The Associations Between Lung Function And Rapid Eyes Movement Sleep In Healthy Adults: A Population-Based Cohort Study In Southwest China

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Research Article

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Abstract

Background: To explore and understand associations between lung function and sleep architectures in healthy adults.

Methods: Seventy-two participants (mean age 55.9 years, 72.2% female) were recruited from the Southwest China cohort study conducted at the West China hospital. Forced expiratory volume in first second (FEV1) and the ratio of FEV1 to forced vital capacity (FEV1/FVC) were measured using a spirometer for all participants. Participants' objective sleep architectures, including sleep duration, rapid eye movement (REM) time, light and deep sleep were monitored using a Doppler radar sensor.

Linear regression was used to analyze the associations between lung function measures and sleep architecture.

Results: Results for FEV1/FVC were found to be positively correlated with REM sleep time ($\beta = 0.29$, $p = 0.013$). There was no positive correlation with sleep duration ($p = 0.44$), light sleep ($p = 0.83$) or deep sleep ($p = 0.60$) in regression model, including the use of lung function as the only predictor. Results for FEV1 demonstrated a tendency of positive correlation with REM sleep ($\beta = 0.22$, $p = 0.07$) and deep sleep ($\beta = 0.21$, $p = 0.073$), but it was not associated with sleep duration ($p = 0.53$) or light sleep ($p = 0.54$). After adjusting for all confounders, the results of FEV1/FVC remained positively correlated with REM sleep time ($\beta = 0.28$, $p = 0.028$).

Conclusion: Our findings further confirmed that lung function is closely related to sleep architectures in healthy population, particularly, the result for FEV1/FVC is positively correlated with REM sleep.

Background

With the rapid development of current society, lack of sleep has become a global health concern. Sleeping problems have affected up to 31–56% of the populations in Europe and America [1–2], and 8.3–49.7% of the population in China [3–4]. There is growing evidence suggesting that sleep deprivation plays a crucial role in individuals' well-being and quality of life. Specifically, studies have found that sleep deprivation is often associated with certain physical diseases such as cardio-cerebrovascular and metabolic diseases [5–7]. Lack of sleep has also been found to affect mental health and increase the risk of dementia [8, 9].

The relationship between sleep and lung function has been extensively studied for a long time [10, 11], and most related studies have focused on patients with pulmonary diseases such as asthma, chronic obstructive pulmonary disease, or cystic fibrosis [11–16]. For example, lung function has been found to be inversely correlated with the percentage of activity levels during sleep in children with asthma [11]. Furthermore, asthmatics with the greatest decline in lung function from the afternoon to the morning spent less time in slow-wave sleep [13]. In contrast, sleep was also found to be associated with lung function. For example, studies have shown that both short- and long-term self-reported sleep duration are associated with lower predictive lung function measures [14]. Notably, reduction in lung function and

rapid eye movement (REM) sleep time were also found in myasthenia gravis and lipid storage diseases, but their associations have not been examined in previous studies [17, 18]. Although many disease-oriented studies have shown that lung function and sleep are closely related, but in healthy adults, the relationship between the two remains unclear. Therefore, the aim of this study was to explore the association between lung function and sleep architecture in healthy adults.

Methods

Study population

A total of 72 adults (age 55.9 ± 5.8 years, 72.2% male) were recruited for the cohort study in Southwest China [19]. All participants in this cohort study were from communities of Longquan, Pidu, Mianzhu and Ganzi in Sichuan province. All participants were over 20 years old. Basic information of subjects were collected using standard structured questionnaires, and blood routine, biochemical, urine routine, and pulmonary function tests were performed on all subjects. Additionally, participants aged 40 years or older were assigned to undergo chest computed tomography.. The cohort started in 2019 and is still going on. Participants in this study did not have asthma, chronic obstructive pulmonary disease, head trauma, depression, anxiety, schizophrenia, stroke or other neuropsychiatric disorders. This study was approved by Ethics Committee of West China Hospital, Sichuan University, and written informed consent was obtained from all individual participants in the study.

