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ORIGINAL RESEARCH

Hypoxic Burden and T90% as Predictive Indicators of Cardiovascular Risk and Myocardial Ischemia in Patients with Obstructive Sleep Apnea

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Purpose: This study analyzed the role of hypoxic burden and the percentage of time with blood oxygen saturation below 90% (T90%) in assessing the myocardial ischemia and cardiovascular risk in obstructive sleep apnea (OSA) patients using portable sleep monitors.

Patients and Methods: We conducted a prospective observational study of hospitalized OSA patients diagnosed by portable sleep monitors at a single tertiary center in Southern China from January 2022 to March 2024. Cardiovascular risk was assessed with the China-PAR model including anthropometric measurements and risk factors. Myocardial ischemia was evaluated via electrocardiogram. Factors including hypoxic burden severity categories, apnea-hypopnea index severity categories, respiratory event durations (apnea%, hypopnea%, and combined%), and oxygen desaturation metrics (T90%/T85%/T80%) were analyzed with binary logistic regression for 10-year atherosclerotic cardiovascular disease (ASCVD) risk and myocardial ischemia evaluation in OSA patients. The diagnostic value was analyzed with the receiver operating characteristic curve.

Results: A total of 311 OSA patients were included, with a median age of 53 years, 75.6% of whom were male. Among them, 51.4% demonstrated electrocardiogram changes indicative of myocardial ischemia, and 55.3% had moderate-to-high 10-year ASCVD risk. Patients with moderate-to-high ASCVD risk had higher hypoxic burdens and T90%. Both the hypoxic burden and T90% showed significant predictive value for cardiovascular risk stratification. Clinically meaningful thresholds were established: 125.8%min/h for hypoxic burden and 3.05% for T90% in ASCVD risk prediction (area under the curve 0.747–0.754), and 112.6%min/h and 4.20% for myocardial ischemia detection (area under the curve 0.741–0.769).

Conclusion: The hypoxic burden and T90% obtained from portable sleep monitors can be valuable indicators for assessing cardiovascular risk in OSA patients. Cardiovascular risk stratification increases patient and physician vigilance toward the detrimental effects of OSA and provides practical decision points for clinicians for further evaluation and treatment.

Keywords: obstructive sleep apnea, hypoxic burden, myocardial ischemia, cardiovascular disease risk

Introduction

Obstructive sleep apnea (OSA) is characterized by recurrent sleep disturbances leading to intermittent hypoxemia, hypercapnia, and disrupted sleep architecture.[1–3] An epidemiological study indicates that the estimated prevalence of OSA with an apnea-hypopnea index (AHI) ≥5 events/hour ranges from 17% to 26% in men and 9% to 28% in women, with rates of 4% to 9% in middle-aged men and 1% to 2% in middle-aged women.[4] According to the diagnostic criteria of AHI ≥5 events/hour, it is estimated that there are 176 million OSA patients in China, with 66 million being moderate to severe cases.[5,6] Studies have demonstrated that OSA can lead to nocturnal hypoxia, resulting in sympathetic activation, inflammation, oxidative stress, metabolic disorders, and endothelial dysfunction, potentially leading to multi-organ and multi-system damage such as cardiovascular diseases, diabetes, arrhythmias, cerebrovascular accidents, and cognitive impairments.[3,7–9] Untreated severe OSA patients have a mortality rate 3.8 times higher than that of the general

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population. The probability of stroke occurrence in the OSA population is 4.33 times higher than in the control group, with a mortality rate 1.98 times higher than the control group.[10,11]

The primary assessment indicators for OSA currently include total AHI, lowest blood oxygen saturation, longest apnea duration, and longest hypoventilation period. Clinical experience demonstrates that relying solely on these indicators does not provide a comprehensive reflection of the severity of the patient's condition. The longest apnea duration, longest hypoventilation period, and lowest blood oxygen saturation measurements offer insights at specific time points, while the AHI value merely indicates the frequency of events throughout the night without capturing the duration and extent of hypoxia.[12,13] This lack of effective evaluation indicators leads to inadequate understanding and assessment of OSA conditions, resulting in insufficient patient awareness of the condition's severity and subsequently lower rates of consultation, diagnosis, and treatment for OSA.[14] Economical and efficient screening for patients with OSA, coupled with a thorough evaluation of their condition, can enhance patient awareness and facilitate early intervention, thereby generating significant societal benefits and enhancing the overall quality of life for the population. The China-PAR model has been developed to validate 10-year risk predictions for atherosclerotic cardiovascular disease (ASCVD) among the Chinese population. This model incorporates various factors, including gender, age, waist circumference, total cholesterol, high-density lipoprotein cholesterol, treated or untreated systolic blood pressure, current smoking status (yes/no), diabetes mellitus (yes/no), and family history of ASCVD.[15] It emphasizes anthropometric measurements and risk factors that are commonly observed in patients with OSA. Therefore, the China-PAR model is particularly suitable for assessing the 10-year ASCVD risk in patients with OSA in our study.

