

# Prevalence of Obstructive Sleep Apnea Using Home Sleep Test in Taiwan During the Coronavirus Disease Pandemic

Tyron Tai-Chun Chou<sup>1\*</sup>, Hsin-Chien Hsu<sup>1-3,\*</sup>, Chih-Wen Twu<sup>4,5</sup>, Wen-Kuan Huang<sup>6</sup>, Hung-Meng Huang<sup>1,7</sup>, Shih-Han Weng<sup>8</sup>, Ming-Chih Chen<sup>2</sup>

<sup>1</sup>Department of Otolaryngology, Taipei City Hospital, Taipei City, Taiwan; <sup>2</sup>Graduate Institute of Business Administration, College of Management, Fu Jen Catholic University, New Taipei City, Taiwan; <sup>3</sup>General Education Center, University of Taipei, Taipei City, Taiwan; <sup>4</sup>Department of Otorhinolaryngology, Head and Neck Surgery, Changhua Christian Hospital, Changhua County, Taiwan; <sup>5</sup>Department of Post-Baccalaureate Medicine, National Chung Hsing University, Taichung City, Taiwan; <sup>6</sup>Division of Hematology/Oncology, Department of Internal Medicine, Chang Gung Memorial Hospital at Linkou, Chang Gung University College of Medicine, Taoyuan City, Taiwan; <sup>7</sup>Department of Otolaryngology, School of Medicine, College of Medicine, Taipei Medical University, Taipei City, Taiwan; <sup>8</sup>Department of Education and Research, Taipei City Hospital, Taipei City, Taiwan

\*These authors contributed equally to this work

Correspondence: Ming-Chih Chen, Institute of Business Administration, College of Management, Fu Jen Catholic University, No. 510, Zhongzheng Road, Xinzhuang District, New Taipei City, 242062, Taiwan, Email 081438@mail.fju.edu.tw

**Background:** Obstructive sleep apnea syndrome (OSAS) is a common disorder associated with serious sequelae. The current gold standard diagnostic method, polysomnography, is costly and time consuming and requires patients to stay overnight at a facility.

**Aim:** This study aimed to reveal the prevalence of OSAS in general adult population using a home sleep test (HST) during the coronavirus disease 2019 (COVID-19) pandemic.

**Methods:** This prospective cohort study was conducted by the Department of Otolaryngology, Taipei City Hospital, Taipei, Taiwan, between January 2020 and December 2021. A total of 1372 patients aged 30–70 years completed an HST using a Type 3 portable sleep monitor (PM). The apnea-hypopnea index (AHI) was analyzed to assess the association of OSAS with age, body mass index (BMI), sex, Epworth Sleepiness Scale (ESS) and the Sleep Apnea Risk Assessment questionnaire (STOP-Bang questionnaire) rating.

**Results:** The mean age of the patients (782 men, 57%; 590 women, 43%) was  $49.24 \pm 11.04$  years. OSAS was detected in 954 (69.5%) patients with 399 (29.1%) mild OSAS; 246 (17.9%) moderate OSAS; and 309 (22.5%) severe OSAS. Among these, the prevalence of moderate-to-severe OSAS was 143 (10.4%) in women and 412 (30.0%) in men. The mean age was the highest ( $51.29 \pm 11.29$ ) in the mild OSAS group and lowest ( $47.08 \pm 10.87$ ) in the healthy group. OSAS severity was greater with increasing BMI,  $23.39 \pm 3.44$  in the healthy group and  $29.29 \pm 5.01$  in the severe OSAS group. A positive correlation was also noted between the ESS/STOP-Bang questionnaire rating and OSAS severity.

**Conclusion:** The prevalence of OSAS in Taiwan was 69.5% in our study. It showed strong evidence that OSAS has important public health consequences and PMs are simple, fast, feasible, and cost-effective tools for OSAS screening in the home environment, especially during the COVID-19 pandemic.

**Keywords:** COVID-19, obstructive sleep apnea, portable sleep monitor, home sleep test, apnea-hypopnea index

## Introduction

Sleep-disordered breathing (SDB) is a major public health concern worldwide. Obstructive sleep apnea syndrome (OSAS) is the most predominant form of SDB, accounting for more than 80% of cases.<sup>1,2</sup> The general prevalence of OSAS in the United States is approximately 15%.<sup>3</sup> Obstruction or collapse of the upper respiratory tract occurs during sleep, resulting in apnea or hypopnea, which in turn causes hypoxia.<sup>4</sup> In the long term, this condition is associated with serious sequelae, such as hypertension, cerebrovascular disease, heart failure, atrial fibrillation, and coronary heart disease.<sup>5</sup> In addition, it increases the risk of chronic diseases, such as diabetes mellitus,<sup>6</sup> male impotence,<sup>7</sup> anxiety,

and depression.<sup>8</sup> The most serious risk is an increase in the probability of sudden death,<sup>9</sup> which is 2.5 times higher in patients affected with OSAS than in an average person.<sup>10</sup>

