.09	81.37	2.13	4.31	81.08

Table 7: Mann-Whitney analysis of the measurements of the upper airway in class I

Class I	Oropharyngeal airway			nasopharyngeal airway		
	Depth	**Width**	**area**	**Width**	**Depth**	**area**
Mann-Whitney U	8.000	41.000	20.000	32.000	37.000	33.000
Wilcoxon W	86.000	119.00	98.000	60.000	115.00	111.00
Z	-2.876-	-.085-	-1.859-	-.845-	-.423-	-.761-
Asymp. Sig. (2-tailed)	.004	.933	.063	.398	.673	.447
Exact Sig. [2*(1-tailed Sig.)]	.003	.967	.068	.432	.711	.482

Table 8: Mann-Whitney analysis of the measurements of the upper airway in class II

CLASS II	**Oropharyngeal airway**			**nasopharyngeal airway**		
	Depth	**Width**	**area**	**Width**	**Depth**	**area**
Mann-Whitney U	32.000	34.500	35.000	31.000	32.000	31.000
Wilcoxon W	77.000	79.500	80.000	67.000	68.000	67.000
Z	-.385-	-.144-	-.096-	-.481-	-.385-	-.481-
Asymp. Sig. (2-tailed)	.700	.885	.923	.630	.700	.630
Exact Sig. [2*(1-tailed Sig.)]	.743	.888	.963	.673	.743	.673

Discussions

The main aim of this study was to establish the characteristics of the OA and NA in adults with skeletal Class II malocclusion Using 3DCT, and to investigate possible relationships between the upper airway and anteroposterior growth type. Skeletal patterns according to the ANB angle were chosen, because this is one of the most used criteria in the determination of the anteroposterior relationship between the maxilla and the mandible [24-28]. Nevertheless, this angle might be influenced by the anteroposterior position of nasion relative to Points A and B, among other factors, and some authors have suggested that the diagnosis of such discrepancies must be based on more than 1 anteroposterior appraisal [26,29-30], so we included wits value, AF-BF distance to support our results.

The subjects ranged from 17 to 42 years of age (average, 31 years), so they had already undergone their adolescent growth spurt; thus, we did not evaluate the correlation between airway measurements and age. In the progress of sampling, we found statistically significant correlation between nasopharyngeal airway measurements and the cephalometric measurements determining anteroposterior growth patterns (table 4), and this was in agreement with Grauer et al 2009 [1], who found statistically significant relationship between the volume of the inferior component of the airway and the anteroposterior jaw relationship.

We found that class II subjects have smaller depth and area of nasopharyngeal airway than class I (table2), Park et al ,2011[9] found in their subjects that Children with Class II malocclusion have smaller volume of the pharyngeal airway than do children with Class I and III malocclusion. Claudino et al, 2013 also found The Class II subjects had smaller minimum and mean areas (lower pharyngeal portion, velopharynx, and oropharynx) than did the Class I, III groups. [31] Alves et al [32] compared 3D airways of adult skeletal Class II and Class III patients, and concluded that pharyngeal airway width had statistical significance differences between the 2 groups, whereas we didn't see any significant differences in airway width in our subjects. These differences could be related to the use of different subjects, different positions and projected planes. The OA measurements in class II group were also smaller than class I, but not significant.

Within our subjects regardless the anteroposterior position, Pearson's correlation test showed:

- strong negative correlation between each of ANB angle, wits value and the Depth of NA, and moderate negative one between ANB angle and nasopharyngeal airway CSA, and that means: the greater the ANB angle, the smaller the NA depth and area.
- Moderate negative correlation between AF-BF and between the Depth and CSA of NA.
- Moderate positive correlation between SNB angle and the Depth of NA, and that means that in angel class II, the less anteroposterior growth or position of the mandible, the less depth of nasopharyngeal airway, (table 4)

Claudino et al, 2013 found a negative correlation between the ANB value and airway volume in the lower pharyngeal portion and the velopharynx (both sexes) and in the oropharynx (just in male subjects) [31]. Within our class II subject regardless gender, Pearson's correlation test showed strong negative correlation between wits value and the CSA of the Oropharyngeal airway. We also found very strong positive correlation between the CSA of both of OA and NA with their depth and width, and a moderate positive correlation between the depth and width of the OA in class II subject (table 3). Regarded to gender, we didn't see any significant differences between males and females in airway measurements except in Oropharyngeal depth of class I subjects, females have narrower OA depth than males. Grauer et al 2009 [1] also didn't find statistically significant relationship between volume of the airway and sex. Whereas Shigeta et al [33] found larger airway volumes in men than in women.

Maybe the small sample size in our study did not allow an adequate statistical appreciation of the differences between the sexes. With larger numbers in each group, other differences would have been statistically significant. So further studies with larger groups are recommended.

Conclusions

1. The Class II malocclusion had a narrower nasopharyngeal airway than the Class I group.
2. There is a strong correlation between the depth and area of NA and each of ANB, WITS, AF-BF.
3. No differences in airway measurements between males and females except in Oropharyngeal depth of class I subject, but we still need further studies with larger samples to have more accurate results.