The investigation into cardiovascular risks among patients with OSA during episodes of hypoxia is gaining increasing significance. Nocturnal hypoxia can induce oxidative stress, inflammation, sympathetic activation, endothelial dysfunction, metabolic dysregulation, and pro-thrombotic effects and drive ASCVD and myocardial ischemia.[16–18] Previous studies have shown that recurrent hypoxia in OSA is related to pulmonary arterial hypertension, and vascular and microvascular diseases in patients.[1,2,10,11,19] The importance of new body indices and hypoxic burden metrics in the assessment of cardiovascular disease risk in OSA patients cannot be overlooked. For example, Yeşildağ M et al reported that the body roundness index, a novel body metric for defining and predicting cardiovascular risk in patients with OSA, was significantly associated with the oxygen desaturation index, a critical metric that measures hypoxic burden and links OSA to cardiovascular conditions.[20] However, the association between hypoxia events and patient prognosis assessment remains unclear. The hypoxic burden is calculated by dividing the sum of the product of the desaturation area associated with each pause or hypopnea event by the total sleep time. It can be automatically calculated by advanced sleep monitoring data analysis software, reflecting the intensity and duration of hypoxic events.[21] The percentage of time with blood oxygen saturation below 90% (T90%) reflects the total duration of hypoxia throughout the night.[22] However, due to the lack of comprehensive prognostic analysis, there are currently no standardized grading criteria for the hypoxic burden and T90%. The role of hypoxic burden and T90% in assessing the condition and prognosis of OSA patients remains to be further explored.

Polysomnography (PSG) is considered the primary diagnostic tool for identifying OSA. However, the equipment associated with PSG is costly, requires a specific installation environment, involves complex operation, demands high proficiency from medical personnel, necessitates completion in medical facilities during the examination process, and often leads to a suboptimal patient experience. These factors make it challenging to use PSG efficiently in screening for OSA among high-risk populations. Studies have shown that portable sleep monitors demonstrate a high level of agreement with PSG outcomes and offer reliable diagnostic capabilities for OSA, prompting an increased recognition of their clinical utility.[23,24]

Here, by using portable sleep apnea monitors, we investigated the relationship between oxygen desaturation burden and T90% and myocardial ischemia and cardiovascular risk, promoting the establishment of a more comprehensive OSA assessment system. Our research has the potential to serve as a foundation for OSA patients to receive enhanced diagnostic and therapeutic interventions, ultimately leading to improved patient outcomes.

Materials and Methods

Ethics Statement

This study was carried out in accordance with the Declaration of Helsinki. All procedures were performed in compliance with relevant laws and institutional guidelines and have been approved by the Ethics Committee of Shenzhen Qian Hai She Kou Free Trade Zone Hospital (No.: 2021K-057). Informed content was obtained from all patients.

Study Participants

This prospective observational study was conducted at a single tertiary center in Southern China from January 2022 to March 2024. Hospitalized patients who underwent portable sleep apnea screening tests after being highly suspected of having OSA were screened. Only patients who were subsequently diagnosed with OSA were included. Inclusion criteria: 1) patients with daytime sleepiness, lack of energy after waking up, fatigue, or insomnia. 2) patients who woke up due to suffocation, wheezing, or choking at night. 3) patients with habitual snoring or breathing interruptions. 4) patients with dizziness. 5) patients with hypertension or poor response to hypertension treatment. 6) patients with emotional disorders. Exclusion criteria: 1) patients with known coronary artery diseases; 2) patients with a history of stroke; 3) patients with arrhythmias or those who used antiarrhythmic medications; 4) patients with cardiomyopathy; 5) patients with valvular heart disease; 6) patients who had electrolyte imbalances; 7) patients with severe kidney insufficiency.

Diagnostic Criteria for OSA

The diagnosis and initial assessment of OSA were based on the International Classification of Sleep Disorders.[25] The diagnostic threshold for OSA was defined by an AHI of ≥ 5 events per hour, where AHI values of 5–15 were classified as mild, 15–30 as moderate, ≥ 30 as severe, and ≥ 60 as extremely severe. The severity of nocturnal hypoxia was classified into five categories: normal, mild, moderate, severe, and very severe, determined by the lowest oxygen saturation levels: ≥90%, 85%-89%, 80%-84%, and <80%.

Sleep Monitoring

Participants were instructed to wear the portable sleep monitor, Phillip Alice Night One (Respironics, CA, USA), for overnight sleep monitoring. This device has been validated against PSG and has demonstrated a high level of agreement with PSG outcomes.[23,24] Sleep duration was assessed by considering the position, nasal airflow patterns, and self-reported sleep onset time of patients. Data was collected using Sleepware G3 4.0.1.0 (Respironics, CA, USA), manually reviewed and interpreted. Then, the hypoxic burden and other assessment parameters were automatically calculated. The recorded indicators included: AHI, hypoxic burden, supine hypoxic burden, non-supine hypoxic burden, lowest blood oxygen saturation, percentage of total sleep time with apneas, percentage of total sleep time with hypopneas, and percentage of total sleep time with blood oxygen saturation below 90% (T90%), 85% (T85%), 80% (T80%).

Electrocardiogram (ECG) Examinations

All patients underwent routine ECG examinations. The ECGs were assessed and reported by physicians at or above the attending level. The ECG indicators for evaluating myocardial ischemia included: 1) ST segment depression or elevation (ST segment depression in two or more adjacent leads, with limb leads ≥ 0.05 mV or precordial leads ≥ 0.1 mV); 2) T wave flattening or inversion); 3) ST-T changes; 4) positive PTFV1 (P-wave terminal force in electrocardiogram lead V1).

