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# Diagnostic accuracy of a mathematical model to predict apnea–hypopnea index using nighttime pulse oximetry

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**Abstract.** The intent of this study is to develop a predictive model to convert an oxygen desaturation index (ODI) to an apnea–hypopnea index (AHI). This model will then be compared to actual AHI to determine its precision. One thousand four hundred and sixty-seven subjects given polysomnograms with concurrent pulse oximetry groups ( $n = 734$ ) in order to develop a predictive model of AHI using ODI. Quadratic regression was used for model development. The coefficient of determination ( $r^2$ ) between the actual AHI and the predicted AHI (PredAHI) was 0.80 ( $r = 0.90$ ), which was significant at a  $p < 0.001$ . The areas under the receiver operating characteristic curve ranged from 0.96 for AHI thresholds of  $\geq 10$  and  $\geq 15/h$  to 0.97 for thresholds of  $\geq 5$  and  $\geq 30/h$ . The algorithm described in this paper provides a convenient and accurate way to convert ODI to a predicted AHI. This tool makes it easier for clinicians to understand oximetry data in the context of traditional measures of sleep apnea. © 2016 Society of Photo-Optical Instrumentation Engineers (SPIE) [DOI: 10.1117/1.JBO.21.3.035006]

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## 1 Introduction

Obstructive sleep apnea (OSA) is a condition that involves multiple episodes of airway closure and/or reduction in airflow that affects 2% to 4% of the population.<sup>1</sup> OSA has been associated with adverse medical conditions including congestive heart failure,<sup>2</sup> stroke,<sup>3</sup> pulmonary<sup>4</sup> and systemic<sup>5</sup> hypertension, cancer,<sup>6</sup> and increased mortality.<sup>7</sup> Traditionally, sleep apnea has been assessed via a nighttime polysomnogram. This diagnostic procedure continues to be the gold standard for the evaluation of sleep apnea.

Numerous studies have looked at the role of pulse oximetry in the assessment of OSA.<sup>8–14</sup> These previous investigations have developed several methods for predicting an apnea–hypopnea index (AHI) from oximetry data; these include: cumulative time below an oxyhemoglobin saturation (SaO<sub>2</sub>) of 90% (CT90),<sup>8</sup> the number of SaO<sub>2</sub> events that drop either 3% or 4% [oxygen desaturation index (ODI)],<sup>9,10,15</sup> a measure of SaO<sub>2</sub> variability ( $\Delta$  index),<sup>11,12</sup> a central tendency measure,<sup>13</sup> and a multilayer perceptron neural network.<sup>16</sup> However, in our review of the literature, we uncovered only two other studies that have attempted to convert oximetry to an AHI.<sup>14,16</sup> In the Magalang et al. study, both the  $\Delta$  index and a composite measure of various oximetry indices were found to have coefficients of determination of 0.60 and 0.70, respectively. The Marcos et al. study produced a more accurate predictive formula than Magalang et al. However, scoring of the polysomnograms did not appear to utilize the updated guidelines recommended by the American Academy of Sleep Medicine (AASM).<sup>17</sup>

Therefore, the goal of this study is to develop a new predictive model of AHI using oximetry data by utilizing more recent pulse oximetry technology, a large sample size, and the newer AASM recommended scoring guidelines to evaluate the gold standard attended polysomnograms. We believe that by taking into account these factors, we will be able to develop a new predictive model that outperforms all previous models. Our predictive model will focus on ODI since it appears to be the most sensitive and specific oximetry index,<sup>9,18</sup> and is therefore an ideal target for conversion to AHI.

## 2 Methods

### 2.1 Patient Population

Approval for the study was granted by the Institutional Review Board at the Weill Cornell Medical College. One thousand four hundred and sixty-seven subjects given attended polysomnograms with concurrent pulse oximetry at the Center for Sleep Medicine, Weill Cornell Medical, were utilized for this analysis (see Table 1 for demographic data). All subjects  $\geq 18$  years old studied between April 14, 2010, and February 7, 2012, who had not received positive airway pressure therapy and/or supplemental oxygen therapy on their polysomnogram were included in this analysis. Subjects were randomized and split into a model development group ( $n = 733$ ) and a verification group ( $n = 734$ ).

