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Ultrasonography of the neck in patients with obstructive sleep apnea

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Abstract

Introduction—In resource-limited settings, obstructive sleep apnea (OSA) often goes undiagnosed as polysomnography (PSG) is expensive, time-consuming, and not readily available. Imaging studies of upper airway have been tried as alternatives to PSG to screen for OSA. However, racial differences in upper airway anatomy preclude generalizability of such studies. We sought to test the hypothesis that ultrasonography (USG), an inexpensive, readily available tool to study soft tissue structures of the upper airway, would have predictive value for OSA in South Asian people.

Methods—Adult patients with sleep-related complaints suspicious for OSA were taken for overnight PSG. After the PSG, consecutive patients with and without OSA were studied with submental ultrasonography to measure tongue base thickness (TBT) and lateral pharyngeal wall thickness (LPWT).

Results—Among 50 patients with OSA and 25 controls, mean age was 43.9 ± 11.4 years, and 39 were men. Patients with OSA had higher TBT (6.77 ± 0.63 cm vs 6.34 ± 0.54 cm, *P* value = 0.004) and higher LPWT (2.47 ± 0.60 cm vs 2.12 ± 0.26 cm, *P* value = 0.006) compared to patients without OSA. On multivariate analysis, TBT, LPWT, and neck circumference were

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Author contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Bhavesh Mohan Lal and Surabhi Vyas. The first draft of the manuscript was written by Bhavesh Mohan Lal and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate Institute ethics committee approval was taken and the study was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. All persons gave their informed consent prior to their inclusion in the study.

Conflict of interest All authors declare that they have no conflict of interest. ResMed provided a philanthropic donation to UC San Diego School of Medicine, San Diego 92121, 358 CA, USA.

identified as independent factors associated with OSA. These variables could identify patients with severe OSA with a sensitivity of 72% and a specificity of 76%.

Conclusion—Patients with OSA have higher tongue base thickness and lateral pharyngeal wall thickness proportionate to the severity of the disease, independent of BMI and neck circumference. These findings suggest that sub-mental ultrasonography may be useful to identify patients with severe OSA in resource-limited settings.

Keywords

Obstructive sleep apnea; Tongue base thickness; Lateral pharyngeal wall thickness; Apnea–hypopnea index

Introduction

Sleep is essential for a healthy, productive life. Chronically disturbed sleep can lead to serious neuro-cognitive and cardio-metabolic consequences. Obstructive sleep apnea (OSA) is the most common sleep-related disorder. It is estimated that globally at least 3–5% males and 2–7% females suffer from OSA [1]. The prevalence of OSA is even higher in India, with an estimated prevalence of 9.6% [2]. Early diagnosis and treatment with CPAP therapy can lead to improvement in cardio-metabolic disturbances and quality of life [3].

Overnight polysomnography (PSG) is the preferred test for the diagnosis of OSA. However, in resource-limited settings, OSA often goes undiagnosed as PSG is expensive and not readily available. Imaging studies have been tried as alternatives to PSG to screen for OSA. Upper airway narrowing due to bony and/or soft tissue restrictions predis-poses individuals to upper airway collapse during sleep and development of OSA. Thus, imaging of upper airway may help in identifying individuals at risk of OSA.

Upper airway soft tissue thickness has an important role in the pathogenesis of OSA. Upper airway soft tissue thickness is not merely a representation of generalized fat deposition in the body [4]. This finding is highlighted by the fact that non-obese patients with OSA have disproportionate fat deposition in the upper airway with upper airway narrowing [4]. In contrast, obese patients without OSA patients do not have thicker upper airway soft tissues as compared to non-obese counterparts [5]. Apart from the pathophysiologic significance, upper airway anatomy helps predict response to various treatment modalities [6, 7]. Studies have also noted a possible genetic role and familial aggregation of thicker soft tissue structures in upper airway, suggesting a role of imaging modalities to screen high-risk relatives of patients with OSA [8]. Thus, assessing upper airway anatomy in patients with OSA may be of paramount importance.

Imaging studies from Western countries have noted significant differences in upper airway soft tissue structures in patients with OSA [9–14]. However, similar studies in Asian populations have given mixed results [3, 15–19]. Studies comparing the upper airway anatomy of patients with OSA from Asia with those from Western countries have demonstrated that Asian patients have predominantly bony restrictions rather than soft tissue restrictions [20, 21]. The contribution of upper airway soft tissue structures to the pathogenesis of OSA in Asian patients is not clear.

X-ray cephalometry, magnetic resonance imaging (MRI), and computed tomography (CT) have been used to study the upper airway anatomy. CT scan and X-ray are now generally avoided due to risks of radiation exposure and poor soft tissue visualization. While MRI provides excellent soft tissue resolution and is free of radiation risks, it is expensive, time-consuming, and not readily available, particularly in under-resourced areas [22]. Recently, ultrasonography (USG) has been utilized to study the various upper airway structures in patients with OSA [3, 17, 23–25]. Sub-mental USG is an inexpensive, rapid, readily available and safe method to study the upper airway anatomy.

