

Hospital-Based Polysomnography May Overestimate Obstructive Sleep Apnoea Severity: Comparison of Hospital-Based and Home-Based Measurements with a Single-Lead Electrocardiogram Patch

Wen-Te Liu

Taipei Medical University

Shang-Yang Lin

Taipei Medical University

Cheng-Yu Tsai

Imperial College London

Yi-Shin Liu

Taipei Medical University

Chia-Mo Lin

Shin Kong Wu Ho-Su Memorial Hospital

Kang-Yun Lee

Shuang Ho Hospital, Taipei Medical University

Dean Wu

Shuang Ho Hospital, Taipei Medical University

Yi-Chun Kuan

Shuang Ho Hospital, Taipei Medical University

Hsin-Chien Lee

Taipei Medical University Hospital

Cheng-Jung Wu

Shuang Ho Hospital, Taipei Medical University

Wun-Hao Cheng

Taipei Medical University

Ying-Shuo Hsu (✉ sulisky@gmail.com)

Shin Kong Wu Ho-Su Memorial Hospital

Keywords: apnoea–hypopnea index (AHI), cyclic variation of heart rate index (CVHRI), obstructive sleep apnoea (OSA), Polysomnography (PSG)

Posted Date: July 12th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-665078/v1>

License:  This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Purpose: Obstructive sleep apnoea (OSA) is a global health concern, and polysomnography (PSG) is the gold standard for assessing OSA severity. However, the sleep parameters of home-based and in-laboratory PSG vary because of environmental factors, and the magnitude of these discrepancies remains unclear.

Methods: We enrolled 125 Taiwanese patients who underwent PSG while wearing a single-lead electrocardiogram patch (RootiRx). After the PSG, all participants were instructed to continue wearing the RootiRx over the 3 subsequent nights. Scores on OSA indexes, namely the apnoea–hypopnea index, chest effort index (CEI), cyclic variation of heart rate index (CVHRI), and combined CVHRI and CEI (Rx index), were determined. The patients were divided into 3 groups based on PSG-determined OSA severity. The variables (various severity groups and environmental measurements) were subjected to mean comparisons and their correlations were examined by Pearson’s correlation coefficient.

Results: The hospital-based CVHRI, CEI, and Rx index differed significantly among the severity groups. All 3 groups exhibited a significantly lower percentage of supine sleep time in the home-based assessment relative to in the hospital-based assessment. Significant positive correlations were noted between the variations in the supine percentage (Δ Supine%) and the OSA indexes. For the patients with high sleep efficiency ($\geq 80\%$), significant correlations were observed between the Δ Supine% and Δ Rx index.

Conclusion: The high supine percentage of sleep may cause OSA indexes’ overestimation in hospital-based PSG. Sleep recording at home with patch-type wearable devices may aid accurate OSA diagnosis.

Brief Summary

The complicated devices and environmental factors of polysomnography may affect the diagnostic accuracy of obstructive sleep apnea. To compare the sleep parameters obtained in the hospital and at home, we used a validated single-lead electrocardiogram patch with a 3-axis accelerometer when undergoing polysomnography in a hospital, and the patient was instructed to wear the patch for 3 consecutive days. This study observed that hospital-based indexes and supine percentage were higher than those at home and there are positive correlations between the variations in those indexes and supine percentage. Patch-type wearable devices may aid in more personalized obstructive sleep apnea severity determination.

Introduction

Obstructive sleep apnoea (OSA) is a major health concern in modern society. A systematic review published in 2017 reported that OSA prevalence ranges between 9% and 38% in the general population. (1) Moreover, OSA has been demonstrated to be associated with several comorbidities, including metabolic syndrome, cardiovascular diseases, and neurodegenerative diseases.(2, 3) Regarding OSA diagnosis, polysomnography (PSG) is the gold standard for determining the apnea–hypopnea index

(AHI), which is used to classify OSA severity. However, PSG is complicated and inconvenient to implement. Patients typically undergo PSG with multiple leads on their bodies at a hospital sleep centre. The discomfort involved in the PSG itself can cause sleep disturbance. Moreover, relevant studies have indicated that the sleep parameters obtained using PSG could be underestimated or overestimated because of environmental factors or the first-night effect.(4)

Therefore, to assess OSA severity in contexts where the results are less likely to be affected by environmental factors, the American Academy of Sleep Medicine (AASM) has classified unattended home monitoring devices into 3 types.(5) The most common home sleep apnoea testing (HSAT) devices available are type-3 devices that include parameters for evaluating respiratory status, cardiac function, and pulse oxygen saturation (SpO₂). Type-4 devices consider 1 or 2 of these parameters. Studies have applied wearable devices operated using various technologies, such as actigraphy, finger-based pulse oximetry, and single-channel electrocardiography, for the home-based recording of sleep parameters.(6–8) More recently, a biosensor that integrates an electrocardiography module and a 3-axis accelerometer was developed, demonstrating favourable reliability and accuracy in evaluating OSA severity.(9) Although various wearable devices have been used for OSA severity assessment, uncertainties remain regarding the differences between hospital-based PSG parameters and home-based sleep variables.

Several investigations have compared HSAT results and hospital-based sleep parameters. One study suggested that home-based AHI values are underestimated relative to hospital-based AHI values.(10) This disparity may be attributed to the lack of sleep stage measurement at home, which leads to overestimation of total sleep time. Another study reported night-to-night variability in the results of hospital-based PSG, with relatively weak correlations between test–retest AHI values.(11) Hospital-based AHI measurements might not accurately represent sleep status because they are easily affected by the different percentages of time spent in various sleeping positions depending on the scenario.(12) Consequently, uncertainty remains regarding the association between home-based and hospital-based measurements of OSA severity. Moreover, to the best of our knowledge, no studies have undertaken the acquisition of long-term sleep parameters or conducted in-depth evaluations based on variations in sleeping position.

To determine long-term home sleep parameters and prevent sleep disturbance caused by cumbersome instruments, the cyclic variation of heart rate index (CVHRI) can be used as a potential surrogate for screening OSA severity. This index is calculated according to the specific heart rate alternation in progressive bradycardia when an apnoea event occurs and is followed by abrupt tachycardia on breathing resumption.(13) Several relevant studies have been performed to improve the algorithm and validate the associations between CVHRI and AHI.(14–16) CVHRI can also be directly determined by analysing single-lead electrocardiogram (ECG) signals.(17) The CEI is also a potential surrogate for OSA risk screening. Chest wall motion is directly affected by sleep respiratory events—that is, chest wall movement is reduced when an apnoea event occurs. Studies have asserted that sleep-disordered breathing events are characterised by chest wall distortion and paradoxical chest wall movement caused

by the respiratory effort against airway obstruction.(18, 19) Hence, the CVHRI and CEI are potential alternative indexes for the non-invasive observation of sleep parameters over multiple days.

