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Original article

Re-evaluation of subtypes of positional OSAS by clustering algorithms

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Abstract. *Study Objectives:* Obstructive sleep apnea syndrome (OSAS) is a common sleep disorder that occurs in approximately 5–10% of the general population, and characterized by excessive daytime sleepiness, disruptive snoring, recurrent episodes of apnea or hypopnea and nocturnal hypoxemia. The subtypes of positional OSAS (PPs) are defined by conventional classification determined by the apnea-hypopnea index (AHI). However, there were not enough studies about the classification and characterization of PPs in the literature. The aim of this study is to determine the new subtypes of PPs by data mining algorithms. *Methods:* The study was admitted by 514 patients with OSAS with 24 attributes which was analysed by K-means clustering, C&RT and CHAID decision tree algorithms by RStudio programming. Chi-square test was used for cross-validation and Kappa statistics were used to compare the re-evaluated values with classical values. *Results:* In all methods, two clusters for PPs were obtained and the CHAID algorithm gave us the most accurate results. The value for AHI nodes in CHAID was considered as a cut-off value, and cross-validated with the cut-off value obtained by AUC-ROC analysis with high accuracy (92%). *Conclusion:* It can be concluded that specific treatments should be developed for new subtypes of PPs considering the centroids of 14 significant attributes.

Keywords: Positional sleep apnea, Clustering, Decision tree, Data mining

Introduction

Obstructive sleep apnea (OSA) characterized by excessive daytime sleepiness, disruptive snoring, recurrent episodes of apnea (no airflow) or hypopnea (partially obstructed airflow) and nocturnal hypoxemia, is a common sleep disorder that occurs in approximately 5–10% of the general population, regardless of race and ethnicity if it remains untreated, it rapidly creates serious cardiovascular, respiratory and nutritional problems (1,2,3). OSA has been accepted as a unique clinic picture for a long time, however, it is considered as heterogeneous regarding an anatomical or non-anatomical pathophysiological causality, and stratified further by age (4,5). Moreover, multiple genes, environmental influences, and development factors are also closely related to OSAS. So its pathophysiology continues to remain a mystery for both basic researchers and clinicians. Over the years, we have learned more about the pathophysiology and potential effects of OSA which were used for phenotyping of OSAS patients. Although OSA phenotypes were mostly described based on the clinical characteristics of the disease, by combining anthropometrics, sleep data and comorbidities in patterns corresponding to the most common clinical presentations of OSA (6). Therefore, for a long time OSA has been accepted as a unique clinic picture without associating the apnea-hypopnea index (AHI) with positions and sleep stages, but today OSA does not have a standard clinical picture, different clinical types have been defined with the improvement of positive airway pressure treatment (7,8).

There is no consensus for classifying of OSA into various phenotypes. One of the phenotypes mostly used is positional OSAS, which occurs predominantly during sleep in the supine position (9). However, the mechanisms of PPs are not fully explained, it is thought that there is a possible interaction with upper airway collapsibility or reduced lung volume (7). Mild to moderate OSAS may be comprised of several phenotypes about polysomnographic (PSG) features. Positional OSA (PPs) being a phenotype of OSA, occurs predominantly during sleep in the supine position (10). Although the mechanisms of PPs are not fully explained, it is thought that there is a possible interaction with upper airway collapsibility or reduced lung volume (7). The most common definition for positional OSAS (i.e., spOSA) used today, was first described by Cartwright (1984) as overall AHI was ≥5/h and a supine AHI was at least two times higher than non-supine (11). The positional dependency index (PDI) was also defined to define the positional dependency with the lateral AHI divided by the supine AHI (12), but there were not enough studies about classification and characterization of PPs in the literature (9,13). Recently two researchers suggested two different classifications for PPs. One of them was classifying PPs into two subtypes, i.e supine-predominant OSA (spOSA) and supine-isolated OSA (siOSA) (9,14). The other was classifying PPs into three subtypes depending on the degree of AHI in order to develop specific treatments, i.e while in the non-supine position: subtype I (i.e., siOSA) which fulfilled a non-supine AHI <5/h, subtype II which fulfilled a non-supine AHI ≥5/h and <15/h, and subtype III which fulfilled a non-supine AHI ≥15/h. According to this classification, it was found that positional OSA subtypes had different clinical characteristics and it was supposed that that subtyping of positional OSA was helpful for developing specific treatment strategies according to positional tendency (15).

