Original Article

The correlation between oxygen saturation indices and the standard obstructive sleep apnea severity

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Submission: 18-07-2019
Accepted: 16-12-2019
Published: 03-04-2020

Abstract:

OBJECTIVE: Currently accepted guidelines categorize obstructive sleep apnea (OSA) severity according to the Apnea–Hypopnea Index (AHI). However, it is unclear how to best define OSA severity. The present study sought to evaluate the concurrent validity of the widely accepted AHI by correlating it with various oxygen saturation (SpO_2) and polysomnographic parameters.

METHODS: The study utilized the data of a previous survey concerning the prevalence of OSA among a middle-aged Saudi population (n = 2682). Among the 346 individuals who underwent polysomnography, 178 had total sleep times of at least 240 min with rapid eye movement (REM) sleep and were included in the study. The standard classification of OSA severity was compared with different SpO_2 and polysomnographic parameters.

RESULTS: The study found that there were correlations between the standard OSA severity based on AHI severity classification and different SpO_2 and polysomnographic parameters, including the desaturation index (DI), the sum of all desaturations, desaturation below 90%, the average duration of respiratory events, and indices of total arousals and respiratory arousals. All of these parameters correlated directly with OSA severity classification ($P < 0.001$ for each). However, REM sleep duration and SpO_2 nadir were inversely correlated with OSA severity ($P < 0.003$ and < 0.001, respectively). In addition, only the DI, SpO_2 nadir, and respiratory arousal index were predictors of OSA severity, as determined through a multiple logistic regression analysis.

CONCLUSION: Our findings support the clinical reliability of the currently used standard classification of OSA severity based on the AHI.

Keywords:

Apnea–Hypopnea Index, hypopnea, obstructive sleep apnea, oxygen saturation, polysomnography

Obstructive sleep apnea (OSA) is an increasingly common, chronic, sleep-related breathing disorder that affects 5%–20% of the general population.[1] OSA is characterized by the frequent collapse of the upper airway passage, resulting in temporary cessations of breathing or disruptions in breathing rhythm (apneas).[2] These effects, in turn, increase the intensity of respiratory efforts against a closed extrathoracic upper airway. A further consequence is a significant decrease in the partial pressure of oxygen in the blood (arterial hypoxemia) and a high concentration of carbon dioxide in the blood (nocturnal hypercapnia), which leads to a reduction in tissue oxygenation levels (intermittent nocturnal recurrence hypoxia), augmentation of respiratory efforts, and increased sympathetic stimulation, which can subsequently lead to arousals. Polysomnography (PSG) remains the gold standard for the diagnosis of OSA. The current guidelines categorize OSA severity into mild (5–14 incidents/h of sleep), moderate (15–29

Access this article online

Quick Response Code:

Website: www.thoracicmedicine.org

DOI: 10.4103/atm.ATM_215_19

How to cite this article: Wali SO, Abaalkhail B, AlQassas I, Alhejaili F, Spence DW, Pandi-Perumal SR. The correlation between oxygen saturation indices and the standard obstructive sleep apnea severity. Ann Thorac Med 2020;15:70-5.

incidents), and severe (≥30 incidents) according to the Apnea–Hypopnea Index (AHI).[3] However, there is a lack of clarity as to what best defines OSA severity. Currently, research is being conducted to identify new tools and parameters to provide greater precision in the diagnostic characterization of the disorder's severity.[4]

Oxygen saturation (SpO_2) parameters have recently attracted interest among researchers as accurate markers of OSA severity and have even started to challenge the AHI as the exclusive or even primary measure for this purpose. These alternative parameters have included the SpO_2 nadir, average saturation, percentage of time with SpO_2 below 90%, and the desaturation index (DI). The results published by the European Sleep Apnea Database project revealed that DI was superior to AHI in predicting hypertension.[5] In addition, hypopnea accompanied by 4% desaturation was independently associated with cardiovascular disease.[6] These findings suggest that SpO_2 parameters may possibly play a major role in classifying the severity of OSA, and this conclusion might be explained by the fact that, compared with the AHI, measurements such as the DI better reflect the degree of hypoxia during sleep, in as much as the AHI does not indicate the degree of hypoxia.[5] Furthermore, the current cutoff of what is believed to be "normal AHI," <5 events/h, has been challenged by the Wisconsin Sleep Cohort, as patients with an AHI between 0.1 and 4.9 had 1.4 times the risk of developing hypertension compared with patients with an AHI of 0.[7]

In this study, we sought to assess the American Academy of Sleep Medicine (AASM) classification of OSA severity by comparing it with various SpO_2 parameters and PSG findings.