Tongue thickness and lateral pharyngeal wall thickness contribute to antero-posterior and lateral narrowing of the upper airway respectively. Studies have highlighted the role of these structures in patients with OSA. Thus, we planned to evaluate these structures using USG in patients with and without OSA. We hypothesized that patients with OSA would have higher tongue base thickness and lateral pharyngeal wall thickness proportionate to OSA disease severity.

Research objectives

Primary objective: To assess and compare tongue base thickness and lateral pharyngeal wall thickness in patients with and without OSA.

Secondary objective: To study the relationship between tongue base thickness and lateral pharyngeal wall thickness with the severity of OSA and assess the predictive ability of submental ultrasonography for severe OSA.

Materials and methods

Study design and participants

This prospective observational study was conducted in a tertiary care center in North India between January 2020 and December 2021. Adult patients (age ≥ 18 years) who presented to our outpatient department with different sleep-related complaints suspicious for OSA were recruited for the study after informed consent. The sample size was calculated to be 36 cases based on studies by Liu et al. and Chen et al. so as to achieve a power of 80% and a two-sided level of significance of 5% for detecting the difference in means of lateral pharyngeal wall thickness and tongue base thickness respectively in patients with and without OSA [23, 26]. However, due to difficulty in finding controls, 50 cases and 25 controls with sleep-related complaints were recruited after overnight polysomnography. Pregnant women, those under 18 years of age, and those with chronic obstructive airway disease, congestive heart failure, local neck lesions, and active neurologic event were excluded. Patients with co-existing other sleep disorders and those with known severe OSA on continuous positive airway pressure therapy were also excluded. The study was approved by our Institutional Ethics Committee.

Anthropometry and polysomnography

A detailed history and physical examination including anthropometric measurements were performed for all the patients recruited. Anthropometric measurements included assessment of weight, height, fat mass, fat percentage, neck circumference, and waist circumference. Patients were then subjected to an overnight polysomnography using Alice PDx (Respironics Inc., PA, USA) and were classified into either having OSA or not having OSA based on apnea/hypopnea index (AHI) scored using the American Association of Sleep Medicine guidelines, 2012, by a blinded registered sleep technician [27].

Case: A patient with sleep-related complaints with AHI ≥ 5 events/h on overnight polysomnography.

Control: A patient with sleep-related complaints with AHI < 5 events/h on overnight polysomnography.

The morning following polysomnography, patients were taken for submental ultrasonography to measure tongue base thickness and lateral pharyngeal wall thickness. The data were entered simultaneously in an Excel format.

Sub-mental ultrasonography

Submental ultrasonography was performed using Samsung Sono-Ace R7 USG machine. C2–5 curvilinear probe and linear LN5–12 probe were used in gray scale 2-dimensional mode. All ultrasonographic studies were performed by a single radiologist, who was blinded to the sleep apnea status of the patient. The radiologist had 15 years of experience having performed more than 100 neck ultrasounds and more than 500 ultrasound studies every year.

The sub-mental approach was used to visualize the structures of interest. Patients were placed supine on the examination couch with the neck exposed, in the Frankfurt plane. The patient was advised to breathe normally through nose and avoid swallowing or making tongue movements during measurements unless instructed to do so.

Lateral pharyngeal wall thickness (LPWT)

Methods described by Liu et al. were used to measure the lateral pharyngeal wall thickness with some modifications [23]. Using the linear probe, oblique coronal plane of the parapharyngeal space was scanned by keeping the probe longitudinally on the lateral side of the neck, just below the lateral border of the occipital bone. The long axis of the internal carotid artery was then identified using the color Doppler. The lateral wall of pharynx appeared as an echogenic line on real-time ultrasonography and the lumen of the pharynx was completely obscured due to gas shadowing. The location of the pharynx was further confirmed by asking the patient to swallow saliva and seeing the vibration artifacts. The distance between the medial wall of internal carotid artery and the echogenic surface of the pharynx represented the lateral pharyngeal wall thickness in an oblique coronal plane (see Fig. 1). The measurements were repeated thrice and the average value was taken. The procedure was then repeated on the contralateral side and the average values on both sides were added to get lateral pharyngeal wall thickness of that patient.

Tongue base thickness (TBT)

Curvilinear probe was used to measure tongue base thickness. The probe was placed longitudinally in the mid-sagittal plane. The tongue outline was identified as an echogenic line due to the air-mucosal interface, which was confirmed by asking the patient to swallow or make tongue movements. The farthest point on the tongue base was identified and its distance from the skin was measured (see Fig. 2). The same procedure was repeated thrice and the average value was taken as tongue base thickness.

