Original Article

Relationships between Sleep-Disordered Breathing and Blood Pressure and Excessive Daytime Sleepiness among Truck Drivers

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Sleep-disordered breathing is a risk factor for hypertension, cardiovascular disease and accidents in the general population, but little is known about this correlation among professional truck drivers. To examine the relationships of sleep-disordered breathing with blood pressure levels and excessive daytime sleepiness among truck drivers, we conducted a population-based cross-sectional study of 1,313 subjects aged 20–69 years registered in the Japanese Trucking Association. The 3% oxygen desaturation index was selected as an indicator of sleep-disordered breathing, representing the number of desaturation events per hour of recording time in which blood oxygen fell by ≥3% by overnight pulse oximetry. The Epworth Sleepiness Scale was used to estimate excessive daytime sleepiness. There were significant positive associations between the 3% oxygen desaturation index levels and both diastolic blood pressure levels and Epworth Sleepiness Scale scores. The multivariate odds ratio of hypertension was 2.0 (1.1–3.6) for a 3% oxygen desaturation index of ≥15 in reference with a 3% oxygen desaturation index of <5. This association was more evident among those aged ≥40 years and overweight subjects. Further, the multivariate odds ratio of an Epworth Sleepiness Scale of ≥11 was 2.3 (1.1–4.9) for a 3% oxygen desaturation index of ≥15 in reference with a 3% oxygen desaturation index of <5. This association was more evident among those aged ≥40 years. The associations of sleep-disordered breathing severity with diastolic blood pressure levels and excessive daytime sleepiness suggest the need for sleep-disordered breathing screening among truck drivers for prevention of hypertension and potential traffic accidents. (*Hypertens Res* 2006; 29: 605–610)

***Key Words*: sleep-disordered breathing, oxygen desaturation, daytime sleepiness, blood pressure**

Introduction

Sleep apnea syndrome is characterized by episodes of apnea or hypopnea during sleep. Several clinical studies have indicated that excessive sleepiness is associated with increased risk of traffic accidents among patients with obstructive sleep apnea-hypopnea syndrome (*1–4*). Previous cross-sectional studies in Western countries have shown that sleep-disordered breathing is positively associated with the prevalence of hypertension (*5–8*). We have also reported that the severity of sleep-disordered breathing as measured by the oxygen desaturation index was significantly associated with blood pressure levels among middle-aged Japanese men (*9*). The

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prospective study of the Wisconsin Sleep Cohort Study reported a dose-response association between sleep-disordered breathing severity at baseline and the incidence of newly diagnosed hypertension (*10*). We have recently reported that the prevalence of sleep-disordered breathing was 9% among community-dwelling men aged 40–69 years and that sleep-disordered breathing was positively associated with systolic (SBP) and diastolic blood pressure (DBP) levels (*9*). However, to date, no data have been made available on the association of sleep-disordered breathing with blood pressure levels and excessive daytime sleepiness among Japanese professional truck drivers. Our *a priori* hypothesis is that professional truck drivers with sleep-disordered breathing are more likely to have hypertension and excessive daytime sleepiness. In the present study, we used pulse oximetry and the Epworth Sleepiness Scale to evaluate sleep-disordered breathing and daytime sleepiness, and to examine the association between nocturnal oxygen desaturation and blood pressure levels and excessive daytime sleepiness among truck drivers.

Methods

Subjects

The study subjects were Japanese professional truck drivers, aged 20–69 years, who were members of the Japan Trucking Association, resided in Tokyo or Niigata Prefecture in Japan, and had not been treated for sleep-disordered breathing. Between December 2004 and February 2005, we recruited 1,470 participants, 932 from Tokyo Prefecture and 538 from Niigata Prefecture. We excluded 27 subjects with missing data on pulse oximetry and 157 subjects who reported a nightly sleep time of <4 h. Therefore, 1,313 participants (1,258 men and 55 women), including 107 subjects using antihypertensive medication, were enrolled in the present study. For each subject, physician epidemiologists or trained staff members explained the study protocol, and obtained informed consent. The study was approved by the Medical Ethics Committee of the University of Tsukuba.

