



# Using clinical data to predict obstructive sleep apnea

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**Background:** Obstructive sleep apnea (OSA) is a common disorder and associated with motor vehicle accidents, reduced quality of life and various comorbidities. It is necessary to identify clinical parameters that may predict the presence and severity of OSA.

**Methods:** Subjects with suspected OSA were consecutively recruited for development and validation of the models. Clinical data collected from participants included general information, OSA-related symptoms, questionnaire responses, and physical examination. Logistic and linear regressions were used to develop models to determine the presence and severity of OSA.

**Results:** All 202 subjects (157 men, 45 women; age range, 18–68 years) underwent polysomnography (PSG) and clinical assessment, of whom 62.3% were diagnosed with OSA. The presence of OSA was defined using the equation,  $1.00 \times \text{central obesity} + 2.05 \times \text{snoring} + 1.80 \times \text{witnessed nocturnal apnea} + 1.73 \times \text{lateral narrowing} - 3.25$ ; and apnea-hypopnea index (AHI) was defined using,  $12.5 \times \text{central obesity} + 17.1 \times \text{witnessed nocturnal apnea} + 6.2 \times \text{tonsillar size} + 9.0 \times \text{lateral narrowing} - 19.7$ . The model demonstrated a sensitivity of 81.1% (95% CI: 73.2–87.5%) and a specificity of 76.0% (95% CI: 64.7–85.1%) at the optimal cut-off value for OSA detection. The positive and negative likelihood ratios were 3.4 (95% CI: 2.2–5.1) and 0.3 (95% CI: 0.2–0.4), respectively. The area under the receiver operating characteristic curve for the predictive model (83.7%) was significantly greater than that of the Berlin Questionnaire (53.5%), Epworth Sleepiness Scale (61.1%), and STOP-BANG questionnaire (73.8%). 101 subjects were recruited as the validation group. The models to determine the presence and severity of OSA had an accuracy of 0.812 and 0.416 in the validation group.

**Conclusions:** Results of the present study suggest that a combination of clinical data may be helpful in identify patients who are at increased risk for OSA.

**Keywords:** Obstructive sleep apnea (OSA); clinical variables; prediction

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## Introduction

Obstructive sleep apnea (OSA) is a common disorder characterized by repetitive episodes of upper airway collapse during sleep, resulting in abnormal ventilation, intermittent

oxygen desaturation, hypercapnia, oxidative stress, and sleep fragmentation (1-3). OSA is an original disease due to its close relationship with coronary artery disease, heart failure, stroke, arrhythmias, hypertension, and metabolic dysfunction (4,5). An estimated 1 billion adults worldwide

may have OSA, which poses significant health and economic burdens (6).

Although polysomnography (PSG) is widely accepted as the gold standard diagnostic tool for OSA and co-existing sleep disorders (7), it is a time-consuming and labor-intensive procedure. Hence, a wide range of risk factors, such as habitual snoring, nocturnal choking, daytime sleepiness, enlarged tonsils, and body size parameters, have been used to establish various clinical prediction algorithms, questionnaires, and clinical tools for prospectively identifying individuals who are at increased risk for OSA (8-13). Risk factors associated with OSA and predictive accuracy have varied across studies (14,15). Thus, it is necessary to take advantage of comprehensive clinical data from patients with and without OSA to construct appropriate prediction models for determining the presence and severity of OSA. We hypothesized that efficient models to investigate the likelihood of OSA can be established by combining all significant clinical parameters.

We present the following article in accordance with the TRIPOD reporting checklist (available at <https://jtd.amegroups.com/article/view/10.21037/jtd-20-3139/rc>).

## Methods

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The present study was approved by the Institutional Review Board of Beijing Tongren Hospital (Beijing, China; TRECKY2019-049), and written consent was obtained from all subjects.

### Subjects

Subjects 18 to 70 years of age, who were referred for PSG to the Sleep Medicine Center of Beijing Tongren Hospital, were recruited in the experimental group consecutively for the development of the model from June to October 2019. The validation group was obtained from November to December 2019. Individuals with OSA-related surgical history (e.g., tonsillectomy, uvulopalatopharyngoplasty, and nasoseptoplasty), psychiatric disorders, and pregnancy were excluded.

