Twenty-Four-Hour Ambulatory Oxygen Desaturation and Electrocardiographic Recording in Obstructive Sleep Apnea Syndrome

AKIKO NODA, PH.D.,* RIEKO ITO,† TAMOTSU OKADA, M.D., PH.D.,‡ FUMIHIKO YASUMA, M.D., PH.D., FCCP,§
NOBUO NAKASHIMA, M.D., PH.D.,† MITSUHIRO YOKOTA, M.D., PH.D., FACC†

*Nagoya University School of Health Sciences, †Department of Clinical Laboratory Medicine, ‡Nagoya University College of Medical Technology, §The First Department of Internal Medicine, Nagoya University Hospital, Nagoya, Japan

Summary

Background: Although nocturnal pulseoximetry is routinely performed in obstructive sleep apnea syndrome (OSAS), pulseoximetry over a 24-h period has not been studied.

Hypothesis: The purpose of the study was to determine whether simultaneous 24-h oxygen desaturation and electrocardiographic (ECG) recording might be used to screen for daytime sleep sequelae in patients with OSAS.

Methods: Simultaneous recording of arterial oxygen saturation (SpO₂) and ECG was conducted over a 24-h period in 18 male patients with OSAS (mean age 51.3 years) who were diagnosed by standard polysomnography (PSG), and in 15 age-matched healthy subjects (mean age 52.7 years) as controls to evaluate circadian variation of these parameters. The measures of heart rate variability (HRV) were calculated from 24-h ambulatory ECGs. Seventeen patients with OSAS showed excessive daytime sleepiness (EDS). We calculated the duration in which SpO₂ decreased to <90% (duration of SpO₂<90%). The number of apnea/hypopneas per hour (AHI) during sleep was investigated with Apnomonitors (Chest MI, Co., Tokyo) on the same day as the SpO₂ recordings.

Results: Controls showed no episodes of oxygen desaturation. In patients with OSAS, driving (33.3% of patients with OSAS) was the most common activity in which SpO₂ decreased to <90%, followed by daytime napping (27.8%) and resting after meals (22.2%). The duration of SpO₂<90% over a 24-h period correlated significantly with the duration levels

recorded during sleep ($r = 0.99$, $p < 0.05$) and in the afternoon ($r = 0.62$, $p < 0.05$), and with the AHI ($r = 0.55$, $p < 0.05$), but not with the duration of SpO₂<90% in the morning. The number of ventricular premature beats correlated significantly with the duration of SpO₂<90% for a 24-h period, but not with measures of HRV. Ventricular tachycardia was found in two (11.1%) and ST-T depression in three patients (16.6%) with underlying cardiac diseases.

Conclusion: Our results suggest that daytime sleep attacks accompanied by oxygen desaturation in patients with moderate to severe OSAS may contribute to the occurrence of traffic or cardiovascular accidents. We conclude that 24-h ambulatory recordings of SpO₂ and ECG are useful for screening for daytime sleep sequelae associated with the potential risk of this pathology in OSAS during social activities.

Key words: oxygen desaturation, sleep apnea syndrome, electrocardiography, excessive daytime sleepiness, 24-h SpO₂ recording

Introduction

Sleep apnea can lead to hypoxia, hypercapnia, and respiratory acidosis,^{1,2} and nocturnal measurement of arterial oxygen desaturation is used for screening of sleep apnea syndrome (SAS).^{3,4} Increased mortality in obstructive sleep apnea syndrome (OSAS)^{5–9} is mainly attributed to the involvement in traffic accidents^{10–12} and complication of cardiovascular diseases such as cardiac arrhythmias.^{13–15} Several studies demonstrated an increased rate of car crashes and poor driving performance in subjects with sleep apnea. Some traffic accidents as a result of OSAS seem to occur while driving and to be caused by excessive daytime sleepiness (EDS), which is a consequence of a disturbed sleep with frequent apneas.^{10–12} Although arterial oxygen desaturation may occur during daytime activities as well as during night sleep, pulseoximetry over a 24-h period has not been studied in OSAS.