The aims of this study were twofold: (1) to determine new subtypes of PPs with cluster analysis, (2) to document the clinical characteristics of the new classification and compared to non-positional OSA and three subtypes of PPs.

Materials and Methods

Subjects and study design

We performed a retrospective cross-sectional study, collecting data from 1017 patients who were examined by polysomnography (PSG) for OSAS between 2005 and 2016. These patients were selected consecutively from the subjects admitted to the sleep clinic with fatigue or poor concentration attributable to disrupted sleep. Among them, 514 patients (384 men and 130 women) with the symptoms of nocturnal snoring and/or excessive daytime sleepiness and sleep apnea, and diagnosed as OSAS (AHI>5 events/hr) were included in the study. Exclusion criteria were as follows: psychiatric causes of sleep disorder, use of sedatives, muscle relaxants, age<18 years, and the other sleep disorders. The study protocol was conducted according to the revised Declaration of Helsinki and was approved by the local Research and Ethics Committee of our hospital (No: 05/04/2017-52).

Demographic characteristics: (age, sex, and BMI), current cigarette smoking status, history of pre-existing diseases, current drug use, sleep history, medical history including cardiovascular or metabolic diseases, medication use, and habits were obtained by a standardized questionnaire before the sleep recording. Waist circumference was measured at the narrowest part of the waist located between the lower rib and the iliac crest, and hip circumference was measured at the level of the greatest gluteal protuberance in a horizontal plane parallel to the floor (16, 17). The BMI was calculated as weight in kg divided by the square of height measured by a scale, BMI>30 kg/m^2 was defined as obese. BMI, which is a measure of total fatness, was classified into one of the following four BMI categories: BMI < 18.5 kg/m^2 (underweight), 18.5 kg/m^2 ≤ BMI < 25 kg/m^2 (normal weight), 25 kg/m^2 ≤ BMI < 30 kg/m^2 (overweight), or BMI ≥ 30-34.9 kg/m^2 (I class obese), BMI ≥ 35-39.9 kg/m^2 (II class obese), BMI ≥ 40 kg/m^2 (morbid obese) (18). Written informed consent was obtained from all subjects.

Polysomnography (PSG)

Compumedics; 44 channels E series polysomnography (PSG) systems (Abbotsford, VIC, Australia) was used for overnight PSG recordings which included an electroencephalogram (EEG) (C3-A2, C4-A1, O1-A2, and F4-A1); bilateral electrooculogram, right and left masseter muscles and lower leg electromyogram; oronasal flow, measured by a nasal cannula; thoracic and abdominal respiratory movements, recorded by piezoelectric belts; electrocardiogram (ECG); oxygen saturation, measured by finger oximetry; and body position. A desaturation event (dip) was considered when oxygen saturation (*SaO2*) decreased by 3% or more with the baseline. Audio and video recordings were carried out simultaneously to distinguish SB episodes from non-specific orofacial activities.

The total sleep time, sleep efficiency, and sleep stages were scored according to the Rechtschaffen and Kales criteria by two trained sleep clinicians who were blind to the clinical characteristics of each patient (19). Apnea was defined as the complete cessation of airflow for at least 10 seconds and a decrease in 3% or more capillary oxygen saturation was accepted as desaturation. A hypopnea is scored if airflow decreases ≥ 30% for ≥ 10 seconds and is associated with either ≥ 3% desaturation or arousal (20). An average number of desaturation episodes per hour of recording is defined as oxygen desaturation index (ODI) (21, 22). The diagnosis of OSA was made when the AHI was >5/h per hour. The number of obstructive events per hour (AHI) was used as a measurement to quantify OSA: mild OSA (AHI 5–15 events/h), moderate OSA (AHI 15–30 events/h), and severe OSA (AHI>30 events/h) according to the report of the American Academy of Sleep Medicine task force (23).