### Clinical data collection

Clinical assessment of all subjects was performed on the same day as PSG including the following.

### General information

Sex, age, history of alcohol consumption, history of smoking, comorbidities (diabetes mellitus, hyperlipidemia, cardiovascular disease, asthma, and hypertension) were confirmed, either by self-report or associated test results, or medication taken by the subjects.

### OSA-related symptoms

Selection of risk factors was based on previous studies (16), including snoring, witnessed nocturnal apnea, nocturia, struggling for breath upon awakening, insomnia, dry mouth in the morning, morning headaches, non-restorative sleep, excessive daytime sleepiness [estimated using the Epworth Sleepiness Scale (ESS)] (9), diurnal fatigue, cognitive function impairment (subjective memory or attention deficits), and rhinitis symptoms. Details regarding these symptoms were obtained by self-report or bed-fellow reporting. The definitions of symptoms are summarized in *Table 1*.

### Questionnaires

All subjects with suspected OSA were required to complete three different questionnaires. The STOP-BANG questionnaire ( $\geq 3$  positive items were considered to be at high risk for OSA) (10), Berlin Questionnaire ( $\geq 2$  positive catalogs were regarded as a higher OSA risk group) (11), the ESS (score ranging from 0 to 24, with higher scores indicating more daytime sleepiness) (9).

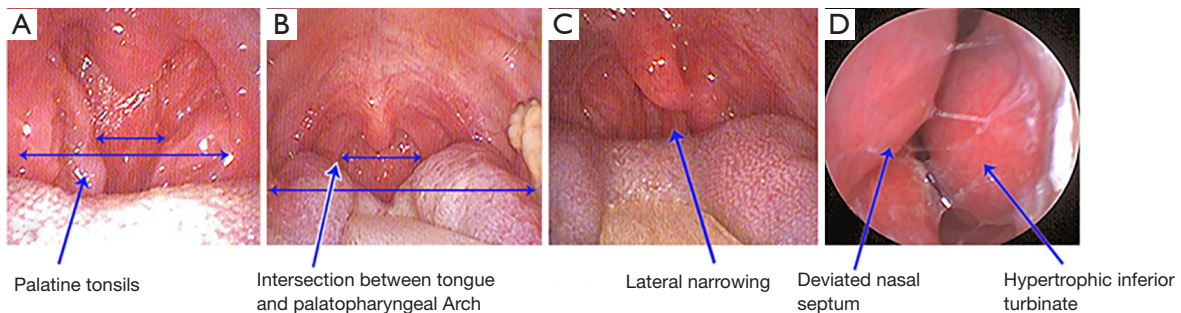
### Physical examination

Body measurements were completed with the subjects wearing light clothing and in the standing position including body height(m) and weight(kg), body mass index (BMI, expressed as  $\text{kg}/\text{m}^2$ ), BMI grade (normal  $<24 \text{ kg}/\text{m}^2$ ;  $24 \text{ kg}/\text{m}^2 \leq$  overweight  $\leq 28 \text{ kg}/\text{m}^2$ ; obese  $>28 \text{ kg}/\text{m}^2$ ), neck circumference (measured at the level of the thyroid cartilage), waist circumference (measured from a linear distance around the middle between the 12th rib and the top of the iliac crest at the end of expiration), and central obesity (defined as waist circumference  $>90$  cm for men and 85 cm for women) (17). Evaluation of the upper airway structures is shown in *Figure 1*. Measurement of tonsillar size was performed according to Brodsky grading scale (grade 1, tonsils occupy  $\leq 25\%$  of the oropharyngeal airway; grade 2, tonsils occupy  $25\% <$  oropharyngeal airway  $\leq 50\%$ ; grade 3, tonsils occupy  $50\% <$  oropharyngeal airway  $\leq 75\%$ ; grade 4, tonsils occupy  $>75\%$  of the oropharyngeal airway) (18). The determination of pharyngeal grade was