Accordingly, we examined the usefulness of 24-h monitoring of SpO₂ and electrocardiogram (ECG), and evaluated the relationship between sleep-disordered breathing and cardiac arrhythmia or ST-T changes in 24-h ECGs.

Address for reprints:

Mitsuhiko Yokota M.D., Ph.D., FACC
Cardiovascular Section
Department of Clinical Laboratory Medicine
Nagoya University Hospital
Tsurumai-cho, Showa-ku
Nagoya 466, Japan

Received: February 9, 1998

Accepted with revision: April 22, 1998

Methods

We studied 18 men with OSAS (aged 39 to 68 years, mean age 51.3 years) who were diagnosed by standard polysomnography¹⁶ (PSG), and 15 age-matched healthy men without OSAS (mean age 52.7 years) as controls. Fourteen patients with OSAS had EDS; 3 patients had EDS and insomnia; 7 patients had hypertension (systolic blood pressure ≥ 160 mmHg or diastolic blood pressure ≥ 95 mmHg); 4 patients had hypertension and left ventricular hypertrophy (end-diastolic left ventricular wall thickness ≥ 12 mm); 1 patient had hypertension, left ventricular hypertrophy, and old myocardial infarction; and 1 patient had transient atrial fibrillation. No patient with OSAS had severe lung disease or congestive heart failure.

Using an ambulatory pulseoximeter (Pulsox 5, Minolta Co., Tokyo), we measured arterial oxygen saturation (SpO₂) and heart rate for 24 h in each subject, with a sampling taken every 5 s. Data were stored in a memory card (MC-8) and then heart rate and SpO₂ were analyzed with a microcomputer (PC-9801-VX, NEC, Japan). We calculated the duration in which SpO₂ decreased to $< 90\%$ (duration of SpO₂ $< 90\%$) over a 24-h period: during sleep, during daytime, in the morning, and in the afternoon, respectively. We expressed SpO₂ data graphically by a plotter (PC-8826, NEC), which identified a decrease in SpO₂ of $> 4\%$ in 5 s. Details of computer analysis of SpO₂ data have been described elsewhere.¹⁷

On the same day, the number of apnea/hypopneas per h (AHI) was recorded during sleep at home using an Apno-monitor¹⁸ (Chest MI, Co., Tokyo), and 24-h ambulatory ECG recordings were obtained by Holter monitor (Marquette Electronics, Inc., Milwaukee, Wis.), with bipolar leads of CM₅ (standard V₅ leads position) and CC₅. During ECG monitoring, each subject performed his daily routine and kept a diary of symptoms and physical activities (waking, sleeping, exercise, etc.).

We measured heart rate variability (HRV) for evaluation of autonomic activity. Power spectral analysis was performed with the Marquette 8000/T system and R-R interval analysis software (version 002A). QRS complexes were identified, and only normal-to-normal intervals were analyzed. The results were calculated by 256-point Fourier transformation. Marquette spectral measures were computed hourly, and the overall average of the test duration was determined. These data were quantified by area in two frequency bandwidths: 0.04 to 0.15 Hz (low frequency power): LF ln(ms²), and 0.15 to 0.40 Hz (high frequency power): HF ln(ms²), and are expressed in units of ms² (squared amplitude). The values were transformed in a log scale.

The following nonspectral indices were determined: The mean of all coupling intervals between normal beats (mean NN), the standard deviation of the mean NN (SDNN), the standard deviation of the 5-min mean R-R intervals (SDANN), the mean of all 5-min standard deviations of RRs (SD), the root-mean square of the difference in the successive RRs (rMSSD), and the proportion of adjacent RRs showing a difference of > 50 ms (pNN50).

Statistics

Results are expressed as mean $\pm$ SD. Data were analyzed by analysis of variance (ANOVA). A probability (p) value of < 0.05 was considered statistically significant. Correlations were determined by linear regression analysis.