The primary objective of this study was to compare the data on sleep parameters obtained in overnight PSG at the hospital and over several days at home through a single-lead ECG patch with a 3-axis accelerometer (RootiRx), with the results expected to provide an in-depth understanding of how sleep position and the environment affect OSA severity. Moreover, we investigated changes in sleeping position in various sleep environments to determine the correlations between the percentage of sleep time spent in a supine position and OSA severity for both in-laboratory PSG and RootiRx.

Methods

Ethics

This study was conducted at the sleep centres of Shin Kong Wu Ho-Su Memorial Hospital (SKH; Taipei City, Taiwan) and Shuang Ho Hospital (SHH; New Taipei City, Taiwan). The study was approved by the institutional review boards of both hospitals (SKH: 20171003R; TMU-JIRB: N201709023), and written informed consent was obtained from all participants before any examination.

Study Population

We recruited patients with reported snoring or with suspected sleep-disordered breathing who were referred to the sleep centres of SKH and SHH between February 2018 and January 2019. The inclusion criteria were as follows: patients (1) aged between 18 and 80 years (2) who were not pregnant, (3) did not have a diagnosis of other cardiovascular diseases, and (4) had a total PSG recording time of >6 h. To reduce the possibility of OSA severity overestimation caused by short sleep time in the hospital setting, a large proportion of patients (103 of 125) with high sleep efficiency (SE) were recruited from the sleep centres to form 2 subgroups ($SE \geq 80\%$ and $SE \geq 90\%$). The patients underwent PSG while wearing a wireless single-lead ECG monitoring patch (RootiRx, Rooti Labs, Taipei, Taiwan). After the PSG was completed, the patients were instructed to continue wearing the provided patch over the 3 subsequent nights to collect relevant sleep parameters under home sleep conditions. All the values for the hospital- and home-derived sleep parameters were used for further analysis and comparison.

PSG Results

PSG is a systematic process through which (1) physiological parameters are collected during sleep and (2) the underlying causes of sleep disorders are assessed on the basis of various physiological signals. Notably, PSG is considered a standard method for diagnosing sleep-related breathing disorders, including OSA, central sleep apnea, and sleep-related hypoventilation or hypoxia (20). We obtained PSG recordings by using the Compumedics Grael PSG system (SKH) or the ResMed Embla N7000 and Embla MPR systems (SHH). We scored the sleep stages and respiratory events according to the updated standard diagnostic criteria and scoring guidelines of the AASM.(21, 22) Licensed PSG technicians scored the

results at both sleep centres, and these scores were confirmed by at least 2 other technicians to ensure accuracy. We determined the AHI value of each patient to classify them into the following 3 groups: no-to-mild (AHI < 15 events/h), moderate ($15 \leq \text{AHI} < 30$ events/h), and severe (AHI ≥ 30 events/h) OSA.

Home Sleep Recording

We obtained the home sleep parameters through observation with RootiRx. The technical details of this device and the definition of the obtained sleep parameters, including the CVHRI, CEI, and combined CVHRI and CEI (Rx index), were documented in our previous study.⁽²³⁾ In the current study, the CVHRI, CEI, and Rx index were determined first at the sleep centres through PSG and subsequently at home for 3 consecutive nights. The triaxial accelerometer in the device assessed the percentage of sleep time spent in different positions. All of the derived data were then separated into hospital and home data groups for comparison.

Statistical Analysis

All statistical analyses, the framework of which is presented in Figure 1, were conducted using SPSS software (IBM SPSS Inc., Chicago, IL, USA). First, we conducted the Shapiro–Wilk test to examine the normality of the continuous variables. The baseline characteristics of the patients in the OSA groups were compared, using one-way analysis of variance (normally distributed data) or the Kruskal–Wallis test (nonnormally distributed data) for the continuous variables and the chi-square test for the categorical variables. Subsequently, we performed the Student's *t* test (normally distributed data) or the Mann–Whitney U test (nonnormally distributed data) to compare the sleep parameters and positions obtained at the sleep centres and at home. The correlations between the variations in the percentage of sleep time spent in a supine position ($\Delta\text{Supine}\%$) and the CVHRI (ΔCVHRI), CEI (ΔCEI), and Rx index ($\Delta\text{Rx index}$), were investigated through the Spearman rank correlation test. All tests were two tailed, and differences were considered significant at $P < .05$.

Results

Sample Characteristics

A total of 125 patients were included. Table 1 presents the baseline characteristics of the patients according to OSA severity. In the sample, 33, 31, and 61 patients were classified as having no-to-mild OSA, moderate OSA, and severe OSA, respectively. No significant differences in age or sex were noted among the 3 groups. Regarding the participants' body profiles, a significantly higher body mass index (BMI) and higher neck circumference were observed in the moderate and severe OSA groups. Regarding the hypoxemia-related indicators, mean SpO₂, minimum SpO₂, and oxygen desaturation index ($\geq 3\%$) were significantly lower in the severe OSA group than in the moderate OSA and no-to-mild OSA groups.

Table 1

Demographic Characteristics of Participants Grouped According to OSA Severity and Assessed Through Hospital-Based PSG

Categorical Variables	No-to-Mild Group (<i>n</i> = 33)	Moderate Group (<i>n</i> = 31)	Severe Group (<i>n</i> = 61)	<i>P</i> value
Age (year)	42.0 ± 11.0	45.3 ± 12.4	45.2 ± 12.8	.44 ^a
BMI (kg/m ²)	24.4 ± 2.9	25.5 ± 3.7	28.7 ± 4.5	< .01 ^b
Sex (male/female)	22/11	23/8	51/10	.16 ^c
Neck circumference (cm)	37.0 ± 2.5	37.5 ± 3.6	39.9 ± 3.4	< .01 ^b
Mean SpO ₂ (%)	96.6 ± 1.1	95.9 ± 1.1	91.5 ± 4.4	< .01 ^b
Lowest SpO ₂ (%)	89.3 ± 5.8	84.6 ± 4.5	75.3 ± 10.2	< .01 ^b
ODI-3% (events/h)	3.3 ± 3.9	8.8 ± 7.9	44.8 ± 23.1	< .01 ^b
AHI (events/h)	8.4 ± 3.7	21.5 ± 4.5	54.0 ± 18.5	< .01 ^b
OSA: obstructive sleep apnoea; PSG, polysomnography; BMI: body mass index; SpO ₂ : pulse oxygen saturation; ODI-3%: oxygen desaturation index ≥ 3%; AHI: apnoea–hypopnea index; ns: nonsignificant.				
Data are expressed as means ± standard deviations.				
^a One-way analysis of variance				
^b Kruskal–Wallis test				
^c Chi-square test				