Statistical analysis

IBM SPSS version 24 and Stata 16.1 were used for statistical analysis. Quantitative variables were expressed as mean and standard deviation, and categorical variables were expressed in frequency and proportion. The normal distribution of the variables was assessed by visual inspection of the histograms and normality Q-Q plots. Two-sample *t*-tests with equal variances were used to compare the population means between the two groups for quantitative variables. Pearson's chi-squared test was used to analyze the means of the two groups for the categorical variables. One-way ANOVA was used to compare the means of groups across different severities of OSA for the quantitative variables after confirming equal variances between the groups with Bartlett's test. Linear regression was used to adjust the outcome variable (tongue base thickness and lateral pharyngeal wall thickness) for the differences in independent variables in both the groups. The strength of association between ultrasound parameters and the severity of OSA (as measured by AHI) was measured using Spearman's correlation. Partial correlation was used to adjust for differences in neck circumference and BMI and assess the correlation between continuous variable AHI and ultrasound parameters TBT and LPWT. Multivariate logistic regression was used to find the independent predictors of severe OSA. P value < 0.05 was considered statistically significant.

Baseline demographic details

The baseline demographic details of the patients are as shown in Table 1. A total of 103 patients were screened. Twenty-eight patients were excluded due to various exclusion criteria. Eleven patients were already on CPAP therapy, 7 patients had COPD, 4 patients had heart failure, 3 patients had local neck lesions/scars, 2 patients had goitrous neck swelling, and 1 patient had history of cerebro-vascular accident. Seventy-five patients were finally recruited in our study. A total of 25 controls and 50 cases were included in the study. This enrollment included 39 males and 36 females. The mean age was 43.9 ± 11.4 years. Patients with OSA had higher weight, higher BMI, higher fat mass, higher fat percentage, higher neck circumference, and higher waist circumference. While 13 out of 50 patients (26%) in OSA group had a BMI ≥ 40 kg/m^2, only 2 out of 25 patients (8%) in non-OSA group had a BMI ≥ 40 kg/m^2.

All the co-morbidities were equally distributed in the two groups except hypertension which was significantly higher in patients with OSA compared to those without OSA. The mean AHI of patients in non-OSA group was 3.2 ± 1.2 events/h. Patients with mild OSA had a mean AHI of 9.8 ± 2.7 events/h. Patients with moderate OSA had a mean AHI of 21.8 ± 3.7 events/h. Patients with severe OSA had a mean AHI of 63.5 ± 24.0 events/h.

Results

Ultrasonographic findings in patients with and without OSA

The mean tongue base thickness of the study population was 6.63 ± 0.63 cm (range: 5.34–8.11 cm). The mean tongue base thickness in patients with OSA was 6.77 ± 0.63 cm (range: 5.52–8.11 cm) compared to patients without OSA with a mean tongue base thickness of 6.34 ± 0.54 cm (range: 5.34–7.36 cm), *P* value of 0.004.

The mean lateral pharyngeal wall thickness of the study population was 2.35 ± 0.54 cm (range: 1.47–3.98 cm). The mean lateral pharyngeal wall thickness in patients with OSA was 2.47 ± 0.60 cm (range: 1.62–3.98 cm) compared to patients without OSA who had a mean lateral pharyngeal wall thickness of 2.12 ± 0.26 cm (range: 1.47–2.46 cm), *P* value of 0.006.

Ultrasound parameters across different severities of OSA (Table 2)

The patients were divided into three categories — no OSA (AHI < 5 events/h), mild-moderate OSA (AHI between 5 and 30 events/h), and severe OSA (AHI ≥ 30 events/h). Using one-way ANOVA, there was a significant positive correlation between severity of OSA and tongue base thickness (*P* value < 0.001), severity of OSA, and lateral pharyngeal wall thickness (*P* value = 0.003).

AHI was used to represent the severity of OSA. There was a positive correlation between AHI and tongue base thickness with a Spearman's correlation coefficient of 0.493, *P* value < 0.0001 (see Fig. 3). There was a positive correlation between AHI and lateral pharyngeal wall thickness with a Spearman's correlation coefficient of 0.292, *P* value = 0.011 (see Fig. 4).

Test for independent association between USG parameters and OSA

Patients with OSA had higher neck circumference and higher BMI compared to patients without OSA. Using linear regression, adjusting for the higher BMI and neck circumference, there was a positive independent association between tongue base thickness and presence of OSA (adjusted *P* value = 0.012, $r^2 = 0.117$) and a positive independent association between lateral pharyngeal wall thickness and presence of OSA (adjusted *P* value = 0.031, $r^2 = 0.151$).

A partial correlation was used to find independent association between AHI and ultrasound parameters adjusting for BMI and neck circumference. There was an independent positive correlation between AHI and tongue base thickness with a partial correlation coefficient of 0.473 (*P* value < 0.001). There was an independent positive correlation between AHI and lateral pharyngeal wall thickness with a partial correlation coefficient of 0.308 (*P* value = 0.008).

Correlation between AHI, USG parameters, and different variables (see Table 3)

AHI had a positive correlation with BMI, neck circumference, fat mass, and waist circumference. AHI had no significant correlation with fat percentage. Among all the variables, tongue base thickness had the strongest association with AHI (severity of OSA) followed by neck circumference, waist circumference, lateral pharyngeal wall thickness, BMI, and fat mass.

Tongue base thickness had no correlation with neck circumference, BMI, fat mass, fat percentage, or waist circumference. Lateral pharyngeal wall thickness had positive correlation with neck circumference, BMI, fat mass, and fat percentage, but there was no correlation between lateral pharyngeal wall thickness and waist circumference.