Definitions of positional OSA

The sleeping position was analyzed by a position sensor on the chest and confirmed by a lowlight camera. Patients categorized as having positional or non-positional OSA according to the criteria by Cartwright (1984) (11): if overall AHI was ≥5/h and a supine AHI was at least two times higher than non-supine AHI. And then, patients with PPs were further categorized into three subtypes: Group I: non-supine AHI <5/h, Group II: non-supine AHI ≥5/h and <15/h and Group III: non-supine AHI ≥15/h (15). The positional dependency index (PDI) of all patients was described as the lateral AHI divided by the supine AHI. If the PDI is less than 0.5, patients are described as having positional dependency, if greater than 0.5, patients do not have positional dependency (12).

Statistical Analyses

Statistical analyses were performed by SPSS 25.0 and SPSS Modeler 18.0 (IBM Inc., Chicago, IL, USA), and checked by RStudio programming also. Descriptive statistics were presented as mean±SD for continuous variables and frequencies & percentages for categorical variables. K-means clustering, C&RT and CHAID decision trees algorithms with gain plots were used to cluster the dataset. Chi-square test was used for cross-validation and Kappa statistics was used to compare the re-evaluated values with classical values. ROC analysis was used to determine the cut-off value for non-supine AHI. The student t-test was used to compare the results between the independent two groups. $p<0.05$ values were considered as statistically significant results for 5% Type-I error.

Results

A total of 514 patients (384 male/130 females with a mean age of 48.89±0.49 years) were analyzed in this study. Of the 514 subjects, 38.7% (n=199) fulfilled the Cartwright's criteria for positional OSA. Patients with positional OSAS had less severe sleep apnea ($p<0.001$) measured by AHI, ODI, but higher lowest O_2 saturation ($^{***}p<0.001$); younger age ($^{*}p<0.05$); lower BMI ($^{***}p<0.001$). The PP group had significantly higher percentages of stages N3 and rapid eye movement sleep (REM) and a lower percentage of stage N1 sleep. However, sleep architecture, total sleep time, sleep efficiency and co-morbidities (hypertension, diabetes mellitus, and coronary artery disease) did not show significant differences between the groups.

AHI is routinely used to classify the severity of OSAS in adults; AHI<5 events/hour normal, AHI=5-14.99 mild, AHI:15-29.99 moderate AHI≥30 severe.

The PPs were clustered using proportional scale demographic and clinical characteristics of patients.

The data from the patients included age, height, weight, BMI, neck circumference, waist circumference, TST, PUKI value, REM, stage 1, stage 2, stage 3, $Sa0_2$ desaturation, ODI, arousal index, PLMI, apnea-hypopnea duration, AHI, $AHI_{non\text{-}supine}$, AHI_{supine}, bruxism, PDI variables were selected for clustering. Initially, three clusters were determined and the K-means clustering method was used first. The central points of each variable were calculated for the specified clusters. The ANOVA result of variables suitable for clustering revealed significant differences at central points of BMI, waist circumference, REM, stage 2, ODI, arousal, PLMI, apnea-hypopnea duration, AHI, and AHI_{supine} for the clusters. However, the frequency of OSAS severity did not match with the clusters (Kappa=0.015; *P=0.043*). The reason for the inconsistency between the actual classification and the prediction classification originated from the group of severe OSAS patients (Table 1). The patients were especially clustered at a moderate group after the clustering of the variables. The decision trees methods were used from different clustering algorithms. First, the CHAID algorithm, which usually yields successful results, was applied.

For the algorithm, OSAS severity groups were determined as a dependent variable and the other variables were determined as an independent. As a result, two nodes appeared for $AHI_{non\text{-}supine}$. Two nodes were determined for AHI at above and below of 28.3 value for the node above of 3.4 value of which determined for $AHI_{non\text{-}supine}$ at above and below of 3.4 value (Cross-Validation prediction=0.276). A 51.2% (n = 102) of success rate was found at the branches determined according to the OSAS severity (Figure 1).

For the same dataset, another decision tree algorithm named C & RT was applied. The patients with mild severity had higher predictive probabilities (*p=0.513*). The probability value for moderate and severity groups was found around *p= 0.245*. Two nodes were determined for $AHI_{non\text{-}supine}$ at 6.75 cut-off points. Below 6.75 cut-off points, 93.5% mild patients and above 6.75 cut-off point 44.6% moderate and 53.3% severe patients were predicted (Figure 2).