Hospital- and Home-Based Sleep Parameters

Table 2 and Fig. 2 present the variations in the hospital- and home-based sleep parameters. Notably, the severe OSA group exhibited significantly higher means in the hospital-based measurement than in the home-based measurement (CVHRI, hospital: 33.8 ± 21.1 events/h, home: 20.4 ± 18.2 events/h; CEI, hospital: 18.2 ± 12.2 events/h, home: 13.1 ± 9.9 events/h; Rx index, hospital: 40.9 ± 21.1 events/h, home: 27.1 ± 18.4 events/h). In all groups, the percentage of supine sleep time in the hospital setting (range: 72.5%-74.1%) was significantly higher than that in the home setting (range: 48.9%-58.0%). Moreover, OSA severity, as classified by AHI in the hospital setting, decreased to a milder grade at home in 54.4% and 41.6% of participants in classification by CVHRI and CEI, respectively.

Table 2
Comparison of the Sleep Parameters Obtained by RootiRx in Hospital and Home Settings

Variables	Group	Hospital	Home	P value
CVHRI (events/h)	No-to-mild, <i>n</i> = 33	10.3 ± 8.1	9.3 ± 9.9	.50 ^a
	Moderate, <i>n</i> = 31	11.8 ± 8.5	10.1 ± 7.0	.41 ^b
	Severe, <i>n</i> = 61	33.8 ± 21.1	20.4 ± 18.2	< .01 ^a
CEI (events/h)	No-to-mild, <i>n</i> = 33	5.4 ± 4.4	5.0 ± 2.7	.78 ^a
	Moderate, <i>n</i> = 31	9.2 ± 4.4	7.6 ± 4.1	.16 ^a
	Severe, <i>n</i> = 61	18.2 ± 12.2	13.1 ± 9.9	< .01 ^a
Rx index (events/h)	No-to-mild, <i>n</i> = 33	14.2 ± 8.6	14.0 ± 8.6	.79 ^a
	Moderate, <i>n</i> = 31	18.4 ± 8.0	16.0 ± 6.6	.20 ^a
	Severe, <i>n</i> = 61	40.9 ± 21.1	27.1 ± 18.4	< .01 ^a
Supine sleep time (%)	No-to-mild, <i>n</i> = 33	72.5 ± 27.0	58.0 ± 17.9	< .01 ^a
	Moderate, <i>n</i> = 31	77.7 ± 21.4	56.0 ± 18.0	< .01 ^a
	Severe, <i>n</i> = 61	74.1 ± 23.9	48.9 ± 21.9	< .01 ^a
PSG: polysomnography; CVHRI: cyclic variation of heart rate index; CEI: chest effort index; Rx index: combination of the CVHRI and CEI; ns: nonsignificant. Data are expressed as means ± standard deviations. All <i>P</i> values were derived from the (a) Mann–Whitney U test or (b) Student’s <i>t</i> test depending on whether the data sets met the normality assumptions.				

Sleeping Position and Sleep-Related Indexes

Figure 3 reveals the correlations between the Δ Supine% and the sleep-related parameters (Δ CVHRI, Δ CEI, and Δ Rx index). Significantly positive correlations between Δ CVHRI ($r = 0.27$, $P < .01$), Δ CEI ($r = 0.29$, $P < .01$), and Δ Rx index ($r = 0.33$, $P < .01$) with Δ Supine% were observed.

Variations in Sleeping Position and Sleep-Related Indexes in Patients with High SE

Table 3 presents the alterations in sleep parameters determined in the hospital and home settings in patients with high SE (> 80% in the hospital-based PSG). Notably, 103 patients had high SE, including 24, 24, and 55 patients in the no-to-mild, moderate, and severe OSA groups. Significant differences in the

CVHRI, CEI, Rx index, and percentage of supine sleep time between the hospital- and home-based measurements were noted in the severe OSA group. In the moderate OSA group, the home-based Rx index and percentage of supine sleep time were significantly lower than those measured in the sleep centres. Moreover, in patients with SE > 90% ($n = 46$), the home-based measurements of the means of the Rx index and percentage of supine sleep time were significantly lower than the corresponding hospital-based measurements (Fig. 4).

Table 3
Comparison of the Home- and Hospital-Based RootiRx Results in the High Sleep Quality Groups (Sleep Efficiency $\geq 80\%$)

Variables	Group	Hospital	Home	<i>P</i> value
CVHRI (events/h)	No-to-mild, $n = 24$	10.14 \pm 8.66	9.36 \pm 10.36	.70 ^a
	Moderate, $n = 24$	12.15 \pm 7.34	9.88 \pm 6.65	.27 ^b
	Severe, $n = 55$	34.39 \pm 21.27	20.17 \pm 17.89	< .01 ^a
CEI (events/h)	No-to-mild, $n = 24$	6.02 \pm 4.91	5.10 \pm 2.98	.90 ^a
	Moderate, $n = 24$	9.08 \pm 4.65	7.00 \pm 3.12	.17 ^a
	Severe, $n = 55$	18.22 \pm 11.44	13.58 \pm 10.21	< .05 ^a
Rx index (events/h)	No-to-mild, $n = 24$	14.45 \pm 9.28	14.06 \pm 9.29	.83 ^a
	Moderate, $n = 24$	18.55 \pm 7.22	15.48 \pm 6.00	.12 ^b
	Severe, $n = 55$	41.42 \pm 21.01	27.16 \pm 18.41	< .01 ^a
Supine sleep time (%)	No-to-mild, $n = 24$	69.40 \pm 28.43	54.93 \pm 19.26	.02 ^a
	Moderate, $n = 24$	80.51 \pm 19.85	57.60 \pm 17.91	< .01 ^a
	Severe, $n = 55$	75.07 \pm 23.81	48.97 \pm 22.28	< .01 ^a
CVHRI: cyclic variation of heart rate index; CEI: chest effort index; Rx index, combination of the CVHRI and the CEI; ns: nonsignificant.				
Data are expressed as means \pm standard deviations.				
All <i>P</i> values were derived from the (a) Mann–Whitney U test or (b) Student’s <i>t</i> test depending on whether the data sets met the normality assumptions.				