Sensitivity and specificity of USG parameters for detecting severe OSA

Multivariate logistic regression analysis with TBT, LPWT, BMI, and neck circumference as potentially independent influencing variables identified neck circumference, TBT, and LPWT as independent predictors of severe OSA. With these three factors, the probability of severe OSA was obtained by the formula:

$$Log(P/1 - P) = 1.16 * Neck\,circumference + 6.06 * TBT + 3.73 * LPWT$$

The optimal cut-off for the predicting the probability of severe OSA was calculated to be 0.36 on receiver operating characteristic (ROC) curve. The ROC curve for identifying patients with severe OSA is as shown in Fig. 5 (area under curve = 0.819). At this cut-off, the parameters predicted severe OSA with a sensitivity of 72% and a specificity of 76%.

Discussion

In this prospective observational study, we studied the upper airway anatomy using USG in 50 patients with OSA and 25 controls with sleep-related complaints. Patients in the OSA group were more obese with higher weight, BMI, fat mass, body fat percentage, neck circumference, and waist circumference compared to patients without OSA. Obesity is associated with obstructive sleep apnea and is a major risk factor for the development of OSA [28, 29]. All the co-morbidities were equally distributed in the two groups except hypertension which was more frequent in the OSA group, a finding which could represent the cardio-metabolic effect of OSA and obesity [30]. In the study by Gupta et al. on a similar population, 50% of the patients in the OSA group had hyper-tension compared to just 10% in the control group [18].

Patients with OSA had significantly higher tongue base thickness than patients without OSA. Similar USG findings were also noted by Chen et al. and Shu et al. from Taiwan. Our technique was similar to that used by Chen et al. Our values are more in line with those obtained by Chen et al. and different from those obtained by Shu et al. due to difference in the technique used [3, 26].

The tongue base contributes to the antero-posterior narrowing of the upper airway. Many studies on Western population have consistently observed that patients with OSA had bigger tongues compared to patients without OSA [9–14]. However, similar studies in Asian population have given mixed results. While Gupta et al., Lahav et al., and Shu et al. had demonstrated a positive correlation between tongue size and OSA, Okubo et al., Guo et al., and Ahn et al. did not demonstrate any significant difference in tongue size [3, 15–19].

Schorr et al. in his study demonstrated that Japanese-Brazilian OSA patients had smaller tongue volume and tongue length than White OSA patients [21]. Xu et al. in his study demonstrated that Chinese OSA patients had smaller tongue volume compared to Icelandic OSA patients [20]. Kim et al. in his study showed higher fat deposition in the base of the tongue in patients with OSA, highlighting the significance of tongue base thickness [11]. Gupta et al. had studied tongue length using MRI in similar population and noticed that patients with OSA had higher tongue length [18].

The tongue base thickness did not correlate with BMI, neck circumference, waist circumference, fat mass, or body fat percentage. A similar finding was also indirectly observed by Apolloni et al. who studied upper airway anatomy using MRI among patients without OSA across different classes of obesity [5].

Patients with OSA had significantly higher lateral pharyngeal wall thickness compared to patients without OSA. Our findings provided values which were in between those obtained by Liu et al., Hussein et al. (higher than ours), and Bilici et al. (lower than ours) [23–25]. Lateral pharyngeal wall thickness contributes to the lateral narrowing of upper airway and has been consistently demonstrated to be higher in patients with OSA compared to patients without OSA in almost all studies barring a few Asian studies such as that by Okubo et al. [16]. Schorr et al. in his study did not find any significant difference in the lateral pharyngeal wall thickness between Japanese-Brazilian and white patients with OSA [21]. Similarly, Xu et al. compared lateral pharyngeal wall volume between patients with OSA from China and Iceland and found no significant difference in the two groups [20].

There was a positive correlation between AHI and tongue base thickness, and AHI and lateral pharyngeal wall thickness. Furthermore, this positive correlation persisted even after adjusting for BMI and neck circumference. This finding indicates that tongue base thickness and lateral pharyngeal wall thickness have independent associations with the presence and severity of OSA. Similar findings were also obtained by Liu et al. for lateral pharyngeal wall thickness [23]. While Shu et al. did not find an independent association between tongue base thickness and AHI after adjusting for potential confounding variables, Chen et al. found an independent association between tongue base thickness and AHI [3, 26]. The lateral pharyngeal wall thickness was associated with body habitus of the patient unlike tongue base thickness.

Tongue base thickness, lateral pharyngeal wall thickness, and neck circumference were found to be independent predictors of severe OSA in our study. Shu et al. also recognized neck circumference as an independent variable associated with OSA [3]. These three parameters could predict severe OSA with a sensitivity of 72% and a specificity of 76%.

To the best of our knowledge, our study was the first study to use USG to study upper airway structures in Indian patients with sleep-related complaints. We demonstrated that upper airway structures contribute to the development of OSA in Indian population. We validated the role of USG as an inexpensive, readily available screening test for the diagnosis of severe OSA in Indian patients.