Results

Table I shows the characteristics of the patients with OSAS. Twenty-four-hour mean lowest SpO₂ and duration of SpO₂ $< 90\%$ were 58.3% (38–77%) and 132 min (41–432 min). The controls showed no episodes of oxygen desaturation $< 90\%$. In

TABLE I Characteristics of patients with obstructive sleep apnea syndrome (OSAS)

Age (years)	51.3 $\pm$ 10.9 (28–68)
Height (cm)	167 $\pm$ 4.98 (162–182)
Weight (kg)	77.1 $\pm$ 10.2 (60–100)
BMI (kg/m ²)	27.7 $\pm$ 2.89 (24–35)
AHI (/h)	45.1 $\pm$ 15.8 (24–77)
Measurement of 24-h heart rate variability	
Low frequency [ln(ms ²)]	5.59 $\pm$ 0.79 (4.71–7.25)
High frequency [ln(ms ²)]	4.21 $\pm$ 0.81 (3.11–5.93)
meanNN (ms)	752 $\pm$ 84.1 (587–861)
SDNN (ms)	112 $\pm$ 30.1 (71–183)
SDANN (ms)	95.9 $\pm$ 31.2 (49–152)
SD (ms)	48.3 $\pm$ 17.4 (31–95)
rMSSD (ms)	22.7 $\pm$ 9.92 (14–38)
pNN50 (%)	4.89 $\pm$ 6.02 (0.7–24.4)
24-H monitoring by Pulsox 5	
Lowest SpO ₂ (%)	58.3 $\pm$ 13.1 (38–77)
Duration of SpO ₂ $< 90\%$ (min) ^a	132 $\pm$ 118 (41–432)
During sleep	
Lowest SpO ₂ (%)	62.0 $\pm$ 14.0 (38–82)
Duration of SpO ₂ $< 90\%$ (min) ^a	112 $\pm$ 106 (39–360)
During the day	
Lowest SpO ₂ (%)	67.8 $\pm$ 12.6 (44–93)
Duration of SpO ₂ $< 90\%$ (min) ^a	19.6 $\pm$ 20.6 (0–87)
Activity in which the duration of SpO ₂ $< 90\%$	
Driving	6 (33.3%)
Daytime sleep	5 (27.8%)
Resting after meal	4 (22.2%)

Mean $\pm$ standard deviation.

^a Duration of SpO₂ $< 90\%$: The duration of nocturnal oxygen saturation $< 90\%$.

Abbreviations: BMI = body mass index, AHI = number of apnea/hypopnea episodes per hour, mean NN = mean of all coupling intervals between normal beats, SDNN = standard deviation of the mean NN, SDANN = standard deviation of the 5-min R-R intervals, rMSSD = root-mean square of the difference in the successive RRs, pNN50 = proportion of adjacent RRs showing a difference of > 50 ms, SpO₂ = arterial oxygen saturation.

TABLE II Incidence of ventricular premature beat and supraventricular premature beat

	30/h [†]	10/h [†]	Couplet	Run
VPB (%)	1 (5.5)	2 (11.1)	2 (11.1)	2 (11.1)
SVPB (%)	1 (5.5)	0 (0)	8 (44.4)	3 (27.2)

Abbreviations: VPB = ventricular premature beat, SVPB = supraventricular premature beat.

patients with OSAS, we found that SpO₂ decreased <90%, not only during nighttime sleep but also during daytime naps, and some daytime naps were asymptomatic (Figs. 1, 2). Driving a car was the most common activity during which the level of SpO₂ fell <90% (33.3% of patients with OSAS), followed by daytime napping (27.8%) and resting after meals (22.2%) (Table I).

The duration of SpO₂ <90% during 24-h monitoring correlated with the duration levels recorded during sleep ($r = 0.99$, $p < 0.05$), in the afternoon ($r = 0.62$, $p < 0.05$), and with AHI ($r = 0.55$, $p < 0.05$), but not with the duration of SpO₂ <90% in the morning. There was no difference in the duration of SpO₂ <90% between its occurrence in the morning and in the afternoon.

