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Dimensional and volumetric analysis of the oropharyngeal region in obstructive sleep apnea patients: A cone beam computed tomography study

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ABSTRACT

Background: Obstructive Sleep Apnea (OSA) is a potentially life-threatening condition in which there is a periodic cessation of breathing (for 10 sec or longer) that occurs during sleep in the presence of inspiratory effort. The aim of the study was to assess volumetric and dimensional differences between OSA patients and normal individuals in the upright posture.

Material and Method: The present study was conducted on CBCT scans of 32 patients who were divided into two groups –Group I (control group) and Group II (OSA subjects). Group I consisted of 16 patients with normal airway with ESS score from 2 to 10, STOP BANG Questionnaire score of <3 and who had undergone CBCT for various diagnostic reasons. Group II had patients with ESS score >10, STOP BANG Questionnaire score of > 3, AHI index >5. Linear and angular parameters, volume and minimum cross-section area (MCA) of oropharyngeal airway, anteroposterior length and lateral width at MCA was compared amongst the groups.

Results: The oropharyngeal volume, MCA, and the anteroposterior and lateral width of the airway at MCA of the OSA subjects was significantly lesser than that of normal subjects. The length of both soft palate and tongue was significantly more in Group II. The angle between the nasopharyngeal airway and the oropharyngeal airway was significantly more obtuse in Group II.

Conclusion: The reduction in oropharyngeal volume in OSA patients could be attributed to different anatomical and pathophysiological factors that were corroborated with the findings of the present study.

Key Words: Airway, cone beam computed tomography, length, obstructive, oropharyngeal, sleep apnea, tongue

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INTRODUCTION

Obstructive sleep apnea (OSA) is a potentially life-threatening condition, in which there is a periodic cessation of breathing (for 10 s or longer) that occurs during sleep in the presence of inspiratory effort, resulting in excessive daytime sleepiness (EDS) during the waking hours.

OSA exhibits a prevalence of 2% in the adult female population and 4% in the adult male population,[1] with greater predilection in obese persons, in individuals older than 65 years,[2] and in hypertensive or heart failure patients.[3]

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Several causes for OSAs have been suggested. It appears to result from a variable combination of anatomical and pathophysiological factors, some of which may be under genetic control.[3] These various factors result in constriction of the upper airways giving rise to an increase in the negative pressure during inspiration that necessitates an increase in pharyngeal dilator muscle contraction to maintain airway patency. However, this has been observed only during wakefulness, whereas pharyngeal muscle contraction was shown to decrease during sleep, resulting in an inability to maintain airway patency, thus contributing to the development of OSA.[1]

OSA results in the constellation of signs and symptoms such as chronic persistent snoring, EDS, cognitive impairment,[4] and impaired ability to operate a motor vehicle.

The diagnosis of OSA is performed with the help of polysomnography (PSG) that determines the apnea–hypopnea index (AHI). It is now accepted that a diagnosis of clinically significant OSA is made when AHI is more than 5 and the patient presents with the clinical features related to OSA.

For many years, two-dimensional lateral cephalometric images have been used to look for anatomic differences[5-11] between OSA patients and normal individuals (non-OSA) that could increase the propensity toward OSA, since the maximum airflow velocity and pressure gradients are found at the minimal cross-sectional area (MCA) of a conduit,[12] and the evaluation of the MCA and total volume is only possible with three-dimensional (3D) imaging techniques.

Among the various 3D imaging techniques available, cone beam computed tomography (CBCT) was selected for the current study as it is a lower dose, lower cost alternative with the limitation of exposure to the region of interest in comparison to the conventional computed tomography (CT) scans.

In previous studies, investigation of airway in OSA patients has been conducted on CBCT scans taken in the supine position. However, it has been observed that the soft palate, epiglottis, and entrance of the esophagus move posteriorly with the positional change from an upright to a supine position.[13] Therefore, the volume of the oropharyngeal airway and the MCA always decrease in the supine position. Considering this, it was decided to assess the volumetric and dimensional differences between OSA patients and normal individuals in the upright posture. In addition, when a CBCT scan is taken in upright posture, the head is stabilized with a cephalostat, therefore postural variations in the dimensions of the oropharynx can be eliminated and accurate comparisons can be made.