Assessment of the 10-Year Atherosclerotic Cardiovascular Disease (ASCVD) Risk

The process for assessing the 10-year ASCVD risk using the China-PAR model involved two steps.[15] In Step 1, high-risk individuals were directly identified based on specific criteria, including 1) diabetic patients aged ≥40 years; 2) LDL ≥4.9 mmol/L or total cholesterol ≥7.2 mmol/L; 3) chronic kidney disease at stage 3/4. Due to the potential impact of kidney insufficiency on electrolytes and electrocardiographic waveforms, patients with chronic kidney insufficiency were

excluded from this study. In Step 2, the remaining patients were subjected to the 10-year ASCVD risk assessment using the China-PAR model. Patients were categorized as either having low or moderate-to-high risk of ASCVD.

Data Collection

The baseline clinical data of patients were collected, including medical history, personal history, medication history, height, weight, abdominal circumference, and current residence. The data on biochemical indicators (such as total cholesterol, high-density lipoprotein, low-density lipoprotein (LDL), and triglycerides) were also collected.

Sample Size Calculation and Power Analysis

The sample size was determined using the standard formula. Assuming a moderate effect size corresponding to an expected odds ratio (OR) of approximately 3–10 and an estimated risk of ASCVD around 50% (α=0.05), we calculated a necessary sample size of approximately 200 to 350 participants for adequate statistical power.

Power analysis was conducted to validate the statistical power of our sample size, using the following formula: Power = 1 - β, where β indicates Type II error rate (commonly set at 0.2 for 80% power).

Statistical Analysis

Statistical analyses were conducted using SPSS 19.0 software. The normally distributed continuous data are expressed as mean ± standard deviation, and comparisons between two groups were performed using independent samples *t*-test. The non-normally distributed continuous data are expressed as median (interquartile range), and group comparisons were conducted using the Kruskal–Wallis *H*-test. Categorical data are presented as counts (percentages) and were analyzed using the χ^2-test. A *P*-value of < 0.05 was considered statistically significant.

Binary logistic regression was used to analyze the relationships between the factors in the model and the risk for moderate-to-high 10-year ASCVD and myocardial ischemia. The factors analyzed in the model included AHI, hypoxic burden quartiles, percentage of total sleep time with apneas, percentage of total sleep time with hypopneas, percentage of total sleep time with apneas and hypopneas, T90%, T85%, T80%, and grade of lowest blood oxygen saturation. Hypoxic burden, percentage of total sleep time with hypopneas, percentage of total sleep time with apneas, and percentage of total sleep time with apneas and hypopneas were categorized into four quartiles. Confounders including gender, age, waist circumstance, total cholesterol, high-density lipoprotein, treated or untreated systolic blood pressure, current smoking (yes/no), diabetes mellitus (yes/no), and family history of ASCVD were adjusted. The OR and 95% confidence interval (CI) values were recorded. The receiver operating characteristic (ROC) curve was plotted to assess the diagnostic values of the hypoxic burden and T90%. The area under the curve (AUC), *P*-value, the optimal cut-off value, sensitivity, specificity, and Youden's index were calculated. The maximum Youden's index corresponds to the optimal balance of sensitivity and specificity, thereby determining the optimal cutoff value.

Results

Baseline Clinical Data of Patients

This study included a total of 311 hospitalized patients diagnosed with OSA from January 2022 to March 2024. Basic clinical information of the patients is summarized in Table 1. The median age of the included patients was 53 years, with 75.6% being male and 24.4% female. Among the patients, 51.4% (160 cases) showed ECG changes of myocardial ischemia. Additionally, 55.3% (172 cases) had moderate-to-high 10-year ASCVD risk. As shown in Table 2, the first to third hypoxic burden quartiles for patients with low 10-year ASCVD risk were 44.2 min/h, 73.8 min/h, and 123.4 min/h, respectively. In contrast, the corresponding quartiles for patients with moderate to high risk were 83.0 min/h, 176.1 min/h, and 373.2 min/h. For patients who exhibited negative changes on the ECG indicating myocardial ischemia, the first to third quartiles were 42.8 min/h, 69.8 min/h, and 129.4 min/h, compared to 95.3 min/h, 179.3 min/h, and 384.3 min/h for those with positive changes.

Table 1 Clinical Information of Patients

Category	**N=311**
Male, n (%)	235 (75.6)
Female, n (%)	76 (24.4)
Median age (years)	53 (46–60)
Waist circumference in men (cm)	95.4±8.5
Waist circumference in women (cm)	84.5±10.7
Body mass index (kg/m^2)	27.3±4.5
Hypoxic burden (% min/h)	192.5±12.9
Supine Hypoxic burden (% min/h)	137.6±8.4
Non-supine Hypoxic burden (% min/h)	54.9±5.7
Percentage of total sleep time with hypopnea (%)	6.8±0.32
Percentage of total sleep time with apnea (%)	14.1±0.92
Percentage of total sleep time with apnea and hypopnea (%)	20.9±0.93
T90%	9.9±0.92
T85%	3.8±0.61
T80%	1.8±0.36
Apnea-hypopnea index (times/h)	28.8±1.2
Apnea-hypopnea index 5–15, n (%)	100 (33.2)
Apnea-hypopnea index 15–30, n (%)	99 (31.8)
Apnea-hypopnea index 30–60, n (%)	80 (25.7)
Apnea-hypopnea index >60, n (%)	32 (10.3)
Total cholesterol (mmol/l)	4.90±1.23
High-density lipoprotein (mmol/l)	1.13±0.29
Low-density lipoprotein (mmol/l)	3.19±0.87
Diabetes mellitus, n (%)	37 (11.9)
Hypertension, n (%)	179 (57.6)
Current smoking history, n (%)	104 (33.4)
Family history of cardiovascular disease, n (%)	13 (4.2)
Myocardial ischemia changes on ECG, n (%)	160 (51.4)
Moderate-to-high 10-year ASCVD risk, n (%)	172 (55.3)

Notes: The demographic and clinical characteristics are presented. Data are expressed as mean ± standard deviation, median (interquartile range), or n (%).
Abbreviations: ECG, electrocardiogram; ASCVD, atherosclerotic cardiovascular disease.