Pulmonary Function Testing

All enrolled participants underwent standard lung function measurements using spirometry (Yeager, Germany, model master screen pneumo) according to the American Thoracic Society/European Respiratory Society guidelines [20]. The following lung function indicators were selected for further analysis: forced expiratory volume in one second (FEV1%), and the ratio of FEV1 to forced vital capacity (FEV1/FVC).

Objective Sleep Measures

Objective sleep was monitored for two or three consecutive nights using a Doppler radar sensor overnight (2019 version, YOLI, Guangzhou Zhongkeboyue Medical Tec., Co. LTD, China). The monitoring unit was placed on a bedside table or a chair at the same height as the bed. Participants were told to turn on the monitoring device before going to bed and turn it off when they woke up. Monitor collected participants' vital signs and gross motor activity at bedtime. All raw actigraphic data were uploaded to the manufacturer's platform and calculated automatically. Substantial evidence confirms the accuracy of activity maps for polysomnography and suggests that activity maps can be used as an alternative to home polysomnography [21–24]. The following sleep structures were used for further analysis: sleep

duration, REM time, light sleep, and deep sleep. The Apnea-Hypopnea index was also withdrawn from the monitoring report.

Subjective Sleep Quality Measurements

Subjective sleep quality was assessed using the Pittsburgh Sleep Index Scale (PSQI) [25]. The PSQI is a widely used self-report questionnaire with 19 questions designed to assess sleep quality over the past month. It contains seven components, including subjective sleep quality, sleep latency, duration and efficiency, nocturnal arousal, sleep need medication, and daytime functioning. The total score ranges from 0 to 21 points, with higher scores indicating poorer sleep quality, and above 6 points being considered poor sleep quality.

Other Relevant Covariates

Based on previous studies, considering their association with sleep[3], the following factors were withdrawn from baseline data and included as covariates: age, sex, marital status (married or never), smoking status (yes or no), drinking status (yes or no), and body mass index (BMI). All subjects underwent weight and height measurements wearing light clothing and bare feet. Height and weight were measured with an accuracy of 0.1cm and 0.1kg, respectively. BMI (kg/m^2) was calculated by dividing weight (kg) by the square of height (m), and was classified as underweight (BMI less than 18.5), normal weight (18.5-24), overweight (24-28), or obese (more than 28) according to the Cooperative Meta-analysis Group of China obese Task Force report [26].

Statistical analysis

Continuous data were presented as means with standard deviation (SD), and categorical data were presented as percentages. Sleep architecture (sleep duration, REM sleep time, light and deep sleep) and lung function measures (FEV1 and FEV1/FVC) were used as continuous variables and analyzed using linear regression. Two regression models were used, the simple model used lung function measures as the sole predictor, and the second set of models adjusted for age, gender, marital status, BMI, smoking and drinking status. Age and BMI were used as continuous variables, and the remaining factors were modeled as dichotomous variables. Considering that airway obstruction may affect sleep and lung function, we also performed a sensitivity analysis including the apnea-hypopnea index as a confounding factor in the multivariate model.

Results

Subjects characteristics

A total of 72 participants were enrolled, with a mean age of 55.9 ± 5.8 (range 39 - 69) years, with 63.8% of participants between the ages of 50 and 60. Women (72.2%) made up the majority of the participants. Mean BMI was 24.0 ± 2.9 (range 18.5 - 29.8) kg/m^2 , and mean PSQI score was 6.7 ± 3.4 , and 43 (59.7%) had subjectively poor sleep (PSQI ≥ 5). The demographic characteristics of all participants are shown in Table 1.

Table 1
Characteristic features and sleep architectures of the study participants.