MATERIALS AND METHODS

The present study was conducted on CBCT scans of 32 patients who were divided into two groups - Group I (control group) and Group II (OSA patients). The mean age of Group I was 44.75 ± 11.73 years (31–65), and for Group II, it was 52.94 ± 13.09 years (34–72). The sample for the study was matched for their ages. For both the groups, patients above the age of 30 years were selected, as the prevalence and severity of OSA are seen to increase with age. This study was approved by the Ethical Committee of BBDCODS, Lucknow, India. Informed consent was taken from all the patients for using their CBCT scans for the study purpose. The body mass index (BMI) and neck circumference were recorded for all patients of both the groups by a single operator.

Selection of sample

Group I

Group I consisted of 16 patients who were selected from 25 patients who had undergone CBCT for various other diagnostic reasons (e.g., temporomandibular joint problems, condylar hyperplasia, assessment of impacted and supernumerary teeth, etc.) and had normal airway.

These 25 patients were asked to fill out a specialized case history form of a specialized center for respiratory disorders and sleep evaluation, designed to screen OSA. It consisted of general medical history, history of OSA symptoms, the Epworth sleepiness scale (ESS), and the STOP-BANG questionnaire. The ESS is a simple questionnaire measuring the general level of daytime sleepiness. This is a measure of the probability of falling asleep in a variety of situations. ESS scores of 2–10 are considered normal.

The STOP-BANG questionnaire is a scoring model consisting of eight easily administered questions starting with the acronym STOP-BANG and its scores are based on Yes/No answers (score: 1/0). A score of ≥3 indicates that the patient has high propensity to be diagnosed for OSA.

Inclusion criteria

1. Age >30 years
2. No history of snoring or any respiratory disorder
3. ESS score from 2 to 10
4. A STOP-BANG questionnaire score of <3
5. Having anatomically normal airway as seen on CBCT scan with no radiologically evident pathology in the airway.

All CBCT images were obtained with the Carestream (CS) 9300 3D imaging system.

Group II

Group II consisted of 16 patients who were selected from the records of 25 patients diagnosed with OSA at the same specialized center.

The patients with suspected symptoms of OSA are diagnosed for it by following a standard protocol, the details of which are as follows:

1. The patients fill out a specialized case history form designed to screen OSA as described before
2. The patients who have significant signs and symptoms of OSA and abnormal scores on ESS scale (>10) and the STOB-BANG questionnaire (>3) are advised to undergo overnight PSG
3. Based on the results of PSG, from the patients diagnosed for OSA, patients with AHI of > 5 were selected
4. These patients are then referred by the concerned specialist for a CBCT scan*.

Exclusion criteria

The patients with heart disease including a history of myocardial infarction, angina; renal disease; pulmonary disorder; history of stroke; anxiety/panic disorder; neurological disorder such as epilepsy; narcolepsy; restless leg syndrome; drug abuse/dependence; diabetes; liver disease; history of alcoholism, or excessive intake of caffeinated beverages and tobacco products were excluded from the study.

Cone beam computed tomography scans

The CBCT scans were taken with the patients in an upright posture and in a natural head position using a cephalostat. The patients were asked to swallow any saliva to clear the oral cavity and pharynx and then to close their mouths lightly to place their upper and lower teeth in contact with each other before scanning.

The CBCT scans were imported into the Digital Imaging and Communications in Medicine viewer (CS 3D Imaging Software 3.2.9 by Carestream Dental, By Cybermed Inc Korea). The slice thickness in each plane (sagittal, axial, and transverse) was 300 µm.

For the evaluation of the oropharyngeal airway, the following measurements were made by a single operator using a computerized software.

Linear and angular measurements on the mid-sagittal slice

Nine linear and one angular measurements were taken on the mid-sagittal slice using CS 3D Imaging Software 3.2.9 after identifying landmarks as shown in Figures 1 and 2.