**Table 1** Definitions of OSA-related symptoms

Symptom	Definition
Snoring	≥3 times/week
Non-restorative sleep-awakening with unrefreshing feel	≥3 times/week
Dry mouth in the morning	≥3 times/week
Witnessed nocturnal apnea	≥3 times/week
Struggling for breath upon awakening	≥3 times/week
Diurnal fatigue-a subjective sense of weariness	≥3 times/week
Excessive daytime sleepiness	ESS score range from 0–24
Nocturia-getting up to urinate	≥2 times/night
Cognitive function impairment	subjective memory or attention deficits during the past 12 months
Rhinitis symptoms-watery nasal discharge, sneezing, nasal obstruction and nasal itching	a history of the typical symptoms during the past 12 months
Insomnia-attempting to fall asleep more than 30 minutes or waking up during the night and falling asleep again more than 30 minutes	≥5–15 times/month
Morning headaches	≥3 times/week

OSA, obstructive sleep apnea; ESS, Epworth Sleepiness Scale.



**Figure 1** Examples of the evaluation of the upper airway structures. (A) Measurement of tonsillar size. (B) Measurement of pharyngeal grade. (C) Representative example of lateral narrowing. (D) Representative examples of deviated nasal septum and hypertrophic inferior turbinate. See text for detailed description.

dependent on the location of the intersection between the tongue and palatopharyngeal arch, relative to the tongue diameter: grade 1, palatopharyngeal arch intersects at the edge of the tongue; grade 2, palatopharyngeal arch intersects at  $\geq 25\%$  of the tongue diameter; grade 3, palatopharyngeal arch intersects at  $\geq 50\%$  of the tongue diameter; grade 4, palatopharyngeal arch intersects at  $\geq 75\%$  of the tongue diameter) (12). The procedure was performed without protruding the tongue and using a tongue depressor if necessary. Lateral narrowing was considered when visible lateral wall tissue impinged the posterior oropharyngeal

space (19). Nasal examination was performed to determine the presence of a deviated nasal septum and/or hypertrophic inferior turbinates, using an endoscope with the patient seated and the head slightly back.

Thirty subjects' examination was performed by three otolaryngologists and kappa statistical analysis was used to evaluate the degree of interexaminer agreement (20).

### PSG

One night of PSG (Alice 5 or Bond) was performed after

**Table 2** Characteristics between experimental and validation groups

Characteristics	Experimental group	Validation group	P value
Sex	(Male) 77.7%	(Male) 83.2%	0.27
Age	39.5 (31.8, 48.3)	43 (33.0, 52.0)	0.51
BMI	26.9 (24.5, 29.4)	26.5 (24.3, 29.2)	0.28
Neck circumference	40 (37.9, 42.3)	40.8 (38.1, 42.5)	0.84
AHI	26.6 (9.6, 54.8)	23 (8.5, 47.3)	0.16
ESS	8 (5.8, 13.0)	8 (5.0, 12.0)	0.87

Data are expressed as median (interquartile range) or percentage (%). ESS, Epworth Sleepiness Scale; BMI, body mass index; AHI, apnea-hypopnea index.

clinical assessment. Electroencephalogram (C3/A2, C4/A1, O1/A2, and O2/A1), electrooculogram, and submental electromyogram were recorded using surface electrodes. Moreover, electrocardiography, nasal airflow (measured using nasal cannulae with a pressure transducer), oral airflow (measured using a thermistor), chest wall, and abdominal movements (recorded by inductance plethysmography) pulse oximetry, video and audio recordings, and body position were also included. Definitions of respiratory events were based on American Academic Sleep Medicine (AASM) criteria, performed by experienced accredited sleep technologists blinded to the clinical assessment results. Apnea was defined as a drop in the peak signal excursion by  $\geq 90\%$  of pre-event baseline and the duration of the drop was  $\geq 10$  s. Hypopnea was defined as a drop in the peak signal excursion  $\geq 30\%$  and the duration  $\geq 10$  s and  $\geq 3\%$  oxygen desaturation from pre-event baseline or the event is associated with an arousal (21). The apnea-hypopnea index (AHI) was calculated as the total number of apneas and hypopneas per hour of sleep time. All eligible subjects were assigned to either the control group (AHI  $< 15$  events/h) or the OSA group (AHI  $\geq 15$  events/h).

