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Slow-wave sleep is associated with incident hypertension in patients with obstructive sleep apnea: a cross-sectional study

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Abstract

Objective: This study aimed to examine the association between slow-wave sleep ([SWS] N3 stage) and the risk of hypertension in patients with obstructive sleep apnea (OSA) or primary snorers.

Methods: A retrospective cross-sectional study of 1145 participants who were evaluated for suspected OSA at our Sleep Medical Center were included. Among these participants, 1022 had OSA and 123 were primary snorers. Logistic regression modeling was performed to evaluate the association between the prevalence of hypertension and combined OSA and SWS based on polysomnographic measurements.

Results: Patients with OSA in the lowest SWS quartile (quartile 1, $<2.0\%$) showed a two-fold increased risk of hypertension after adjustment for confounding factors compared with primary snorers (odds ratio, 2.13 [95% confidence interval 1.54–2.06]). In logistic analysis stratified according to SWS quartiles, there was no significant difference in the risk of hypertension between patients with OSA and primary snorers in quartile 1. However, in the highest quartile (quartile 4), SWS was significantly associated with incident hypertension in patients with OSA rather than primary snorers.

Conclusion: SWS is associated with prevalent hypertension in patients with OSA. Notably, a low proportion of SWS confers a stronger association with incident hypertension than OSA.

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Introduction

Hypertension is the leading cause of cardiovascular death and disability,[1] and contributes to stroke, ischemic heart disease, heart failure, peripheral artery disease, and renal disease.[2] Sleep-disordered breathing, particularly obstructive sleep apnea (OSA), is strongly associated with hypertension.[3,4] Cross-sectional and longitudinal studies have shown a dose-response relationship between OSA and hypertension.[5–8] In a recent meta-analysis, therapy for OSA using continuous positive airway pressure ventilation modestly reduced systolic (−2.58 mmHg) and diastolic (−2.01 mmHg) blood pressure (BP).[9] Another clinical study reported a significant reduction in daytime BP using continuous positive airway pressure treatment in patients with OSA and refractory hypertension.[10]

Human sleep is divided into rapid eye movement and non-rapid eye movement sleep. Non-rapid eye movement is further divided into the three stages of N1 (previously known as stage 1), N2 (previously stage 2), and N3 (previously stages 3 and 4), and is also referred to as slow-wave sleep (SWS).[11] SWS is considered to be "deep" or "restorative" sleep, and has some effects on the highest arousal threshold. The effects of SWS are not absolutely clear, and are related to memory,[12] learning,[13] and performance of perceptual and visuomotor functions.[14] SWS is also associated with decreased sympathetic nervous activity and increased vagal tone, which in turn contribute to elevated heart rate and BP.[15] Patients with OSA show a reduced proportion of SWS compared with non-OSA patients, even after adjustment for confounders in clinical analysis.[16] However, there is little evidence regarding whether sleep architecture (i.e., the time spent in each stage of total sleep) affects BP.

To the best of our knowledge, to date, only two studies that investigated community cohorts showed that SWS was associated with prevalent hypertension.[17,18] However, little is known about the combined effect of SWS and OSA on the association with increased hypertension risk. Recently, Ren et al.[19] investigated the association between SWS and prevalent hypertension in patients with OSA in a dose-dependent manner. The current study aimed to examine the association between SWS and the risk of hypertension in patients with OSA or primary snorers.

Methods

Subjects

The present investigation was a retrospective cross-sectional study involving consecutive adults without continuous positive airway pressure treatment since May 2016 at the Sleep Medical Center, Tianjin Medical University General Hospital (Heping, China). All data are anonymous and comply with the restrictive requirements of personal data protection authority. This study protocol was approved by the Ethical Committee of Tianjin Medical

University General Hospital (No. IRB2019-WZ-175, Tianjin, China) and informed consent was obtained from each participant.

All participants were Chinese adults ($\geq$18 years of age) who were evaluated for suspected OSA at the Sleep Medical Center. They were interviewed using a comprehensive questionnaire to collect information, including age, anthropometric data, smoking habits, alcohol consumption, medication use, medical history, and the Epworth Sleepiness Scale score. Excessive daytime sleepiness was defined as an Epworth Sleepiness Scale score $\geq$10. Diabetes mellitus was determined on the basis of fasting blood glucose levels $\geq$7 mmol/L or glycosylated hemoglobin $\geq$6.5%, and/or the use of antidiabetic medication. Hypertension was defined as either diastolic BP $\geq$90 mmHg or systolic BP $\geq$140 mmHg, at either evening or morning measurement, or a history of hypertension or antihypertension therapy.[20]

Individuals with other sleep disorders (e.g., insomnia, central sleep apnea, and neuromuscular disease), and/or current or recent (within the past 3 months) use of hypnotics, antidepressants, anxiolytics, or any other antipsychotics were excluded from the study.