1. The distances between posterior nasal spine (PNS), base of the tongue, tip of the epiglottis, and tip of the soft palate were measured, and the corresponding opposite points on the posterior pharyngeal wall (PPW) were also measured [Figure 3]
2. Length of the soft palate and tongue [Figure 3], intermaxillary space, retrognathion (Rg) to C2

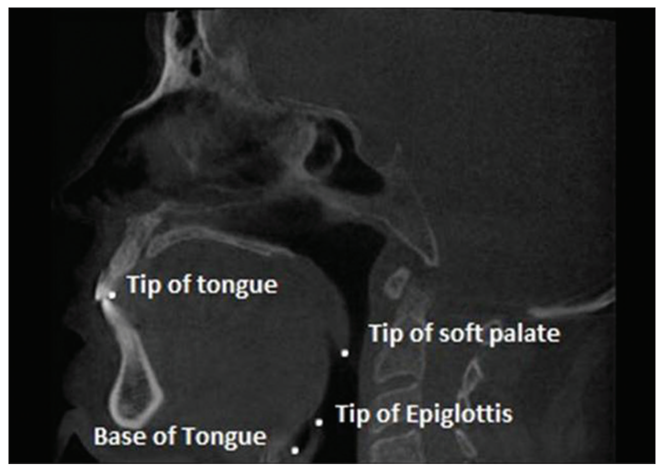


Figure 1: Landmarks used in the present study.

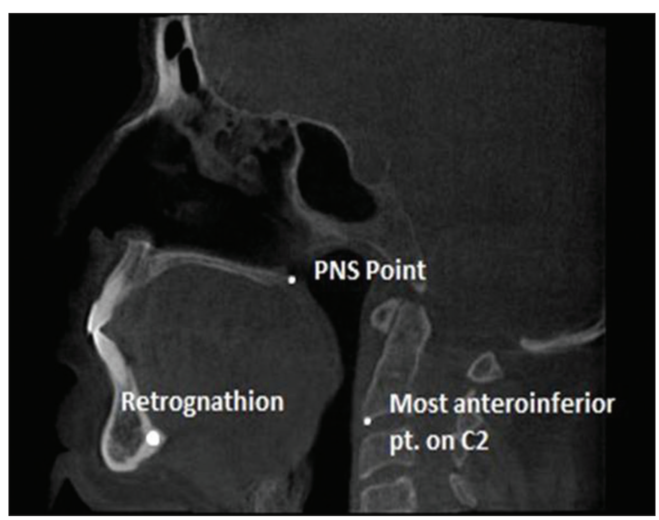


Figure 2: Landmarks used in the study.

and soft tissue thickness at C2 were measured [Figure 4]

3. Angle between a line passing through the middle of the nasopharyngeal airway and the middle of the oropharyngeal airway was measured [Figure 4].

The volume of the oropharyngeal airway

To define the volume of oropharyngeal airway, the mid-sagittal slice is cropped on CS 3D imaging software 3.2.9 [Figure 5], where in:

- The upper border was defined by a line parallel to the FH plane joining the PNS point to the PPW
- The lower border was defined by another line parallel to the FH plane which extends from the most anteroinferior point of the C2 vertebrae to the anterior pharyngeal wall.

The cropped volume is then exported to the OnDemand3DApp Version 1.0 (Built 1.0.9.2341) software by Cybermed Inc. (Korea) [Figure 6]. For defining the other boundaries of the airway, the opacity values of the oropharyngeal airway are fed to the software using the 3D segmentation pick tool, by picking the points of similar opacity in the airway. The software then sculpts out and automatically computes the volume of the selected region [Figure 7].

Calculation of the minimum cross-sectional area of the oropharynx

On the cropped oropharyngeal airway on the OnDemand3DApp Version 1.0 (Built 1.0.9.2341) software, along the region of increased constriction of the oropharyngeal airway, the cross-sectional area is calculated automatically on the corresponding ten axial slices that are within this region of interest. From the ten axial slices, the axial slice with the MCA is selected [Figure 8]. On the same slice, anteroposterior (AP) length and the lateral width (Lat) of the airway were also computed.

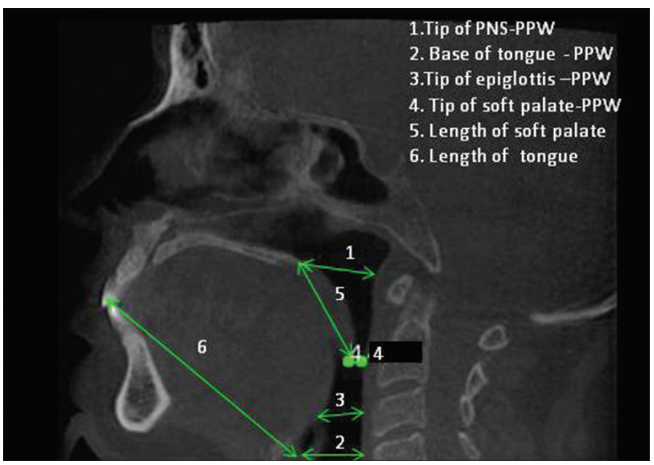


Figure 3: Parameters to evaluate airway.