### Statistical analysis

Continuous variables are expressed as mean and standard deviation or median [inter quartile range (IQR)], where appropriate, and ordinal variables are expressed as percentages. The Mann-Whitney U test was used to compare non-normally distributed continuous. The Chi-squared test or Fisher's exact test was used to compare categorical variables. Differences with  $P < 0.05$  (only two-tailed) were considered to be statistically significant. Significant variables identified in the primary case control

analysis were entered into logistic and linear regression analyses to develop predictive models for OSA status and AHI. Finally, the diagnostic accuracy between the prediction model and other sleep questionnaires was examined using receiver operating characteristic (ROC) curve analysis. Two operating points were selected from the ROC curve: one was selected for the maximum diagnostic efficiency—was based on the best fitting sensitivity, specificity; one was selected for the other for high (90%) specificity. Statistical analysis was performed using SPSS version 26.0 (IBM Corporation, Armonk, NY, USA).

### Results

Ultimately, 202 eligible subjects were included in the experimental group for development of the models, of whom 77.7% were male. The median age was 39.5 years (range, 18–68 years) and the median BMI was 26.9  $\text{kg}/\text{m}^2$  (IQR, 24.5–29.4  $\text{kg}/\text{m}^2$ ). The entire group had a large neck circumference [median neck circumference 40 cm (IQR 37.9–42.3 cm)]. The proportion of patients with OSA was 62.3%. The median AHI of the entire group was 26.6 events/h (IQR, 9.6–54.8 events/h). One hundred and one eligible subjects were included in the validation group. There was no difference in age, sex, BMI, AHI, and ESS between groups (Table 2).

### Subject clinical characteristics

Demographic information and clinical characteristics of the subjects are summarized in Table 3. Patients with OSA were more likely to be male and older. A higher prevalence of a history of smoking and alcohol consumption was observed in the OSA group than in the control group.

However, because the data were also analyzed according to sex, which was assumed to be a confounding factor, alcohol consumption in males was the only significant difference between subjects with OSA and controls. There was significant difference in hyperlipidemia between the OSA and control groups; however, there were no statistically significant differences in other comorbidities.

Significant differences were observed with regard to typical and atypical complaints, including snoring, witnessed nocturnal apnea, struggling for breath upon awakening, excessive daytime sleepiness, nocturia, and dry mouth in the morning. With regard to physical examination, all indicators of obesity (BMI, BMI grade, central obesity, and neck circumference) were significantly greater in the OSA group than in the control group. Furthermore, a higher proportion of tonsillar enlargement, deviated nasal septum, lateral narrowing, and pharyngeal narrowing were observed in the OSA group. Additionally, kappa value for tonsillar size (0.84), pharyngeal grade (0.77), lateral narrowing (0.81), deviated nasal septum (0.76) and hypertrophic inferior turbinates (0.64) represented good agreement.

### Logistic and linear regression analysis

All important clinical variables identified in the univariate analysis were entered into the regression model. Finally, a logistic regression model consisting of 4 predictors was established (Table 4). Snoring yielded the most significant contribution, followed by witnessed nocturnal apnea. OSA status was defined using the following Eq. [1]:

$$\begin{aligned} OSA = & 1.00 \times \text{central obesity} + 2.05 \times \text{snoring} \\ & + 1.80 \times \text{witnessed nocturnal apnea} \\ & + 1.73 \times \text{lateral narrowing} - 3.25 \end{aligned} \quad [1]$$

in which 1 = presence of snoring, witnessed nocturnal apnea, central obesity or lateral narrowing and 0 = absence of snoring, witnessed nocturnal apnea, central obesity, or lateral narrowing. The optimal cut-off value on the ROC was 0.61, yielding a sensitivity of 81.1% (95% CI: 73.2–87.5%) and a specificity of 76.0% (95% CI: 64.7–85.1%). The LR+ and LR– ratios were 3.4 (95% CI: 2.2–5.1) and 0.3 (95% CI: 0.2–0.4), respectively. The operating point with a high specificity (90%) was 0.82, yielding a sensitivity of 56.7% (95% CI: 47.6–65.5%), and a specificity of 90% (95% CI: 81.7–96.2%). The LR+ and LR– ratios were 6.1 (3.0–12.5) and 0.5 (0.4–0.6), respectively.