Correlations Between Sleep-Related Indexes and Sleeping Position in Patients with High SE

Figure 5 presents the correlation between the Δ Supine% and Δ Rx index in patients with high SE. In patients with $SE \geq 80\%$, Δ Rx index was significantly positively correlated with Δ Supine% ($r = 0.35$, $P < .01$). In addition, in patients with $SE \geq 90\%$, Δ Rx index was significantly correlated with Δ Supine% ($r = 0.29$, $P < .01$).

Discussion

The present study compared OSA index values and the percentage of supine sleep time using RootiRx device in both hospital and home settings. Because patch-type wearable devices cause less interference to individuals' sleep than do PSG measurements, lower values for parameters such as the CVHRI, CEI, Rx index, and percentage of supine sleep time were noted in the home setting (Table 2 and Fig. 2). Moreover, significant correlations were observed between the variations in the percentage of supine sleep time and the OSA index values (Fig. 3). In other words, greater changes in the sleep time spent in the supine position were correlated with greater changes in the OSA index values. Participants with $SE \geq 90\%$ in hospital also exhibited higher Rx index values and higher percentages of supine sleep time in the hospital setting (Fig. 4). Furthermore, even in patients with $SE \geq 80\%$ and $SE \geq 90\%$ in hospital settings, significant correlations were observed between increased Δ Rx index values and Δ Supine% (Fig. 5), indicating that patch-type wearable devices such as RootiRx may cause less interference to sleeping position than does PSG even when these individuals exhibited high SE in hospital settings. According to our literature review, this is the first study to investigate these correlations between variations in sleeping position and OSA indexes in hospital- and home-based data.

Higher OSA indexes were noted in the hospital than at home, indicating that in-laboratory PSG may overestimate OSA severity. This finding may be partially ascribed to environmental factors, such as the equipment, testing room, and bed, which may hinder changes in sleeping position.

Discrepancies between OSA severity measurements obtained in hospitals and at home have been documented. A study conducted in 1996 centred on the effects of PSG on sleeping position, suggesting that PSG may influence the diagnosis of positional OSA.(24) In that study, 12 patients with positional OSA who had undergone standard PSG returned for 2 additional nights of study without the attachment of PSG leads. The mean percentage of supine sleep time (56%) was greater during the PSG night than during the non-PSG nights. A large-scale retrospective study (2019) on positional OSA treatment with the Sleep Position Trainer, a vibrating device, reported that the PSG apparatus caused an increase in the percentage of supine sleep time and may increase the measured OSA severity.(25) The median AHI decreased from 13.3/h to 10.3/h ($P < .001$), and 33% of the patients exhibited a change in OSA severity (AHI obtained in hospital settings vs adjusted AHI obtained at home). These outcomes support our findings that PSG measurements may affect sleeping position and increase the percentage of sleep time in the supine position. Therefore, the effects of PSG equipment on sleeping position may lead to higher AHI values, leading to the overestimation of OSA severity.

The significant correlations between the Δ Supine% and differences in OSA indexes, including the Δ CVHRI, Δ CEI, and Δ Rx index, indicated that the increase in the percentage of supine sleep time and the corresponding increase in OSA severity might be a general pattern rather than being limited to specific patient groups. Moreover, this finding has clinical relevance because if sleeping position is influenced by the PSG apparatus and this causes significant overestimation of OSA severity, treatment strategies are likely to be affected.

Some may argue that OSA severity as determined through PSG may be affected by other environmental factors. To address this concern, we analysed the sleep parameters in participants with high SE, in whom the possibility of OSA severity overestimation owing to sleep stage can be largely excluded. Because such patients had long sleep times in the hospital setting, the AHI values obtained from PSG and the OSA index values obtained from the RootiRx were not categorised according to short sleep time. In other words, in patients with high SE, the overestimation of OSA severity is more likely to be attributable to sleeping position than to alterations in total sleep time. Moreover, the Δ Rx index was significantly correlated with the Δ Supine% in the high SE groups. These results suggest that the overestimation of OSA severity in hospitals may be mainly due to patients' sleeping positions. Therefore, the home-based OSA index values likely represent the participants' actual OSA severity because they were not restricted by cumbersome PSG devices and could freely alter their sleeping position.

This study has some limitations. First, the RootiRx data set lacked sleep staging measurements obtained through electroencephalography. The RootiRx device determines the sleep stage of the wearer by using a validated algorithm, such as a fast Fourier transform and neural networks.(26–28) Although the accuracy of the predicted sleep stage and estimated total sleep time was approximately 85–90%, the arousal response or the precise percentages of rapid eye movement (REM) sleep and non-REM sleep could not be obtained. The associations between the first-night effect, REM latency, and duration should be further explored.(29) Second, during RootiRx recording, the effects of environmental factors in the hospital and home sleep environments could not be controlled. Environmental factors include radiant temperature, air temperature, relative humidity, carbon dioxide concentration, illumination, and equivalent noise level.(30) Moreover, ECG signals are the mechanism of the RootiRx device. Thus, the CVHRI index could have been affected by abnormal heart rhythms, such as atrial fibrillation and ventricular tachycardia (with or without pacemaker implantation) and arrhythmia caused by any other type of cardiovascular condition. Hence, in patients with related heart diseases, the Rx index and CVHRI might not be accurate measures of OSA. In such patients, CEI may be a more suitable parameter for diagnosing OSA.

Conclusion

This study compared hospital- and home-based sleep parameters by using the RootiRx, a wearable device that uses a single-lead ECG patch. The current results provide evidence to support that hospital-based PSG may overestimate OSA severity because patients spend a higher percentage of sleep time in the supine position in hospital settings. Home-based sleep recording with patch-type wearable devices may complement PSG in accurate OSA diagnosis.

Abbreviations

AASM American Academy of Sleep Medicine

AHI Apnea–hypopnea index

BMI Body mass index

CEI Chest effort index

CVHRI Cyclic variation of heart rate index

ECG Electrocardiogram

HSAT Home sleep apnoea testing

OSA Obstructive sleep apnea

PSG Polysomnography

SE Sleep efficiency

SHH Shuang Ho Hospital

SKH Shin Kong Wu Ho-Su Memorial Hospital

SpO₂ Pulse oxygen saturation

Declarations

Author contributions

All authors substantially contributed to conceptualising and designing the study, analysing the data, drafting the article, and critically revising the manuscript for crucial intellectual content. All authors have read and approved the final version of the manuscript for publication.

Declaration of interests

The authors have no conflict of interests to declare.

Data sharing

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Acknowledgements

We appreciate the contribution of all participants to this study.