The gold standard diagnostic test for OSAS is polysomnography (PSG), which is expensive to perform, requires the patient to stay overnight in a sleep laboratory, and to be monitored by a sleep technician. PSG is cumbersome because multiple sensors are used, and patients may experience anxiety and discomfort associated with sleeping in unfamiliar environment. Furthermore, depending on the geographic location, PSG might be unavailable, or there might be a long wait time before a patient can undergo this test.<sup>11,12</sup>

Treatments for OSAS involve lifestyle modification, medical intervention, and surgery. These include weight management, continuous positive airway pressure (CPAP), or medical drugs such as melatonin that may help to improve sleep quality.<sup>13</sup> Although CPAP is the first-line and gold standard for OSAS management, various surgical techniques such as uvulopalatopharyngoplasty, lateral pharyngoplasty, or barbed reposition pharyngoplasty may be an alternate for those unwilling or intolerant to CPAP.<sup>14,15</sup>

The purpose of our study was to share our experience in using the home sleep test (HST) in the Taiwanese adult population during the coronavirus disease (COVID-19) pandemic. Owing to the rapid spread of COVID-19 during the pandemic, people confined themselves to limited activities and refrained from staying overnight in medical facilities. We considered that, in such situations, the use of a portable HST device could play a key role in screening for OSAS. Compared with PSG, a portable sleep monitor (PM) is an easier and more cost-effective tool for sleep monitoring at home; moreover, these devices can be used for screening several individuals with OSAS, particularly when the need to avoid the complexity of in-hospital stay arises.

## Methods

### Study Design and Participants

This prospective cohort study was conducted by the Department of Otolaryngology, Taipei City Hospital, Taipei, Taiwan, between January 2020 and December 2021. Our research was aimed at identifying the prevalence of OSAS using HST in Taiwan during the COVID-19 pandemic. The patients were referred from twelve district health centers in Taipei who were considered as potential candidates for the study if they had symptoms such as excessive sleepiness during the daytime, snoring, breathlessness, and episodes of hypopnea or apnea, which are associated with OSAS, as reported by bed partners and assessed by the senior otolaryngologist. Thereafter, a total of 1372 patients completed the HST using a Type 3 PM. The apnea-hypopnea index (AHI) was analyzed for age, body mass index (BMI), sex, Epworth Sleepiness Scale (ESS) and Sleep Apnea Risk Assessment questionnaire (STOP-Bang questionnaire) ratings.

### Details of the PM

According to the classification of the American Academy of Sleep Medicine (AASM), PMs can be classified into four categories. Type 1 PM requires technicians to operate and monitor the device using at least seven monitoring items and body position sensors. The PSG devices used at hospitals or sleep centers belong to this category. A Type 2 PM does not require technicians to operate and monitor the device; however, the monitoring items are similar to those in Type 1 PMs, and at least seven monitoring items and body posture sensors are required. The next two types of PMs are classified as portable PSG devices. A Type 3 PM is a portable home sleep detection instrument with at least four monitoring items (including blood oxygen concentration, nasal flow, breathing action, heart rhythm, and electrocardiogram). A Type 4 PM is a portable home sleep detection instrument with at least two monitoring items (such as, blood oxygen concentration and nasal flow).<sup>16–18</sup>

In our study, we used a Type 3 PM (ApneaLink Air<sup>TM</sup>, Resmed, San Diego, CA, USA), which is an easy-to-use, lightweight, self-operated instrument with high sensitivity and specificity. This PM can monitor five items: blood oxygen concentration, nasal flow, breathing movement, heart rhythm, and snoring. It consists of a chest elastic band, pulse oximeter, and nasal cannula. After every test, the PM must be disinfected using ozone (O<sub>3</sub>) and the nasal cannula must be disposed of. In addition to recording the AHI, it can also automatically analyze the hypopnea index, degree of airflow limitation, number of snores, and blood oxygen saturation index. Further, it can distinguish between obstructive and

central SDB. The variables had configurable thresholds, and the definition of a hypopnea event was set to 3% oxygen desaturation, which met the requirements of the AASM.

The AHI can be used as an indicator of severity in adults, as follows: AHI < 5, normal; AHI ≥ 5 and < 15, mild SDB; AHI ≥ 15 and < 30, moderate SDB; and AHI ≥ 30, severe SDB.

## Questionnaire

Study participants were recruited and interviewed by a sleep technician and research assistant. Consenting individuals completed the ESS and STOP-Bang questionnaire. The ESS is a self-administered questionnaire with 8 questions on a 4-point scale (0–3) (0= No chance of dozing, 1= Slight chance of dozing, 2= Moderate chance of dozing, 3= High chance of dozing). Total scores range from 0 to 24 and an ESS score of 0–10 was considered mild daytime sleepiness, 11–15 moderate daytime sleepiness, and 16–24 severe daytime sleepiness. The STOP-Bang questionnaire consists of eight dichotomous (yes/no) items related to the clinical features of sleep apnea. The total score ranges from 0 to 8. The risk is assessed as follows: low risk, “yes” responses to 0–2 questions; intermediate risk, “yes” responses to 3–4 questions; and high risk, “yes” responses to 5–8 questions, “yes” responses to 2 or more of the 4 STOP questions + male sex, “yes” responses to 2 or more of the 4 STOP questions + BMI > 35 kg/m<sup>2</sup>, or “yes” responses to 2 or more of the 4 STOP questions + neck circumference > 40 cm.