Methods

The Institutional Review Board Committee of King Abdulaziz University Hospital approved the experimental protocol. This is a retrospective study utilized the data of a previous survey on the prevalence of OSA among a middle-aged Saudi population.[1] The polysomnographic equipment used to diagnose OSA in the prevalence survey was of Type 2 (SOMNOmedics plus; SOMNOmedics, Randersacker, Germany) and consisted of continuous recordings from surface leads for electroencephalography, electrooculography, electromyography (submental and bilateral anterior tibialis muscles), electrocardiography, nasal pressure, nasal and oral airflow (thermocouple), chest and abdominal impedance belts for respiratory muscle efforts, pulse oximetry for SpO_2 and pulse rate, a tracheal microphone for snoring, and body position sensors for sleep position. Pulse oximetry for SpO_2 ranged from 70% to 100% ±2 for adults using the finger clip sensor. SpO_2 measures ranged from 70 to 99, with a percentage resolution of 16 bits. The wavelength used was red (660 nm) and infrared (910 nm).[1]

Patients with an AHI of ≥5 were categorized as having OSA, whereas those with excessive daytime sleepiness (EDS) and an AHI of ≥5 were categorized as having OSA syndrome.[8-10] OSA severity was determined according to the AASM criteria using AHI: 5–15, mild; 15–30, moderate; and >30, severe.[3]

In this study, this standard classification of OSA severity was compared with SpO_2 and other PSG parameters. These parameters included the following: DI; SpO_2 nadir and average SpO_2; the sum of all desaturations; desaturation <90%; average duration of apnea and hypopnea; AHI during rapid eye movement (REM) and non-REM sleep independently; duration of REM sleep; and total arousal and respiratory arousal indices. The study was limited to PSG studies of individuals with a total sleep time (TST) of at least 240 min and who also went into REM sleep. These criteria were used to ensure the proper assessment of the severity of OSA by obtaining at least 4 h of sleep recordings and REM sleep where obstructive respiratory events are expected to be worst.

Definitions

1. Desaturations index: Number of oxygen desaturations per hour of sleep
2. SpO_2 nadir: An indication of the minimum pulse oximetry SpO_2 value during the TST
3. Average SpO_2: Average value of the complete SpO_2 curve
4. Sum of all desaturations: Percentage of the duration of all desaturations from the TST
5. Desaturation below 90%: Percentage of the TST spent with SpO_2 below 90%
6. Average duration of apnea/hypopnea: Average duration of apnea/hypopnea during the TST
7. Total arousal index: Number of all arousals per hour of TST
8. Respiratory arousal index: Number of arousals per hour of TST that correlates with respiratory events.

Statistical analysis

The data were collected and analyzed using the Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL, USA), version 21. The data are presented as the mean ± standard deviations for continuous variables and percentage frequencies for categorical variables. Comparisons of continuous variables among AHI groups were conducted using one-way analysis of variance, while Chi-square test was used to compare between discrete variables. Statistical significance was set at an alpha level of 0.05 with $P < 0.05$, with a two-tailed

probability. Spearman's rank correlation (Spearman's rho) analysis was used to test the strength and direction of the association between OSA severity (using AHI classification with SpO_2, discrete ordinal variable at three levels) and PSG parameters (these parameters included the following: DI; SpO_2 nadir and average SpO_2; the sum of all desaturations; desaturation <90%; average duration of apnea and hypopnea; AHI during REM and non-REM sleep independently; duration of REM sleep; and total arousal and respiratory arousal indices, continues variables). Multiple logistic regression analysis with the Wald Chi-square statistical test was performed with AHI classification as a binary outcome (mild category vs. moderate and severe combined for meaningful interpretation of logistic model) to identify independent predictors of severity presented by odds ratios (ORs) and 95% confidence intervals (95% CIs).

Results

Of the 346 patients who underwent PSG, 178 had a PSG of at least 240 min duration with REM sleep and of these, 129 had OSA based on an AHI ≥5; these patients had a mean age of 44.6 ± 6.4 years, a body mass index (BMI) of 31.3 ± 6.2 kg/m^2, and a female participants n = 66, 37% and male participants n = 112, 63%. Twenty-one participants had EDS based on an Epworth Sleepiness Scale of ≥10. The mean severity scores of OSA are reported in Table 1.