BP measurement

Clinical BP was measured on two occasions using a periodically calibrated electronic sphygmomanometer (HEM-7132; OMRON, Tokyo, Japan) on the right arm. BP was measured in the evening, approximately 2 hours before the start of sleep recording (20:00–21:00 hours) and in the morning after the end of the overnight sleep measurement (06:00–07:00 hours). The accuracy of this monitor is reported to be $\pm$3 mmHg. The recorded BP measurement was the average of two consecutive readings with a 5-minute interval after a 10-minute rest while supine.

Polysomnography

All participants underwent a single full night of attended polysomnographic (PSG) recording in the Sleep Medical Center. They were permitted to follow their habitual sleep time from 21:00 to 22:00 hours to 06:00 to 07:00 hours. Sleep parameters were scored manually using the American Academy of Sleep Medicine Manual v2.3 2016.[21] Subjects with a total sleep time $<$6 hours were considered to be short sleepers, while those with a total sleep time $\geq$6 hours were considered to be normal sleepers, as described previously.[22,23]

Obstructive apnea was defined as cessation of airflow for at least 10 s in the presence of respiratory effort, whereas hypopnea was identified as a $\geq$30% reduction in airflow for at least 10 s and was associated with either a $\geq$3% decrease in oxygen saturation or arousal. The apnea–hypopnea index (AHI) was calculated as the average number of apnea and hypopnea events per hour. Individuals with OSA were classified according to an AHI $\geq$5, whereas those with an AHI $<$5 were classified as primary snorers. The percentage of time spent in sleep with an oxygen saturation $<$90% was defined as T90%. The overall arousal index was scored as the number of arousal events per hour during sleep. Sleep efficiency was defined as the percent of total sleep time (total time spent sleeping as recorded by PSG) divided by the time in bed.

Statistical analysis

Data are expressed as mean $\pm$ standard deviation for continuous variables if there was a normal distribution or as median and interquartile range if there was not a normal distribution. Categorical variables are presented as a percentage. Comparisons between groups were performed using analysis of variance, the Kruskal–Wallis test, or the χ^2 test as

appropriate. To determine potential nonlinear associations, the percentage of SWS was categorized into quartiles. Quartile 4 was chosen as the reference for the percentage of SWS because it had the lowest risk for hypertension. In the first step, the associations between hypertension with OSA alone and with SWS quartiles alone were examined separately. In the second step, with primary snorers as the reference group, adjusted odds ratios (ORs) and corresponding 95% confidence intervals (CIs) for hypertension were determined in the combined effect of OSA and SWS. Subsequently, the adjusted OR for hypertension associated with OSA in each SWS quartile stratum was calculated.

Logistic regression models were used to assess the independent associations between SWS quartiles and OSA with prevalent hypertension, and interaction effects. Model 1 was adjusted for age, sex, body mass index, neck and waist circumference, smoking, alcohol use, history of cardiovascular disease and diabetes, and the Epworth Sleepiness Scale score. Model 2 was adjusted for variables included in model 1, as well as total sleep time and sleep efficiency. Model 3 was adjusted for variables included in model 2, as well as the AHI, arousal index, and T90%.

Data were analyzed using SPSS version 23.0 (IBM Corporation, Armonk, NY, USA). Differences with $P < 0.05$ were considered to be statistically significant. Test power was estimated using G*Power version 3.1 (Universität Düsseldorf, Düsseldorf, Germany) at the significance level of 0.05 ($\alpha = 0.05$) and the effect size of 0.1 for all statistical tests.

Results

This study included 1145 adults. Among these participants, 1022 had OSA and 123 were primary snorers. Demographic information, clinical characteristics, and PSG parameters are shown in Table 1 (power = 0.925).