As a result of the analysis, it was understood that there had to be two clusters. The K-means algorithm re-applied by selecting two clusters because of the analysis results was found to be highly significant at AHI_{supine} and $AHI_{non\text{-}supine}$ values than clusters. The number of elements of identified clusters was calculated as 72 and 127. ROC analysis was applied for $AHI_{non\text{-}supine}$ values according to the groups determined for these clusters (Figure 3). The area under the curve was found significant (AUC=0.734; ***$p<0.001$; %95 CI: 0.653-0.815). The cut-off value for $AHI_{non\text{-}supine}$ was calculated as 9.18.

The cross-validation results between the two groups after clustering and AHI re-coded for the above and below of value were significant (McNemar $p<0.001$; Kappa=0.786; $p<0.001$). The descriptive measures of the variables calculated for $AHI_{non\text{-}supine}$ = 9.18 were presented in Table 2. The mean of waist circumference, BMI, AHI, $AHI_{non\text{-}supine}$, and AHI_{supine} were significantly higher in severe patients. And also ODI was significantly higher in severe P-OSAS patients.

When positional OSAS patients were compared according to subgroups, BMI, ODI, AHI,

Table 1. The clustering groups and OSAS classification

P-OSAS classification (AHI)	Real data		Predicted data	
	(n)	**%**	**(n)**	**%**
< 5	102	51,3	125	62,8
5-15	48	24,1	62	31,1
> 15	49	24,6	12	6,1