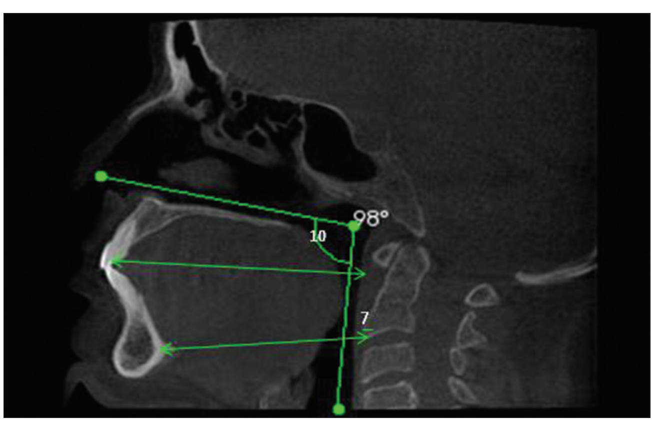


Figure 4: Other parameters to evaluate airway.

Figure 5: Cropped oropharyngeal airway on CS 3D software.

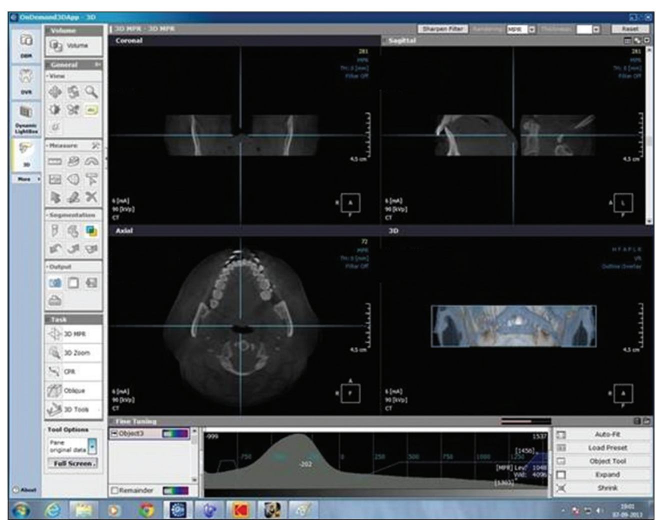


Figure 6: Cropped oropharyngeal airway exported to OnDemand 3D APP software.

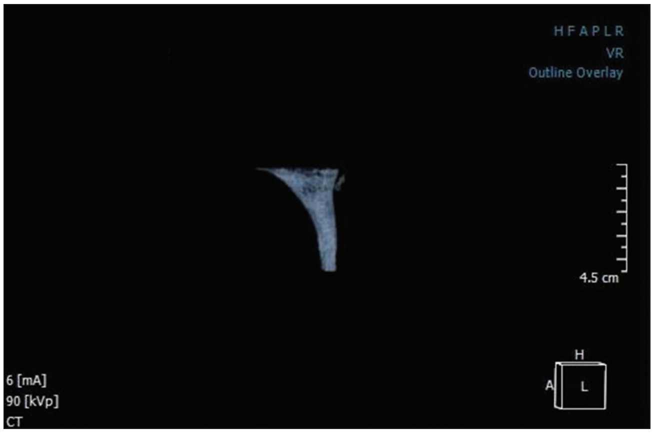


Figure 7: Sculpting out of oropharyngeal airway.

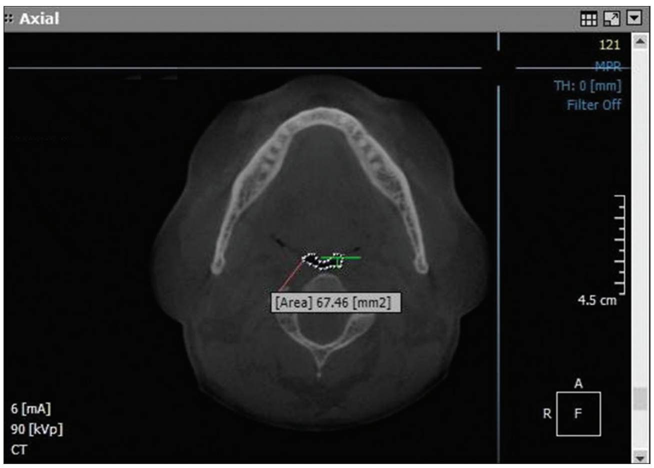


Figure 8: Minimum cross-sectional area.