Demographic and PSG characteristics of all individuals who were stratified according to quartiles of percent time in SWS are shown in Table 2. Subjects in the lowest SWS quartile (quartile 1, $< 2.0\%$) were more likely to be men ($P < 0.001$) and were significantly associated with an older age ($P < 0.001$), neck and waist circumference ($P < 0.001$ and $P = 0.002$, respectively), and smoking ($P = 0.002$). Those in quartile 1 had a significantly higher AHI ($P < 0.001$), overall arousal index ($P < 0.001$), percentage of N1 sleep ($P < 0.001$), nocturnal oxygen desaturation ($P < 0.001$), and T90% ($P < 0.001$).

Subjects in quartile 1 of SWS showed the highest incidence of hypertension (n = 286 [59.8%]), whereas those in quartile 4 had the lowest risk for hypertension (n = 287 [42.9%]) (Figure 1). Patients with OSA had a significantly higher incidence of hypertension within the different SWS quartiles compared with primary snorers (all $P < 0.05$).

Logistic regression was used to examine the independent association of prevalent hypertension with OSA and SWS. Patients with OSA had a significantly higher incidence of hypertension than primary snorers (model 3: OR 2.33 [95% CI 1.55–3.50]) (Table 3). Compared with patients in quartile 4 of SWS (reference), those in quartile 1 had an elevated risk for incident hypertension by approximately 76% (model 3: OR 1.76 [95% CI 1.23–2.48]; $P = 0.010$).

The adjusted OR and corresponding 95% CI for hypertension associated with the combination of OSA and SWS, which reflected the interaction effect between OSA and SWS ($P = 0.001$), are shown in Figure 2. With primary snorers as the reference group, OSA in quartile 1 of SWS increased the odds of hypertension by 113% (OR 2.13 [95% CI 1.54–2.06]; $P = 0.001$). In contrast, patients with OSA

Table 1. Characteristics of the study population by presence or absence of incident hypertension.

Variables	All	Hypertension	No hypertension	P value
n	1145	575	570	
Demographic and clinical characteristics				
Age (years)	47.8 ± 14.0	51.2 ± 13.6	44.4 ± 13.6	<0.001
Male sex, n (%)	858 (74.9)	433 (75.3)	425 (74.6)	0.784
Body mass index (kg/m^2)	29.3 ± 5.4	30.5 ± 5.5	28.1 ± 5.0	<0.001
Neck circumference (cm)	41.5 ± 4.0	42.4 ± 3.9	40.7 ± 3.8	<0.001
Waist circumference (cm)	103.3 ± 13.1	106.8 ± 13.1	99.7 ± 12.1	<0.001
Smoker, n (%)	537 (46.9)	287 (49.9)	250 (43.9)	0.044
Alcohol consumption, n (%)	584 (51.0)	306 (53.2)	278 (48.8)	0.140
Diabetes, n (%)	180 (15.7)	134 (23.3)	46 (8.1)	<0.001
CVD, n (%)	113 (9.9)	88 (15.3)	25 (4.4)	<0.001
ESS score	7.9 ± 7.1	8.6 ± 7.3	7.3 ± 6.8	0.002
EDS, n (%)	455 (39.7)	254 (44.0)	201 (35.3)	0.006
Sleep characteristics				
AHI (events/hour)	38.3 ± 27.7	43.2 ± 27.6	33.2 ± 26.9	<0.001
OSA, n (%)	1022 (89.3)	536 (93.2)	486 (85.3)	<0.001
Time in bed (minutes)	459.9 ± 27.2	459.4 ± 27.9	460.5 ± 26.4	0.487
TST (minutes)	390.8 ± 56.4	388.2 ± 54.6	393.5 ± 51.8	0.110
Short sleepers, n (%)	178 (15.5)	101 (17.6)	77 (13.5)	0.061
Sleep efficiency (%)	85.6 ± 10.9	85.6 ± 10.7	85.6 ± 11.1	0.141
Arousal index (events/hour)	22.6 ± 17.9	23.6 ± 18.6	21.6 ± 17.1	0.057
%N1 sleep (%)	22.0 ± 15.6	23.8 ± 15.8	20.1 ± 15.1	<0.001
%N2 sleep (%)	54.4 ± 13.8	54.3 ± 14.0	54.5 ± 13.4	0.758
%N3 sleep (%)	8.5 ± 7.6	7.4 ± 7.2	9.5 ± 7.8	<0.001
%REM sleep (%)	15.1 ± 6.5	14.7 ± 6.2	16.0 ± 6.6	0.056
Lowest oxygen saturation (%)	76.3 ± 13.6	74.1 ± 13.8	78.6 ± 12.9	<0.001
Mean oxygen saturation (%)	93.7 ± 3.5	93.2 ± 3.7	94.2 ± 3.0	<0.001
T90% (%)	11.9 ± 17.9	14.0 ± 18.9	9.7 ± 16.5	<0.001