Role of the funding source

This work was supported by the Taiwan Ministry of Science and Technology (MOST 108-2634-F-038-003) and Shin Kong Wu Ho-Su Memorial Hospital (2020SKHADR025). The funders had no role in the study design, data collection and analysis, publication decision, or preparation of the manuscript.

Patients' consent and permission to publish

The study protocol was approved by the Joint Institutional Review Board of Taipei Medical University (TMU-JIRB: N201709023) and Shin Kong Wu Ho-Su Memorial Hospital (SKH: 20171003R). The consent forms were obtained from all the participants before data collection in this study. This study was conducted in compliance with the ethical standards of Joint Institutional Review Board of Taipei Medical University as well as with the Helsinki Declaration.

References

1. Senaratna CV, Perret JL, Lodge CJ, Lowe AJ, Campbell BE, Matheson MC, et al. Prevalence of obstructive sleep apnea in the general population: a systematic review. *Sleep medicine reviews*. 2017;34:70-81.
2. Sweed RA, Hassan S, Abd ElWahab NH, Aref SR, Mahmoud MI. Comorbidities associated with obstructive sleep apnea: a retrospective Egyptian study on 244 patients. *Sleep and Breathing*. 2019;23(4):1079-85.
3. Gaig C, Iranzo A. Sleep-disordered breathing in neurodegenerative diseases. *Current neurology and neuroscience reports*. 2012;12(2):205-17.
4. Newell J, Mairesse O, Verbanck P, Neu D. Is a one-night stay in the lab really enough to conclude? First-night effect and night-to-night variability in polysomnographic recordings among different clinical population samples. *Psychiatry research*. 2012;200(2-3):795-801.
5. Collop NA, Anderson Wt, Boehlecke B, Claman D, Goldberg R, Gottlieb DJ, et al. Clinical guidelines for the use of unattended portable monitors in the diagnosis of obstructive sleep apnea in adult patients. *J Clin Sleep Med*. 2007;3(7):737-47.
6. Sadeh A, Hauri PJ, Kripke DF, Lavie P. The role of actigraphy in the evaluation of sleep disorders. *Sleep*. 1995;18(4):288-302.
7. Puri RS, Athanassiadis AG, Gill N, Sathya SS, Rathod G, Wahi A, et al., editors. Design and preliminary evaluation of a wearable device for mass-screening of sleep apnea. 2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC); 2016: IEEE.
8. Surrel G, Aminifar A, Rincón F, Murali S, Atienza D. Online obstructive sleep apnea detection on medical wearable sensors. *IEEE transactions on biomedical circuits and systems*. 2018;12(4):762-73.

9. Selvaraj N, Narasimhan R, editors. Automated prediction of the apnea-hypopnea index using a wireless patch sensor. 2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society; 2014: IEEE.
10. Bianchi MT, Goparaju B. Potential underestimation of sleep apnea severity by at-home kits: rescoring in-laboratory polysomnography without sleep staging. *Journal of Clinical Sleep Medicine*. 2017;13(4):551-5.
11. Levendowski DJ, Zack N, Rao S, Wong K, Gendreau M, Kranzler J, et al. Assessment of the test-retest reliability of laboratory polysomnography. *Sleep and Breathing*. 2009;13(2):163-7.
12. Sunnergren O, Broström A, Svanborg E. Positional sensitivity as a confounder in diagnosis of severity of obstructive sleep apnea. *Sleep and Breathing*. 2013;17(1):173-9.
13. Guilleminault C, Winkle R, Connolly S, Melvin K, Tilkian A. Cyclical variation of the heart rate in sleep apnoea syndrome: Mechanisms, and usefulness of 24 h electrocardiography as a screening technique. *The Lancet*. 1984;323(8369):126-31.
14. Hayano J, Watanabe E, Saito Y, Sasaki F, Fujimoto K, Nomiyama T, et al. Screening for obstructive sleep apnea by cyclic variation of heart rate. *Circulation: Arrhythmia and Electrophysiology*. 2011;4(1):64-72.
15. Khandoker AH, Palaniswami M, Karmakar CK. Support vector machines for automated recognition of obstructive sleep apnea syndrome from ECG recordings. *IEEE transactions on information technology in biomedicine*. 2008;13(1):37-48.
16. Penzel T, McNames J, De Chazal P, Raymond B, Murray A, Moody G. Systematic comparison of different algorithms for apnoea detection based on electrocardiogram recordings. *Medical and Biological Engineering and Computing*. 2002;40(4):402-7.
17. Junichiro Hayano M, Eiichi Watanabe M, Yuji Saito M, Fumihiko Sasaki M, Keisaku Fujimoto M, Tetsuo Nomiyama M, et al. Screening for Obstructive Sleep Apnea by Cyclic Variation of Heart Rate.
18. Staats BA, Bonekat HW, Harris CD, Offord KP. Chest wall motion in sleep apnea. *American Review of Respiratory Disease*. 1984;130(1):59-63.
19. Wang F-T, Hsu M-H, Fang S-C, Chuang L-L, Chan H-L. The Respiratory Fluctuation Index: A global metric of nasal airflow or thoracoabdominal wall movement time series to diagnose obstructive sleep apnea. *Biomedical Signal Processing and Control*. 2019;49:250-62.
20. Rundo JV, Downey R, 3rd. Polysomnography. *Handb Clin Neurol*. 2019;160:381-92.
21. Berry RB, Brooks R, Gamaldo C, Harding SM, Lloyd RM, Quan SF, et al. AASM scoring manual updates for 2017 (version 2.4). *American Academy of Sleep Medicine*; 2017.
22. Berry RB, Budhiraja R, Gottlieb DJ, Gozal D, Iber C, Kapur VK, et al. Rules for scoring respiratory events in sleep: update of the 2007 AASM Manual for the Scoring of Sleep and Associated Events. Deliberations of the Sleep Apnea Definitions Task Force of the American Academy of Sleep Medicine. *J Clin Sleep Med*. 2012;8(5):597-619.
23. Hsu Y-S, Chen T-Y, Wu D, Lin C-M, Juang J-N, Liu W-T. Screening of Obstructive Sleep Apnea in Snoring Patients Using a Patch-Type Device With Electrocardiogram and 3-Axis Accelerometer.