Measurement of Blood Pressure Levels and Confounding Variables

All participants completed self-administered questionnaires with items on SBP and DBP, height and weight, ethanol intake per day, the number of cigarettes smoked per day, the use of antihypertensive medication and the score on the Epworth Sleepiness Scale (the Epworth Scale has 8 items with a value of 0–3, for a total score of 0–24) (*11*). Hypertension was defined as SBP ≥ 160 mmHg, DBP ≥ 95 mmHg and/or use of antihypertensive medication. Body mass index was calculated as weight (kg) divided by the square of height in m (m^2). The usual weekly alcohol intake was estimated in units of "go," a traditional Japanese unit of volume corresponding to 23 g ethanol, and then converted to g of ethanol per day (*12*, *13*). One "go" is 180 ml of sake, and corresponds to one bottle (633 ml) of beer, two single shots (75 ml) of whiskey, or two glasses (180 ml) of wine. Persons who smoked one or more cigarettes/day were defined as current smokers. Epworth Sleepiness Scale scores of ≥ 11 were taken to represent excessive daytime sleepiness, as in a previous study (*14*).

Assessment of Sleep-Disordered Breathing

A pulse-oximeter (PULSOX-3Si; Minolta Co., Osaka, Japan) was attached to the left wrist during one night of sleep at home. The sensor probe was fitted to the ring finger and secured with tape by each subject. The internal memory of this device stores the values of blood oxygen saturation by performing a moving average for the last 5 s, updated every second; this sampling time was short enough to avoid underestimation of oxygen desaturation (*15*). Data were downloaded to a personal computer *via* an interface (PULSOX IF-3; Minolta) and analyzed using proprietary software supplied with the equipment (DS-3 version. 2.0a; Minolta). We used the 3% oxygen desaturation index as an indicator of sleep-disordered breathing. The value of the 3% oxygen desaturation index was taken as the mean value over an at least 4-h period of sleep, as estimated by pulse oximetry. Since the duration of sleep estimated by pulse oximetry is often longer than the true total sleep time, the subjects kept a sleep log in order to exclude the waking time from the analysis and thereby minimize potential overestimation of the sleep duration. The criteria for sleep-disordered breathing were defined by the 3% oxygen desaturation index level as 5 and 15 events/h, corresponding to mild and moderate-to-severe sleep-disordered breathing, respectively.

The validity of the pulse oximetry was confirmed by synchronous overnight recording of both PULSOX-3Si and standard polysomnography among 256 consecutive patients (mean body mass index, 26.8 kg/m^2) who had been referred to a sleep-disordered breathing center: 94% sensitivity and 93% specificity for detecting an apnea-hypopnea index of ≥ 20 determined by polysomnography was achieved using a cut-off threshold of 3% oxygen desaturation index $=10$, and 85% sensitivity and 100% specificity for detecting an apnea-hypopnea index of ≥ 20 using a cut off threshold of 3% oxygen desaturation index $=15$ (*16*). The trial to determine the reproducibility of pulse oximetry of two overnight pulse oximetry measurements was conducted in 61 men. There was no significant difference between the median values of the 3% oxygen desaturation index on the first (5.4/h) and the second (4.8/h) nights ($p=0.95$), and Spearman's rank correlation coefficient between the two measures was 0.81 (*9*).

Statistical Analysis

Age-adjusted mean values and prevalence of selected cardiovascular risk characteristics were calculated according to the

Table 1. Age- and Sex-Adjusted Means ± SEM and Prevalence of Selected Cardiovascular Risk Characteristics According to 3% Oxygen Desaturation Index among 1,313 Truck Drivers

	3% oxygen desaturation index			*p* for trend
	0–4	5–14	≥15	
Number	976	249	88	
Age (years)	42.2±0.3	47.0±0.7	47.3±1.2	<0.001
Epworth Sleepiness Scale	5.5±0.1	6.2±0.2	6.9±0.4	<0.001
Epworth Sleepiness Scale ≥11 (%)	8.1	11.6	15.6	0.01
Body mass index (kg/m^2)	23.2±0.1	25.6±0.2	28.5±0.3	<0.001
Current ethanol intake (g/day)	22.9±1.2	30.0±2.4	27.5±3.9	0.06
Current smokers (%)	66	61	59	0.05
SBP (mmHg)	126.4±0.5	128.8±1.0	131.5±1.6	0.002
DBP (mmHg)	78.5±0.7	83.2±1.4	85.4±2.3	0.001
SBP for no antihypertensive medication use (mmHg)*	125.0±0.5	127.5±1.0	131.0±1.7	<0.001
DBP for no antihypertensive medication use (mmHg)	77.7±0.8	83.0±1.6	83.6±2.7	0.001
Use of antihypertensive medication (%)	6.8	9.7	18.0	0.006
Hypertension (%)†	11.7	14.0	32.1	<0.001