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Table 2 The Quartile Distribution of Hypoxic Burden Among Patients with Moderate-to-High ASCVD Risk and Myocardial Ischemia

Index	Hypoxic Burden (% min/h)		
	First Quartile	Second Quartile	Third Quartile
Low 10-year ASCVD risk	44.2	73.8	123.4
Moderate to high 10-year ASCVD risk	83.0	176.1	373.2
Negative myocardial ischemia changes on ECG	42.8	69.8	129.4
Positive myocardial ischemia changes on ECG	95.3	179.3	384.3

Abbreviations: ASCVD, atherosclerotic cardiovascular disease; ECG, electrocardiogram.

Comparison of Sleep Monitoring Characteristics in Patients with Different ASCVD Risk Levels

Kruskal–Wallis *H*-test indicated significant differences in sex, age, and medical history (Table 3). Independent samples *t*-test revealed no significant difference between the low 10-year ASCVD risk group and the moderate-to-high 10-year ASCVD risk group with the lowest blood oxygen saturation (Table 3). However, significant differences were observed in AHI, hypoxic burden, supine hypoxic burden, non-supine hypoxic burden, percentage of total sleep time with apnea, percentage of total sleep time with hypopnea, percentage of total sleep time with apnea and hypopnea, T90%, T85%, and T80% (Table 3).

Table 3 Comparison of Sleep Monitoring Parameters in OSA Patients with Low versus Moderate-to-High 10-year ASCVD Risk

Index	Patients with Low 10-Year ASCVD Risk (n=139)	Patients with Moderate-to-High 10-Year ASCVD Risk (n=172)	*P*-value
Sex (n, %)	Male (94,67.6)	Male (138,80.2)	0.003
Age [years, Q2 (Q1-Q3)]	51 (42–55)	57 (48–65)	0.003
History of diabetes (n, %)	3 (2.0)	34 (20.7)	<0.0001
History of hypertension (n, %)	47 (34.0)	132 (76.8)	<0.0001
Current smoking history (n, %)	36 (28.6)	68 (37.8)	0.011
History of cardio-cerebrovascular disease (n, %)	2 (0.7)	11 (7.3)	0.03
Waist circumference (cm)	89.9±10.5	95.1±10.3	0.289
Body mass index (kg/m^2)	26.0±3.8	28.3±4.8	0.063
Total cholesterol (mmol/l)	4.94±1.08	4.86±1.34	0.004
High-density lipoprotein (mmol/l)	1.17±0.30	1.09±0.29	0.531
Low-density lipoprotein (mmol/l)	3.17±0.76	3.21±0.95	0.009
Hypoxic burden (% min/h)	101.0±111.6	266.4±266.2	<0.0001
Supine hypoxic burden (% min/h)	77.7±73.2	186.0±172.4	<0.0001
Non-supine hypoxic burden (% min/h)	23.3±47.6	80.4±121.6	<0.0001
Apnea-hypopnea index (times/h)	20.7±18.2	35.4±21.3	<0.0001
Percentage of total sleep time with apnea (%)	8.1±10.4	19.0±18.4	<0.0001
Percentage of total sleep time with hypopnea (%)	5.9±4.0	7.8±6.6	<0.0001

(*Continued*)

Table 3 (Continued).

Index	Patients with Low 10-Year ASCVD Risk (n=139)	Patients with Moderate-to-High 10-Year ASCVD Risk (n=172)	*P*-value
Percentage of total sleep time with apnea and hypopnea (%)	14.0±10.9	26.6±17.8	<0.0001
T90%	4.3±11.6	14.4±17.9	<0.0001
T85%	1.3±7.4	5.9±12.5	<0.0001
T80%	0.5±3.3	2.9±7.9	<0.0001
Lowest blood oxygen saturation percentage (%)	78.8±10.9	77.2±10.5	0.950

Notes: Data are presented as mean ± standard deviation, Q2 (Q1-Q3) (for age), or n (%) and were compared using independent samples *t*-test, Kruskal–Wallis *H*-test, and the χ^2-test, respectively.
Abbreviations: OSA, obstructive sleep apnea; ASCVD, atherosclerotic cardiovascular disease; Q1, first quartile; Q2, second quartile; Q3, third quartile; T90%/T85%/T80%, percentage of total sleep time with blood oxygen saturation below 90%, 85%, and 80%.

Analysis of Baseline Clinical Data and Sleep Monitoring Measures Concerning Myocardial Ischemia Changes

As shown in Table 4, the Kruskal–Wallis *H*-test indicated that there were no significant differences in sex and age between patients with and without myocardial ischemia changes on ECG. The independent samples *t*-test showed no significant differences in body mass index, total cholesterol, high-density lipoprotein, or LDL between the two groups. In terms of sleep monitoring indicators, there were no significant differences between the two groups in the percentage of total sleep time with hypopneas, T85%, T80%, or lowest blood oxygen saturation. However, significant differences were found in AHI, hypoxic burden, supine hypoxic burden, non-supine hypoxic burden, percentage of total sleep time with apneas, percentage of total sleep time with apneas and hypopneas, and T90% between the two groups.