- Journal of Clinical Sleep Medicine. 2020;jcsm. 8462.
24. Metersky ML, Castriotta RJ. The effect of polysomnography on sleep position: possible implications on the diagnosis of positional obstructive sleep apnea. *Respiration*. 1996;63(5):283-7.
 25. Vonk P, de Vries N, Ravesloot M. Polysomnography and sleep position, a Heisenberg phenomenon? *HNO*. 2019;67(9):679-84.
 26. Karlen W, Floreano D. Adaptive sleep–wake discrimination for wearable devices. *IEEE Transactions on Biomedical Engineering*. 2010;58(4):920-6.
 27. Karlen W, Mattiussi C, Floreano D, editors. Adaptive sleep/wake classification based on cardiorespiratory signals for wearable devices. 2007 IEEE Biomedical Circuits and Systems Conference; 2007: IEEE.
 28. Karlen W, Mattiussi C, Floreano D. Sleep and wake classification with ECG and respiratory effort signals. *IEEE Transactions on Biomedical Circuits and Systems*. 2009;3(2):71-8.
 29. Byun J-H, Kim KT, Moon H-j, Motamedi GK, Cho YW. The first night effect during polysomnography, and patients' estimates of sleep quality. *Psychiatry Research*. 2019;274:27-9.
 30. Choi JH, Kim EJ, Kim YS, Choi J, Kim TH, Kwon SY, et al. Validation study of portable device for the diagnosis of obstructive sleep apnea according to the new AASM scoring criteria: Watch-PAT 100. *Acta oto-laryngologica*. 2010;130(7):838-43.

Figures

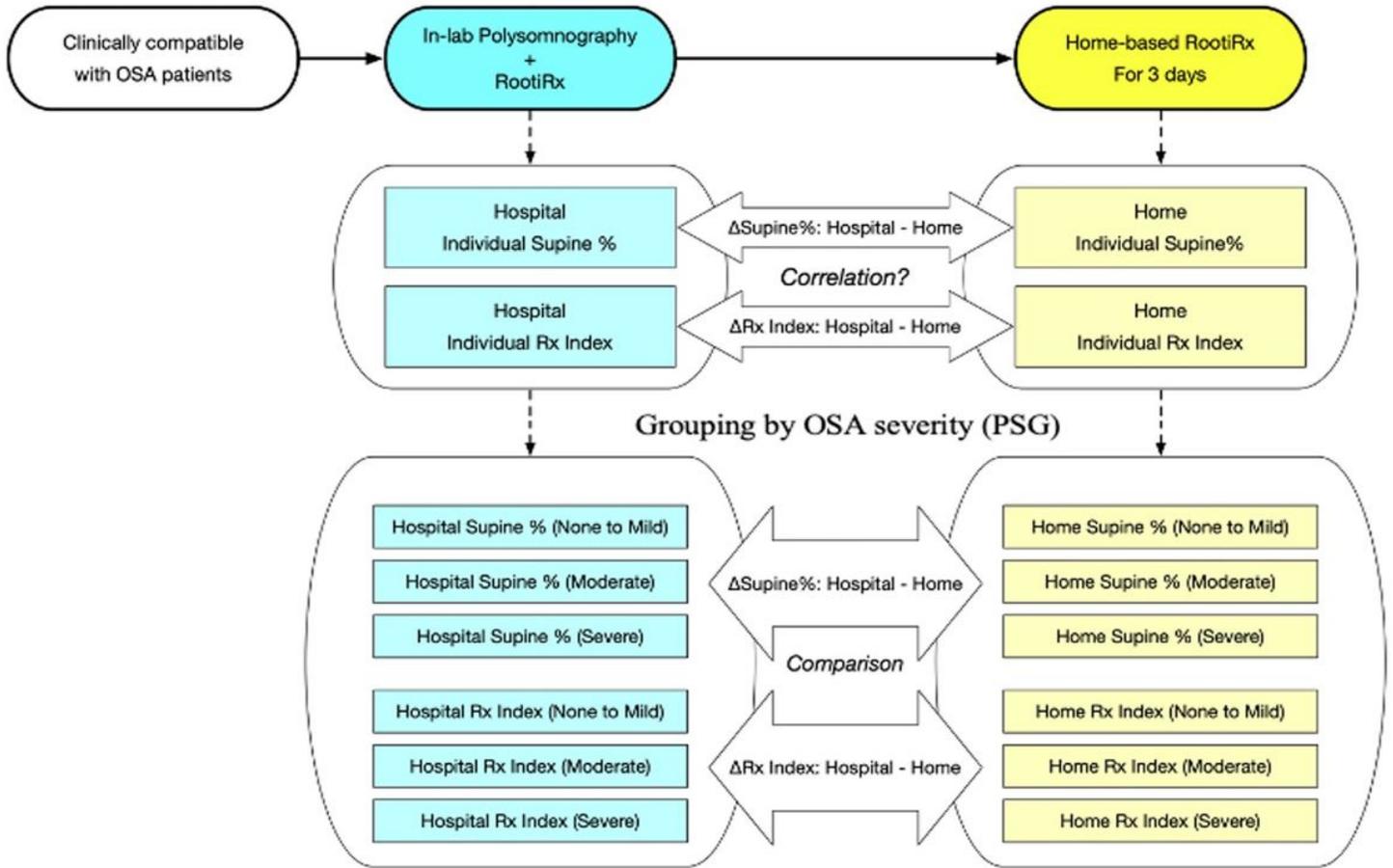


Figure 1

Study Framework. Abbreviations: OSA, obstructive sleep apnoea; PSG, polysomnography; Rx index, combination of the cyclic variation of heart rate index and the chest effort index.