Statistical tools

All the measurements were taken using Statistical Package for Social Sciences Software, version 18 by IBM SPSS Statistics. Level of significance was set as <0.05 to be significant and 0.01 as highly significant.

Measurement reliability

Reliability of measurements was done by repeating the measurements of two patients selected each from Group I and Group II at 15-day interval. The measurements were made again on the images from CBCT scans after identifying the landmarks. The comparison was done between the first and second set of readings by Student's *t*-test. Statistically, no significant difference was noted between them.

RESULTS

Table 1 shows BMI values with statistically insignificant difference between the groups. Mean neck circumference value did not show any statistically significant difference between the groups as shown in Table 2.

Table 1: Categorization and comparison of patients in two groups according to body mass index

BMI category (kg/m^2)	Group I (*n*=16)	Group II (*n*=16)	*P*
Normal weight (18.5-24.9)	2	0	0.072
Overweight (25.0-29.9)	8	4	
Obese Grade I (30-34.9)	5	7	
Obese Grade II (>35)	1	5	
Mean BMI±SD (range)	29.3±3.6 (22.2-35.0)	33.1±4.2 (27.3-40.9)	

P>0.05 (NS). NS: Not significant; BMI: Body mass index; SD: Standard deviation

Table 2: Comparison of patients in two groups according to neck circumference

parameter	Group I	Group II	*Z*	*P*
Mean neck circumference	38.1±2.0 (35-42)	40.1±3.6 (35-45)	1.631	0.110

P>0.05 (NS). NS: Not significant

Table 3 shows the comparison of different measurements in the oropharyngeal region between the Group I and Group II patients.

DISCUSSION

OSA is a chronic disease characterized by recurrent episodes of cessation of breathing due to the upper airway obstruction during sleep.

In recent studies on airway morphology of OSA patients, lateral cephalograms have been largely replaced by 3D visualization techniques for the assessment of airway in all the three planes of space. Among the different 3D imaging techniques, CBCT has emerged as the most popular technique as the acquisition time of CBCT is less than a CT scan; there is less chance of patient movements such as during breathing, swallowing, or other involuntary movements.

Since the sleep apneic events occur in the supine position during sleep, most of the investigations on the morphology of the airway of OSA patients have been carried out in this position. Considering the effect of gravity on various oropharyngeal structures, it was decided to conduct this study using CBCT scans taken in the upright posture.

As obesity is considered a predisposing factor for OSA, the indicators of obesity such as BMI and the neck circumference of the patients were recorded for

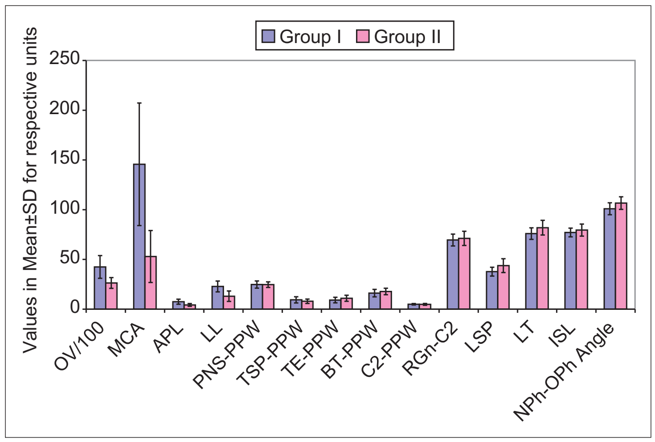
Table 3: Comparison of different oropharyngeal measurements between two groups