### 2.2 Polysomnogram

Previously described standard techniques were employed on all-night attended sleep recordings using Grass Technologies

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**Table 1** Demographic information about the 1467 subjects. Abbreviations are as follows: BMI, body mass index; h, hours; Avg, average; O<sub>2</sub> Sat, oxygen saturation; NREM, nonrapid eye movement sleep; REM, rapid eye movement; HR, heart rate; BPM, beats per minute; TST, total sleep time; and Min, minute.

	Subject group ( <i>n</i> = 1467)			
	Model development group		Model validation group	
	Mean ± SD	Count	Mean ± SD	Count
Gender	Female	288		273
	Male	444		460
Age (years)	48.47 ± 16.17		49.8 ± 16.81	
BMI (kg/m <sup>2</sup> )	28.20 ± 6.90		27.94 ± 6.56	
Epworth score	8 ± 5		8 ± 5	
ODI total (events/h)	8.5 ± 12.7		7.9 ± 10.3	
AHI total (events/h)	14.7 ± 19.6		14.00 ± 17.3	
Avg O <sub>2</sub> Sat total (%)	94.5 ± 6.4		94.5 ± 6.4	
Avg O <sub>2</sub> Sat wake (%)	92.5 ± 16.5		93.5 ± 13.3	
Avg O <sub>2</sub> Sat NREM (%)	92.0 ± 15.7		93.1 ± 12.3	
Avg O <sub>2</sub> Sat REM (%)	87.3 ± 25.5		89.7 ± 6.4	
Average HR total (BPM)	64 ± 11		64 ± 10	
Sleep efficiency (% TST)	74.4 ± 20.1		74.8 ± 18.1	
Total sleep time (Min)	346 ± 106		351 ± 103	

Note: No significant differences were found between the model development and validation groups on any variable listed above at a  $p < 0.05$  using independent *t*-tests.

Twin<sup>®</sup> digital polysomnographs with an integrated Nonin clip oximetry (see below for additional details on oximetry). Standard polysomnogram montage and digital filter settings recommended by the AASM were employed.<sup>19</sup> Respiratory effort was measured by Sleepsense<sup>®</sup> inductive plethysmography belts placed around the rib cage and abdomen. Airflow was determined by the Pro-Tech PTAF lite<sup>®</sup> pressure transducer on the baseline study. The nasal cannula for the pressure transducer was placed at the level of the upper lip in midline position. A continuous electrocardiogram recorded heart rate and rhythm. Respiratory events were classified according to AASM criteria: an apnea was defined as a decrease in peak nasal pressure of >90% of baseline lasting at least 10 s. Hypopnea was defined as a decrease of >30% of the baseline nasal pressure lasting at least 10 s and associated with a ≥4% drop in oxyhemoglobin saturation. All records were reviewed by board-certified sleep specialists and scored by registered polysomnographic technicians.

### 2.3 Pulse Oximetry

The oximeter used was the Nonin Xpod<sup>®</sup> model 3011 with an adult finger clip sensor (Nonin 8000AA) utilizing PureSAT<sup>®</sup> technology that automatically adjusts to provide pulse to pulse

averaging of 3 s or faster (based on pulse rates 60 BPM and greater). ODI was calculated by the number of ≥4% drops in oxyhemoglobin saturation over total recording time.