Data are shown as n (%) for categorical variables and other variables are shown as mean ± standard deviation.
CVD, cardiovascular disease; ESS, Epworth Sleepiness Scale; EDS, excessive daytime sleepiness (ESS score ≥10); AHI, apnea–hypopnea index; OSA, obstructive sleep apnea (AHI ≥5); TST, total sleep time; REM, rapid eye movement; T90%, percentage of time spent in sleep spent at <90% oxygen saturation.

in quartiles 3 and 4 did not show a significantly higher odds of hypertension.

Stratified logistic regression analysis showed that the odds of hypertension with OSA was not significantly different in the lowest SWS quartile compared with primary snorers in the same SWS quartile (model 3: quartile 1, OR 1.09 [95% CI 0.48–3.01]) (Table 4). In contrast, the OR was pronounced in the quartile 4 stratum (model 3: OR 2.92 [95% CI 1.54–5.82]).

Discussion

In the current study, we found a relationship between a reduction in SWS and a risk for hypertension in a cross-sectional study of primary snorers and patients with OSA. After adjustment for potential confounding factors, the incidence of hypertension was synergistically increased in patients with a combination of lower SWS and OSA. To date, this is only the second analysis to

Table 2. Baseline sample characteristics by quartiles of slow-wave sleep.

Variables	Quartile 1 <2.0%	Quartile 2 2.0%–7.1%	Quartile 3 7.2%–13.1%	Quartile 4 >13.1%	P value
n	286	286	286	287	
Demographic and clinical characteristics					
Age (years)	51.6 ± 13.3	49.8 ± 13.4	46.4 ± 7.8	43.5 ± 14.6	<0.001
Male sex, n (%)	236 (82.5)	226 (79.0)	211 (73.8)	185 (64.5)	<0.001
BMI (kg/m^2)	29.9 ± 5.5	29.3 ± 5.4	28.9 ± 5.2	29.1 ± 5.6	0.151
Neck circumference (cm)	42.6 ± 3.9	41.7 ± 3.9	41.1 ± 3.8	40.7 ± 4.0	<0.001
Waist circumference (cm)	105.8 ± 13.0	103.2 ± 13.1	102.2 ± 12.5	101.9 ± 13.5	0.002
smoker, n (%)	155 (54.2)	141 (49.3)	130 (45.5)	111 (38.7)	0.002
Alcohol use, n (%)	157 (54.9)	166 (58.0)	134 (46.9)	127 (44.4)	0.002
Hypertension, n (%)	171 (59.8)	148 (51.7)	133 (46.5)	123 (42.9)	<0.001
Diabetes, n (%)	55 (19.2)	39 (13.6)	45 (15.7)	41 (14.3)	0.257
CVD, n (%)	33 (11.5)	28 (9.8)	28 (9.8)	24 (8.4)	0.591
ESS score	8.7 ± 7.4	9.1 ± 7.6	7.6 ± 6.8	6.2 ± 6.0	<0.001
EDS, n (%)	129 (45.1)	137 (47.9)	106 (37.1)	83 (28.9)	<0.001
Sleep characteristics					
AHI (events/hour)	52.5 ± 28.5	42.5 ± 26.4	31.7 ± 21.7	26.3 ± 24.6	<0.001
OSA, n (%)	274 (95.8)	264 (92.3)	257 (89.9)	227 (79.1)	<0.001
Time in bed (minutes)	460.3 ± 28.0	461.5 ± 28.9	458.3 ± 26.3	459.6 ± 25.6	0.571
TST (minutes)	389.3 ± 62.5	397.3 ± 56.1	386.9 ± 52.6	389.8 ± 52.6	0.139
Short sleepers, n (%)	44 (15.4)	43 (15.0)	47 (16.4)	44 (15.3)	0.970
Sleep efficiency (%)	85.2 ± 12.0	86.7 ± 10.8	85.1 ± 10.7	85.4 ± 10.2	0.268
Arousal index (events/hour)	31.5 ± 21.3	22.9 ± 17.2	19.9 ± 14.9	16.1 ± 13.5	<0.001
%N1 sleep (%)	32.7 ± 19.4	23.4 ± 13.1	20.3 ± 11.2	13.5 ± 9.8	<0.001
%N2 sleep (%)	53.2 ± 18.6	57.4 ± 12.6	60.0 ± 11.1	51.1 ± 10.3	<0.001
%REM sleep (%)	13.5 ± 6.2	14.7 ± 6.1	15.8 ± 6.5	17.1 ± 6.7	<0.001
Lowest oxygen saturation (%)	72.3 ± 15.9	74.3 ± 14.2	78.3 ± 11.6	80.4 ± 11.8	<0.001
Mean oxygen saturation (%)	92.7 ± 3.8	93.4 ± 3.6	94.3 ± 2.7	94.5 ± 3.1	<0.001
T90% (%)	18.2 ± 20.7	13.4 ± 18.2	9.0 ± 15.6	6.9 ± 14.4	<0.001