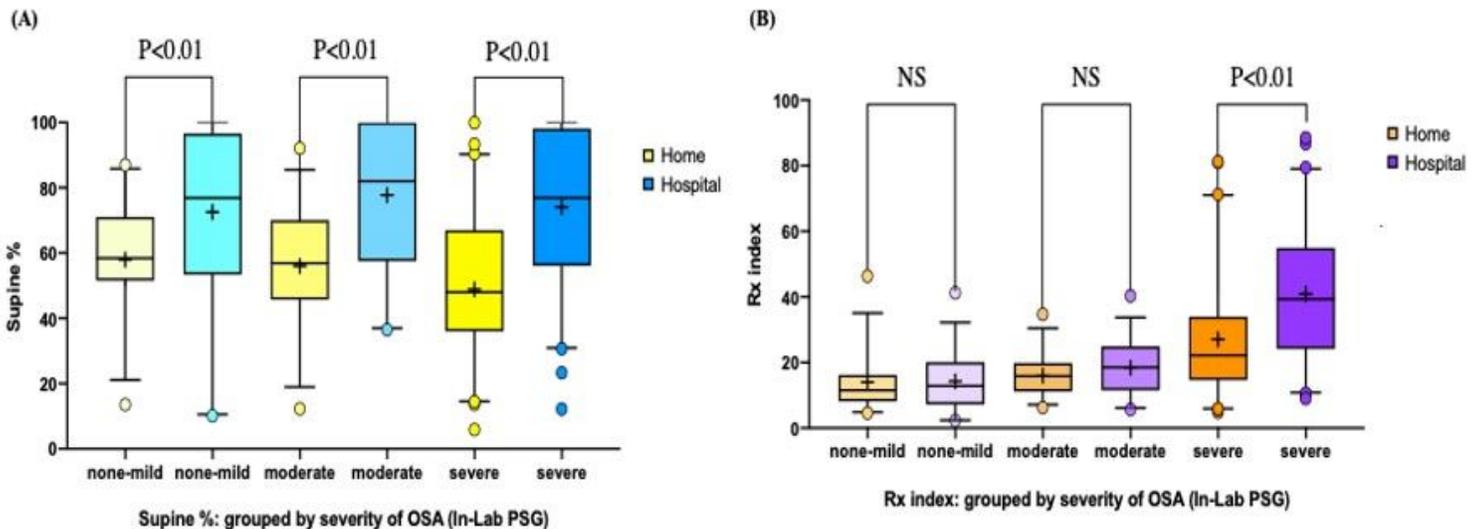


Figure 2

Comparison of the Variation in the Percentage of Supine Sleep Time and Rx Index Values Obtained in Hospital and Home Settings. (A) Percentage of supine sleep time in the various OSA severity groups; (B) Rx index in the various OSA severity groups. Abbreviations: Rx index, combination of the cyclic variation of heart rate index and the chest effort index; OSA, obstructive sleep apnoea; PSG, polysomnography; ns, nonsignificant.

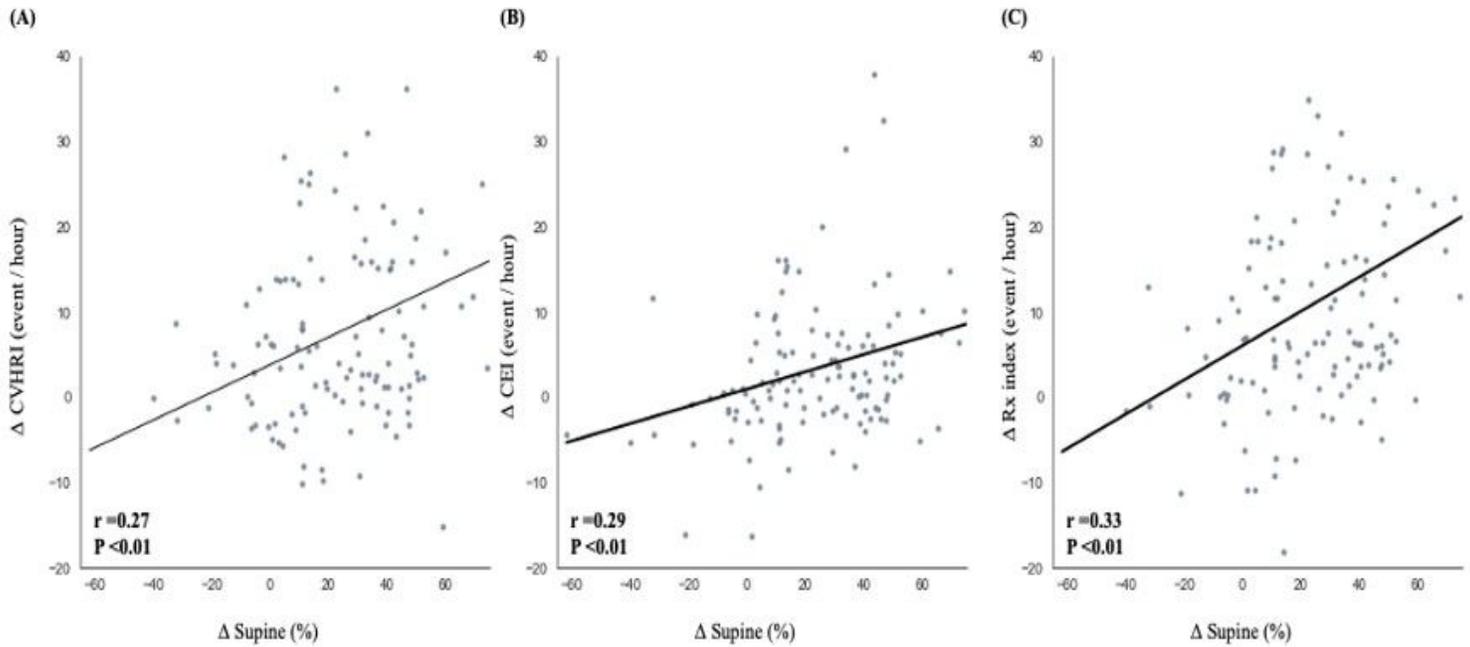


Figure 3

Correlations Between the Variations in the Hospital- and Home-Based Measurements of the Percentage of Supine Sleep Time and the RootiRx Parameters. Correlation between CVHRI (A), CEI (B), Rx index, (C) and variations in the percentage of supine sleep time. Abbreviations: CVHRI, cyclic variation of heart rate index; CEI: chest effort index; Rx index, combination of the CVHRI and the CEI.