Our study had a few limitations: non-obese patients were under-represented in our study. Thus, we are supportive of further studies to assess the generalizability of our findings. Ultrasonographic parameters used by us were indirect indicators of the upper airway narrowing. Also, dynamic changes in upper airway structures with respiration and changes with sleep were not studied. Based on our study designs, the causative role of soft tissue thickness for OSA cannot be established.

Conclusion

Indian patients with OSA have significantly thicker upper airway soft tissue structures, proportionate to the severity of OSA. This finding is independent of the body habitus of the patient. These findings suggest that submental ultrasonography may reliably measure the important soft tissue structures in upper airway to help identify patients with severe OSA in an inexpensive and safe manner.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Abbreviations

USG	Ultrasonography
MRI	Magnetic resonance imaging
CT	Computed tomography
OSA	Obstructive sleep apnea
LPWT	Lateral pharyngeal wall thickness
TBT	Tongue base thickness
CPAP	Continuous positive airway pressure
PSG	Polysomnography
AHI	Apnea/hypopnea index
NC	Neck circumference

WC	Waist circumference

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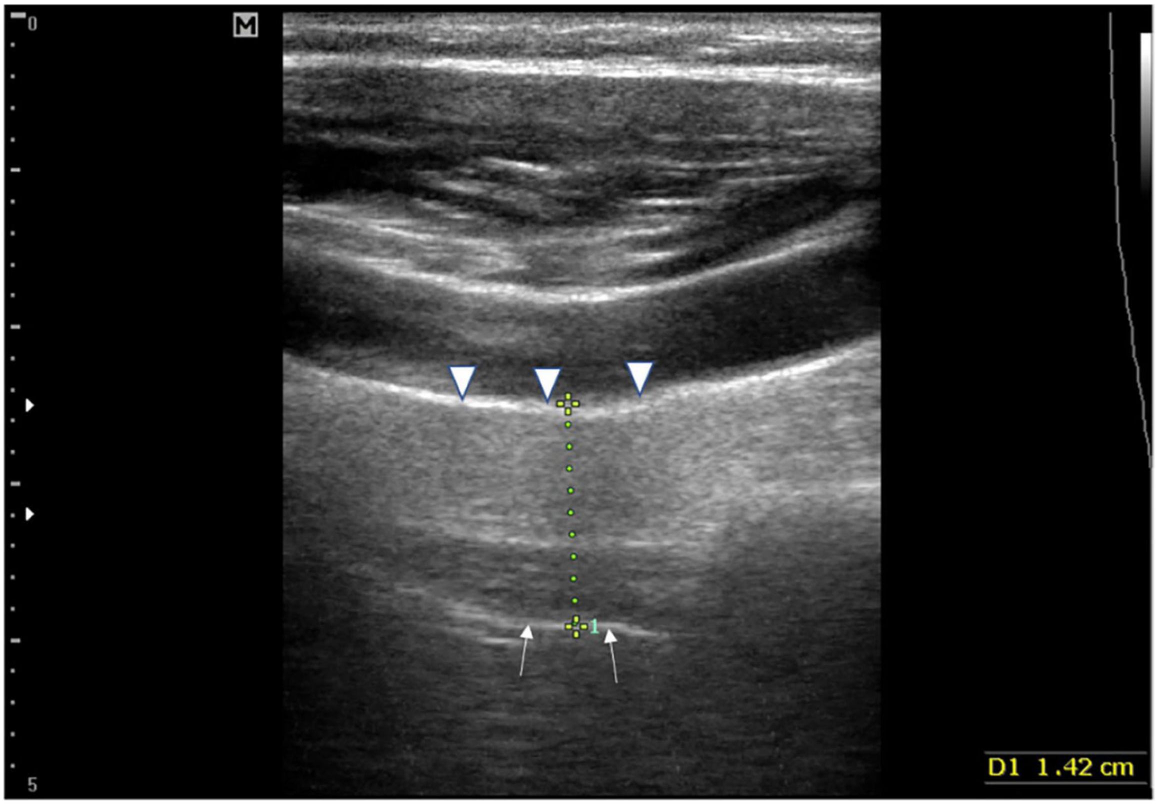

Fig. 1.

This image depicts the measurement of lateral pharyngeal wall thickness. The white arrowheads represent the internal wall of internal carotid artery and the white arrows represent the pharynx. The distance between the two points represents the lateral pharyngeal wall thickness on that side