### 2.4 Statistical Analysis

SPSS version 21 and R version 3.2.1 were used for statistical analysis. Linear, multivariate adaptive splines, segmented, and quadratic regression modeling were used to develop the predictive models of AHI using ODI. A log transformed (to address a non-normal distribution of the residuals) quadratic regression model provided the best fit compared to the other models. Therefore, the results listed below are based only on the transformed quadratic model. The regression algorithm was developed with 733 subjects. Verification of the model was performed using a separate group of 734 subjects (see Table 1 for demographic information on the subject groups). Sensitivity and specificity are shown for AHI break points of ≥5/h, ≥10/h, and ≥15/h due to the frequent use of these threshold levels in clinical practice to determine the need for treatment of sleep apnea. In addition, an AHI threshold of ≥30/h is also shown to illustrate the role of our predictive model in identifying subjects with severe sleep apnea. Confidence intervals (CI) are all listed as 95%.

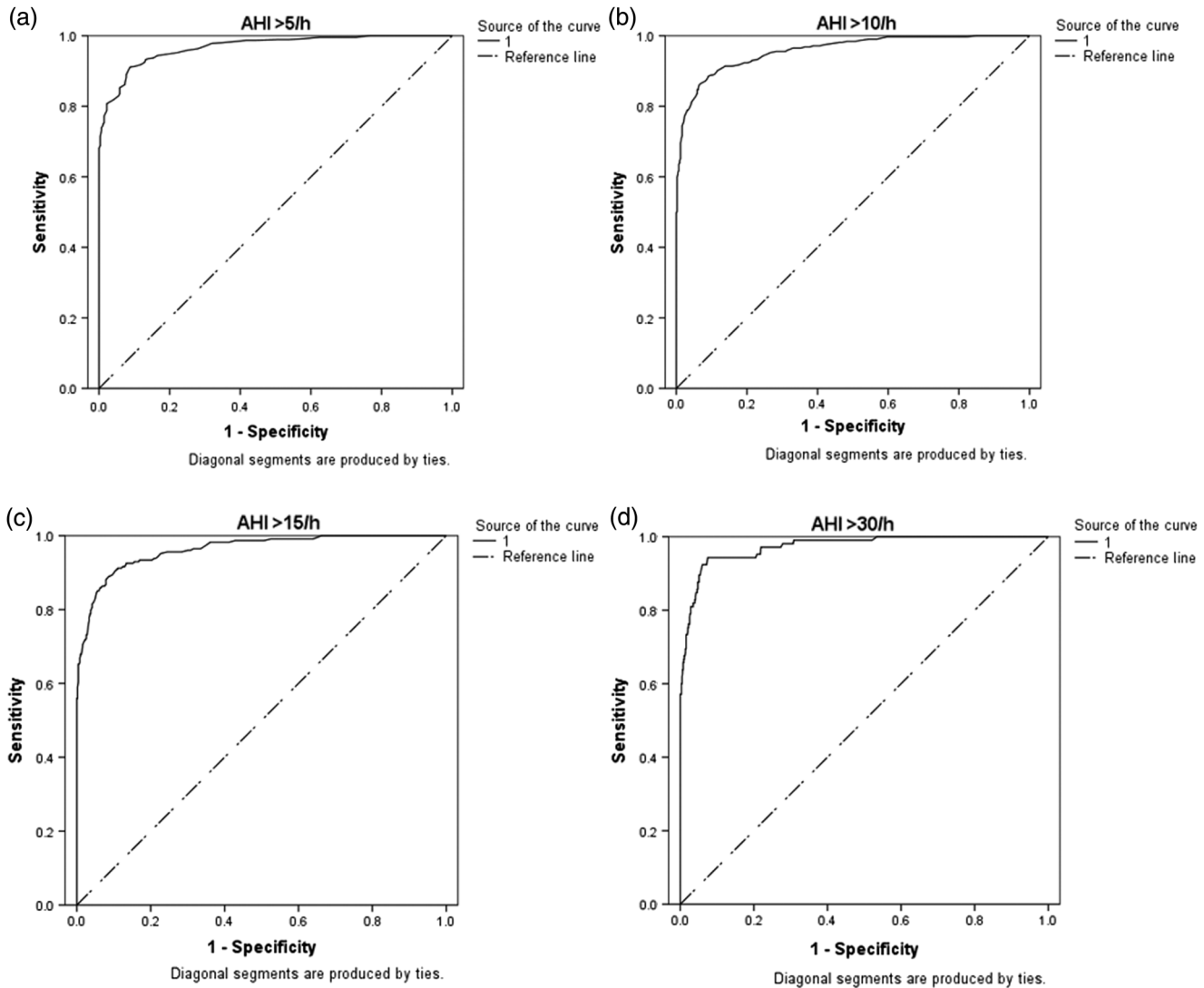
### 3 Results

The coefficient of determination ( $r^2$ ) between the actual AHI and the predicted AHI (PredAHI) was 0.80 ( $r = 0.90$ ), which was significant at  $p < 0.001$ . PredAHI determined a correct AHI ±5/h in 76% of subjects. The intraclass correlation for single measures using an absolute agreement definition was 0.88 (CI 0.87 to 0.90). The subjects that had a PredAHI greater than ±5/h were significantly older,  $t(732) = -5.311$ ,  $p < 0.001$ ; had a higher AHI,  $t(732) = -16.89$ ,  $p < 0.001$ ; and a lower sleep efficiency,  $t(732) = 5.12$ ,  $p < 0.001$ .

The AUC was  $0.97 ± 0.005$  (SE), CI 0.96 to 0.98 for an AHI of ≥5/h,  $0.96 ± 0.007$  (SE), CI 0.94 to 0.97 for an AHI ≥10/h,  $0.96 ± 0.007$  (SE), CI 0.95 to 0.98 for an AHI of ≥15/h, and  $0.97 ± 0.008$  (SE), CI 0.96 to 0.99 for an AHI of ≥30/h [see Fig. 1 for receiver operating characteristic (ROC) curves and Table 2 for other measures of test precision]. The asymptotic significance level for AUC at all tested thresholds was  $p < 0.001$ .