Parameter	Group I (*n*=16)				Group II (*n*=16)				Significance of difference (Mann-Whitney U-test)	
	Mean	SD	Range		Mean	SD	Range			
			Minimum	Maximum			Minimum	Maximum	*Z*	*P*
OV	4241.3	1138.4	3137.5	6466.7	2632.3	540.4	1694.3	3277.0	4.560	<0.001
MCA	145.60	61.64	85.85	284.60	52.91	26.09	17.62	93.99	4.711	<0.001
APL	7.43	2.55	4.54	14.47	4.21	1.37	1.12	6.90	4.146	<0.001
LL	22.78	5.41	13.63	31.52	12.95	5.25	5.00	25.10	3.883	<0.001
PNS to PPW (PNS-PPW)	24.72	3.58	18.20	31.50	24.62	2.80	19.30	29.30	0.170	0.867
TSP to PPW	9.33	3.15	4.70	15.20	7.92	2.21	4.10	14.10	1.133	0.270
TE to PPW	9.09	2.82	6.30	16.60	10.88	3.07	7.60	16.40	1.717	0.086
BT to PPW	16.07	3.76	9.60	22.30	17.76	3.26	11.00	22.30	1.245	0.224
C2 to PPW (C2-PPW)	4.89	0.70	3.50	6.40	4.78	0.89	3.10	6.40	0.303	0.870
RGn to C2	69.49	5.95	60.80	79.10	71.12	7.14	57.80	82.10	0.735	0.468
LSP	37.69	4.44	29.70	47.60	43.71	6.90	32.80	56.40	2.733	0.005
LST	75.91	5.82	64.60	83.10	81.86	7.39	69.80	92.70	2.130	0.032
ISL	77.04	4.38	69.70	84.80	79.46	6.09	67.90	88.40	1.094	0.287
Angle between nasopharyngeal and oropharyngeal airway	100.88	6.00	91.00	113.00	106.63	6.33	98.00	120.00	2.192	0.029

P>0.05: Not significant; *P*<0.05: Significant; *P*<0.01: Highly significant; *P*<0.001: Very highly significant. OV: Oropharyngeal volume; MCA: Minimal cross-section area; APL: Anteroposterior length; LL: Lateral length; TSP: Tip of soft palate; TE: Tip of epiglottis; BT: Base of tongue; RGn: Retrognathion; LSP: Length of soft palate; LST: Length of tongue; ISL: Intermaxillary space length; SD: Standard deviation; PNS: Posterior nasal spine; PPW: Posterior pharyngeal wall

the two groups. Mean BMI and neck circumference were significantly higher in OSA patients in many of the previous studies,[14-17] in contrast to the results of our study. Although the mean BMI and neck circumference of the OSA patients were higher than the controls in our study and majority of OSA patients were in obesity Grade I and Grade II categories, the difference was not significant statistically because the sample size of our study was small.

The oropharyngeal volume for Group I was significantly higher than that for Group II [Graph 1]. Our findings correlate with the data from the study by Lowe *et al.*,[12] wherein the patients with more severe sleep apnea tended to have a larger tongue volume and a smaller airway volume. Similarly, Abramson *et al.*[18] found that the airway volume of OSA patients was found to decrease significantly with an increase in the respiratory distress index. In a study by Ogawa *et al.*[19] using CBCT scans, the mean oropharyngeal volume for non-OSA individuals was higher than that for OSA patients, but the difference between the two groups was not statistically significant. Although their method of computing airway volume was similar to the present study, the reason for their insignificant group difference could be that they did not carry out critical screening for controls. The controls were classified as non-OSA based on the absence of snoring and other OSA symptoms, unlike proper screening for OSA by filling up a specialized



Graph 1: Graphical representation of comparison of different oropharyngeal measurements between two groups.

questionnaire in the present study. Similarly in a study conducted by Enciso *et al.* (2010),[5] the difference was statistically insignificant, as their control group had individuals with AHI <10, whereas in our study, according to the recently accepted criteria, an individual with an AHI of more than 5 was considered as an OSA patient. Another study[6] demonstrating an insignificant difference was because OSA patients and controls were not matched for age and BMI.

The mean MCA in our study for Group II was significantly lesser than Group I [Graph 1], and similar findings were noted in the previous studies.[4,18-20] In these previous studies,[4,19] oropharyngeal volume did not show a significant difference whereas MCA demonstrated significant differences, suggesting its importance in OSA patients. This was also confirmed by a study by Kyung *et al*. 2004[21] where it was observed that with the use of mandibular advancement oral device in OSA patients, MCA increased significantly. The statistically significant differences were not observed between OSA group and control group either because of discrepancy in sample size or different measurement techniques being used in few studies.[18,19,22] In a study[16] using magnetic resonance imaging (MRI), no significant group differences were observed with respect to MCA since MRI scan takes a much longer time to obtain the data than a CBCT scan, a patient undergoes several cycles of inspiration and expiration during the scan time and therefore, measurements could not be as accurate as those on a CBCT scan.

