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Evaluating the relationship between oropharyngeal airway volume and risk of sleep apnea: A cone-beam computed tomography study

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ABSTRACT

Background: The aim of this study was to compare oropharyngeal airway measurements among high- and low-risk individuals for obstructive sleep apnea syndrome.

Materials and Methods: In this cross-sectional study on patients referred for cone-beam computed tomography (CBCT) imaging before dental implant surgery, inclusion criteria were individuals aged >30 years, Class I occlusion, without anomalies of the head and neck, dentulous individuals, systemically healthy, and without defects in the airways. The exclusion criteria were individuals whose responses to the study questionnaires did not match that of their companions and images with artifacts. These patients and their relatives/housemates were requested to fill in the Epworth Sleepiness Scale and Berlin questionnaires. Based on the answers, the patients were classified as high-risk groups, and patients formed low-risk groups. CBCT images were obtained with 85 kVp and 35 mAs and analyzed using ITK-Snap and Mimics. Oropharyngeal airway volume, minimum cross-sectional area, both mesiodistal and anterior–posterior distances in the same axial cut, and linear length between the posterior pharyngeal wall and nasal spine/soft palate/tongue on the midsagittal slice were measured. The level of significance was considered 0.05 for the independent samples *t*-test and Chi-square test. Pearson's correlation coefficient was chosen to discover correlations between CBCT measurements and patients' age, body mass index (BMI), and neck circumference.

Results: In total, 32 individuals participated with a mean age of 50.2 and 53.2 years in the high-risk and low-risk groups, respectively. Ten females and six males comprised the high-risk group, and eight females and eight males formed the low-risk group. Higher BMI and neck circumference existed in the high-risk group, and they both showed a direct relationship with the Epworth score. Oropharyngeal measurements presented significant differences between the two groups, except for the distance between the base of the tongue and the posterior pharyngeal wall ($P = 0.86$).

Conclusion: Oropharyngeal airway volume and minimal cross-sectional area can be used as a predictor for obstructive sleep apnea, and CBCT imaging is beneficial for this purpose.

Key Words: Cone-beam computed tomography, oropharyngeal airway, sleep apnea

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INTRODUCTION

Obstructive sleep apnea syndrome (OSAS) is clinically defined as multiple attacks of diminished respiration (hypopnea) or complete cessation of inhalation (apnea) during sleep.[1] Ineffective efforts made for breathing lead to repeated choking, elevated negative pressure in the chest, and frequent awakening of the patient.[2] Not only this syndrome is life-threatening, but also it causes hypoxemia, vascular and heart diseases, xerostomia, morning headache, exhaustion, daily drowsiness, and a higher risk of vehicular or occupational accidents.[3,4] In addition, in elderly patients, OSAS runs as a separate risk factor for myocardial infarction.[5] As time goes by, this syndrome proceeds and is aggravated: in the early stages, one might only complain of snoring and daytime sleepiness. However, with age, sleep disorders progress to apnea.[6,7] The reported prevalence of OSAS is 17% in the general population.[8,9] Despite its importance, most individuals with apnea are unaware of their condition and the management procedures.[10] Therefore, early diagnosis of at-risk patients is a priority for clinicians and is considered a public health issue.[11]

A polysomnographic survey is the gold standard to diagnose OSAS and includes miscellaneous examinations during sleep, such as electroencephalography, electromyography, measuring heart rate, respiration rate, and O_2 saturation.[6] Polysomnography is not considered a screening tool because it is high-priced, time-consuming, complicated, and inaccessible for everyone, as it must be performed in sleep clinics.[12,13] Hence, easier, more feasible, and low-cost tests are taken into account. Multiple questionnaires have been developed to aid in recognizing individuals with OSAS. Among them is the Berlin questionnaire (BQ), which was created in 1996 at the Conference on Sleep in Primary Care in Berlin, Germany.[14] It has a sensitivity of 86% and specificity of 77% and serves as a reliable means to differentiate patients with apnea. The second one is the Epworth Sleepiness Scale (ESS), which was invented in 1991 in Australia and has been accepted by the American Sleep Association.[15] It is reported to have 40%–76% sensitivity and 31%–79% specificity[16] and assesses excessive sleepiness throughout the day. Previous studies suggest using both BQ and ESS to reach the highest specificity.[17,18]

Collapsibility of the upper airway in snorer patients is more than in normal individuals and depends on the shape and size of the airway.[19] Bamagoos *et al*.[20] recently found out that reformed pharyngeal anatomy and eventually decreased collapsibility of the pharyngeal airway are the main mechanism of mandibular advancement therapy in OSAS patients.