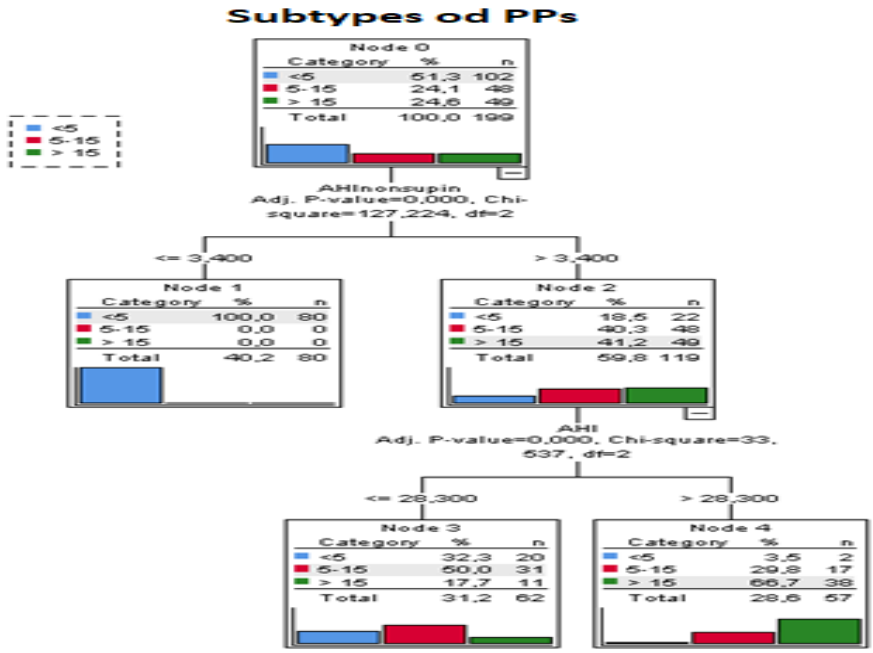

Figure 1. The cluster of P-0SAS patients according to CHAID algorithm

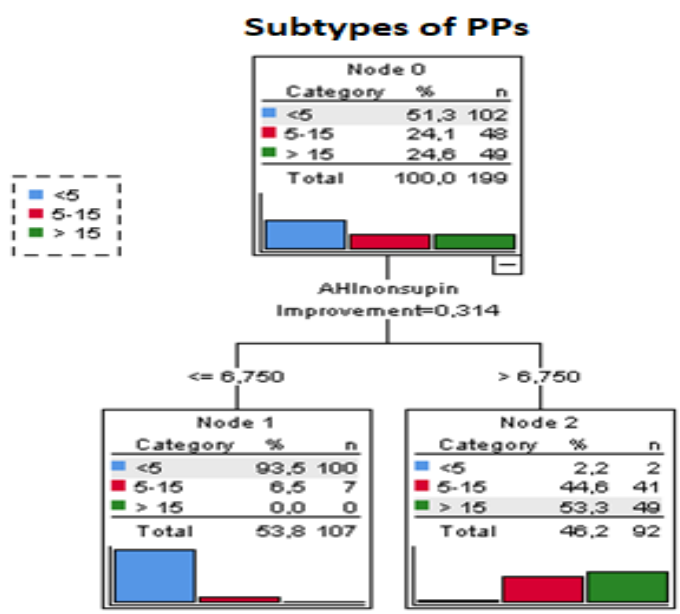

Figure 2. The cluster of P-0SAS patients acoording to CHAID algorithm

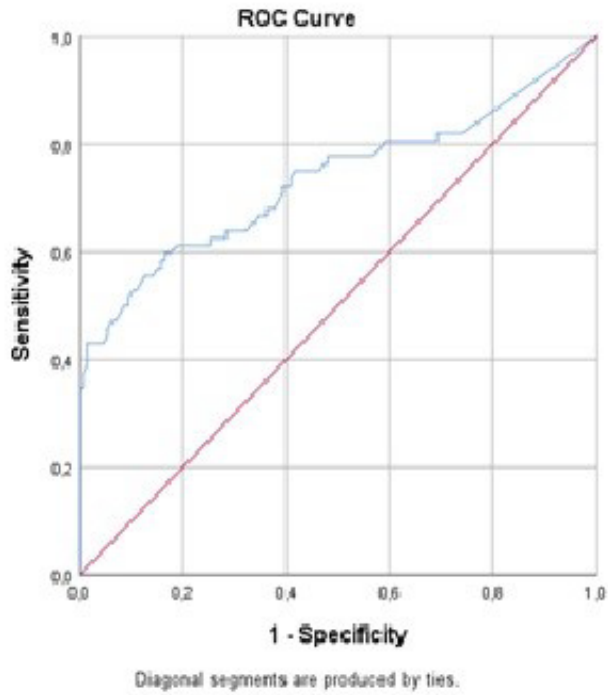

Figure 3. The ROC curve of $AHI_{non\text{-}supine}$ for cut-off=9,18

non-supine and supine AHI variables were found to be significantly different. When non-positional patients were added to these patients, the same variables were found to differ significantly. The averages of non-positional OSAS patients were generally significantly different in the 5-15 and > 15 subgroups. When the variables were compared according to the new subgroups formed in two groups, only the mean values of non-supine AHI variable were significantly different between the groups. When both classifications were considered together, only the difference of non-supine AHI variable was significant according to the interaction term of old and new subgroups as a result of multivariate analysis ($p= 0.004$). Besides, when Kruskal's Gamma was calculated for the correlation coefficient between classical and new PPs classes, it was found to be 0.995 ($p<0.001$), and it was found that the two subclasses were highly compatible with the classical evaluation in the evaluation of PPs classes.

Discussion

There have been various definitions for positional OSA, however, the most common definition for the positional OSA was that the overall AHI was ≥5/h, and a supine AHI was at least two times higher than non-supine AHI (9,11). Using this criterion, the first large population study of positional dependency showed the positional OSAS of 55.9% in a series of 574 patients (19,24), found the prevalence of positional OSA as 75.6%, and they said that this finding was consistent with 67-75% of the Asian population (14,24,25) , but was higher than 50-60% in Western countries (10,18,27). However, a lower prevalence (38.7%) of the positional OSA was found in our study that is consistent with the reports from 9% to 60% (26,28,29). This lower prevalence could be explained by the size of the population, anatomic variations or socio-cultural and environmental factors (e.g. life habits, diet).

Table 2. The comparison of patient parameters due to the cut-off point of $AHI_{non\text{-}supine}$ =9.18

	Mean±SD		*p*
	Mild PPs (n=124)	**Severe PPs (n=75)**	
AHI (*events/hour*)	24.9±23.14	33.89±16.6	*0.004**
$AHI_{non\text{-}supine}$ (*events/hour*)	2.76±2.91	19.34±8.09	*<0.001**
AHI_{supine} (*events/hour*)	33.52±23.46	57.66±20.93	*<0.001**
Age (*year*)	46.82±11.79	48.64±11.29	*0.286*
BMI (kg/m^2)	28.89±4.79	30.36±4.31	*0.030**
Waist circumference (*cm*)	97.34±15.08	103.32±11.22	*0.011**
Stage 1	10.98±8.77	12.13±11.03	*0.416*
Stage 2	62.75±10.96	61.52±10.87	*0.440*
Stage 3	13.66±8.83	14.25±7.19	*0.629*
Sleep Efficiency	92.37±6.94	92.13±7.78	*0.822*
REM	12.38±7.81	12.77±7.35	*0.726*
ODI (*events/hour*)	22.18±19.9	30.81±15.69	*0.002**
Arousal	56.47±99.56	51.5±110.84	*0.744*
Apnea-hipoapnea duration (*minute*)	74.84±72.85	96.55±79.05	*0.050*