Characteristic	Mean (SD or percentage)
Age, years	55.9 (5.8)
Gender (female, %)	52 (72.2)
Marital status (married, %)	65 (90.2)
Body mass index (kg/m^2)	24.0 (2.9)
Overweight (%)	33 (45.8)
Obesity (%)	4 (5.5)
Drinking (%)	13 (18.0)
Smoking (%)	9 (12.5)
Apnea-hypopnea index	8.8 (7.3)
FEV1 (L)	2.44 (0.5)
FEV1/FVC (%)	76.7 (6.3)
Sleep duration (hours, actigraphy-derived)	7.52 (1.4)
REM time (hours, actigraphy-derived)	1.37 (0.5)
Light sleep time (hours, actigraphy-derived)	4.76 (1.2)
Deep sleep time (hours, actigraphy-derived)	1.05 (0.4)
Subjective sleep quality (PSQI scores)	6.7 (3.4)
Poor sleep (PSQI > 5, %)	43 (59.7)
FEV1: forced expiratory volume in the first second (FEV1%); FEV1/FVC: the ratio of FEV1 to forced vital capacity (FEV1/FVC); REM: rapid eye movement; PSQI: Pittsburgh sleep quality index; SD: Standard Deviation.	

Overall, all participants slept on average 7.52 ± 1.4 hours, with 47 (65.2%) sleeping more than 7 hours. The mean REM duration was 1.37 ± 0.5 hours, the mean light sleep was 4.76 ± 1.2 hours, and the mean deep sleep was 1.05 ± 0.4 hours (Table 1).

The association between sleep architectures on simple models.

Simple model demonstrated that FEV1/FVC was positively associated with REM sleep time ($\beta = 0.29$, $t = 2.54$, $p = 0.013$), but not with sleep duration ($p = 0.44$), light sleep ($p = 0.83$) or deep sleep ($p = 0.60$). Results showed a positive trend between FEV1 and REM sleep ($\beta = 0.22$, $t = 1.84$, $p = 0.07$), and deep sleep ($\beta = 0.21$, $t = 1.82$, $p = 0.073$), but not with sleep duration ($p = 0.53$) or light sleep ($p = 0.54$) (Table 2).

Table 2
Results of simple models regressing the 4 sleep architectures on lung function.

	β (SE)	p value
FEV1		
Sleep duration	0.076 (0.33)	0.528
REM time	0.215 (0.12)	0.070
Light sleep time	-0.073 (0.28)	0.542
Deep sleep time	0.212 (0.10)	0.073
FEV1/FVC		
Sleep duration	0.094 (0.03)	0.435
REM duration	0.290 (0.01)	0.013
Light sleep time	-0.025 (0.02)	0.833
Deep sleep time	0.064 (0.01)	0.595
FEV1: forced expiratory volume in the first second; FEV1/FVC: the ratio of FEV1 to forced vital capacity; REM: Rapid eye movement; SE: standard error.		

The association between sleep architectures on models adjusting for covariates.

A multivariate model including lung function measures and all covariates as predictors showed that FEV1/FVC was positively associated with REM sleep time ($\beta = 0.28$, $t = 2.26$, $p = 0.028$). Sensitivity analyses including the apnea-hypopnea index in multivariate model yielded similar results ($\beta = 0.28$, $t = 2.21$, $p = 0.031$). FEV1/FVC was not associated with sleep duration ($p = 0.42$), light sleep duration ($p = 0.91$), or deep sleep duration ($p = 0.46$) (Table 3). After adjusting for these covariates, FEV1 was not associated with sleep duration ($p = 0.94$), REM sleep ($p = 0.31$), light sleep ($p = 0.77$) or deep sleep ($p = 0.72$) (Table 3).

Table 3
Results of linear models regressing the 4 sleep architectures on lung function after controlling for confounding factors ^a

	β (SE)	p value
FEV1		
Sleep duration	0.014 (0.49)	0.936
REM time	0.177 (0.17)	0.306
Light sleep time	-0.051 (0.41)	0.772
Deep sleep time	0.060 (0.14)	0.724
FEV1/FVC		
Sleep duration	0.106 (0.03)	0.423
REM time	0.279 (0.01)	0.028
Light sleep time	-0.014 (0.02)	0.914
Deep sleep time	0.094 (0.01)	0.456
^a Age, gender, marital status, body mass index, smoking, alcohol drinking were included in the models.		
FEV1: forced expiratory volume in the first second; FEV1/FVC: the ratio of FEV1 to forced vital capacity; REM: Rapid eye movement; SE: standard error.		