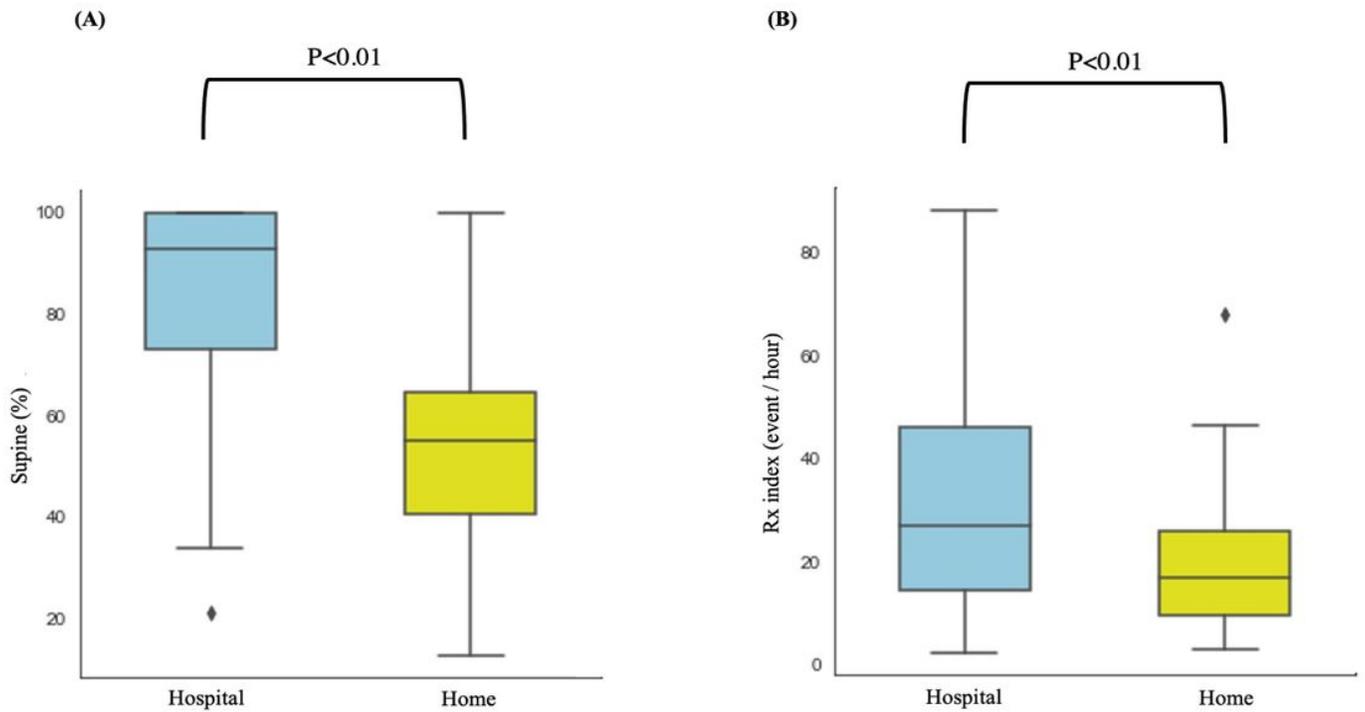


Figure 4

Variation of the Percentage of Supine Sleep Time and the Rx Index Values Determined in Hospital and Home Settings in the High SE Group ($\geq 90\%$; $n = 46$). (A) Variation in the percentage of supine sleep in various sleep environments; (B) Variation in Rx index values in various sleep environments.

Abbreviations: Rx index, combination of the cyclic variation of heart rate index and the chest effort index.

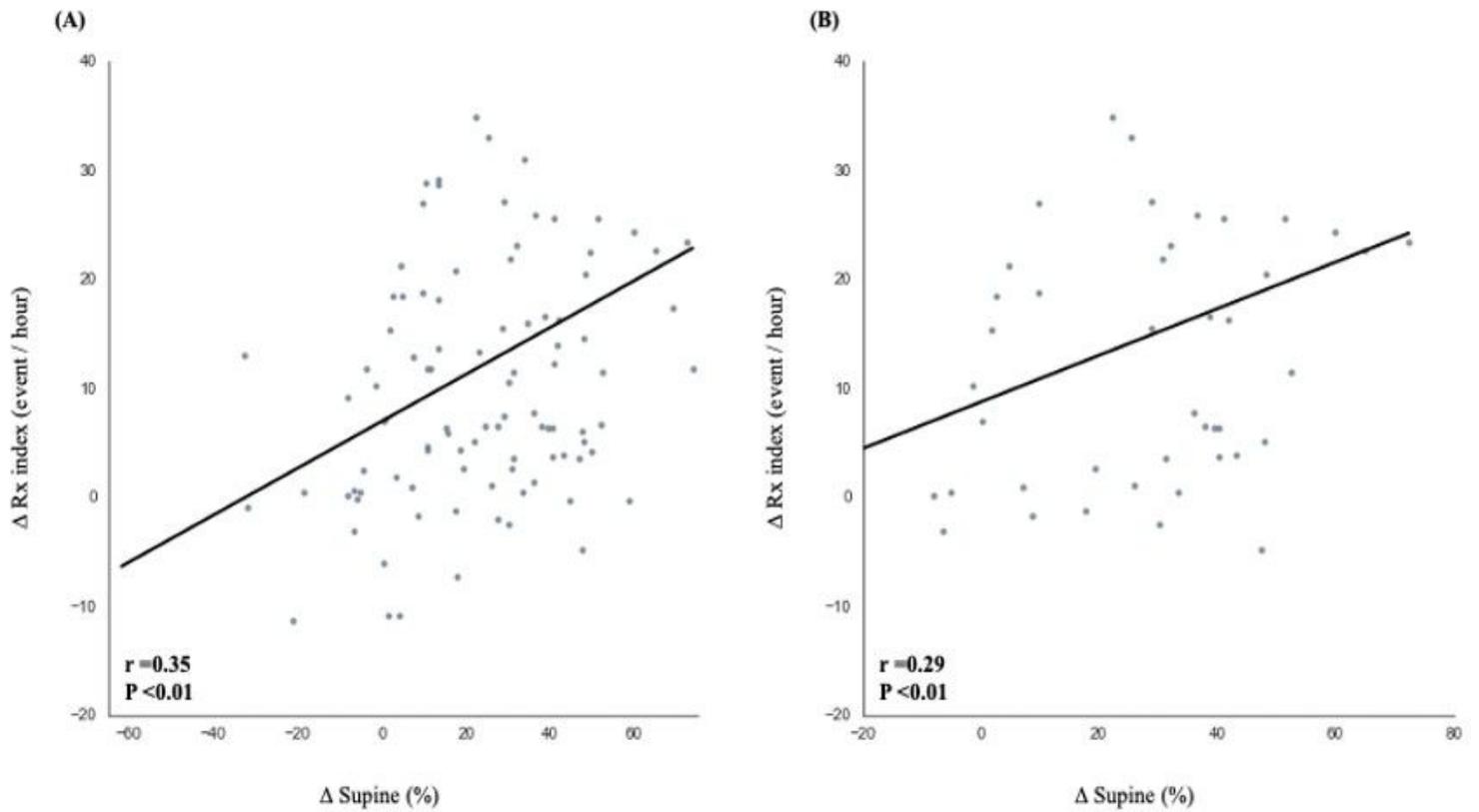


Figure 5

Correlations Between the Variations Between Hospital- and Home-Based Measurements of the Percentage of Supine Sleep Time and the RootiRx Parameters in the High SE Groups. (A) Correlation between the variations in the percentage of supine sleep time and Rx index values in patients with SE \geq 80% (n = 103); (B) Correlation between the variations in the percentage of supine sleep time and Rx index values in patients with SE \geq 90% (n = 46). Abbreviations: SE, sleep efficiency; Rx index, combination of the cyclic variation of heart rate index and the chest effort index.