Investigating the morphological and anatomical features of the upper airway in OSAS patients has gained popularity among researchers, and using cone-beam computed tomography (CBCT) is preferable because it is precise in determining the margins of air spaces and soft tissues, identifies the definite site of obstruction, exposes the patient with lesser radiation, and is more economic than computed tomography.[21,22]

This study aimed to compare oropharyngeal airway dimensions on the CBCT images of patients with high- and low-risk status for OSAS.

MATERIALS AND METHODS

This cross-sectional study involved patients who were admitted to the Department of Oral and Maxillofacial Radiology at the School of Dentistry, Isfahan University of Medical Sciences, between April 2017 and December 2018 for CBCT assessment of the jaw bones before dental implant insertion. Inclusion criteria were as follows: individuals aged >30 years (as aging may cause physical alterations that induce obstructive apnea),[23] those with Angle Class I occlusion, those without cleft lip/palate and other anomalies of the head and neck, dentulous individuals, those without diabetes, those who were nonsmoker, nonpregnant individuals, those without a history of myocardial infarction less than a year ago, those who were not taking antidepressants, and those without nasal polyps or any defects and lesions in the airways. The exclusion criteria were individuals whose responses to the study questionnaires did not match that of their roommate/family member and CBCT images with motion artifacts.[17]

The sample size was calculated using the following formula:

$$n = \frac{\left(z_{1-\frac{\alpha}{2}} + z_{1-\beta}\right)^2 (\delta_1^2 + \delta_2^2)}{d^2}$$

where, α = 0.05, $1-\beta$ = 0.80, $\delta 1$ = 1138.4, and $\delta 2$ = 540.1. Therefore, assuming a power of 80% and a significance level of 0.05, a minimum of

16 individuals in each risk group is required to demonstrate a difference of 882 mm^3 and 47 mm^2 for the mean values of oropharyngeal volume and smallest oropharyngeal area, respectively.

The variables of the study were the risk of sleep apnea and oropharyngeal airway volume.

Persian version of the BQ (sensitivity: 86% and specificity: 53%) and ESS (sensitivity: 59% and specificity: 76%)[24] was filled out by participants and their roommates/family members. The blood pressure, height, weight, and neck circumference at the level of the thyroid cartilage were measured. By dividing weight by square height, body mass index (BMI) was calculated in kilograms per square meter.

Based on the answers to both questionnaires, patients were classified as the "high-risk" group (scored >10 in ESS and 2 or 3 positive sections out of three categories of BQ) or the "low-risk" group (scored ≤10 in ESS and 0 or 1 positive section out of three categories of BQ). One of the researchers (oral and maxillofacial radiologist) clinically performed all measurements and gathered records and personal information of the patients through the questionnaires.

CBCT images were obtained by the Galileos Comfort unit (Sirona, Bensheim, Germany) with a 204° rotational arc, scan time of 14 s, and 15 cm × 15 cm field of view, while the patient was positioned upright and laser-localizing light matched the midsagittal plane of the face. Using head straps, the patients were stabilized and told to grab the handles of the unit, hold their breath, and close their eyes to avoid motion artifacts. The operator (an expert oral and maxillofacial radiologist) selected 85 kVp, 35 mAs, and a high-resolution program with a 0.280 mm isometric voxel size. CBCT scans were obtained and exported in lossless compression and anonymized mode and digital imaging and communications in medicine (DICOM) 3.0 format into CDs. The CDs were coded, and the patient's name was unknown to other researchers. The anonymized DICOM images were then transferred from CD to ITK-Snap and Mimics software.

To calculate oropharyngeal airway volume, ITK-Snap version 3.6.0 (http://www.itksnap.org/pmwiki/pmwiki.php) was utilized. To work with this software, the first step was to demarcate the boundaries of the region of interest on all three planes (sagittal, axial, and coronal) in a rectangular area. On sagittal slices, the superior border was confined by the posterior nasal spine (PNS) and the inferior border by the most anterior–inferior point of the second cervical vertebrae. On axial slices, the anterior margin was limited to PNS, and the sides were restricted by lateral pterygoid plates. The next step was to choose the segment three-dimensional (3D) tool and threshold an optimal contrast between soft tissues and air on grayscale images. Then, bubbles were placed in the airway, taking care not to invade soft tissues on all three planes. The software automatically segmented the airway by connecting the bubbles. Finally, the software created a 3D replica of the airway [Figure 1] and computed the volume in cubic millimeters. An oral and maxillofacial radiologist (7 years of experience) measured the distances between PNS, uvula, the base of the tongue, and posterior pharyngeal wall on a midsagittal slide and using the software's linear measurement tool.