### 4 Discussion

This analysis shows that an accurate prediction of AHI can be made using a regression formula derived from ODI, with areas under the ROC curve ranging from 0.96 for thresholds of ≥10 and ≥15/h to 0.97 for thresholds of ≥5 and ≥30/h. This is better than most previously published comparisons of ODI to AHI.<sup>10,14,20</sup> Only one other study appears to outperform our model;<sup>9</sup> however, this study does not attempt to convert ODI to a predicted AHI. Moreover, our model was developed and compared to an AHI calculated using the AASM's currently recommended scoring guidelines for respiratory events,<sup>19</sup> and therefore is more applicable for use today. In comparison to the Magalang et al. models,<sup>14</sup> which showed  $r^2$ s of 0.60 and 0.70 for predicting AHI with the  $\Delta$  index alone and a composite measure of oximetry, respectively, our model outperformed these algorithms with an  $r^2$  of 0.80. The Marcos et al.<sup>16</sup> model slightly outperformed our model at an AHI of 15/h (93% versus 91%). However, our model was more accurate at AHIs of 5/h



**Fig. 1** ROC curve for predicted AHI at different cutoff points compared to polysomnograph: (a) 5, (b) 10, (c) 15, and (d) 30.

(84% versus 91%) and 10/h (87% versus 90%). In addition, our model was very accurate at an AHI of 30/h (see Table 2).

Due to the fact that ODI cannot differentiate between central and obstructive events, we do not intend for this algorithm to replace traditional polysomnograms. However, this formula can be useful in diagnosing patients who have had either a home or in-laboratory sleep study, but for whom the flow sensor data are unavailable. It is not uncommon in clinical practice to have patients remove the flow sensor because of discomfort; in these cases, a predicted AHI can be calculated from the ODI, and the respiratory effort activity can be viewed to gain an estimate of central versus obstructive apnea. This formula can also be used with pulse oximeters to convert nighttime oximetry data to AHI in order to determine if additional testing or treatment for sleep apnea is warranted.