Table II summarizes the findings on cardiac arrhythmias detected during 24-h ambulatory ECG monitoring. Ventricular tachycardia was observed in two (11.1%) patients with OSAS and cardiac diseases and was recorded during daytime in the one and during night sleep in the other. Obstructive sleep apnea syndrome was severe in one and moderate in the other: one patient had complicated myocardial infarction and hypertension, and the other had complicated hypertension and mild aortic and mitral regurgitation. No patient had abnormal bradyarrhythmias or conduction defects. The duration of SpO₂ <90% significantly correlated with the number of ventricular premature beats, but not with the number of supraventricular premature beats (Table III). Low frequency (LF) and SD correlated significantly with age (LF: $r = 0.66$, $p < 0.005$, SD: $r = 0.48$, $p < 0.05$), but there was no relationship between the number of ventricular premature beats and age, basal heart rate, or time and frequency domain measures of HRV. ST-T depression was present in three patients and occurred in one patient accompanied by sleep apnea.

Discussion

The prevalence of SAS in the working population is estimated to be 2.0% in women and 4.0% in men.¹⁹ Various psychosocial problems such as hypersomnolence during social activities or traffic accidents caused by falling asleep while driving are known to be the sequelae of OSAS.¹⁰⁻¹²

Our results showed that daytime oxygen desaturation occurred during driving in 33.3% (6/18) of the patients with OSAS. To prevent traffic accidents, the driver with severe OSAS before treatment should be restricted to using public

TABLE III Correlation between number of ventricular premature beats and supraventricular premature beats and the severity of sleep apnea syndrome

	AHI	Duration of SpO ₂ <90%	
		24 h	Sleep
VPB	NS	0.67 ^a	0.58 ^a
SVPB	NS	NS	NS

^a $p < 0.05$.

Abbreviations: AHI = number of apnea/hypopneas per hour. Other abbreviations as in Table II.

transportation or to driving in the company of another driver to replace him if needed. Using 24-h ambulatory pulseoxime-

FIG. 1 Twenty-four-h oxygen desaturation recording in a patient with obstructive sleep apnea syndrome (OSAS). For the oxygen saturation axis (the vertical axis), the hashmarks represent 100, 80, and 60%. The 60% level hashmark also represents the 100% level for the next hour. Oxygen saturation in this case was recorded from 2 P.M. on Day 1 to 2 P.M. on Day 2. This patient (43 years old, male) with an apnea/hypopnea index of 40.0, suffered from severe OSAS. He showed symptoms of excessive daytime sleepiness. Notable falls of SpO₂ <80% were detected in this patient during resting after meals (from about 11:40 A.M. to 12:10 P.M.) and in the afternoon (from 5:10 P.M. to 5:55 P.M.), but he did not recognize these symptoms.

FIG. 2 The duration of oxygen desaturation (top) and the level of SpO₂ (bottom) for 24 h in the same patient as in Figure 1.

try, the patient, as well as medical staffs, would be aware of those daytime activities during which unrecognized sleep and subsequent oxygen desaturation frequently occurred, and thus could control the involvement of these activities with the risk. Therefore, we stress the clinical usefulness of 24-h SpO₂ recording.

The increased morbidity and mortality rate in patients with severe OSAS can be attributed mainly to its coexistence with various cardiovascular diseases.⁵⁻⁹ Although the mechanism of cardiac arrhythmias associated with sleep apnea is not completely understood, autonomic nervous system imbalance and the degree of oxygen desaturation caused by frequent apneas may be related to the occurrence of cardiac arrhythmias.^{1, 2, 13-15} In our study, there was no significant correlation with the number of ventricular premature beats and measures of HRV or age which influence autonomic control of the cardiovascular system in OSAS; however, we found a significant correlation between the number of ventricular premature beats and the degree of oxygen desaturation. Recent reports²⁰ have suggested that prevalence of cardiac arrhythmias was low in OSAS patients without serious cardiac or respiratory disease, and sleep apnea did not convey an increased risk for cardiac arrhythmias to most patients. The severity of OSAS as well as the condition of other underlying disease may account for differences in the relationship between cardiac arrhythmias and OSAS. All patients in our study had moderate to severe OSAS (AHI ≥ 20), and in 13 of 18 patients (72.2%) OSAS was complicated by cardiac disease. In particular, ventricular tachycardia and ST-T depression occurred in patients with severe OSAS and cardiovascular complications. Our findings suggest that patients with