## Statistical Analysis

Data were analyzed on a personal computer using SAS version 9.4 software (SAS Institute Inc., Cary, NC, USA). Differences between the means of independent variables with a normal distribution between men and women were assessed using a two-sample *t*-test (Table 1). Differences in the mean values between the healthy and OSAS groups were assessed using the Welch and Brown–Forsythe test (Table 2). A box plot was used to present the comparison between the ESS/STOP-Bang ratings and AHIs. In addition, the ROC curve (receiver operating characteristic curve) and intraclass correlation coefficient (ICC) were used to evaluate the accuracy of PM. Statistical significance was set at *P* < 0.05.

## Ethical Considerations

All patients consented to study participation by signing informed consent forms before enrolment. This study was approved by the Institutional Review Board of Taipei City Hospital, Taipei, Taiwan (TCHIRB-10908003-E). Type 3 PM (ApneaLink Air) did not pose any hazard to the patients.

**Table 1** Distribution of AHI<sup>a</sup>, Age, BMI<sup>b</sup>, ESS<sup>c</sup> and STOP-Bang by Patient Sex

	Total (n = 1372)	Men (n = 782)	Women (n = 590)	P-value
<b>AHI</b>	18.58 ± 19.93 (0–111.9)	23.72 ± 21.3 (0–111.9)	11.77 ± 15.53 (0–90.5)	< 0.0001
<b>Age</b>	49.24 ± 11.04 (30–70)	47.53 ± 10.83 (30–70)	51.52 ± 10.91 (30–70)	< 0.0001
<b>BMI</b>	26.05 ± 4.71 (17.0–45.7)	27.30 ± 4.60 (17.0–45.7)	24.4 ± 4.34 (13.7–43.6)	< 0.0001
<b>ESS<sup>c</sup></b>	7.50 ± 4.62 (0–24)	7.95 ± 4.72 (0–24)	6.91 ± 4.41 (0–24)	< 0.001
<b>STOP-Bang</b>	3.02 ± 1.86 (0–8)	3.91 ± 1.67 (0–8)	1.84 ± 1.37 (0–8)	< 0.001

**Abbreviations:** <sup>a</sup>AHI, apnea-hypopnea index; <sup>b</sup>BMI, body mass index; <sup>c</sup>ESS, Epworth Sleepiness Scale.

**Table 2** Distribution of AHI<sup>a</sup>, Age, and BMI<sup>b</sup> in the Healthy and OSAS<sup>c</sup> Groups

	Healthy Group (n = 418)	OSAS Groups (n = 954)			P-value
		Mild (n = 399)	Moderate (n = 246)	Severe (n = 309)	
<b>AHI</b>	Male: Female (32.5%: 67.5%) 2.03 ± 1.43 (0–4.9)	Male: Female (58.6%: 41.4%) 9.32 ± 2.49 (5–14.9)	Male: Female (69.5%: 30.5%) 22.72 ± 3.93 (15–29.9)	Male: Female (78.0%: 22.0%) 49.63 ± 16.67 (30.1–111.9)	< 0.0001
<b>Age</b>	47.08 ± 10.87 (30–70)	51.29 ± 11.29 (30–70)	51.07 ± 10.76 (30–70)	48.09 ± 10.48 (30–70)	< 0.0001
<b>BMI</b>	23.39 ± 3.44 (13.7–35.6)	25.71 ± 1.67 (34–43.4)	27.07 ± 4.25 (17–45.7)	29.29 ± 5.01 (19.5–43.9)	< 0.0001

**Abbreviations:** <sup>a</sup>AHI, apnea-hypopnea index; <sup>b</sup>BMI, body mass index; <sup>c</sup>OSAS, obstructive sleep apnea syndrome.

## Results

Figure 1 shows the flow of patients through this study. There were 2793 patients who registered for our study, of whom 1481 were 30–70 years old and were included in this study. We focused mainly on economically productive population and excluded those older than 70 years old with potential systemic diseases. Among them, 109 patients recorded for less than 4 h, resulting in a failure rate of 7.4% (109/1481). The reasons for failure were as follows: nasal cannula detachment (12/109), pulse oximeter detachment (20/109), and interruption of the examination due to poor adaptation to the HST device (77/109). A total of 1372 patients, 782 men (57%) and 590 women (43%), with an average age of  $47.53 \pm 10.83$  years and  $51.52 \pm 10.91$  years, respectively, were finally included in the analysis. The BMI was  $27.30 \pm 4.60$  in men and  $24.40 \pm 4.34$  in women. The mean AHI was greater in men ( $23.72 \pm 21.3$ ) than in women ( $11.77 \pm 15.53$ ). Differences in AHI, age, BMI, and ESS/STOP-Bang between men and women are shown in Table 1 ( $p < 0.001$ ).