Table 4 Comparison of Clinical Data and Sleep Monitoring Indicators Between Patients with and without Myocardial Ischemia Changes on ECG

Variables	Negative Ischemia Change on ECG (n=151)	Positive Ischemia Change on ECG (n=160)	*P*-value
Sex (n, %)	Male (113, 74.8)	Male (112, 70)	0.616
Age (years)	53 (47–59)	54 (45–61)	0.880
Body mass index (kg/m^2)	26.3±4.1	28.2±4.7	0.062
Total cholesterol (mmol/l)	4.87±1.14	4.91±1.31	0.622
High-density lipoprotein (mmol/l)	1.13±0.27	1.12±0.32	0.737
Low-density lipoprotein (mmol/l)	3.14±0.82	3.24±0.91	0.809
Hypoxic burden (% min/h)	98.1±83.0	281.5±278.0	<0.0001
Supine hypoxic burden (% min/h)	77.1±65.0	194.7±177.6	<0.0001
Non-supine hypoxic burden (% min/h)	21.0±28.6	86.8±128.7	<0.0001
Apnea-hypopnea index (times/h)	19.6±13.4	37.5±23.5	<0.0001
Percentage of total sleep time with apnea (%)	7.6±8.6	20.3±19.2	<0.0001
Percentage of total sleep time with hypopnea (%)	5.9±5.1	7.7±5.9	0.069

(*Continued*)

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Table 4 (Continued).

Variables	Negative Ischemia Change on ECG (n=151)	Positive Ischemia Change on ECG (n=160)	*P*-value
Percentage of total sleep time with apnea and hypopnea (%)	13.5±9.3	27.9±18.3	<0.0001
T90%	4.0±9.6	15.5±18.9	0.003
T85%	1.1±7.3	6.4±12.7	0.084
T80%	0.3±2.4	3.2±8.4	0.111
Lowest blood oxygen saturation percentage (%)	78.2±10.6	77.7±10.8	0.666

Notes: Data are expressed as mean ± standard deviation, median (interquartile range), or n (%) and were compared using independent samples *t*-test, Kruskal–Wallis *H*-test, and the χ^2-test, respectively.
Abbreviations: ECG, electrocardiogram; T90%/T85%/T80%, percentage of total sleep time with blood oxygen saturation below 90%, 85%, and 80%.

Analysis of Factors Influencing 10-Year ASCVD Risk and Myocardial Ischemia in OSA Patients

The binary logistic regression analysis was then performed to evaluate factors influencing 10-year ASCVD risk and myocardial ischemia in OSA patients. The factors included in the model were hypoxic burden grading, AHI grading, percentage of total sleep time with hypopnea, percentage of total sleep time with apnea, percentage of total sleep time with apnea and hypopnea, T90%, T85%, and T80%. Our results showed that hypoxic burden and T90% were significantly associated with the high 10-year ASCVD risk in OSA patients. For the index of hypoxic burden grade, the P-value was 0.024, while hypoxic burden between 75%-100% quartile showed statistically significant risk compared with patients in 0%-25% quartile (Q1), with an OR of 13.5 and a 95% CI of 1.684 to 109.051 (Table 5). For T90%, the P-value was 0.022, with an OR of 1.085 and a 95% CI of 1.012 to 1.164 (Table 5). Similarly, hypoxic burden grade and T90% were significantly associated with myocardial ischemia in patients with OSA. For the index of hypoxic burden grade, the P-value was 0.044. Both Q2, Q3, and Q4 exhibited statistically significant risks compared to patients in the 0%-25% quartile (Q1), with P-values of 0.011, 0.008, and 0.048, respectively. The OR was 3.241 (95% CI: 1.306–8.043), 4.497 (95% CI: 1.494–13.538), and 4.850 (95% CI: 1.017–23.139) for Q2, Q3, and Q4, respectively. For T90%, the P-value was 0.019, with an OR of 1.059 and a 95% CI of 1.009 to 1.110 (Table 6). Additionally, the power analysis showed that with the expected ORs of the hypoxic burden ranging from 3 to 11, our study provided a power greater than 90%. For

Table 5 Analysis of Risk Factors for High 10-Year ASCVD Risk in OSA Patients

Factors	B	*P*-value	OR	95% CI for OR	
				Lower Limit	Upper Limit
Quartiles of hypoxic burden		0.024			
Quartiles of hypoxic burden (Q2)	−0.020	0.969	0.980	0.347	2.766
Quartiles of hypoxic burden (Q3)	0.036	0.956	1.036	0.291	3.685
Quartiles of hypoxic burden (Q4)	2.606	0.014	13.550	1.684	109.051
T90%	0.082	0.022	1.085	1.012	1.164
T85%	−0.159	0.045	0.853	0.730	0.997
T80%	0.109	0.370	1.115	0.879	1.415
Lowest blood oxygen saturation level		0.083			

(*Continued*)

Table 5 (Continued).