severe OSAS, who have concomitant underlying cardiac disease and recurring episodes of oxygen desaturation, may be at increased risk for developing ventricular arrhythmias and ischemic changes even during daytime sleep.

The present study revealed that decrease in SpO₂ occurring during nocturnal sleep was related to levels of SpO₂ recorded in the afternoon, but not in the morning, stressing the clinical importance of 24-h SpO₂ recording in OSAS. Afternoon nap OSAS was frequently recognized by the patients but, in contrast, morning sleep OSAS was not, which may account for the difference between morning sleep and afternoon nap. However, other factors such as severity of OSAS,²¹ sleep stage, or sleep latency in daytime sleep²² and daytime activities might account for this difference.

Recordings of tracheal sound and nasal flow with an Apno-monitor²³ were used for screening of sleep apnea,^{18, 23} but this posed technical difficulties for daytime recordings. Okada *et al.*³ and Lugaresi *et al.*⁴ noted the importance of evaluating SpO₂ levels to assess the severity of apnea/hypopnea. Since it is possible to go about one's daily activities while using a pulseoximeter, 24-h monitoring of ECG and SpO₂ with the Pulsox-5 is a practical method for detecting sleep-disordered breathing associated with potential risk during the day.^{24, 25}

Conclusion

It is important to screen for daytime sleep attacks accompanied by oxygen desaturation in patients with OSAS and to take appropriate therapeutic and preventive measures, as these attacks may contribute to the occurrence of traffic or cardiovascular accidents. Therefore, we confirm the clinical usefulness of 24-h ambulatory pulseoximetry and ECG recording for the evaluation, in particular, of the daytime sequelae of OSAS.

Acknowledgment

The authors thank Dr. Masayoshi Terashima, Dr. Tatsuro Ohta, and Hiroko Inoue for their support.

References

1. Shepard JW: Hemodynamics in obstructive sleep apnea. In *Abnormalities of Respiration during Sleep* (Ed. Fletcher EC), p. 39-61. Philadelphia: Grune & Stratton, Inc., 1986
2. Strohl KP, Saunders NA, Sullivan CE: Sleep apnea syndrome. In *Sleep and Breathing* (Eds. Saunderson NA, Sullivan CE), p. 365-402. New York: Marcel Dekker, Inc., 1984
3. Okada T, Nakahara D, Ozaki N, Ohta T, Terashima M, Kayukawa Y, Iwata Y: An oxygen desaturation index in the study of sleep apnea syndrome. *Sleep Res* 1987;16:400
4. Lugaresi E, Cirignotta F, Montana P, Sforza E: Snoring: Pathogenic, clinical, and therapeutic aspects. In *Principles and Practice of Sleep Medicine* (Eds. Kryger MH, Roth T, Dement WC), p. 621-629. Philadelphia: W.B. Saunders Company, 1994
5. He J, Kryger MH, Zorick FJ, Conway W, Roth T: Mortality and apnea index in obstructive sleep apnea: Experience in 385 male patients. *Chest* 1988;94:9-14