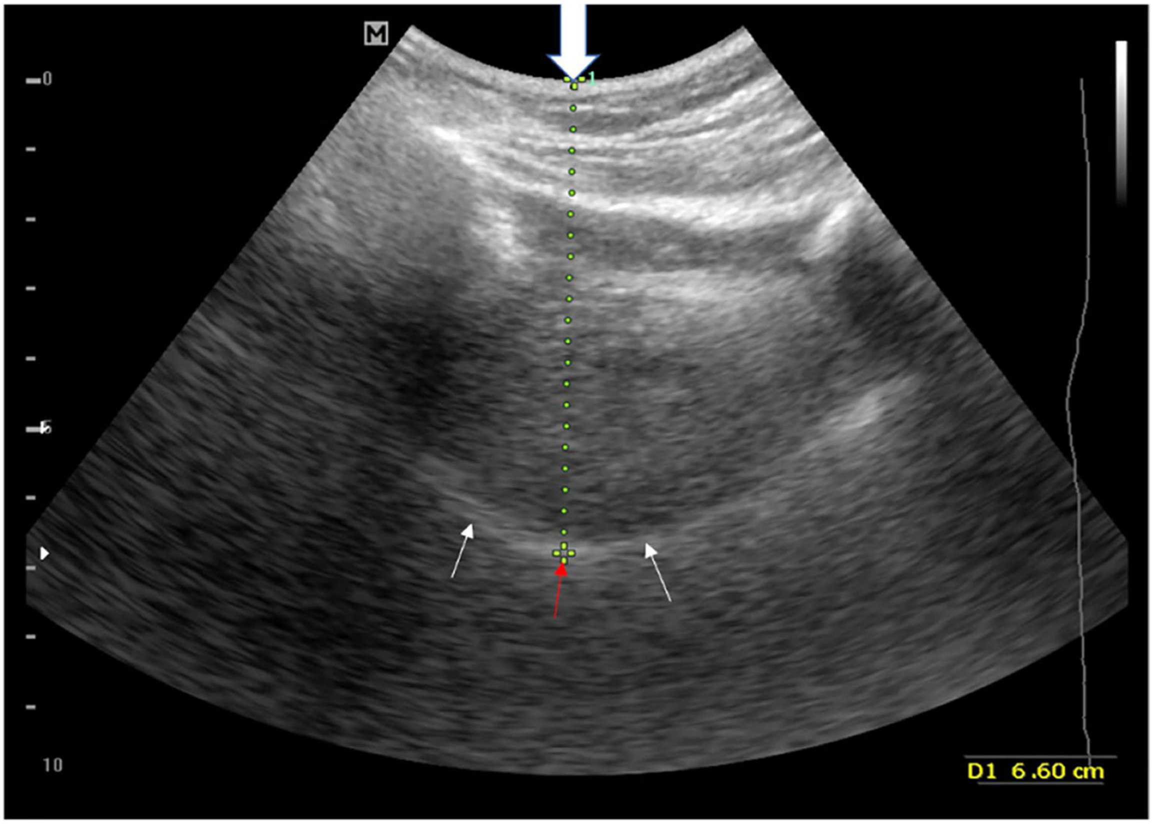

Fig. 2.
The image depicts the measurement of tongue base thickness. The white bold arrow represents the skin surface and the thin arrows highlight the tongue surface. The red arrow represents the tongue base. The distance between these two points is taken as tongue base thickness

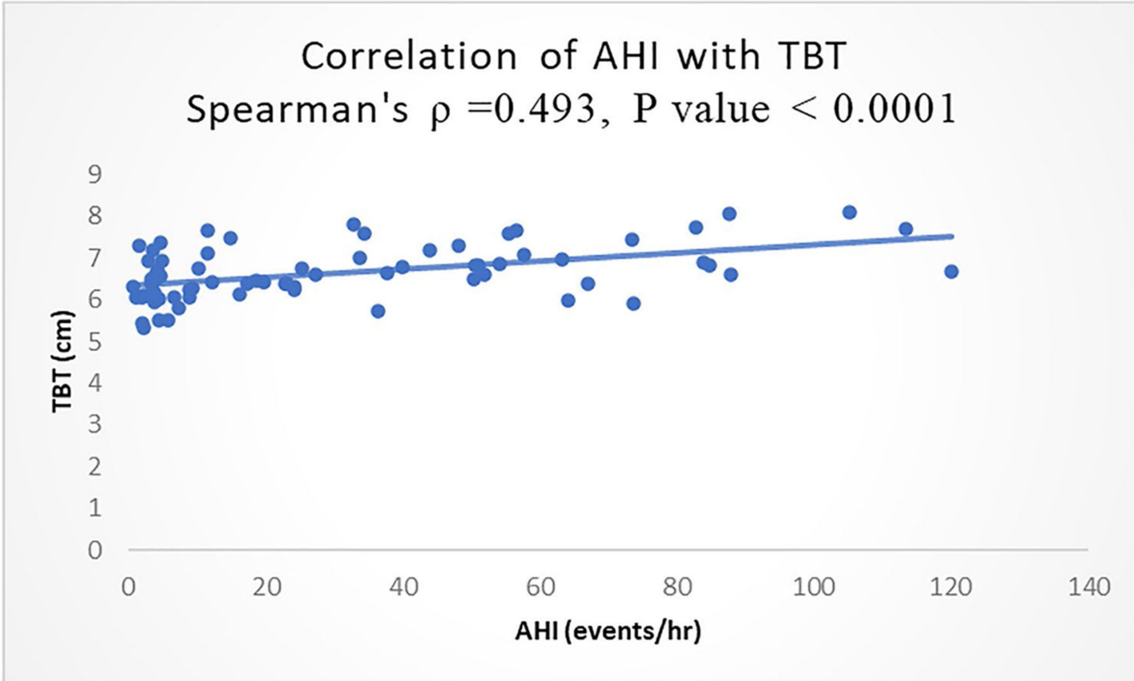

Fig. 3.