A comparison of ROC curves between the predictive

model and other questionnaires is shown in Figure 2. The area under the ROC curve (AUC) was 83.7% (95% CI: 77.9–88.5%) for the predictive algorithm. The AUC of the new predictive model was significantly higher than that of the Berlin Questionnaire [AUC 53.5% (95% CI: 45.2–61.8%);  $P < 0.01$ ], ESS [AUC 61.1% (95% CI: 53.3–68.9%);  $P < 0.01$ ], and STOP-BANG questionnaire [AUC 73.8% (95% CI: 66.9–80.8%);  $P < 0.01$ ]. The linear regression model indicated that AHI was a function of 4 variables [2]:

$$\begin{aligned} AHI = & 12.5 \times \text{central obesity} + 17.1 \\ & \times \text{witnessed nocturnal apnea} + 6.2 \\ & \times \text{tonsillar size} + 9.0 \times \text{lateral narrowing} - 19.7 \end{aligned} \quad [2]$$

The variance inflation factor of the variables demonstrated no substantial indicators of multicollinearity (Table 5).

### Validation

We compared the results of the two predictive models with PSG in the validation group. The logistic regression model would classify subjects with and without OSA and achieved an accuracy of 0.812, a sensitivity of 81.3%, a specificity of 81.1%. The LR+ and LR– ratios were 4.3 and 0.8, respectively. The linear regression model would output a predictive AHI and the subjects would be divided into normal, mild, moderate, and severe group (normal  $< 5$  events/h;  $5 \leq$  mild  $< 15$  events/h;  $15 \leq$  moderate  $< 30$  events/h; severe  $\geq 30$  events/h) and achieved an accuracy of 0.416.

### Model comparisons

Given that the estimation of lateral narrowing is a qualitative parameter and BMI is a common predictor for OSA, we presented the performance (AUC-ROC, sensitivity, specificity) of the models with and without these variables. Additionally, we present the performance of a model based on BMI, neck circumference, and oral cavity measurement (without symptoms) for the prediction of OSA. The results showed that explanatory variables in our model had the best predictive performance (Table 6).

### Discussion

OSA is characterized by repeated episodes of upper airway collapse, which is considered to be the predominant