6. Partinen M, Jamieson A, Guilleminault C: Long-term outcome for obstructive sleep apnea syndrome patients: mortality. *Chest* 1988; 94:1200-1204
7. Guilleminault C: Natural history, cardiac impact, and long-term follow-up of sleep apnea syndrome. In *Sleep/Wake Disorders: Natural History, Epidemiology, and Long-Term Evolution* (Eds. Guilleminault C, Lugaresi E), p. 107-125. New York: Raven Press, 1983
8. Peter JH: Sleep apnea and cardiovascular disease. In *Obstructive Sleep Apnea Syndrome: Clinical Research and Treatment* (Eds. Guilleminault C, Partinen M), p. 81-98. New York: Raven Press, 1990
9. Partinen M, Palomaki H: Snoring and cerebral infarction. *Lancet* 1985;2:1325-1326
10. Findley LJ, Unverzagt ME, Suratt PM: Automobile accident involving patient with obstructive sleep apnea. *Am Rev Respir Dis* 1988;138:337-340
11. George C, Nickerson P, Hanley P, Millar T, Kryger M: Sleep apnoea patients have more automobile accidents. *Lancet* 1987;2:447
12. Strohl KP, Bonnie RJ, Findley L, Fletcher EC, Getsy J, Kryger MH, Millman R, Novak R, Roth T, Walsleben J, Williams A: Sleep apnea, sleepiness, and driving risk. *Am J Respir Crit Care Med* 1994; 150:1463-1473
13. Guilleminault C, Connolly SJ, Winkle RA: Cardiac arrhythmia and conduction disturbances during sleep in 400 patients with sleep apnea syndrome. *Am J Cardiol* 1983;52:490-494
14. Tilkian AG, Motta J, Guilleminault C: Cardiac arrhythmias in sleep apnea. In *Sleep Apnea Syndromes* (Eds. Guilleminault C, Dement WC), p. 197-210. New York: Alan R Liss Inc, 1978
15. Tilkian AG, Guilleminault C, Schroeder JS, Lehrman KL, Simmons FB, Dement WC: Sleep induced apnea syndrome: Prevalence of cardiac arrhythmias and their reversal after tracheostomy. *Am J Med* 1977;63:348-358
16. Philipson EA, Remmers JE: Indication and standards for cardiopulmonary sleep studies. *Am Rev Respir Dis* 1989;139:559-568
17. Yasuma F, Terashima M, Nakashima C, Iida M, Shimokata K, Hayashi H, Okada T: A computer analysis of oximetry: Screening of sleep disordered breathing. *Jpn J Chest Dis* 1993;52:214-219
18. Hida W, Sindoh C, Miki H, Kikuchi Y, Okabe S, Taguchi O, Takishima T, Shirato K: Prevalence of sleep apnea among Japanese industrial workers determined by portable sleep monitoring system. *Respiration* 1993;60:332-337
19. Young T, Palta M, Dempsey J, Skatrud J, Weber S, Badr S: The occurrence of sleep-disordered breathing among middle-aged adults. *N Engl J Med* 1993;328:1230-1235
20. Flemons WW, Remmers JE, Gillis AM: Sleep apnea and cardiac arrhythmias. Is there a relationship? *Am Rev Respir Dis* 1993;148: 618-621
21. Okada T, Kayukawa Y, Ohta T: Hypersomnia and polysomnographic findings in obstructive sleep apnea syndrome. In *Sleep-Wakefulness* (Eds. Mohan Kumar V, Mallick HN, Nayar U), p. 160-163. New Delhi: Wiley Eastern Limited, 1993
22. Yoshiko K, Kitano T, Okada T, Terashima M, Ohta T: Comparative study between AM and PM sleep in the napping. *Jpn Soc of EEG & EMG* 1987;15:311-317
23. Cummisky J, Williams TC, Krumpe PE, Guilleminault C: The detection and quantification of sleep apnea by tracheal sound recordings. *Am Rev Respir Dis* 1982;126:221-224
24. West P, George CF, Kryger MH: Dynamic in vivo response characteristics of three oximeters: Hewlett-Packard 47201A, Biox III and Nellcor N-100. *Sleep* 1987;10:263-271
25. George CF, Millar TW, Kryger MH: Identification and quantification of apneas by computer-based analysis of oxygen saturation. *Am Rev Respir Dis* 1988;137:1238-1240