Factors	B	*P*-value	OR	95% CI for OR	
				Lower Limit	Upper Limit
Mild	1.196	0.083	3.308	0.854	12.823
Moderate	1.498	0.028	4.473	1.175	17.025
Severe	1.698	0.011	5.463	1.472	20.284
AHI grade		0.075			
Moderate	0.500	0.344	1.649	0.584	4.654
Severe	0.875	0.311	2.399	0.442	13.021
Very severe	−1.249	0.363	0.287	0.019	4.224
Percentage of total sleep time with apnea	−10.715	0.010	0.000	0.000	0.079
Percentage of total sleep time with hypopnea	−10.696	0.010	0.000	0.000	0.081
Percentage of total sleep time with apnea and hypopnea	10.708	0.010	44,732.210	12.655	158,118,056.892

Notes: The binary logistic regression analysis was conducted to evaluate factors influencing 10-year ASCVD risk in OSA patients.
Abbreviations: OR, odds ratio; 95% CI, 95% confidence interval; AHI, apnea-hypopnea index; OSA, obstructive sleep apnea; ASCVD, atherosclerotic cardiovascular disease; Q2/Q3/Q4: 25%-50% quartile/50%-75% quartile/75%-100% quartile; T90%/T85%/T80%, percentage of total sleep time with blood oxygen saturation below 90%, 85%, and 80%.

Table 6 Analysis of Risk Factors for Myocardial Ischemia in OSA Patients

Factors	B	*P*-value	OR	95% CI for OR	
				Lower Limit	Upper Limit
Quartiles of hypoxic burden		0.044			
Quartiles of hypoxic burden (Q2)	1.176	0.011	3.241	1.306	8.043
Quartiles of hypoxic burden (Q3)	1.503	0.008	4.497	1.494	13.538
Quartiles of hypoxic burden (Q4)	1.579	0.048	4.850	1.017	23.139
T90%	0.057	0.019	1.059	1.009	1.110
T85%	−0.121	0.095	0.886	0.769	1.021
T80%	0.163	0.331	1.177	0.847	1.635
Lowest blood oxygen saturation level		0.308			
Mild	0.622	0.257	1.863	0.636	5.463
Moderate	0.668	0.214	1.951	0.680	5.601
Severe	0.949	0.063	2.582	0.950	7.022
AHI grade		0.699			
Moderate	−0.105	0.808	0.901	0.387	2.095
Severe	−0.742	0.301	0.476	0.117	1.942
Very severe	−1.054	0.362	0.349	0.036	3.358
Percentage of total sleep time with apnea	1.003	0.757	2.727	0.005	1569.364

(*Continued*)

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Table 6 (Continued).

Factors	B	*P*-value	OR	95% CI for OR	
				Lower Limit	Upper Limit
Percentage of total sleep time with hypopnea	1.022	0.753	2.780	0.005	1612.498
Percentage of total sleep time with apnea and hypopnea	−0.949	0.770	0.387	0.001	222.548

Notes: The binary logistic regression analysis was used to evaluate factors affecting myocardial ischemia in OSA patients.
Abbreviations: OR, odds ratio; 95% CI, 95% confidence interval; AHI, apnea-hypopnea index; OSA, obstructive sleep apnea; Q2/Q3/Q4: 25%-50% quartile/50%-75% quartile/75%-100% quartile; T90%/T85%/T80%, percentage of total sleep time with blood oxygen saturation below 90%, 85%, and 80%.

T90%, even though the ORs were between 1.059 and 1.085, as a continuous variable, the analysis indicated that changes in this index across its range still resulted in sufficient power, estimated between 85% and 92%, confirming the reliability of our findings. These results revealed a significant association between T90% and hypoxic burden with high 10-year ASCVD risk and myocardial ischemia.

ROC Curve analysis of the Diagnostic Value of Hypoxic Burden for Moderate-to-High 10-Year ASCVD Risk and Myocardial Ischemia in OSA Patients

To determine the value of the hypoxic burden and T90% in diagnosing 10-year ASCVD risk and myocardial ischemia, the ROC curve was plotted. The results showed that the hypoxic burden and T90% (Figure 1) had diagnostic values for moderate-to-high 10-year ASCVD risk (Table 7). For hypoxic burden, the area under the curve was 0.747, with P<0.0001. The Youden's index was used to determine the cut-off value of the hypoxic burden, which was 125.8 (% min/h). The corresponding sensitivity and specificity were 62.2% and 77.0%, respectively. For T90%, the AUC was