All the axial slices were visualized carefully in Mimics Research software version 19.0 (Materialise Interactive Medical Image Control System, Leuven, Belgium), and the slice with the smallest cross-sectional area of the oropharyngeal airway was selected. On this slice, the second specialist selected the "measure area" tool and drew dots on the perimeter of the airway. The software automatically quantified the airway area, airway perimeter, anteroposterior width, and lateral length.

The maxillofacial radiologist who performed these measurements was unaware of the patient's name and risk status. To assess intraobserver agreement, 15 CBCT images of nonparticipants were randomly derived from the archive, and the radiologist reexplored them twice within 2 weeks.

Data were transmitted to Statistical Package for the Social Sciences (SPSS, version 24.0, IBM, Armonk,

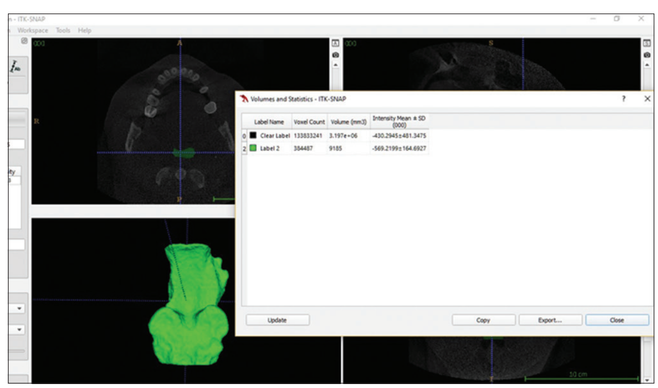

Figure 1: Volume calculated in cubic millimeters by ITK-Snap software.

NY, USA) for analysis. The level of significance was considered 0.05 for the independent samples *t*-test and Chi-square test. Pearson's correlation coefficient was chosen to discover correlations between CBCT measurements and patients' age, BMI, and neck circumference.

All procedures followed were under the Helsinki Declaration of 1964 and later versions, and the ethics approval for this study was granted by the Research Ethics Committee of Isfahan University of Medical Sciences (under permit number #IR.MUI.REC.1396.2.038). Written informed consent was obtained from all individuals involved in the study.

RESULTS

Initially, 34 participants were included in the study. One patient was excluded as a result of a mismatch between the questionnaire results of the individual and their roommate, and another patient was excluded due to the presence of motion artifacts in the CBCT image. Therefore, 32 individuals were analyzed in this study. The mean age of the high-risk and low-risk groups was 50.2 and 53.2 years, respectively; the independent samples *t*-test showed no significant differences (P = 0.45). Ten females and six males comprised the high-risk group, and eight females and eight males formed the low-risk group. The Chi-square test indicated no difference in the frequency distribution of sexes between the two groups (P = 0.48). The two risk groups differed significantly in the mean values of weight, BMI, neck circumference, and Epworth score ($P < 0.05$), but not in the mean values of blood pressure and height ($P > 0.05$) [Table 1]. The intraobserver agreement was good for radiographic measurements (Cronbach's alpha value was 0.82). Surveying CBCT images of the oropharyngeal region designated significantly lower quantities for all airway measurements in the high-risk group, except for the distance of the tongue base to the posterior pharyngeal wall, which was not significantly different (P = 0.86) [Table 2]. Analysis of the airway dimensions in both sexes revealed no significant differences between males and females ($P > 0.05$). Pearson's correlation coefficients indicated a negative correlation between BMI and airway measurements, except for PNS to posterior pharyngeal wall distance (r = 0.486). BMI and neck circumference had no significant relation to the distance between the uvula and the pharyngeal wall ($P > 0.05$). Excluding the base of the tongue to pharyngeal wall distance, neck circumference showed significant negative correlations with airway dimensions. Both BMI and neck circumference positively correlated with the Epworth score (r = 0.857 and r = 0.819). The highest negative correlations were between the volume of oropharyngeal airway and BMI and neck circumference (r = −0.864 and r = −0.790) [Table 3].