All SpO_2 parameters were found to be associated with AHI severity ($P < 0.001$). For the PSG findings, AHI in both REM and non-REM sleep separately was found to be associated with AHI severity ($P < 0.05$). In addition, total arousals and respiratory arousal indices were again linked with severity based on the AHI ($P < 0.05$). We also found that the means of these variables increased with increasing severity of AHI, except, not surprisingly, duration of REM stage sleep, and SpO_2 nadir, for which the means decreased with increasing severity of AHI ($P < 0.010$ and < 0.001, respectively). Other key measurements that are relevant for assessing OSA were also undertaken. These findings are summarized in Table 2, which show values for the AHI, SpO_2, and PSG parameters among the study participants and further classified into three categories of OSA severity: mild, moderate, and severe [Table 2].

Table 3 shows the correlations that were found between several SpO_2 parameters and standard criteria used for defining sleep apnea severity. These parameters were all found to correlate directly with the standard classification criteria for sleep apnea severity, while SpO_2 nadir showed an indirect correlation. For the PSG parameters, the total arousal index and respiratory arousal index were also found to be directly correlated with AHI severity, while the duration of REM showed an indirect correlation.

Table 4 shows the multiple logistic regression analysis performed with AHI classification as a binary outcome (mild category vs. the moderate and severe categories combined). This analysis was used to identify independent predictors. In addition, forward stepwise methods with Wald Chi-square statistical tests were used. Ten predictors mentioned previously in the statistical analysis section were entered into the model with a stepwise technique, and only the DI, respiratory arousal index, and SpO_2 nadir remained in the model. The model showed that with each one-unit increase in the DI, a 35% increase occurred in the odds of being in the moderate or severe class, independent of the respiratory arousal index and SpO_2 nadir (OR = 1.35, 95% CI: 1.15–1.58, $P < 0.001$). Similar results were found for the respiratory arousal index. For a one-unit increase in the respiratory arousal index, a 53% increase occurred in the odds of being in the moderate or severe class of OSA severity, independent of the DI and SpO_2 nadir values (OR = 1.53, 95% CI: 1.22–1.91, $P < 0.001$). The model also showed that for a one-unit increase in SpO_2 nadir, a 15% decrease occurred in the odds of being in the moderate or severe class, independent of the DI and respiratory arousal index values (OR = 0.85, 95% CI: 0.73–0.99, $P < 0.045$). The goodness-of-fit test had $P = 0.583$, reflecting a good fit, thus indicating that the model was adequate for explaining the outcome variable.

Discussion

The results of this study revealed a direct correlation between the OSA severity based on the AHI and SpO_2 parameters. Total arousal and respiratory arousal indices correlated directly with severity ($P < 0.001$). Moreover, the DI, SpO_2 nadir, and respiratory arousal index were the only predictors of the severity of OSA.

Myllymaa *et al*.[11] also reported the impact of oxygenation in determining OSA severity. The authors demonstrated that significant variability in the AHI might arise when different oxygen desaturation levels are used to score hypopneas, reflecting the influence of these parameters in determining the severity of OSA.[11] Furthermore, Wu *et al*. reported that the mean apnea duration (MAD) and not AHI had a small but significant independent association (OR = 1.072, 95% CI: 1.019–1.128, $P = 0.007$) with moderate-to-severe hypertension.[12] More recently, Zhan *et al*., in a retrospective study, reported weak correlations between MAD and AHI.[13] Moreover, in severe OSA, MAD was significantly associated with worse overnight blood oxygenation and hence recommended as a predictor of blood oxygenation.[13]

When the AHI parameter was adjusted based on the apnea duration and severity of desaturation, the risk ratios of all-cause mortality and cardiovascular mortality were reported to be higher in the moderate and severe OSA groups, based on the adjusted AHI parameters, than in those based on conventional AHI.[14] This finding reflects the importance of these SpO_2 parameters in determining the severity of the syndrome.[14] In this study, these parameters were found to directly correlate with the AHI-based severity, which may strengthen its validity. Furthermore, Kulkas *et al*.[15] reported that novel parameters, including the duration of respiratory events and morphology of oxygen desaturation events, showed significant variation among patients with similar values of AHI. Such outcomes suggest that patients with similar severities based on AHI may have significantly different daytime symptoms and

Table 1. Distribution of apnea-hypopnea index (AHI) classification scores for obstructive sleep apnea (OSA)

Variables	AHI (Mean±SD)
All OSA *n*=129	18.4±13.4
Mild OSA *n*=65 (AHI=5-14)	9.33±2.79
Moderate OSA *n*=46 (AHI=15-29)	21.06±4.16
Severe OSA *n*=18 (AHI ≥30)	44.56±14.93

Table 2: Association between different classes of OSA severity based on AHI, oxygen saturation, and PSG parameters