Table 2 shows the mean and standard deviation of the selected variables for various categories. OSAS was detected in 954 patients (69.5%) in the study population. Among these, 399 (29.1%) had mild OSAS; 246 (17.9%), moderate OSAS; and 309 (22.5%) severe OSAS. The prevalence of moderate-to-severe OSAS was 412 (30.0%) in men and 143 (10.4%) in women. The age difference between the healthy and OSAS groups was significant, and the difference was greater in the patients in the mild and moderate OSAS group than in the healthy controls and patients in the severe OSAS group ( $p$

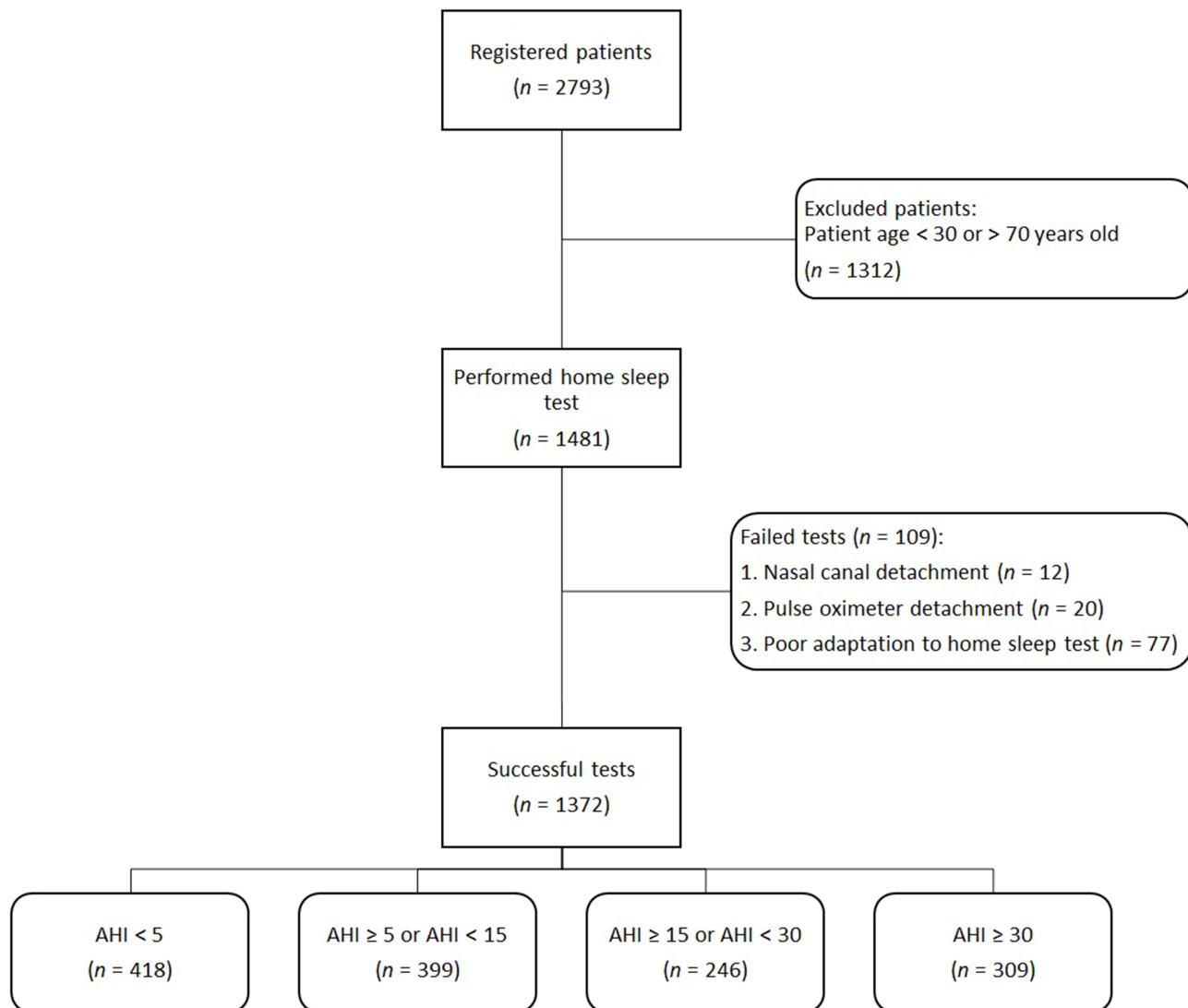
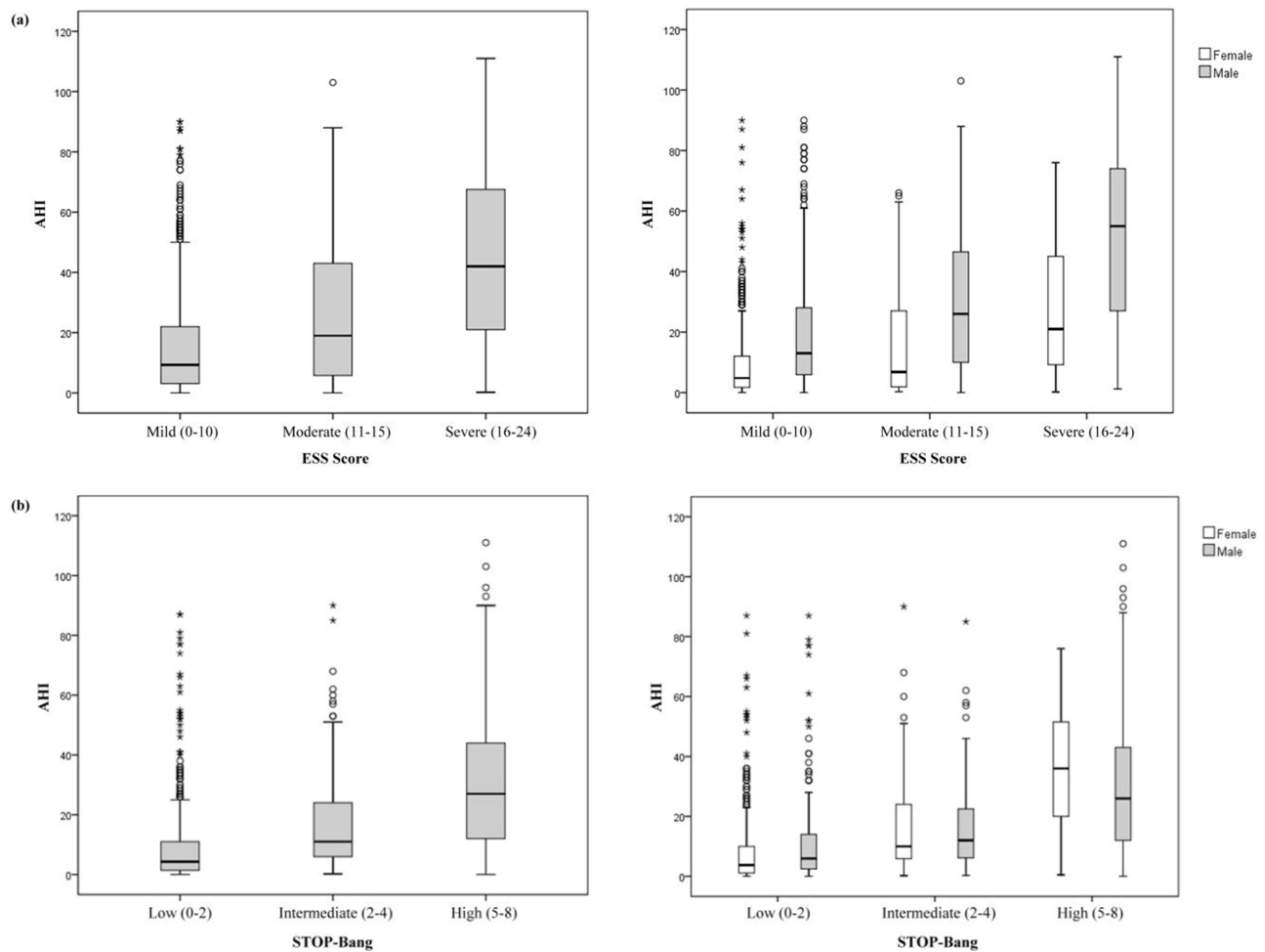