Discussion

In this study, we found that lung function (FEV1/FVC) was significantly associated with REM sleep, but not with duration of sleep, light or deep sleep. Our findings further corroborate the association between lung function and sleep in healthy adults, consistent with previous studies in patients with lung diseases [11, 13, 27].

Most previous studies were performed in patients with lung diseases [11–13, 15, 27]. Besides, most of the previous studies were performed in children [11, 12, 27] or the elderly [10]. For this study, we included more than half of healthy adults, between the ages of 50 and 60. An association between lung function and sleep was also found despite large differences between participants. Our findings suggest that the relationship between lung function and sleep is not limited to patients with relatively impaired lung function, but can also be generalized to healthy individuals.

We found that lung function was significantly associated with REM sleep duration, even after controlling for confounders, suggesting a salient association between lung function and REM sleep. Notably, reductions in measures of lung function measures (maximum ventilatory pressure and FVC) and REM sleep time were also found in myasthenia gravis and lipid storage diseases, but their associations have

not been assessed in previous studies [17, 18]. In cystic fibrosis patients, as the disease worsens, blood oxygen levels drop and REM sleep time decreases, and both measures improve with treatment [16]. Taken together, these results suggest that reduced nighttime oxygen saturation may partially explain the reduction in REM sleep time.

At present, the specific neurobiological mechanisms of REM sleep remain unclear. Electrophysiological studies have shown that the cerebral cortex is highly activated during REM sleeping stage. It is now generally accepted that neural circuits located in the medulla, midbrain, and hypothalamus interact to control the initiation and termination of REM sleep [28, 29]. Decreased lung function may lead to insufficient oxygen for these essential processes, resulting in shorten REM sleep time, as REM sleep time is significantly shortened when patients are hypoxemia [16]. Since REM is an important sleep stage and has been found to be strongly associated with mortality in the general people [30], these findings may help reduce mortality.

Several studies have demonstrated that both short sleep duration (≤ 5 hours) and long sleep duration (≥ 9 hours) are associated with lower predictive value of lung function [14]. Nevertheless, our study did not find an association between FEV1 or FEV1/FVC and sleep duration, neither in a simple model nor after adjusting for other factors, and the results are consistent with two recent studies [12, 17]. Different measures of lung function might explain this difference as one of the explanations.

Limitations

There are some limitations of our study. First, similar to previous cross-sectional studies, a causal relationship between lung function and sleep cannot be established. Poor lung function may affect sleep architecture, and vice versa. Namely, we were unable to infer directionality from the current research. Secondly, our sample size is relatively small, which limits the validity of the conclusions to some extent. Future studies with larger sample size are needed for validation. Third, although sleep was objectively measured using actigraphy in this study, our findings should be validated with polysomnography studies.

Conclusion

In conclusion, our findings further confirm that lung function is closely related to sleep architecture in healthy individuals. Particular, FEV1/FVC was positively correlated with REM sleep.

Abbreviations

FEV1: forced expiratory volume in the first second (FEV1); FEV1/FVC: the ratio of FEV1 to forced vital capacity (FEV1/FVC); REM: rapid eye movement.

Declarations

Ethics approval and consent to participate

All procedures performed in studies involving human participants were in accordance with the ethical standards of the ethics committee of West China Hospital, Sichuan University and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Written informed consent was obtained from all individual participants included in the study.

Consent to publish

Not applicable.

Availability of data and materials

The datasets used and/or analyses during the current study are available from the corresponding authors on reasonable request.

Competing interests

All authors declare no competing interests.

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Authors' Contributions

AP conceptualized and designed the study and drafted the manuscript, DY drafted the manuscript and revised the manuscript, WLi drafted the manuscript, BD prepared the material and acquired the data, WLai performed the analyses, MW acquired the data, YZ acquired the data. LC conceptualized the study and revised the manuscript. All authors contributed to the data interpretation and critical revision of the manuscript. All authors have read and approved the manuscript.

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