References:

1. Grauer et al. Pharyngeal airway volume and shape from cone-beam computed tomography: Relationship to facial morphology. Am J OrthodDentofacialOrthop. 2009 December;136(6):805–814. doi: 10.1016/j.ajodo.2008.01.020
2. Melsen B. Current controversies in orthodontics. Chicago: Quintessence;1991.
3. Angle E. Treatment of malocclusion of the teeth. Philadelphia: SSWhite Manufacturing Company; 1907.
4. Ricketts RM. Respiratory obstruction syndrome. Am J Orthod1968;54:495-507.
5. Linder-Aronson. Adenoids and 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.
6. Moore A. Observations on mouth breathing. Bull N Z SocPeriodontol1972;9-11.
7. Rosen CL. Obstructive sleep apnea syndrome in children: controversiesin diagnosis and treatment. PediatrClin North Am 2004;51:153-67.
8. Kirjavainen M, Kirjavainen T. Upper airway dimensions in ClassII malocclusion. Effects of headgear treatment. Angle Orthod2007;77:1046-53.
9. Park et al :2011 .Three-dimensional analysis of pharyngeal airway form in children with anteroposterior facial patterns. Angle Orthod. 2011;81:1075–1082.
10. Hwang YI, Lee KH, Lee KJ, Kim SC, Cho HJ, Cheon SH, et al. Effect of airway and tongue in facial morphology of prepubertal Class I, II children. Korean J Orthod 2008;38:74–82.
11. Leech H. A clinical analysis of orofacial morphology and behaviorof 500 patients attending an upper respiratory research clinic.Dent Pract 1958;9:57-68.
12. Gwynne-Evans E. Discussion on the mouth-breather. Proc R SocMed 1958;51:279-82.
13. Preston, CB. The upper airway and cranial morphology. In: Graber, TM.; Vanarsdall, R.; Vig, KWL.,editors. Orthodontics: principles and techniques. 4th ed.. St Louis: C.V. Mosby; 2005. p. 117-143.
14. 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.
15. ALVESJR M, BARATIERI C, NOJIMA LI. Assessment of mini-implant displacement using cone beam computed tomography. Clin Oral Implants Res 2011, 10.1111/j; 1600- 0501.2010.02092.x.
16. BARATIERI C, NOJIMA LI, ALVESJR M, Souza MMG, Nojima MG. Transverse effects of rapid maxillary expansion in Class II malocclusion patients: a cone-beam computed tomography study. Dental Press J Orthod2010;15:89–97.
17. Iwasaki et al .Oropharyngeal airway in children with Class III malocclusion evaluated by cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2009;136:318.e1-318.e9
18. KYUNG SH, PARK YC, PAE EK. Obstructive sleep apnea patients with the oral appliance experience pharyngeal size and shape changes in three dimensions. Angle Orthod 2005;75:15-22
19. LAMICHANE M, ANDERSON NK, RIGALI PH, SELDIN EB, WILL LA. Accuracy of reconstructed images from cone-beam computed tomography scans. Am J Orthod Dentofacial Orthop. 2009 Aug;136(2).
20. KUMAR V., LUDLOW J, SOARES CEVIDANES LH, MOL A. In vivo comparison of conventional and cone beam CT synthesized cephalograms. Angle Orthod. 2008 Sep;78(5):873-9
21. Riedel RA. The relation of maxillary structures to cranium in malocclusion and in normal occlusion. Angle Orthod 1952;22:140-5.
22. Chang HP. Assessment of anteroposterior jaw relationship. Am J Orthod Dentofacial Orthop 1987;92:117-22.
23. Jacobson A. The ''Wits'' appraisal of jaw disharmony. Am J Orthod 1975;67:125-38.
24. 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.
25. Ucar FI, Uysal T. Orofacial airway dimensions in subjects with Class I malocclusion and different growth patterns. Angle Orthod 2011; 81:460-8.
26. 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; discussion 306-7.
27. El H, Palomo JM. Airway volume for different dentofacial skeletal patterns. Am J Orthod Dentofacial Orthop 2011;139:511-21.
28. Alves M Jr, Franzotti ES, Baratieri C, Nunes LK, Nojima LI, Ruellas AC. Evaluation of pharyngeal airway space amongst different skeletal patterns. Int J Oral Maxillofac Surg 2012;23:1-6.
29. Hussels W, Nanda RS. Analysis of factors affecting angle ANB. Am J Orthod 1984;85:411-23.

30. Ferrario VF, Sforza C, Miani A Jr, Tartaglia GM. The use of linear and angular measurements of maxillo-mandibular anteroposterior discrepancies. Clin Orthod Res 1999;2:34-41.
31. Claudino et al, Pharyngeal airway characterization in adolescents related to facial skeletal pattern: A preliminary study**.** Am J Orthod Dentofacial Orthop 2013;143:799-809)
32. Alves PV, Zhao L, O'Gara M, Patel PK, Bolognese AM. Three-dimensional cephalometric study of upper airway space in skeletal Class II and III healthy patients. J Craniofac Surg 2008;19: 1497-507.
33. Shigeta Y, Ogawa T, Venturin J, Nguyen M, Clark GT, Enciso R. Gender- and age-based differences in computerized tomographic measurements of the orophaynx. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;106:563-70.