The mean AP length for Group II was significantly lesser than that for Group I [Graph 1], as was also corroborated by Ogawa *et al*.,[19] and contradictory results were given by Enciso *et al*.[5]

The Lat or the transverse diameter (T) at the smallest cross-sectional area of the airway in our study was significantly lesser in Group II than Group I [Graph 1]. Similar findings were reported in various other studies.[4,18,19,22] These findings suggest that a decrease in transverse diameter has an influence on the obstructive events in OSA patients by alteration in pharyngeal shape from elliptical in normal individuals to more circular in OSA patients.

In our study, the angle of the nasopharyngeal airway to the oropharyngeal airway was significantly more obtuse in Group II than in Group I. It has been observed that the factors that predispose to airway collapse are those that decreased intraluminal pressures (obstruction), increased external pressure (obesity, sleeping position), or decreased the resistance to collapse offered by the walls of the pharynx (collapsibility).[18] Poiseuille's law states that the resistance at the site of an obstruction is directly proportional to its length and inversely proportional to the radius.[18] Obstruction due to a decrease in the radius of airway has been observed in our study. In addition to that as the nasopharyngeal to oropharyngeal airway angle is more obtuse in OSA patients, it is suggestive of an increase in the total length of the airway. Thus, this further increases the resistance to airflow. From these findings, it can be suggested that the obstruction caused by even a small decrease in the cross-sectional area of airway can be magnified by an obtuse-angled longer airway. The collapsibility of the airway depends on its shape. As AP length and lateral diameter are decreased in our study as well as in other studies,[4,18,19] the airway shape is altered, making it more prone to collapse.

The length of soft palate in our study was significantly higher in Group II than Group I, as also seen in the previous studies.[17,20,23] In other studies,[6,16,18,23,24] area or volume of soft palate was assessed and found to be more in OSA patients than that of controls.

In our study, it was found that the mean length of tongue was significantly higher in Group II than Group I [Graph 1]. Such significant findings were also reported in a previous study by Pracharktam *et al*.[24] whereas other studies reported an increase in tongue area and volume.[18,23]

There was no significant difference from various landmarks to their correspondingly opposite points on the PPW [Graph 1]. Measurements in similar manner, i.e., at different levels of oropharynx were not made in other previous studies; hence, direct comparisons with other studies[25-27] were not possible. This suggests that a significant AP shortening of airway is observed only at the MCA and not at different fixed levels that could be different from the site of MCA.

Other parameters such as intermaxillary space length (amount of space within which the tongue has to function), the soft tissue thickness measured at the level of the most anteroinferior point of C2 (c) to PPW, and Rg to C point (determines how posteriorly mandible is positioned) were not reduced significantly in the present study in contrast to other studies,[26,27] wherein sample size was larger.

Within the limitations of the present study, it can be suggested that oropharyngeal volume is reduced significantly in OSA patients in comparison to normal individuals, and this could be attributed to different anatomical and pathophysiological factors that were corroborated with the findings of the present study.

Since CBCT scans are fast becoming a routine diagnostic procedure in orthodontics and many adults are opting for orthodontic treatment, orthodontists are in a unique position to identify the anatomical and pathophysiological risk factors of OSA. Therefore, orthodontists can refer the patient to the concerned specialist and thus, aid in early diagnosis and treatment of OSA.

As the sample size of our study was small, a more extensive research with a larger sample size is recommended to check for the applicability of these findings. Further studies can also aim at evaluating the various anatomical and pathophysiological changes induced by orthodontic interventions such as the use of mandibular advancement devices.

The following conclusions were drawn from this study:

1. The oropharyngeal volume, MCA of the oropharyngeal airway, and the AP and lateral length of the airway at this cross-sectional area of the OSA patients were significantly lesser than that of normal individuals. This resulted in obstruction as well as an alteration in pharyngeal shape in the OSA patients, making it more prone to collapse
2. The length of both soft palate and tongue was significantly more in OSA patients than the normal individuals
3. The angle between the nasopharyngeal airway and the oropharyngeal airway is significantly more obtuse in the OSA patients in comparison to the non-OSA controls.

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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 non-financial in this article.

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