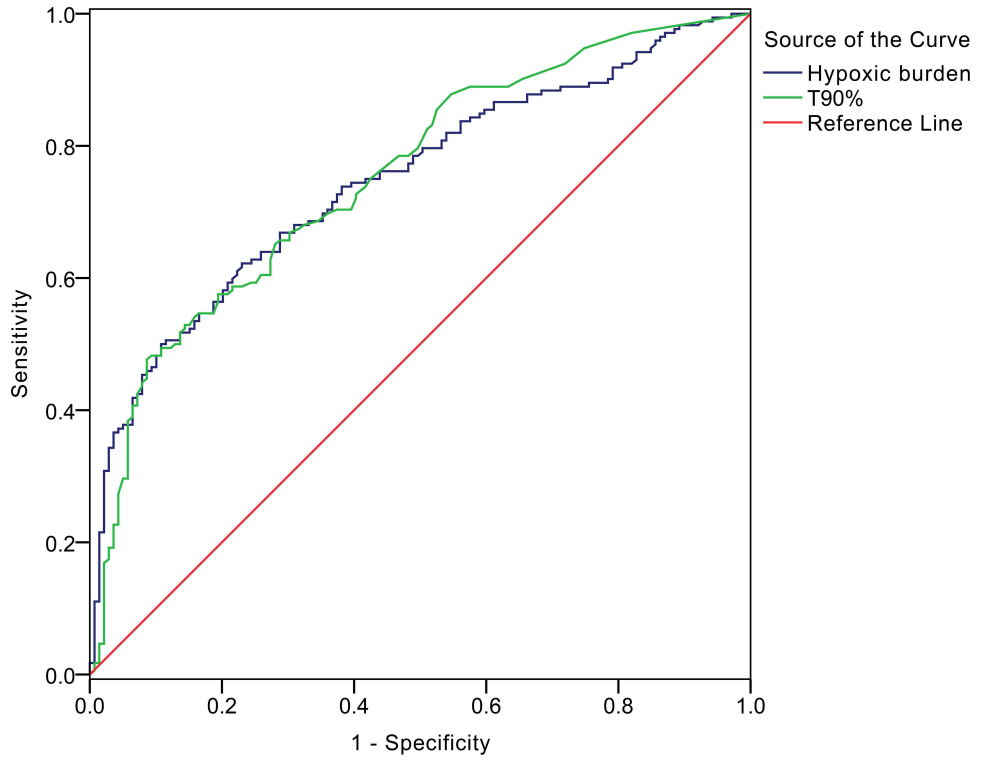

Figure 1 ROC curve analysis of hypoxic burden and T90% in diagnosing moderate-to-high 10-year ASCVD risk in OSA patients.

Table 7 Diagnostic Value of Hypoxic Burden and T90% for Moderate-to-High 10-Year ASCVD Risk in OSA Patients

Index	AUC	*P*-value	Optimal Cut-Off Value	Sensitivity (%)	Specificity (%)	Youden's Index
Hypoxic burden (%min/h)	0.747	< 0.0001	125.8	62.2	77.0	0.392
T90%	0.754	< 0.0001	3.05%	65.1	71.9	0.371

Abbreviations: AUC, area under the curve. T90%, percentage of total sleep time with blood oxygen saturation below 90%.

0.754. The cut-off value of T90% was 3.05%, with the corresponding sensitivity and specificity of 65.1% and 71.9%, respectively.

Similarly, the hypoxic burden and T90% (Figure 2) also showed diagnostic values for myocardial ischemia (Table 8) in OSA patients. The AUC for the hypoxic burden and T90% was 0.769 and 0.741, respectively. The cut-off value for the hypoxic burden was 112.6 (%min/h), with a sensitivity of 70.6% and a specificity of 70.2%. For T90%, the cut-off value was 4.20%, the sensitivity was 60.6%, and the specificity was 77.5%.

Discussion

The results of this study revealed a strong association between hypoxic burden and T90% and both moderate-to-high 10-year ASCVD risk and myocardial ischemia in OSA patients. These indicators, reflecting the intensity and duration of hypoxic events during sleep, provided valuable insights into the severity of OSA and its cardiovascular implications. In fact, the cutoff values derived from this study are highly consistent with clinically observed OSA severity and have significant implications for evaluating patients with a high AHI, short-duration events, and low overall nocturnal hypoxia. These metrics provide essential clinical guidance in determining whether patients require more aggressive treatments, such as continuous positive airway pressure therapy. Rather than relying solely on AHI and minimum oxygen saturation for severity assessment, clinicians are more inclined to consider measures of hypoxia duration and intensity. The hypoxic burden index and T90% more accurately meet the requirements of clinicians. Notably, the traditional evaluation indicators, such as AHI and the lowest blood oxygen saturation, did not have such associations, highlighting

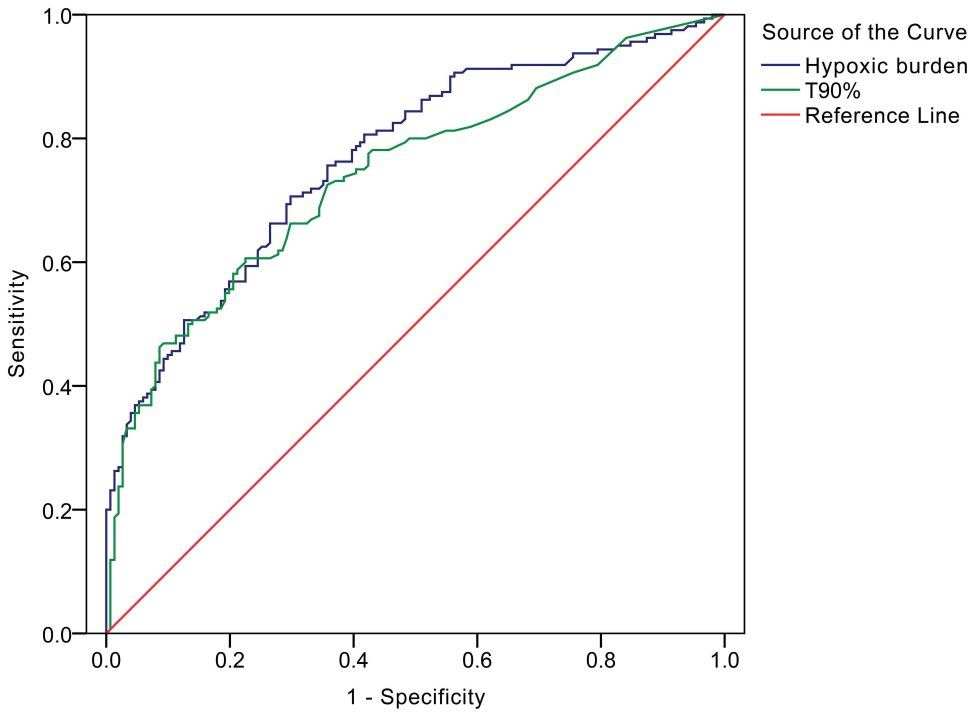

Figure 2 ROC curve analysis of hypoxic burden and T90% in diagnosing myocardial ischemia in OSA patients.