Variables	Severity of OSA			
	Mild (AHI=5-14) *n*=65 Mean±standard error	Moderate (AHI=15-29) *n*=46 Mean±standard error	Severe (AHI=≥30) *n*=18 Mean±standard error	*P**
Desaturation Index	08.15±04.40	19.47±08.00	42.45±18.19	<0.001
Oxygen Saturation Nadir (%)	87.40±00.60	83.10±00.98	75.80±02.30	<0.001
Average SpO_2 (%)	95.70±00.26	95.70±00.20	93.60±00.41	<0.001
Sum of All Desaturations (%)	06.90±00.51	14.12±01.10	27.90±03.90	<0.001
Desaturations<90% (%)	00.78±00.22	02.94±00.68	11.36±03.52	<0.001
REM/AHI	20.30±01.64	38.70±02.60	52.20±04.60	<0.001
Non-REM AHI	07.20±00.40	17.30±00.84	43.40±03.80	<0.001
Average Apnea/Hypopnea Duration (s)	31.00±01.70	37.70±01.80	38.20±03.80	<0.02
Duration of REM (min)	53.90±03.10	45.80±02.90	37.30±04.40	<0.01
Total Arousal Index	18.10±00.87	23.60±01.30	37.10±02.70	<0.001
Resp. Arousal Index	04.60±00.36	09.40±00.67	22.00±03.10	<0.001

*One-way analysis of variance. REM: Rapid eye movements, AHI: Apnea-hypopnea index categorized as mild, moderate, or severe

Table 3: Correlations between OSA severity index and oxygen saturation parameters, PSG parameters, and patient characteristics

Variables	Correlation#	AHI*	Variables	Correlation	AHI
Spearman's Rank Correlation (rho) <0.05					
Desaturation Index	Correlation Coefficient	0.753**	Duration of~REM	Correlation Coefficient	-0.259**
	Sig. (2-tailed)	>0.001		Sig. (2-tailed)	0.003
Oxygen Saturation Nadir	Correlation Coefficient	-0.466**	Total Arousal Index	Correlation Coefficient	0.530**
	Sig. (2-tailed)	>0.001		Sig. (2-tailed)	>0.001
Sum of all Desaturations	Correlation Coefficient	0.574**	Respiratory Arousal Index	Correlation Coefficient	0.684**
	Sig. (2-tailed)	>0.001		Sig. (2-tailed)	>0.001
Desaturations<90	Correlation Coefficient	0.385**	Age	Correlation Coefficient	0.323**
	Sig. (2-tailed)	>0.001		Sig. (2-tailed)	>0.001
Average Apnea/Hypopnea Duration	Correlation Coefficient	0.295**	BMI	Correlation Coefficient	0.227**
	Sig. (2-tailed)	<0.001		Sig. (2-tailed)	0.010

n=129; #Spearman's rank correlation (rho); *AHI=Apnea-hypopnea index categorized as mild, moderate, or severe; ~REM=Rapid eye movements; **Highly significant correlation coefficient; BMI: Body mass index

Table 4: Predictors of the Apnea-Hypopnea Index# identified by forward stepwise multiple logistic regression analysis*

Variables	Regression coefficient (B)	Wald	Multivariate analysis		*P*
			OR	95% CI	
Desaturation index	+0.298	13.76	1.35	1.15-1.58	<0.001
Respiratory arousal index	+0.423	13.90	1.53	1.22-1.91	<0.001
Minimal SpO_2	−0.16	4.03	0.85	0.73-0.99	0.045

*AHI binary outcome: Mild (*n*=65) versus moderate + severe (*n*=64). HL goodness-of-fit test, *P*=0.583. HL=Hosmer-Lemeshow, OR=Odds ratio, CI=Confidence interval, SpO_2=Oxygen saturation, AHI=Apnea-Hypopnea Index. All of the three #*P* values are significant

cardiovascular stress, indicating that these parameters might further predict the severity of OSA.[15] In a similar study, when novel parameters including desaturation severity and obstruction severity were used, the mortality rate was found to be higher in patients with OSA, with higher novel parameter values but similar AHI values than in the remaining patients with OSA.[16] Punjabi *et al*.[17] reported that the percentage of TST with SpO_2 below 90% is an independent predictor of mortality and coronary artery disease.[18] In addition, Muraja-Murro *et al*.[19] divided 267 individuals into four categories based on AHI: normal, mild, moderate, and severe OSA. A novel parameter, the total duration of sleep apnea and hypopnea events, was tested. In the most severe cases, this parameter exceeded 70% of the recorded time, which may increase mortality and morbidity. Thus, this novel parameter could provide additional information for AHI when determining the severity of OSA.[19] In addition, impairment of cognitive function in the form of attention and decision-making in patients with OSA was found to be related to the parameters of hypoxemia and the percent time with SpO_2 <90%.