*The number of no antihypertensive medication use was 917 for 3% oxygen desaturation index 0–4, 219 for 3% oxygen desaturation index 5–14, and 70 for 3% oxygen desaturation index ≥15. †Hypertension was defined as SBP ≥160 mmHg or DBP ≥95 mmHg and/or use of antihypertensive medication. SBP, systolic blood pressure; DBP, diastolic blood pressure.

categories of nocturnal oxygen desaturation levels (3% oxygen desaturation index: <5, 5–14, and ≥15) using the analysis of covariance and the χ^2 test, and a linear trend was tested using the median variables of the nocturnal oxygen desaturation categories. A predicted difference associated with a 5 events/h increment of the 3% oxygen desaturation index level was calculated by multiple linear regression analysis to estimate the independent associations of nocturnal oxygen desaturation levels with blood pressure levels and Epworth Sleepiness Scale scores, while adjusting for the potentially confounding variables of age (years), sex, body mass index (kg/m^2), ethanol intake (g/day), smoking status (non-smokers or current smokers), and area (Tokyo or Niigata). A logistic regression analysis was performed to estimate the independent associations of nocturnal oxygen desaturation levels with hypertension and an Epworth Sleepiness Scale score of ≥11, adjusting for these confounding variables. A linear trend of these confounding variables with nocturnal oxygen desaturation levels was tested using median variables of the nocturnal oxygen desaturation categories. The analyses were also performed using stratification by age (<40 and ≥40 years) and body mass index (<25 and ≥25 kg/m^2). The interactions of 3% oxygen desaturation index levels with age and body mass index in relation to the prevalence of hypertension or Epworth Sleepiness Scale score ≥11 were examined using the cross-product terms.

All statistical analyses were performed using SAS version 8.2 software (SAS Institute Inc., Cary, USA). All probability values for statistical tests were two-tailed, and values of $p<0.05$ were regarded as statistically significant.

Results

The prevalence of a 3% oxygen desaturation index of ≥15 was 6.7% among Japanese truck drivers aged 20–69 years, 4.0% among those aged 20–39 years and 8.5% among those aged 40–69 years. Table 1 shows the age- and sex-adjusted mean values and prevalence of selected cardiovascular risk characteristics according to the categories of nocturnal oxygen desaturation index levels. There were positive associations between the 3% oxygen desaturation index levels and each of age, Epworth Sleepiness Scale score, body mass index, blood pressure levels, prevalence of an Epworth Sleepiness Scale score ≥11, antihypertensive medication use, and hypertension.

Table 2 shows the mean values of blood pressure levels and Epworth Sleepiness Scale scores according to the categories of 3% oxygen desaturation index levels, and the predicted differences in blood pressure levels and Epworth Sleepiness Scale scores associated with a 5 events/h increment of 3% oxygen desaturation index; the analysis was conducted for 1,206 subjects who were not on antihypertensive medication. The 3% oxygen desaturation index levels were associated with DBP but not with SBP after adjustment for age, sex and other confounding variables. The age-adjusted predicted differences associated with a 5 events/h increment of the 3% oxygen desaturation index level were positively associated with SBP and DBP values and Epworth Sleepiness Scale scores. The association between 3% oxygen desaturation index levels and Epworth Sleepiness Scale scores remained significant after adjustment for other confounding variables.

The prevalence of hypertension and an Epworth Sleepiness

Table 2. Means ± SEM of Systolic and Diastolic Blood Pressure Levels and Epworth Sleepiness Scale Scores According to Categories of 3% Oxygen Desaturation Index, and Predicted Differences (SEM) in Blood Pressure Levels and Epworth Sleepiness Scale Scores Associated with 5/h Increment of 3% Oxygen Desaturation Index among 1,206 Subjects without Use of Antihypertensive Medication

	3% oxygen desaturation index			*p* for trend	3% oxygen desaturation index	
	0–4	5–14	≥15		Predicted difference (SEM)	*p* value
Number	917	219	70			
Systolic blood pressure (mmHg)						
Age- and sex-adjusted means	125.0±0.5	127.5±1.0	131.0±1.7	<0.001	0.88 (0.28)	0.002
Multivariate adjusted means	125.8±0.5	125.9±1.0	126.9±1.8	0.62	−0.10 (0.30)	0.74
Diastolic blood pressure (mmHg)						
Age- and sex-adjusted means	77.7±0.8	83.0±1.6	83.6±2.7	0.001	0.88 (0.45)	0.05
Multivariate adjusted means	78.2±0.8	82.4±1.7	81.4±2.9	0.05	0.32 (0.51)	0.53
Epworth Sleepiness Scale (mmHg)						
Age- and sex-adjusted means	5.6±0.1	6.4±0.2	7.0±0.4	<0.001	0.32 (0.07)	<0.001
Multivariate adjusted means	5.6±0.1	6.2±0.3	6.9±0.4	0.002	0.31 (0.08)	<0.001

Multivariate adjustment: age, sex, body mass index, ethanol intake, smoking status, and area.