**Table 3** Characteristics of the subjects

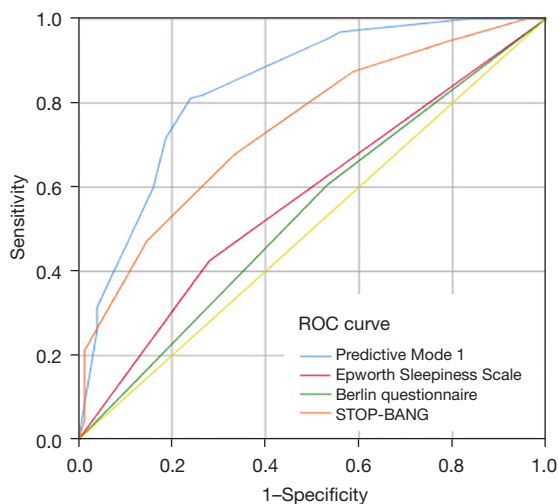
Variable	Control group	OSA group	P value
Snoring	81.3%	98.4%	<0.001
Non-restorative sleep	36.0%	37.8%	0.81
Dry mouth in the morning	54.7%	69.3%	0.037
Witnessed nocturnal apnea	21.3%	69.3%	<0.001
Struggling for breath upon awakening	28.0%	44.1%	0.038
Diurnal fatigue	40.0%	43.3%	0.52
Excessive daytime sleepiness (ESS)	7 [4, 11]	10 [6, 14]	0.008
Nocturia	21.3%	33.9%	0.025
Cognitive function impairment	74.7%	64.6%	0.066
Rhinitis symptoms	61.3%	56.7%	0.519
Insomnia	16.5%	20.0%	0.535
Morning headaches	6.7%	8.7%	0.843
Sex	(Male) 66.7%	(Male) 84.3%	0.003
Age	37 [31, 44]	42 [33, 51]	0.01
Alcohol consumption	(Male) 46.0%	(Male) 71.0%	(Male) 0.003
	(Female) 16%	(Female) 0.0%	(Female) 0.064
History of smoking	(Male) 38.0%	(Male) 51.4%	(Male) 0.118
	(Female) 4.0%	(Female) 5.0%	(Female) 0.873
Diabetes mellitus	4.0%	6.3%	0.654
Hyperlipidemia	26.7%	42.5%	0.021
Cardiovascular disease	2.7%	4.7%	0.465
Asthma	4%	4%	0.807
Hypertension	26.7%	37.8%	0.086
BMI	25.9 (23.6, 28.7)	27.4 (25.6, 30.1)	0.003
BMI Grade	Normal (32.0%)	Normal (11.8%)	0.021
	Overweight (37.3%)	Overweight (48.8%)	
	Obesity (30.7%)	Obesity (39.4%)	
Neck circumference	39.5 (35.6, 41.1)	41.1 (39.0, 42.5)	<0.001
Central obesity	56.0%	83.5%	<0.001
Tonsillar size	Grade 1 (66.7%)	Grade 1 (46.5%)	0.01
	Grade 2 (22.6%)	Grade 2 (31.5%)	
	Grade 3 (8.0%)	Grade 3 (11.8%)	
	Grade 4 (2.7%)	Grade 4 (10.2%)	
Pharyngeal grade	Grade 1 (9.3%)	Grade 1 (3.2%)	<0.001
	Grade 2 (26.3%)	Grade 2 (5.6%)	
	Grade 3 (44.7%)	Grade 3 (46.8%)	
	Grade 4 (19.7%)	Grade 4 (44.4%)	
Lateral narrowing	12%	45.2%	<0.001
Deviated nasal septum	57.3%	74.8%	0.01
Hypertrophic inferior turbinates	37.3%	34.7%	0.701

Data are expressed as median (interquartile range) or percentage (%). OSA, obstructive sleep apnea; ESS, Epworth Sleepiness Scale; BMI, body mass index.

**Table 4** Logistics regression model for OSA status

Variable	Coefficient(B)	SE	P value	OR
Snoring	2.05	0.89	0.021	7.66
Witnessed nocturnal apnea	1.80	0.38	<0.001	6.33
Central obesity	1.00	0.39	0.011	3.09
Lateral narrowing	1.73	0.47	<0.001	5.53

OSA, obstructive sleep apnea.



**Figure 2** ROC curves for predictive model, Epworth Sleepiness Scale, Berlin Questionnaire and STOP-BANG questionnaire. ROC, receiver operating characteristic.

condition exhibited in sleep-disordered breathing. Deemed a risk factor for motor vehicle accidents (22) and reduced quality of life (23), OSA has become a public health issue and, accordingly, has received more attention. The present study used clinical parameters to establish regression models to determine the presence and severity of OSA. In predicting an AHI  $\geq 15$  events/h, our predictive model achieved an accuracy of 0.812, a sensitivity of 81.3%, and a specificity of 81.1% in the validation group.

Habitual snoring and witnessed sleep apnea, which reflect narrowing of the upper airway, were predictors of OSA in our model. Although subjects with snoring were common in both groups, the study population was not from the community, and the OSA group had a higher proportion of such individuals. Results demonstrated that snoring and witnessed apnea were more important predictors than other symptoms because self-reported snoring and breath

holding were associated with the presence of sleep apnea, even within single persons, persons living alone, and those customarily sleeping alone, of both sexes (24). There was little doubt that these nocturnal symptoms were sensitive indicators of OSA. A systematic review based on population-based studies reported that the sensitivity and specificity of snoring and reported apnea were 90% and 19%, and 80% and 42%, respectively, at the level of AHI  $>10$  or 15 events/h (15). A combination of BMI and subjective snoring severity scale, which assesses snoring loudness, frequency, and duration, yielded a high sensitivity (97.4%) and but a low specificity (40%) (25). We only collected data regarding frequency of snoring, rather than loudness and duration, because of its accessibility in practice.