DISCUSSION

Despite clinical seriousness and the progression of OSAS, most affected patients are unaware of their situation. A study reported a 38.5%

Table 1: Age distribution, weight, height, body mass index, systolic and diastolic blood pressures, neck circumference, and Epworth score compared among the two risk groups

Variables	High-risk group, mean±SD	Low-risk group, mean±SD	*P*
Age	50.2±12.5	53.2±9.8	0.45
Weight (kg)	84.4±13.1	68.0±12.7	0.001*
Height (cm)	162.6±8.8	166.2±7.3	0.22
BMI	31.9±4.5	24.6±4.2	<0.001*
Systolic blood pressure (mmHg)	132.7±35.8	127.9±14.7	0.62
Diastolic blood pressure (mmHg)	82.3±23.9	82.6±11.9	0.96
Neck circumference (cm)	39.8±2.1	37.4±1.4	0.001*
Epworth score	15.1±3.5	5.1±3.04	<0.001*

**P*<0.05. BMI: Body mass index; SD: Standard deviation

Table 2: Cone beam computed tomography measurements of oropharyngeal airway compared among the two risk groups

Variables	High-risk group, mean±SD	Low-risk group, mean±SD	*P*
OPAV (mm^3)	5988.1±1108.7	10,884.8±1774.7	<0.001*
Minimum cross-sectional area (mm^2)	65.6±38.6	151.2±38.9	<0.001*
Anterior–posterior width (mm)	3.4±1.5	6.3±2.01	<0.001*
Lateral length (mm)	16.9±4.8	24.1±4.9	<0.001*
Perimeter of the smallest cross-sectional area (mm)	42.1±9.9	55.9±16.7	0.008*
PNS-PPW (mm)	21.2±4.1	25.6±2.7	0.001*
U-PPW (mm)	3.9±1.8	6.3±2.2	0.003*
To-PPW (mm)	16.8±5.1	16.5±4.1	0.86

**P*<0.05. OPAV: Oropharyngeal airway volume; PNS-PPW: Posterior nasal spine to posterior pharyngeal wall distance; U-PPW: Uvula to posterior pharyngeal wall distance; To-PPW: Base of tongue to posterior pharyngeal wall distance; SD: Standard deviation

Table 3: Pearson's correlation coefficients between body mass index, neck circumference, and oropharyngeal airway values and Epworth score

Variables	BMI		Neck circumference	
	P	***r***	***P***	***r***
OPAV	<0.001*	–0.864	<0.001*	–0.790
Minimum cross-sectional area	<0.001*	–0.594	0.001*	–0.561
Anterior–posterior width	0.02*	–0.418	0.04*	–0.358
Lateral length	0.001*	–0.579	<0.001*	–0.595
Perimeter of the smallest cross-sectional area	0.038*	–0.368	0.01*	–0.437
PNS-PPW	0.005*	0.486	0.002*	–0.519
U-PPW	0.36	0.167	0.56	0.106
To-PPW	0.043*	–0.309	0.10	–0.292
ESS	<0.001*	0.857	<0.001*	0.819

*$P<0.05$. OPAV: Oropharyngeal airway volume; PNS-PPW: Posterior nasal spine to posterior pharyngeal wall distance; U-PPW: Uvula to posterior pharyngeal wall distance; To-PPW: Base of tongue to posterior pharyngeal wall distance; BMI: Body mass index

prevalence of OSAS in Iran, which is an outstanding amount.[24] Consequently, researchers are looking forward to miscellaneous economical and uncomplicated methods to assist in the early diagnosis of at-risk individuals.

BQ has been accepted as a highly sensitive screening and epidemiologic tool with a top-level odds ratio for OSAS detection.[25,26] It consisted of 10 questions grouped into three classes regarding snoring, somnolence and tiredness, and hypertension. The Persian version of this questionnaire has 86% sensitivity and 53% specificity.[24] The second widely used questionnaire is ESS, which raises eight questions regarding daily drowsiness and exhaustion.[15] The Persian translated ESS is affirmed to possess a 59% sensitivity and 76% specificity.[27] Studies advocate using both BQ and ESS to upgrade the specificity for differentiating low-risk patients.[17,18]

Similar to previous studies,[24,27,28] we found an average age of 50.2 years and a mean BMI of 31.9 kg/m^2 for the high-risk group, which suggests that mostly middle-aged obese individuals are at the hazard of OSAS. Besides, BMI had a positive correlation with ESS, which is consistent with the findings of Schäfer *et al*.[29] who reported that the degree of breathing difficulties had a significant relation with body weight, BMI, and abdominal fat accumulation. On average, high-risk patients had a neck circumference of 39.8 cm, which was particularly more than the low-risk group. Epworth sleepiness score was also significantly correlated with neck circumference. These outcomes are in line with Ahbab[30] and Onat[31] studies that reported a neck circumference of more than 39 cm in men, which not only acts as an independent risk factor but also can be predictive of OSAS. Despite the aforementioned studies, 62.5% of the high-risk members in our study were women. This may be due to the gender profile of individuals attending the dental school.