**: significant at $p<0.05$ level according to Student t-test*

In positional OSAS patients, the smaller neck and waist circumferences have been usually reported (10,14,27,30), although some studies showed no difference in BMI between positional and non-positional OSA (25,31). In the present study, the between-gender comparison of the circumferences of the neck showed the statistically significant difference between males and females ($p<0.05$), but the circumferences of waist were not different between genders ($p>0.05$). This was consistent with the study of Janssen et al. (2004), who found the waist circumferences of males larger than females which suggested a greater risk in the course of diabetes mellitus (DM) in males (32). In our study, the prevalence of DM and CAD was similar in male and female groups, where the prevalence of HT was different in NPP in males and females. Furthermore, NPP patients had larger neck and waist circumferences which were consistent with the study of Mador et al. (2005) (33). However, when we analyzed the subtypes of PP, we found that neck and waist circumferences of subtype I and II statistically did not differ from each other, but they were statistically different from subtype III which was similar to NPP in male patients. Despite that, the neck circumferences of females in the groups were not statistically different from each other, but the waist circumferences of females in subtype I was found statistically different from other subtypes and NPP which were statistically similar. In this point of view, our findings may explain the reason for the similarity of OSAS incidence in a given age group of male and female genders and also the known association between OSAS and diabetes.

Many studies show that positional OSA is a mild and moderate form of the OSA syndrome, and a difference in AHI was shown between PP and NPP (26,33,34). In the present study, PSG results showed that positional OSA had a mild and moderate degree of sleep apnea, more preserved sleep architecture, lower apnea-hypopnea time, lower ODI, lower PDI, and higher low O_2 saturation than non-positional OSAS. When we analyzed the subtypes, we found that subtype III patients had more severe degree of sleep apnea than patients of subtype I and II and resembled NPP. Although the PP group had significantly higher

percentages of stages N3 and rapid eye movement sleep (REM) and a lower percentage of stage N1 sleep, sleep stages, total sleep time, and sleep efficiency did not differ significantly between subtypes and NPP which is compatible with the previous findings (24).

The main limitation of this study is being a cross-sectional study with a small sample size, but not be a follow-up study. Thus, we do not have the prognostic outcome results of positional OSAS patients, and positional OSAS diagnoses are controversial nowadays. This is a big problem for the definition of positional OSA and it has the relation to the treatment globally.

In the present study, we showed the characteristics of subtypes between genders and found out that subtype III did not differ in clinical features from NPP between genders. Unlike subtype III, subtype I and II were different from NPP, and neck circumferences of subtypes I and II were different between genders which may be related to the difference of neck fat tissue between males and females. However, in clustering analyses, we showed that PDI, ODI and BMI parameters may be used to classify the positional OSAS patients.

The data was collected from a single-night PSG, there is a possibility that PSG phenotypes of positional OSA are not stable and therefore may change over subsequent nights. Because it is well recognized that there is a night-to-night variability of the AHI in patients with OSA (27). This situation might affect the therapy strategy. It was shown that positional OSAS subtype I was independently associated with ODI, subtype II was independently associated with ODI and PDI, and subtype III was independently associated with ODI, PDI, and BMI. Non-positional OSAS was independently associated with ODI, PDI, and waist circumferences. However, to predict the subtypes of PPs and NPPs, the parameters (ODI, PDI, BMI) included in the model was the most successful model in discrimination of subtypes and NPPs accurately (***$p<0.001$), the overall diagnostic accuracy predicted by LDA was 83.1%. Therefore, it can be stated that two clusters of OSAS patients define the subtype specifications of PPs accurately, and suggested that these subtypes of PPs can be used to diagnose and decide the treatment for OSAS patients.

Conflicts of Interest

The authors declare that there is no conflict of interest in this manuscript.

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