Obtaining accurate history is often problematic. Symptoms occur during sleep, exaggerating or disregarding symptoms are obstacle to obtain good history. The collection of subjective history from the subjects is usually insufficient; as such, it is important to examine anatomical abnormalities of the upper airway. Enlargement of soft tissue structures lead to narrowing of the upper airway and increased collapsibility, especially in Far-East Asians with relatively small cranial base dimensions (14). The Mallampati score was initially used to predict difficulty of endotracheal intubation based on the visibility of oral structures with the tongue protruding from the widely open mouth. It was also an independent predictor of both the presence and severity of OSA. For every increase in the Mallampati score, the odds of having OSA increased 2-fold, and the AHI increased by 5 events/h (26,27). Evaluation of oropharyngeal structures revealed that lateral narrowing increased the probability of OSA even after controlling for BMI and neck circumference. Moreover, tonsillar size has been strongly associated with AHI (19,28). Tonsillar size and lateral narrowing were independent predictors in our models, which was consistent with previous studies. The presence of lateral narrowing increase 5-fold of the

**Table 5** Linear regression model for AHI

Variable	Coefficient(B)	VIF	95% CI	P value
Witnessed nocturnal apnea	17.1	1.370	10.2 to 24.0	<0.001
Tonsillar size	6.2	1.088	2.9 to 9.5	<0.001
Central obesity	12.5	1.132	5.6 to 19.3	<0.001
Lateral narrowing	9.0	1.180	2.2 to 15.8	0.01
Intercept	-19.7		-39.5 to 0.0	0.05

VIF, variance inflation factor; AHI, apnea-hypopnea index; CI, confidence interval.

**Table 6** The models' performance

Models	AUC (%)	Sensitivity (%) (95% CI)	Specificity (%) (95% CI)	LR+ (95% CI)	LR- (95% CI)
Predictive model	83.7	81.1 (73.2–87.5)	76.0 (64.6–85.1)	3.4 (2.2–5.1)	0.3 (0.2–0.4)
Model 1	76.3	70.1 (60.5–77.2)	76.0 (67.7–87.3)	2.9 (2.1–5.1)	0.4 (0.3–0.5)
Model 2	79.9	69.3 (60.5–77.2)	78.7 (67.7–87.3)	3.3 (2.1–5.1)	0.4 (0.3–0.5)
Model 3	78.4	75.4 (66.9–82.6)	77.3 (66.2–86.2)	3.3 (2.2–5.1)	0.3 (0.2–0.4)

Predictive model: Snoring, Witnessed nocturnal apnea, Central obesity, Lateral narrowing. Model 1: Snoring, Witnessed nocturnal apnea, BMI, Lateral narrowing. Model 2: Snoring, Witnessed nocturnal apnea, Central obesity. Model 3: Neck circumference, BMI, Tonsillar size, Lateral narrowing, Pharyngeal grade. LR, likelihood ratio; CI, confidence interval; AUC, area under the ROC curve.

odds of having OSA and every increase in tonsillar size was associated with an increase in AHI of 6 events/h. Asking patients to open their mouth to inspect redundant pharyngeal tissue was an essential step in estimating the likelihood of OSA. Obesity is regarded not only as a disease but also a strong risk factor for OSA that cannot be ignored. Waist circumference, BMI, and neck circumference are obesity indices. The cross-sectional study showed that waist circumference was a better predictor than general obesity indices or visceral adiposity indicators (29). Central obesity appears to play a more important role in OSA than other forms of obesity, and AHI has been reported to be significantly correlated with intra-abdominal and subcutaneous abdominal fat (30,31). Results from the present study also suggested that central obesity was a more important predictor included in the model than BMI or neck circumference. Patients with OSA, especially Far-East Asians, may have a low BMI (14). As such, BMI, as an indicator of obesity, could degrade the predictive performance of this risk factor.