Scale score ≥11 were associated with increased levels of the 3% oxygen desaturation index (Table 3). The multivariate odds ratio (OR) of hypertension was 2.0 (95% confidence interval [95% CI], 1.1–3.6) for a 3% oxygen desaturation index of ≥15 in reference with a 3% oxygen desaturation index of <5. The relation between 3% oxygen desaturation index levels and hypertension tended to be more evident among those aged ≥40 years than truck drivers aged <40 years: OR = 2.1 (1.1–3.9) *vs*. 1.2 (0.2–7.4), and tended to be more evident among men with body mass index ≥25.0 kg/m^2 than those with <25.0 kg/m^2: OR = 2.5 (1.2–5.1) *vs*. 1.2 (0.4–3.8), although the interaction did not reach the level of statistical significance ($p = 0.24$ and 0.68, respectively). When hypertension was defined as SBP ≥140 mmHg and/or DBP ≥90 mmHg, the multivariate OR (95% CI) of hypertension for a 3% oxygen desaturation index of ≥15 was 1.7 (1.0–2.8) (not shown in the table).

The multivariate OR of an Epworth Sleepiness Scale score ≥11 was 2.3 (1.1–4.9) for a 3% oxygen desaturation index of ≥15 in reference with a 3% oxygen desaturation index of <5. The relation did not vary between persons with body mass index ≥25.0 kg/m^2 and those with <25.0 kg/m^2 (1.9 [0.7–4.9] *vs*. 3.2 [0.8–12.1]; *p* for interaction = 0.87) and tended to be more evident among those aged ≥40 years than among the <40 years (3.0 [1.1–8.4] *vs*. 1.7 [0.5–5.8]; *p* for interaction = 0.39). Among the subjects with a 3% oxygen desaturation index of ≥15, those with a body mass index ≥25.0 kg/m^2 had more severe sleep-disordered breathing than those with lower body mass indices, and those of age ≥40 years had more severe sleep-disordered breathing than those with younger ages; the prevalences of a 3% oxygen desaturation index of ≥20 and ≥30 were 68% and 38%, respectively, for a body mass index ≥25.0 kg/m^2, and 35% and 5% for lower body mass indices. The prevalences of a 3% oxygen desaturation index of ≥20 and ≥30 were 80% and 30% for ages ≥40 years, and 48% and 24% for the younger ages.

Discussion

The prevalence of sleep-disordered breathing was 4.0% for ages 20–39 years and 8.5% for ages 40–69 years among Japanese truck drivers; the latter value was similar to that of 9% that we previously reported among Japanese male community residents aged 40–69 years (*9*). On the other hand, the prevalence of excessive daytime sleepiness was 9.3% in the present study, which was lower than those reported in foreign countries; 25% of American long-distance truck drivers aged 20–71 years had fallen asleep at the wheel in the past year (*17*); 24% of Australian commercial vehicle drivers (mean age: 42 years) had excessive sleepiness (*18*); and 13% of Chinese commercial bus drivers (mean age: 42 years) had fallen asleep during driving (*19*). We also found a significant association of sleep-disordered breathing with DBP levels and excessive daytime sleepiness among Japanese truck drivers. The association between the sleep-disordered breathing and hypertension tended to be more evident among middle-aged men and overweight men probably because these subgroups had more severe sleep-disordered breathing. Our results are consistent with the results of community-based studies in the United States (*5*–*7*), Europe (*8*) and Japan (*9*).

Our findings are also in line with a previous report that DBP is the first parameter to rise in association with early subclinical obstructive sleep apnea syndrome (*20*). The causal relationship between sleep-disordered breathing and hypertension has been supported by both animal experimental and epidemiological studies. An animal experiment using a canine model demonstrated that daytime blood pressure increased after experimentally induced intermittent airway occlusion during nocturnal sleep and fell after a nighttime sleep with quiet breathing (*21*). A prospective study reported

Table 3. Multivariate Odds Ratios and 95% Confidence Intervals of Hypertension and Epworth Sleepiness Scale ≥11 According to 3% Oxygen Desaturation Index among 1,313 Truck Drivers