Figure 1 Patient flow diagram.

Abbreviation: AHI, apnea-hypopnea index.



**Figure 2** Box plots for comparisons. (a) Box plot for comparing ESS questionnaire rating to AHI. (b) Box plot for comparing STOP-Bang questionnaire rating with AHI. **Abbreviations:** ESS, Epworth Sleepiness Scale; AHI, apnea-hypopnea index; STOP-Bang questionnaire, Sleep Apnea Risk Assessment questionnaire.

< 0.0001). Regarding BMI, the severity of OSAS was significantly greater in patients with increased BMI, and there was a positive correlation between BMI and OSAS severity ( $p < 0.0001$ ).

Box plots of the comparisons between the ESS/STOP-BANG questionnaire ratings and AHIs are shown in Figure 2. A positive correlation was also observed between the ESS/STOP-BANG questionnaire rating and AHI severity ( $p < 0.0001$ ). Table 3 revealed Apnea-hypopnea index (AHI) based on type 3 portable sleep monitor (PM) for questionnaire data for 1372 patients.

**Table 3** AHI<sup>a</sup> Based on Type 3 PM<sup>b</sup> for Questionnaire Data for 1372 Patients

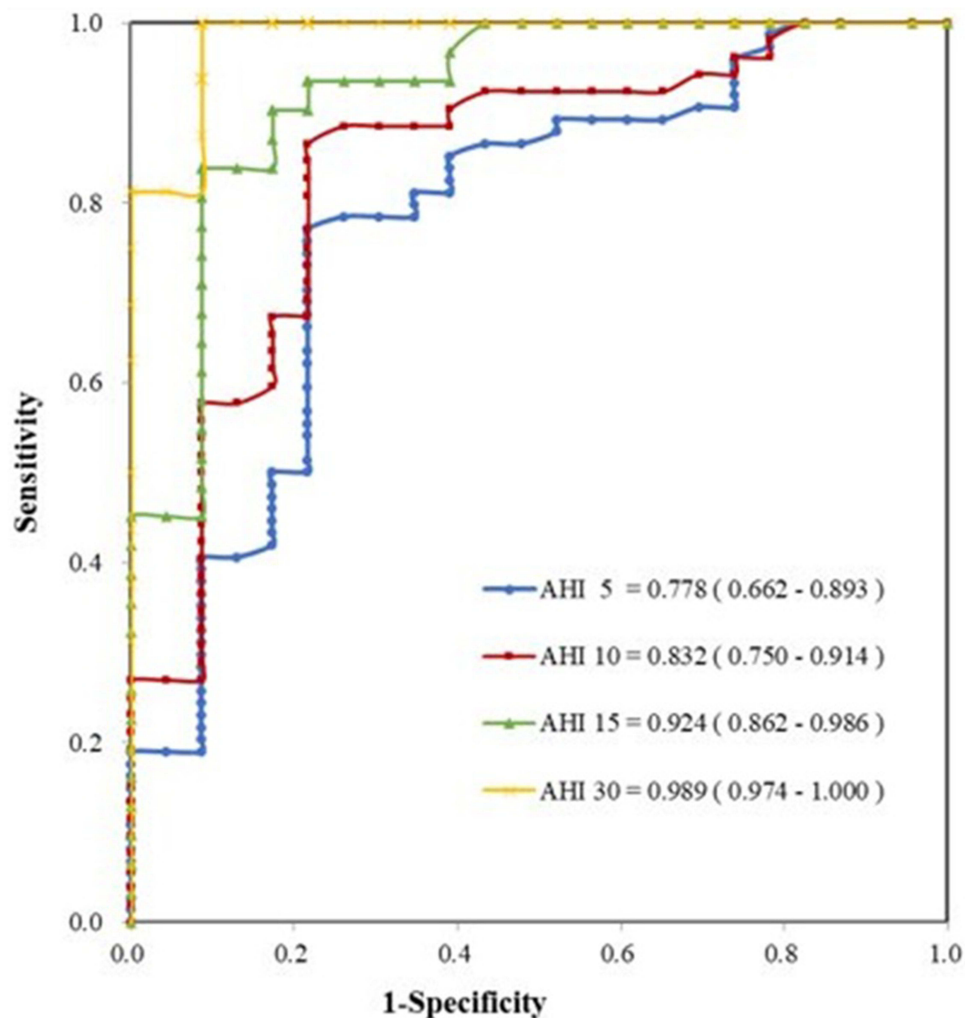
	n	Mean PM AHI	SD
<b>ESS<sup>c</sup></b>			
Mild (0–10)	1057	15.12	19.37
Moderate (11–15)	236	25.68	22.63
Severe (16–24)	79	43.68	28.72
<b>STOP-Bang</b>			
Low (0–2)	600	9.52	13.89
Intermediate (2–4)	459	18.04	15.82
High (5–8)	313	36.73	22.77

**Abbreviations:** <sup>a</sup>AHI, apnea-hypopnea index; <sup>b</sup>PM, portable sleep monitor; <sup>c</sup>ESS, Epworth Sleepiness Scale.

Ninety-seven people also received a type 1 polysomnography (PSG) test in sleep laboratory of Taipei city hospital within one month after HST. Based on the receiver operating characteristic curve (ROC) for the AHI threshold, when the AHI values were 5, 10, 15, and 30, the area under the curve (AUC) was 0.778, 0.832, 0.924, and 0.989, respectively (Figure 3). The intraclass correlation coefficient (ICC) between PSG and PM was 0.929 in Figure 4, indicating that the larger the AHI value cut-off point, the higher the accuracy, correlation, and reliability between PM and PSG. Table 4 showed the sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) in PM (ApneaLink Air) for 97 patients.