Data are shown as n (%) for categorical variables and other variables are shown as mean ± standard deviation.
BMI, body mass index; CVD, cardiovascular disease; ESS, Epworth Sleepiness Scale; EDS, excessive daytime sleepiness (ESS score ≥10); AHI, apnea–hypopnea index; OSA, obstructive sleep apnea (AHI ≥5); TST, total sleep time; REM, rapid eye movement; T90%, percentage of time spent in sleep at <90% oxygen saturation.

assess the association between SWS and OSA with prevalent hypertension. Our findings suggest that, in addition to the AHI, SWS could be clinically related to vascular complications in patients with OSA.

Over the past few decades, sleep disturbances have become exceedingly common in older adults.[24] There is accumulating evidence that sleep disorders,[23] poor sleep quality,[25] and short sleep duration[26] contribute to cardiovascular disease, including hypertension. Most previous analyses examining the relationship between prevalent hypertension and sleep disturbances have drawn attention to sleep-disordered breathing, and some studies have also addressed subjective and objective sleep duration.[17] However, few studies have focused on the effect of sleep architecture on the development of hypertension.[19]

Two studies involving community cohorts reported a significant relationship between lower SWS and a higher risk for hypertension.[17,18] One large-scale analysis[17]

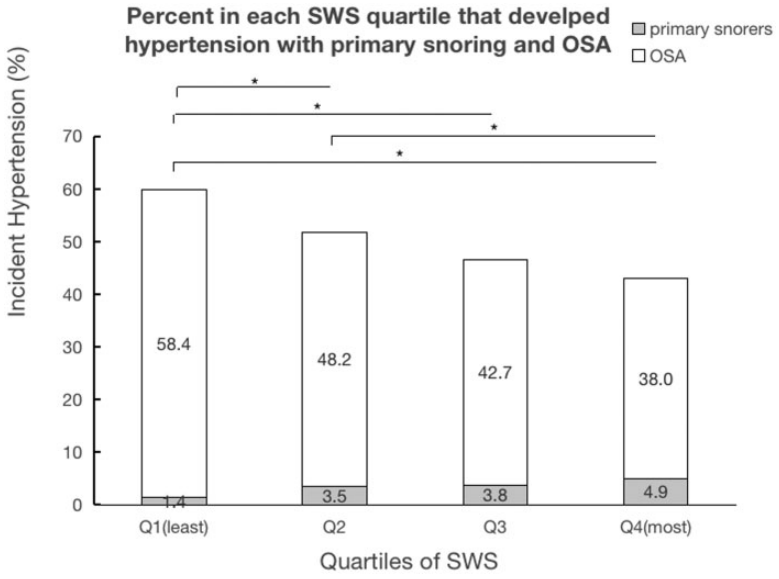

Figure 1. Frequency of hypertension among each quartile of stage N3 (slow-wave) sleep in the primary snoring and OSA groups. *P<0.05.
OSA, obstructive sleep apnea; SWS, slow-wave sleep.

Table 3. Adjusted ORs (95% CIs) for hypertension associated with OSA and quartiles of SWS.