	Number	3% oxygen desaturation index			*p* for trend
		0–4	5–14	≥15	
Hypertension (yes)					
All subjects	1,313	1.0	0.9 (0.6–1.5)	2.0 (1.1–3.6)	0.02
BMI <25 kg/m^2	856	1.0	0.9 (0.5–1.8)	1.2 (0.4–3.8)	0.73
BMI ≥25 kg/m^2	457	1.0	1.0 (0.5–1.8)	2.5 (1.2–5.1)	0.01
Age <40 years	529	1.0	0.9 (0.2–3.6)	1.2 (0.2–7.4)	0.85
Age ≥40 years	784	1.0	1.0 (0.6–1.5)	2.1 (1.1–3.9)	0.02
Epworth Sleepiness Scale ≥11					
All subjects	1,313	1.0	1.4 (0.8–2.4)	2.3 (1.1–4.9)	0.03
BMI <25 kg/m^2	856	1.0	1.7 (0.8–3.5)	3.2 (0.8–12.1)	0.09
BMI ≥25 kg/m^2	457	1.0	1.0 (0.5–2.4)	1.9 (0.7–4.9)	0.20
Age <40 years	529	1.0	1.4 (0.7–3.0)	1.7 (0.5–5.8)	0.41
Age ≥40 years	784	1.0	1.4 (0.7–3.2)	3.0 (1.1–8.4)	0.03

Multivariate adjustment: age, sex, body mass index (BMI), ethanol intake, smoking status, and area.

the risk of incident hypertension as three-fold higher among subjects with an apnea-hypopnea index of ≥15 compared with subjects with an apnea-hypopnea index =0 (*10*). Furthermore, two randomized clinical trials of continuous positive airway pressure treatment have demonstrated significant falls in nighttime and daytime blood pressure levels among hypertensive patients with sleep apnea syndrome (*22*, *23*).

A meta-analysis of nine prospective studies indicated that a long-term difference of 3 mmHg in mean DBP was associated with an approximately 20% reduction in risk of stroke and a 13% reduction in risk of coronary heart disease (*24*). Our present study showed that a 3% oxygen desaturation index of ≥15 corresponded to a 3 mmHg elevation of mean DBP. We also found that excessive daytime sleepiness was associated with the prevalence of a 3% oxygen desaturation index of ≥15, which was consistent with the results from the Sleep Heart Health Study (*25*) and Wisconsin Sleep Cohort Study (*26*). Several clinical studies (*1–4*) and an epidemiological study (*18*) have indicated that excessive sleepiness is associated with increased risk of traffic accidents in sleep-disordered breathing patients. Therefore, the detection and control of undiagnosed sleep-disordered breathing among truck drivers may have a significant impact on the prevention of cardiovascular disease and traffic accidents.

The strength of the present study is that it was the first to examine the status of sleep-disordered breathing during sleep at home for truck drivers, and it had a high participation rate, which gives it the advantage of providing a more realistic estimation of the severity of sleep-disordered breathing compared with hospital/laboratory studies.

The limitations of the present study are, first, that pulse oximetry inherently underestimates respiratory disturbance events during sleep compared with full-polysomnography, particularly in a non-obese population such as that studied here (mean body mass index =24.0 kg/m^2). The sensitivity of detection of apnea/hypopnea events of ≥5/h by polysomnography has been reported to be 68% among subjects with a body mass index ≤27.0 kg/m^2 and 94% among those with a higher body mass index (*16*). Second, the recording time modified by self-report was regarded as the total sleep time, and this value may have been longer than the real sleep time obtained by polysomnography using the electroencephalogram. However, these limitations would be expected to lead to an underestimation rather than an overestimation of the prevalence of sleep-disordered breathing. Third, hypertension was defined using self-reported blood pressure levels. A previous Japanese study of 1,823 men and women aged 40 to 68 years showed that self-reported blood pressure values were highly correlated with actual blood pressure, and their mean differences were small (r=0.73 and 134±18 [mean±SD] *vs*. 133±15 mmHg for SBP, r=0.67 and 78±10 *vs*. 79±10 mmHg for DBP, respectively) (*27*). Fourth, the Epworth Sleepiness Scale used in the present study is a self-report measurement that subjectively assesses excessive daytime sleepiness. However, the subjective measure of the Epworth Sleepiness Scale and more objective measure of the Multiple Sleep Latency Test may result in slightly different values, but can be considered complimentary measures of sleepiness (*28*, *29*).

In conclusion, the significant associations of sleep-disordered breathing severity with DBP, hypertension and excessive daytime sleepiness suggest the need for sleep-disordered breathing screening among truck drivers for prevention of hypertension and potential traffic accidents. Clinical trials are required to examine the effect of sleep-disordered breathing screening for blood pressure control and safe driving among Japanese truck drivers.

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