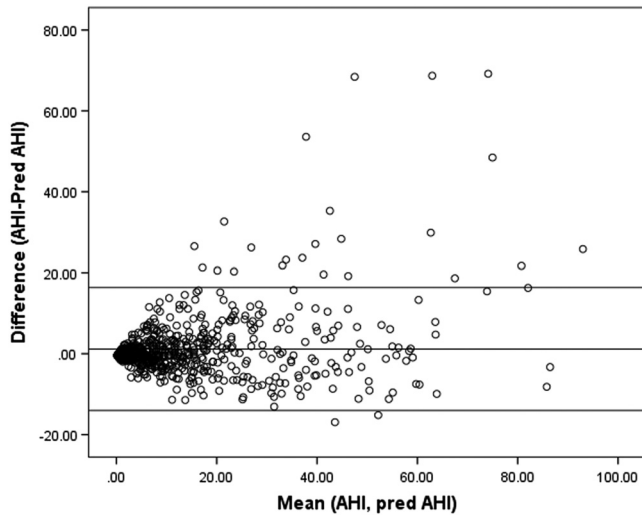
As mentioned in Sec. 1, since the 1990s, studies have shown the value of using oximetry in assessing apnea.<sup>8–14</sup> However, the use of oximetry indices for clinical decision making in sleep disordered breathing remains uncommon. This may be due, in part, to the fact that the AASM (the main governing body for sleep disorder clinics in the United States) has no diagnostic criteria for defining sleep apnea severity using any pure

oximetry index.<sup>17</sup> Moreover, all major insurance providers, including government-run programs such as Medicare, define sleep apnea based on either an AHI or respiratory disturbance index. Therefore, converting oximetry data to an AHI allows a more readily understandable metric that sleep specialists and most nonsleep specialists alike can interpret.

As seen in Fig. 2, PredAHI tends to underestimate AHI in the severe range. This is likely due to the fact that as the actual AHI

**Table 2** Stratified results for predicting sleep apnea using the PredAHI algorithm. PPV, positive predictive value; NPV, negative predictive value.

	Sensitivity	Specificity	PPV	NPV	Accuracy
AHI ≥ 5 h	0.90	0.92	0.95	0.85	0.91
AHI ≥ 10 h	0.86	0.94	0.91	0.90	0.90
AHI ≥ 15 h	0.82	0.96	0.89	0.92	0.91
AHI ≥ 30 h	0.76	0.98	0.85	0.96	0.95



**Fig. 2** The center line of the plot represents the mean; the other two lines indicate  $\pm 2$  SD. It shows data from 734 subjects (the validation set). The gold standard measure of AHI was derived from in-laboratory polysomnography scored according to AASM 2007 guidelines.

becomes very high, the individual apneas tend to be shorter, resulting in fewer respiratory events resulting in  $\geq 4\%$  drop in blood oxygen saturation (e.g., if an average apnea length is 15 s, the maximum AHI is 120/h versus 90/h for an average apnea length of 20 s). However, the accuracy (see Table 2) of PredAHI at the  $\geq 30$ /h AHI threshold is high at 95%. Differentiating whether a true AHI is 50/h versus 90/h is not as important as determining if an AHI is in the severe range; therefore, we do not believe this discrepancy will significantly affect clinical decisions to treat sleep apnea based on our formula. Another limitation of this study is the use of a single testing site. However, the heterogeneity of our patient population in New York City moderates this concern to some degree. Moreover, the use of a large sample size in both developing and validating our model gives confidence in its accuracy.

In summary, the algorithm described in this paper provides a convenient and accurate way to convert ODI to a predicted AHI. This tool makes it easier for clinicians to understand oximetry data in the context of traditional measures of sleep apnea. Our goal is to pair our formula with a commercially available pulse oximeter in order to provide a low-cost screening tool for sleep apnea to determine the need for additional evaluation and/or treatment of sleep disordered breathing. We believe this instrument will be useful for trades such as the transportation industry, which is in need of a low-cost and accurate way to assess for sleep apnea, or for patients living in rural or impoverished areas where traditional attended polysomnography may not be available or may be too costly.

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