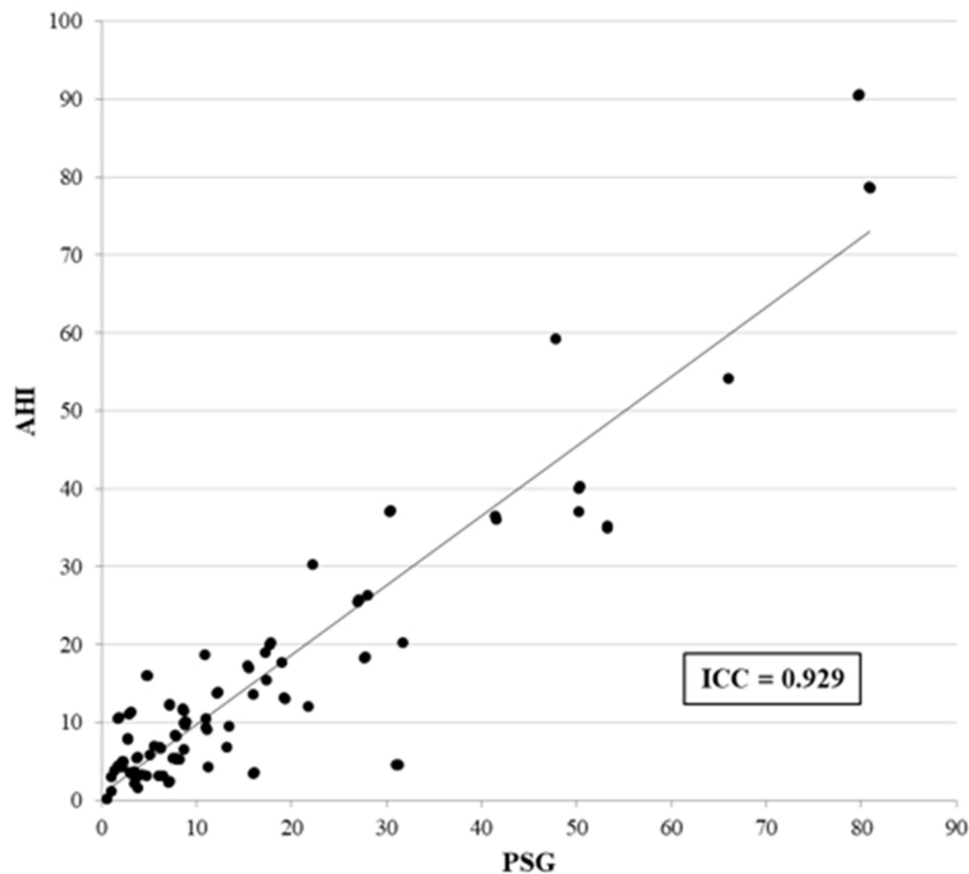
## Discussion

The use of the HST to diagnose OSAS remains controversial.<sup>19</sup> The arguments in using HST are regarding whether a PM can be used as the final diagnostic tool and whether the sensitivity of a patient self-operated PM is sufficient. These arguments were especially prevalent in the past when the sensitivity observed in most studies using PMs to detect OSAS was insufficient.<sup>19,20</sup> Conversely, other studies have shown that using a PM is feasible for diagnosing OSAS and that the results are accurate.<sup>21</sup> Using a PM has high clinical value, as the sensitivity is as high as 90%.<sup>19,22</sup> Type 3 PM is the most widely accepted among the PM types.<sup>17</sup> The sensitivity and specificity of Type 3 PM (ApneaLink Air) in identifying OSAS (AHI  $\geq 5$ ) were 85% and 50%, respectively. However, the sensitivity and specificity in the case of moderate-to-severe OSAS (AHI  $\geq 15$ ) were 91% and 95%, respectively. In our study, the sensitivity and specificity when the AHI  $\geq 15$  were 88.24% and 96.83%, respectively (Table 4). Therefore, this highlights the use of Type 3 PM as a valuable tool



**Figure 3** Receiver operating characteristic curve for 97 patients with polysomnography.

**Abbreviation:** AHI, apnea-hypopnea index.



**Figure 4** Intraclass correlation coefficient (ICC) for the PM-AHI and PSG-AHI for 97 patients.  
**Abbreviations:** AHI, apnea-hypopnea index; PM, portable sleep monitor; PSG, polysomnography.

for diagnosing high-risk moderate-to-severe OSAS; however, OSAS severity may be underestimated in patients with a normal or low AHI.<sup>23</sup> Furthermore, another benefit of using a PM in diagnosing OSAS is the cost of the device. The average cost of an examination completed by a PSG is approximately USD 700, whereas the per test cost by a PM is only USD 250, thus making the PM a much more cost effective tool.<sup>24</sup>

To our knowledge, this is the first comprehensive study that has used the HST to reveal the prevalence of OSAS in general adult population during the COVID-19 pandemic in Taiwan. It was believed that it would be difficult to teach patients how to use a PM and that they would find it difficult to use the device on their own, especially in case of older patients or those with insufficient education and low socioeconomic status. However, research has shown that even in the aforementioned groups, only 15% of patients could not perform the assessment for more than 4 h when using the device

**Table 4** The Sensitivity, Specificity, PPV<sup>a</sup>, and NPV<sup>b</sup> in PM<sup>c</sup> for 97 Patients

	AHI <sup>d</sup>			
	≥ 5	≥ 10	≥ 15	≥ 30
<b>Sensitivity</b>	87.32%	90.57%	88.24%	89.47%
<b>Specificity</b>	53.85%	86.36%	96.83%	100.00%
<b>PPV</b>	83.78%	88.89%	93.75%	100.00%
<b>NPV</b>	60.87%	88.37%	93.85%	97.50%

**Abbreviations:** <sup>a</sup>PPV, positive predictive value; <sup>b</sup>NPV, negative predictive value; <sup>c</sup>PM, portable sleep monitor; <sup>d</sup>AHI, apnea-hypopnea index.

for the first time. After repeated testing, at least 4 h of recording could be completed. In our study, 109 patients recorded for less than 4 h, with a failure rate of 7.4%. There was also no theft or loss of PMs. During the COVID-19 pandemic, refraining from staying overnight in a medical facility was important in reducing the risk of transmission. In addition, to avoid COVID-19 infection during the HST, all portable PMs were disinfected with O3, and a disposable nasal cannula was used.<sup>25</sup> This study screened for potential patients with OSAS using a large amount of HST screening data and achieved the advantages of early diagnosis. Thus, a PM is a simple, fast, economical, and efficient tool for screening patients for OSAS, especially during the COVID-19 pandemic.