Scatter plot demonstrating relationship between AHI and TBT

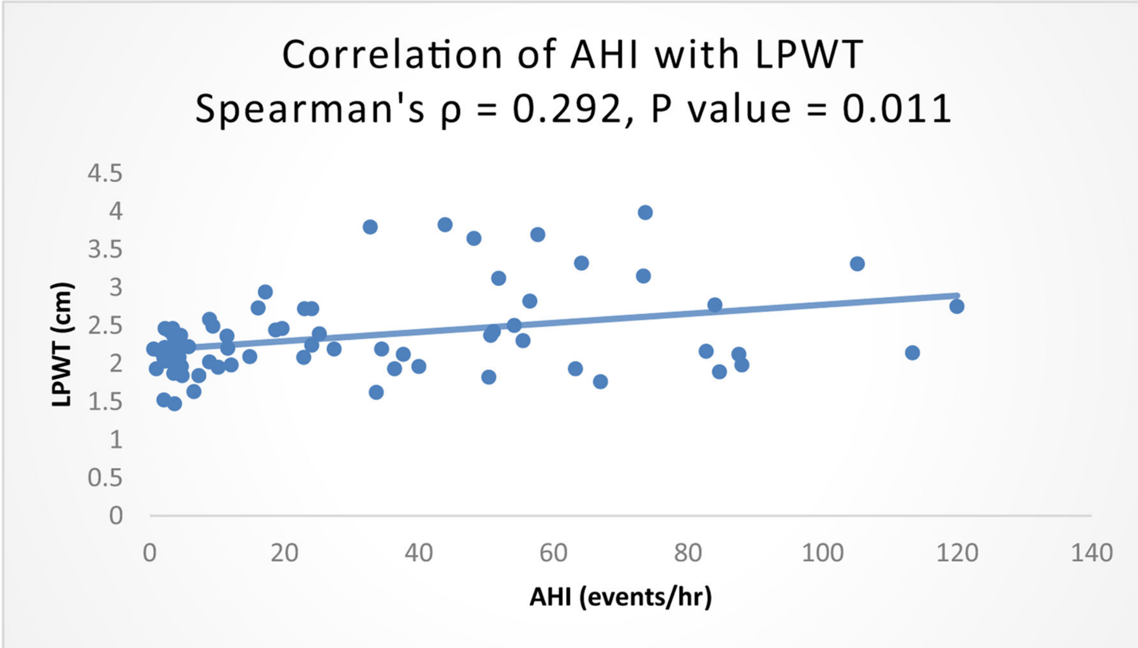

Fig. 4.
Scatter plot demonstrating relationship between AHI and LPWT

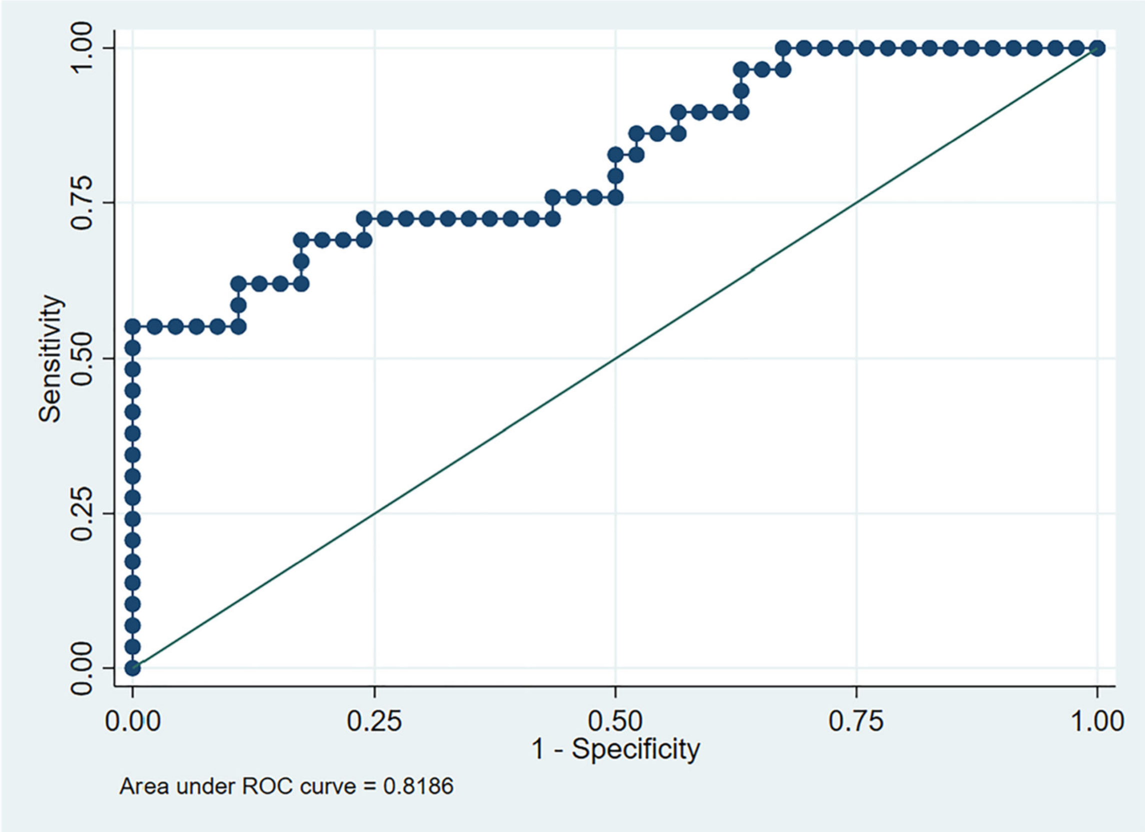

Fig. 5.
Receiver operating characteristics (ROC) curve for predicting the probability of severe OSA using neck circumference, TBT, and LPWT

Table 1

Baseline demographic details of all the patients included in this study

Demographic variable	Non-OSA	OSA	Total	*P* value
Number of patients	25	50	75	-
Age (years)	40.7 ± 10.9	45.5 ± 11.3	43.9 ± 11.4	0.084
Females, *n* (%)	15 (60%)	24 (48%)	39 (52%)	0.327
Weight (kg)	81.6 ± 14.5	94.0 ± 20.2	89.8 ± 19.3	0.008
Height (cm)	162.2 ± 9.7	162.0 ± 9.8	162.1 ± 9.7	0.933
BMI (kg/m^2)	31.6 ± 6.8	35.9 ± 7.5	34.5 ± 7.5	0.018
Fat mass (kg)	27.6 ± 14.6	38.1 ± 18.4	34.6 ± 17.8	0.015
Fat %	32.5 ± 12.2	39.2 ± 12.5	37.0 ± 12.7	0.029
Neck circumference	36.9 ± 3.1	39.6 ± 4.5	38.7 ± 4.2	0.011
Waist circumference	100.8 ± 8.3	108.8 ± 12.7	106.1 ± 12.0	0.006
Co-morbidities				
Diabetes mellitus	2 (8%)	13 (26%)	15 (20%)	0.066
Hypertension	8 (32%)	30 (60%)	38 (51%)	0.022
Hypothyroidism	2 (8%)	10 (20%)	12 (16%)	0.181
Coronary artery disease	1 (4%)	3 (6%)	4 (5%)	0.716
Chronic kidney disease	1 (4%)	3 (6%)	4 (5%)	0.716
Seizure disorder	1 (4%)	1 (2%)	2 (3%)	0.612
Major depressive disorder	1 (4%)	1 (2%)	2 (3%)	0.612
AHI	3.2 ± 1.2	43.4 ± 30.4	30.0 ± 31.2	-