Weissheimer *et al*.[32] compared six software programs of airway analysis and reported that Mimics, ITK-Snap, Dolphin 3D, and OsiriX than Ondemand3D and *In Vivo* Dental were more accurate in calculating the volume of the acrylic oropharyngeal phantom. Almuzian *et al*.[33] weighed oropharyngeal airway volume before and after rapid maxillary expansion surgery and deduced that ITK-Snap software is approved as an accurate, reliable, and cost-effective program for airway segmentation and volume measurement. We employed ITK-Snap software because it is a user-friendly, sensitive, and accurate freeware that rapidly computes oropharyngeal airway volume.[34] Mimics software was utilized for axial measurements of the area and perimeter of the airway.

In the present study, there were diversities in the oropharyngeal airway characteristics between the risk groups. Oropharyngeal airway volume was significantly smaller in high-risk patients. This finding correlates with some studies: Ogawa *et al*.,[34] Tikku *et al*.,[19] Adisen *et al*.,[17] and Buchanan *et al*.,[35] who found considerably smaller volume of oropharyngeal airway in patients with apnea. Although some studies reported no significant differences between low-risk and high-risk individuals,[36-38] our study found significantly smaller axial airway measurements (cross-sectional area, perimeter, anterior–posterior width, and lateral length) in the high-risk group. Similar to our findings, Ogawa *et al*.,[36] Enciso *et al*.,[37] Momany *et al*.,[38] Buchanan *et al*.,[35] Adisen *et al*.,[17] and Tikku *et al*.[19] found the smaller cross-sectional area of the oropharyngeal airway in the OSAS group. By contrast, in a study conducted by Shigeta *et al*.,[39] an insignificant difference in cross-sectional area between case and control groups was reported. This may be because we considered the minimum axial section of the oropharyngeal airway, whereas Shigeta *et al*. measured the cross-sectional area of the airway at the level of the second cervical vertebra in both the groups.

As former studies stated, the collapsibility of the airway is greater in OSAS patients, and thereby, the main mechanism of mandibular advancement therapy is reducing this flexibility by increasing the airway diameter.[40] Airway collapsibility is based on its configuration and can be evaluated through careful assessment of anterior–posterior width and the lateral length of airway cross sections. Our results expressed significantly lower axial airway length and width in high-risk patients, which stands for a more foldable airway in this group. This is in line with the Tikku *et al*.'s study, which also found smaller measures of axial airway diameter and cross dimension.[19] Enciso *et al*.[37] and Buchanan *et al*.[35] reported considerable undersized lateral length, and Ogawa *et al*.[34,36] found notably smaller anterior–posterior width in OSAS patients. By contrast, Shigeta *et al*.[39] and Momany *et al*.[38] detected oversized anterior–posterior dimensions of axial airway transection. This dissimilarity may be explicable by the method of our study: while we used the axial slice with minimum airway area to measure its dimensions, Momany *et al*. used software that automatically analyzed the slice of the most constricted part of the airway,[38] and Shigeta *et al*. considered the axial airway slice at the position of the second cervical vertebra.[39]

Surveying the midsagittal slice revealed significantly shorter distances of the posterior pharyngeal wall to the uvula and PNS in high-risk patients, but no significant difference existed between the two risk groups in their mean distance of pharyngeal wall to the base of the tongue. Adisen *et al*.[17] studied the lateral cephalometric radiographs of young patients and announced significantly narrower space between the posterior pharyngeal wall and uvula, PNS, and base of tongue in the high-risk group. This may be because of the unavoidable superimposition of anatomical structures in lateral cephalometric radiographs, which makes it prone to patient positioning errors, while CBCT images provide an actual and accurate view of the exact midline of the patient. Moreover, it can also be attributed to our selection criteria, as all the partakers in our study were grown-up adults with Class I occlusion, but Adisen *et al*. examined individuals younger than 30 years of age.

One of the limitations of this study is not utilize polysomnographic examination, as some participants refused to cooperate and spent one night at the sleep clinic. However, we referred all the high-risk patients to the sleep center. We suggest further research being conducted on larger groups, applying polysomnographic evaluations as well.

CONCLUSION

CBCT findings of the oropharyngeal airway are significantly different between low-risk and high-risk OSAS patients. We recommend that oropharyngeal airway volume and minimal cross-sectional area measurements on CBCT images could be used to forecast the risk of sleep apnea in individuals.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or nonfinancial in this article.

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