Predictors	n	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
Primary snoring	123	Reference	Reference	Reference
OSA	1022	2.37 (1.60–3.48)	2.32 (1.57–3.45)	2.33 (1.55–3.50)
Quartiles of SWS				
Quartile 1: <2.0%	286	1.98 (1.42–2.77)	1.83 (1.34–2.56)	1.76 (1.23–2.48)
Quartile 2: 2.0%–7.1%	286	1.43 (1.03–1.99)	1.39 (0.98–1.88)	1.31 (0.93–1.82)
Quartile 3: 7.2%–13.1%	286	1.16 (0.83–1.61)	1.10 (0.80–1.58)	1.08 (0.77–1.50)
Quartile 4: >13.1%	287	Reference	Reference	Reference
P for linear trend		0.004	0.006	0.010

Model 1 was adjusted for age, sex, body mass index, neck and waist circumference, smoking, alcohol use, history of cardiovascular disease and diabetes, and the Epworth Sleepiness Scale score; model 2 was adjusted for variables included in model 1, as well as total sleep time and sleep efficiency; model 3 was adjusted for variables included in model 2, as well as the apnea–hypopnea index, the arousal index, and the percentage of sleep time spent at <90% oxygen saturation
OR, odds ratio; CI, confidence interval; OSA, obstructive sleep apnea; SWS, slow-wave sleep.

showed an association between sleep characteristics (sleep-disordered breathing, sleep duration, and sleep architecture), especially SWS, and prevalent hypertension among community dwelling older men. This previous study showed that men in the lowest SWS quartile had an approximately 1.8-fold increased incidence of hypertension compared with men in the highest SWS quartile. Another longitudinal study[18] extended the sample size to confirm these conclusions in middle-aged men and women. The authors in this previous study found that the protective effect of SWS on

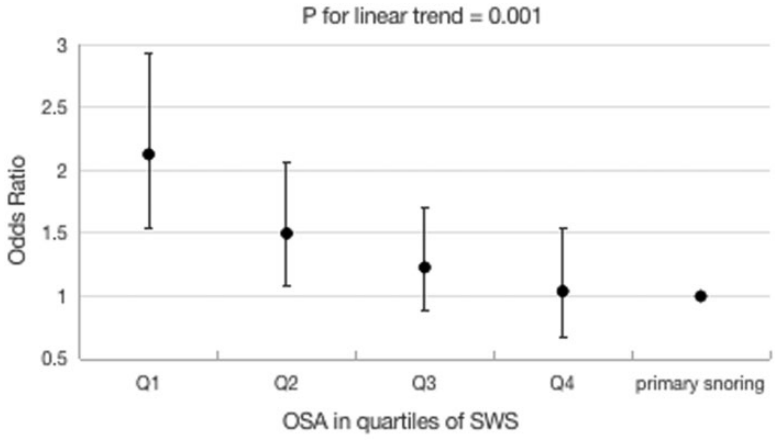

Figure 2. Multivariable adjusted odds ratios and 95% confidence intervals for hypertension associated with various combinations of OSA and quartiles of SWS compared with primary snorers. ORs were adjusted for age, sex, body mass index, neck and waist circumference, smoking, alcohol use, history of cardiovascular disease and diabetes, the Epworth Sleepiness Scale score, total sleep time, sleep efficiency, the apnea–hypopnea index, the arousal index, and the percentage of sleep time spent at <90% oxygen saturation
OSA, obstructive sleep apnea; SWS, slow-wave sleep.

Table 4. Adjusted ORs (95% CIs) for hypertension associated with OSA across different quartiles of SWS.

		Model 1	Model 2	Model 3
Quartiles of SWS	n	OR (95% CI)	OR (95% CI)	OR (95% CI)
Quartile 1: <2.0%				
Primary snoring	12	Reference	Reference	Reference
OSA	274	1.14 (0.51–3.06)	1.10 (0.49–3.02)	1.09 (0.48–3.01)
Quartile 2: 2.0%–7.1%				
Primary snoring	22	Reference	Reference	Reference
OSA	264	1.31 (0.55–3.15)	2.29 (0.57–3.14)	1.27 (0.54–3.10)
Quartile 3: 7.2%–13.1%				
Primary snoring	29	Reference	Reference	Reference
OSA	257	1.48 (0.67–3.26)	1.44 (0.72–3.22)	1.41 (0.68–3.19)
Quartile 4: >13.1%				
Primary snoring	60	Reference	Reference	Reference
OSA	222	3.04 (1.58–5.83)	2.97 (1.56–5.79)	2.92 (1.54–5.82)