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Table 8 Diagnostic Value of Hypoxic Burden and T90% for Myocardial Ischemia in OSA Patients

Index	AUC	*P*-value	Optimal Cut-Off Value	Sensitivity (%)	Specificity (%)	Youden's Index
Hypoxic burden (%min/h)	0.769	< 0.0001	112.6	70.6	70.2	0.408
T90%	0.741	< 0.0001	4.2	60.6	77.5	0.381

Abbreviations: AUC, area under the curve. T90%, percentage of total sleep time with blood oxygen saturation below 90%.

the limitations of current OSA severity assessment indicators. The higher hypoxic burden and T90% underscore the risk of intensity and duration of hypoxic events in 10-year ASCVD risk and myocardial ischemia for OSA patients. Additionally, the findings emphasize the importance of incorporating these advanced indicators into routine clinical practice for a more comprehensive evaluation of cardiovascular risk in OSA patients. These indicators can help clinicians identify high-risk patients early and develop tailored treatment strategies.

The association of cardiovascular risk with hypoxic events in OSA patients is receiving increasing attention. Previous studies[1,2,10,11,19] have indicated that recurrent hypoxia in OSA is related to pulmonary hypertension and vascular and microvascular diseases. The oxygen desaturation index, a critical metric that measures hypoxic burden, links OSA to cardiovascular conditions in the context of hypoxia. It is correlated with the body roundness index, a novel body metric used to define and predict cardiovascular risk in patients with OSA.[20] However, the relationship between hypoxic events and patient prognosis still requires further investigation. The hypoxic burden, which reflects the intensity and duration of hypoxic events, can be automatically calculated by advanced sleep monitoring data analysis software. The T90% reflects the total time spent with blood oxygen saturation below 90% throughout the night, providing insight into the overall severity of OSA during the night.[22] This study indicates that the hypoxic burden and T90% were significantly related to both the 10-year ASCVD risk and myocardial ischemia. As the increase of the hypoxic burden, the risk of moderate-to-high 10-year ASCVD and myocardial ischemia also elevated. Although previous studies have investigated the relationship between T90% and hypoxic burden-related indicators and cardiovascular disease, there is currently a lack of cut-off values for these indicators for risk prediction, leading to an inability to classify the severity of patients and resulting in different research conclusions.[26,27] This study established cut-off values for T90% and hypoxic burden in predicting the risk of myocardial ischemia and cardiovascular disease. These results may provide a basis for defining the severity and offer important guidance for the clinical treatment of myocardial ischemia and cardiovascular complications in patients with OSA.

PSG is limited in clinical use due to its high cost and complex operation. Portable sleep monitors, however, show high consistency with PSG in diagnosing OSA.[23] This study utilized portable sleep monitoring and included 311 OSA patients of different ages and genders from southern China. Given that the portable sleep monitor we used in this study is validated for accuracy and reliability against traditional PSG, it enables clinicians to perform comprehensive assessments in a variety of settings, including home care. This flexibility allows for the timely identification of at-risk patients and could facilitate earlier interventions, which are critical for aggressive management strategies in OSA. Furthermore, the China-PAR model, which is tailored for the Chinese population, was used to assess the 10-year ASCVD risk, allowing for an evaluation of long-term cardiovascular risk. Additionally, ECG was used to assess current myocardial ischemia, providing a comprehensive assessment of both long-term cardiovascular risk and current myocardial ischemia risk in OSA patients.

This study has some limitations. For example, the exclusion of patients with electrolyte disturbances and kidney insufficiency might have underestimated the impact of oxygen desaturation on myocardial ischemia and cardiovascular risk assessment. Another limitation of this study is the modest AUC values and small ORs of the hypoxic burden and T90%, which may limit their clinical utility. Further research is warranted to confirm our findings and explore the applicability of these indices in diverse clinical settings.

Conclusion

This study demonstrates that hypoxic burden and T90% are valuable indicators for assessing cardiovascular risk and myocardial ischemia in OSA patients. These metrics have diagnostic potential for identifying myocardial ischemia and cardiovascular diseases, with implications for clinical practice. While these findings highlight the diagnostic potential of nocturnal hypoxia monitoring for cardiovascular complications, our study is single-center research; further validation in larger, prospective cohorts is necessary before widespread clinical adoption. Additionally, the impact of hypoxia on both short-term and long-term cardiovascular risk events in OSA patients warrants further research and attention.

Abbreviations

OSA, Obstructive sleep apnea; ASCVD, Atherosclerotic cardiovascular disease; PSG, Polysomnography; ECG, Electrocardiogram.

Data Sharing Statement

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

Author Contributions

Wenmei Zeng: Conceptualization, Methodology, Resources, Software, Funding acquisition, Writing – original draft, Writing – review & editing. Sulong Wu: Conceptualization, Methodology, Resources, Writing – original draft, Writing – review & editing. Zhuofan Liu: Conceptualization, Investigation, Resources, Writing – review & editing. Long Yuan: Conceptualization, Investigation, Resources, Writing – review & editing. Bilin Chen: Software, Methodology, Resources, Writing – review & editing. Yan Rong: Conceptualization, Funding acquisition, Formal analysis, Data curation, Writing – review & editing, Project administration. All authors gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors report no conflicts of interest in this work.

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