Fat %, fat percentage; *AHI*, apnea/hypopnea index

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Table 2

USG parameters across different severities of OSA

Category	No OSA (*n* = 25)	Mild-moderate OSA (*n* = 21)	Severe OSA (*n* = 29)	*P* value
TBT (mean ± SD) cm	6.34 ± 0.54	6.45 ± 0.50	7.01 ± 0.62	< 0.001
LPWT (mean ± SD) cm	2.12 ± 0.26	2.30 ± 0.33	2.60 ± 0.72	0.003

TBT, tongue base thickness; *LPWT*, lateral pharyngeal wall thickness

Table 3

Spearman's correlation coefficient between AHI, USG parameters, and different variables

Spearman's correlation between different variables	AHI	TBT	LPWT
Tongue base thickness	$\rho = 0.493$ ($P < 0.0001$)	-	$\rho = 0.201$ ($P = 0.084$)
Lateral pharyngeal wall thickness	$\rho = 0.292$ ($P = 0.011$)	$\rho = 0.201$ ($P = 0.084$)	-
Neck circumference	$\rho = 0.322$ ($P = 0.005$)	$\rho = 0.181$ ($P = 0.121$)	$\rho = 0.234$ ($P = 0.043$)
Body mass index	$\rho = 0.277$ ($P = 0.016$)	$\rho = 0.181$ ($P = 0.121$)	$\rho = 0.304$ ($P = 0.008$)
Fat mass	$\rho = 0.267$ ($P = 0.021$)	$\rho = 0.198$ ($P = 0.089$)	$\rho = 0.296$ ($P = 0.010$)
Fat %	$\rho = 0.180$ ($P = 0.122$)	$\rho = 0.058$ ($P = 0.619$)	$\rho = 0.288$ ($P = 0.012$)
Waist circumference	$\rho = 0.298$ ($P = 0.009$)	$\rho = 0.165$ ($P = 0.157$)	$\rho = 0.168$ ($P = 0.149$)

Fat %, fat percentage; *AHI*, apnea/hypopnea index; *TBT*, tongue base thickness; *LPWT*, lateral pharyngeal wall thickness