Furthermore, sex, age, and BMI are the three most important factors that affect the OSAS prevalence rate.<sup>26</sup> Recent studies have suggested that there are approximately one billion patients with OSAS globally.<sup>27</sup> Middle-aged patients (30–70 years old) with moderate to severe OSAS ( $AHI \geq 15$ ) account for 6–13% of cases (women, 6%; men, 13%). Among men, the prevalence rate is approximately 10% and 17% in the 30–49-year-old group and 50–70-year-old group, respectively. Among women, the prevalence rate is approximately 3% and 10% in the 30–49-year-old group and 50–70-year-old group, respectively.<sup>28</sup> However, the prevalence of OSAS in the general population in another research recorded a much higher prevalence of OSAS and was higher in men. An  $AHI \geq 5$  was recorded 83.8% in men and 60.8% in women, whereas an  $AHI \geq 15$  was noted 49.7% in men and 23.4% in women.<sup>28</sup> The prevalence of OSAS can vary and ranged from 3.7% to 97.3% in Asian adults depending on the population studied and the criteria used for diagnosis.<sup>29</sup> In our study, the prevalence of OSAS was also detected higher in 954 patients (69.5%) in general adult population. The prevalence of moderate-to-severe OSAS was 412 (30.0%) in men and 143 (10.4%) in women. There is strong evidence that OSAS has important public health consequences and might be revised the definition of the disorder.

Obesity plays a large role in OSAS. Although, whilst previously believed that patients with normal BMI were less likely to have OSAS, 20–40% of patients with OSAS are not obese,<sup>30</sup> and most patients with moderate OSAS have BMIs within the normal range.<sup>19</sup> Nevertheless, our study found a relationship among obesity, age, and sex. In terms of obesity, the mean BMI was  $29.29 \pm 5.01$ ,  $27.07 \pm 4.25$ ,  $25.71 \pm 5.67$ , and  $23.39 \pm 3.44$  in the severe OSAS, moderate OSAS, mild OSAS, and healthy groups, respectively. This indicates a positive correlation between obesity severity and OSAS. As for age, mild and moderate OSAS is more common in older age groups. Finally, the male sex was also associated with a higher risk of OSAS than was the female sex.

The questionnaire used in our study also contributed to the screening of OSAS patients. A higher rating on the questionnaire indicated an increased risk of OSAS severity. When considering the questionnaire rating together with obesity, age, and sex, we could precisely screen for potential high-risk OSAS patients without the need for them to visit medical facilities. In our study, even if the rating in the questionnaire was mild in ESS, the mean AHI was higher at  $15.12 \pm 19.37$ . Previous study also found that no association was noted between severity of sleep-disordered breathing and presence of daytime sleepiness, measured with the ESS.<sup>31</sup> Using questionnaires to screen general population alone may mis-diagnosed many potential OSAS patients.

A few limitations of this study must be acknowledged. The AHI value detected with the HST may have been underestimated, which implies that severity may also have been underestimated. This might have been due to patients were forced to sleep in supine position during PSG examinations conducted at a facility.<sup>32</sup> Also, the absence of EEG in type 3 PM to detect arousals that form part of the hypopnea definitions may underestimate the AHI value. In addition, the total sleep period was estimated from the total recording period, which commenced from switching the light off to switching it on. This may have resulted in an overestimation of the actual sleep period and AHI value may have been underestimated.<sup>33,34</sup> In the future, the use of a PM will be more widely accepted in clinical management. The sensitivity and specificity of PMs and PSG may become important indicators.

## Conclusion

The prevalence of OSAS in general adult population aged 30–70 years in Taiwan was higher in our results (69.5%) than previous studies. There is strong evidence that OSAS has important public health consequences and PMs are simple, fast, feasible, and cost-effective tools for OSAS screening in the home environment, especially during the COVID-19 pandemic.



## Data Sharing Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

This study complies with the Declaration of Helsinki.

## Ethics Approval

All patients consented to study participation by signing written informed consent forms before enrolment. This study was approved by the Institutional Review Board of Taipei City Hospital, Taipei, Taiwan (TCHIRB-10908003-E). The Type 3 PM (ApneaLink Air) did not pose any hazard to the patients.

## Consent to Participate

Informed consent was obtained from all individual participants included in the study.

## Consent to Publish

Patients signed written informed consent regarding publishing their data.

## Acknowledgments

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## Disclosure

The authors declare that they have no conflict of interest.

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