A study prospectively studied the utility of four clinical prediction models for predicting the presence of OSA in the referral-based population. These models comprised snoring, witnessed apneas, hypertension, sex, age, BMI,

and circumference. Using the best cutoff points, the sensitivities ranged from 76–96%, specificities from 13–54% (13). These models do not incorporate oral cavity measurements and suffer from poor specificities. Guideline paper suggested that symptoms and physical examination, such as choking at night, snoring, BMI, the Mallampati score, and lateral narrowing, were both essential for possible diagnosis of OSA (16). The predictors in our model, including history, physical examination and obesity, resulted in a more comprehensive inspection of subjects. Ultimately, the external validity of predictive models was performed and the experimental results proved our model is effective in predicting the presence of OSA. We compared our predictive model with other three models. The results demonstrated that removing or replacing original explanatory variables would degrade the predictive performance. Friedman *et al.* use snoring, Friedman tongue position, tonsil size, BMI and sleep questionnaires to construct predictive equation and the sensitivity and specificity of the model were 82% and 83.4%. The prediction improved when incorporating subjective and objective metrics into a single equation (32).

We compared our predictive model with three other questionnaires using ROC analysis. The Berlin



Questionnaire, STOP-BANG questionnaire, and ESS are frequently used in our clinical practice to assess OSA status. Our predictive model demonstrated the best accuracy in detecting OSA. The accuracy of the STOP-BANG questionnaire was suboptimal, whereas the accuracy of the other two questionnaires was unsatisfactory. This result was supported by a meta-analysis that investigated the diagnostic accuracy of various questionnaires (33). It concluded that the STOP-BANG questionnaire was a superior tool for detecting OSA compared with the Berlin Questionnaire and ESS. As discussed, we believe that the relatively lower BMI of Asian patients could directly result in the misclassification of some of patients with OSA.

The predictive performance of clinical models varies significantly. A summary of 4 trials based on combinations of history and physical findings from physicians' perspectives yielded an overall sensitivity of 58% and a specificity of 67%. A six-month prospective study based on the referral population surprisingly obtained a model with a sensitivity of 97.6% and a specificity of 100% according to BMI, neck circumference, and oral cavity measurements (15,34). Discrepancies, however, may be explained by differences in the study populations and method(s) of clinical assessment. In general, clinical prediction algorithms are not sufficient to substitute for PSG or home sleep apnea testing, but could be useful in prioritizing patients for testing or allowing starting continuous positive airway pressure without a sleep study (13,35). Using the operating point with a high specificity (90%), the sensitivity, specificity, LR+ and LR- ratios were 56.7%, 90%, 6.1, and 0.5. When the probability cutoff is chosen that achieve a high specificity, we could minimize the number of false positive tests. In other words, physicians could use the model to minimize the number of patients with an AHI <15 events/h placed into a definitive testing. The performance of predicting OSA severity was less satisfactory, suggesting clinical data was not efficient enough to predict OSA severity or the prediction of OSA severity needed to be divided into subgroups.

There were some limitations to the present study, the first of which was that the external validity of predictive models in different populations was limited. Second, our linear regression model might be less reliable, and establishing predictive model for the severity of OSA in different subgroups in a larger sample size was necessary. Third, referral-based controls in the analysis were supposed to be different from those without apnea in the community. Finally, patients with mild OSA should be included among the controls when defining OSA status at a cut-off of AHI

15 events/h. Thus, more reliable and more reproducible predictive models will be obtained with a larger sample size and validation of our prediction model in different populations will be necessary to overcome some of these limitations in the future.

## Conclusions

Snoring, witnessed nocturnal apnea, tonsillar size, lateral narrowing, and central obesity were used to predict the presence and severity of OSA. The results suggest that it could potentially be useful in clinical applications used to identify patients who are at increased risk for OSA.

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## Footnote

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*Ethical Statement:* The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The present study was approved by the Institutional Review Board of Beijing Tongren Hospital (Beijing, China; TRECKY2019-049), and written consent was obtained from all subjects.

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