Model 1 was adjusted for age, sex, body mass index, neck and waist circumference, smoking, alcohol use, history of cardiovascular disease and diabetes, and the Epworth Sleepiness Scale score; model 2 was adjusted for variables included in model 1, as well as total sleep time and sleep efficiency; model 3 was adjusted for variables included in model 2, as well as the apnea-hypopnea index, the arousal index, and the percentage of sleep time spent at <90% oxygen saturation
OR, odds rate; CI, confidence interval; OSA, obstructive sleep apnea; SWS, slow-wave sleep.

hypertension was highest in quartile 3, not in quartile 4. A recent study[19] showed a significant relationship between SWS and OSA in prevalent hypertension for the first time, and SWS was associated with elevated BP in a dose-dependent manner in OSA. Our findings are consistent with these previous findings. Furthermore, we

found an association between combined OSA and SWS and prevalent hypertension. The higher mean incidence of hypertension (50.2%, 575/1145) observed in our study compared with the three studies mentioned above[17–19] could be explained by the patients with primary snoring and OSA in our cohort. Another study showed that the incidence of hypertension in patients with suspected OSA was 50.8% in 2018,[27] which is in accordance with our study. Our study also showed a higher mean percentage of N3 sleep and the AHI than those in these previous studies, which could be explained by population differences. Furthermore, our data suggested that OSA in patients in the lowest SWS quartile was associated with a >two-fold increased risk for hypertension compared with primary snorers. Notably, the risk for hypertension with OSA in the lowest SWS quartile (quartile 1) was comparable with that of primary snorers in the same quartile. This finding suggests that SWS itself may actually be even more crucial than OSA in affecting prevalent hypertension.

The mechanism of the association between decreased SWS and increased nocturnal BP remains unclear, but is probably related to changes in sympathetic–parasympathetic tone during SWS. In deepening of sleep toward SWS, these changes are primarily mediated by sympathetic–parasympathetic tone through reduction of sympathetic nervous system activity and enhancement of parasympathetic activity.[28,29] To the best of our knowledge, a decline in the nocturnal "dipping" BP pattern is a better predictor of mortality in hypertension, cardiovascular disease, and stroke than daytime BP.[30] Deprivation of experimental SWS in healthy subjects leads to weakening of nocturnal dipping BP during SWS.[29] Several studies have shown that SWS decreases with age.[31] Our study indicates that decreased SWS with aging may contribute to a higher incidence of hypertension. Furthermore, deprivation of SWS is associated with negative effects on neurocognition[12–14] and endocrine function.[15]

Reduced SWS and low sleep quality have been implicated in insulin resistance[32] and associated with metabolic syndrome. Recently, there has been growing interest in interventions to optimize sleep, including drugs,[33,34] transcranial direct-current stimulation, transcranial magnetic stimulation, acoustic stimulation,[35] and exercise intensity.[36] A potential therapeutic target may be alteration of SWS in patients with OSA. A future direction of our research is to determine whether reducing the incidence of hypertension in patients with OSA through enhancement of SWS is possible.

Strengths of our study include the use of objective PSG measurements of sleep parameters and assessment. Moreover, we excluded all subjects who used any hypnotic, antipsychotic, or antiepileptic medications, which may affect sleep characteristics and stage N3 sleep. However, some limitations should be addressed. First, all individuals in our study underwent evaluation of sleep for suspicion of OSA, which may have introduced a selection bias favoring symptomatic OSA. Second, SWS was measured using single full-night PSG. However, a previous study showed that SWS had high night-to-night reproducibility.[37] Third, because of the retrospective nature of our study and the population consisted of subjects with suspected OSA with symptoms of snoring or sleep disorders, the sample sizes for the OSA and primary snoring groups were uneven. This difference in sample sizes probably led to under- or oversampling of one group[38] in the imbalanced cohort. The low number in the control group may have led to statistical bias, especially in calculation of ORs. Finally, BP measurements on two occasions cannot approximate 24-hour BP monitoring, and in particular, cannot reflect

BP changes during the night. Our data also lacked systolic BP and diastolic BP measurements, and consequently, there was a lack of the relationship between BP and the prevalence of hypertension. A high number of participants in our study were previously diagnosed with hypertension and received antihypertensive treatment. Therefore, BP measurements may have been affected by medications.

We conclude that a low percentage of SWS is independently associated with an increased odds of prevalent hypertension after controlling for potential confounders in patients with clinically suspected OSA. Future studies should examine whether interventions for optimizing sleep architecture, especially SWS, contribute to a lower prevalence of hypertension in patients with OSA.

Declaration of conflicting interest

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