Furthermore, a relatively recent study reported that the combined percentage of apnea, hypopnea, and desaturation duration from TST provided greater accuracy for diagnosing OSA patients than conventional AHI.[20] In brief, the literature supports the utility of different novel parameters in determining the severity of OSA, but to our knowledge, this study is the first to report a direct correlation between conventional AHI-based severity and these novel parameters.

The duration of REM sleep was also found to correlate with the OSA severity, although in an inverse relation with OSA severity i.e the shorter the REM the worse is OSA severity ($P \leq 0.003$) [Table 3]. This result possibly occurred because REM sleep may be reduced in OSA. Due to frequent arousals, patients with OSA may not be able to progress into REM sleep.[21] REM sleep is often accompanied by worsening of respiratory events and desaturation compared with non-REM sleep.[21] Based on multiple logistic regression analysis [Table 4], only the respiratory arousal index, DI, and SpO_2 nadir were identified as strong predictors of OSA severity. This finding is not surprising since the number of desaturations per hour of sleep usually correlates to that of respiratory events during sleep. Although desaturation is not a prerequisite for defining apnea, it is often observed concurrently. Furthermore, the definition of hypopnea used in our study is from the AASM, i.e. it requires a desaturation of 3% and/or arousals, which again supports the findings of the regression analysis that both respiratory arousal index and DI are strong predictors of sleep apnea severity.[22] Moreover, a lower SpO_2 nadir during monitored sleep was associated with a more severe syndrome. This finding is supported by Delazer *et al*.[23] who reported that SpO_2 nadir is a significant predictor of OSA severity, and thus, when present, may be used to increase confidence in diagnostic assessment and choice of treatment.

The prevalence rate of OSA has been shown to increase with age; however, in one study, no correlation with severity was identified.[9] In contrast, we found a positive link between OSA severity and age. Aging leads to an increase in parapharyngeal fat deposition, redundancy of soft tissues, and soft palate lengthening, which may explain the relationship found in our study [Table 3].

The study found a direct association between obesity and OSA severity ($P < 0.010$), which is consistent with previously reported studies [Table 3]. The Sleep Heart Health Study reported that the prevalence rate of moderate-to-severe OSA was 3-fold higher in those with the highest BMI than in those with the lowest BMI.[24] In addition, the Wisconsin Sleep Cohort Study reported an approximately 3% change in OSA severity for every 1% change in weight over a 4-year period.[25] In addition, Deng *et al*.[26] found that obesity and aging are important risk factors for OSA severity.

Several limitations associated with the present study warrant mention. This was a retrospective study and hence an indeterminate amount of selection bias and the potential effects of unknown confounding factors could not be avoided. In addition, because this was a *post hoc* analysis, we did not perform an internal or external validation of our data, which would suggest the need for a large, prospective, multicenter study to confirm our findings. Another possible limitation was the fact that objective measures of SpO_2 and other variables were derived from only one full night of PSG; thus, night-to-night variability or first-night effects cannot be excluded. Another factor that may have limited the generalizability of the results was the unequal gender ratio, in which males (n = 112, 63%) were represented nearly twice as often as females (n = 66, 37%). Due to this imbalance, gender was not included as a covariate in the logistic regression analysis.

Conclusion

Despite these shortcomings, the findings of the study support the clinical reliability of the currently used classification of OSA severity based on the AHI. However, further studies are needed to determine more accurate estimates of severity to overcome the above-mentioned disadvantages of using the current severity assessment rules.

Acknowledgments

The authors would like to thank King Abdulaziz City for Science and Technology for supporting this work under project number no. A-L-12-0867. The author would like to sincerely thank all the study participants.

Financial support and sponsorship

The authors would like to thank King Abdulaziz City for Science and Technology for supporting this work under project number no. A-L-12-0867.

Conflicts of interest

The authors have read the journal's policy and have the following potential conflicts. This study was not an industry-supported study. S.R. Pandi-Perumal is a stockholder and the President and Chief Executive Officer of Somnogen Canada Inc., a Canadian Corporation. This does not alter his adherence to all journal policies. He declares that he has no competing interests that might be perceived to influence the content of this article. Other remaining authors declare that they have no proprietary, financial, professional, or any other personal interest of any nature or kind in any product of services and/or company that could be construed or considered as a potential conflict of interest that might have influenced the views expressed in this manuscript.

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