Journal of the Formosan Medical Association (2016) 115, 779–785

Available online at www.sciencedirect.com

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journal homepage: www.jfma-online.com

ORIGINAL ARTICLE

Associations between sleep duration and type 2 diabetes in Taiwanese adults: A population-based study

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Received 5 February 2015; received in revised form 29 December 2015; accepted 26 January 2016

KEYWORDS
adults;
sleep duration;
type 2 diabetes

Background/Purpose: Research on the association between sleep duration and type 2 diabetes in an adult community population has been relatively scarce. The objective of this study was to analyze the association between sleep duration and the risk of diabetes in Taiwanese adults.
Methods: Secondary data analysis was based on the database of Nutrition and Health Survey in Taiwan between 2005 and 2008. A stratified three-staged probability sampling method was used to create a cross-sectional research design and 1533 participants (733 men, 800 women, between 19 years and 64 years of age) were selected in this study. Logistic regression models were conducted to estimate the effect of sleep duration for type 2 diabetes patients.
Results: The average sleep duration for all participants in this study was 7.2 ± 1.4 hours, with 35.1% of the participants having a sleep duration less than 7 hours. After controlling related confounders, such as age, sex, body mass index, abdominal circumference, total cholesterol levels, sleep disturbances, and hypertension, the risk of having diabetes for participants with ≤ 5 hours sleep was 2.04-fold (95% confidence interval, 1.05–3.95) higher than for participants with 7–8.9 hours of sleep. In particular, the risk of having diabetes for young adults (between 19 years and 44 years of age) with ≤5 hours of sleep was 5.24-fold (95% confidence interval, 1.17–23.47) higher than for young adults who reported 7–8.9 hours of sleep.
Conclusion: Our results show that a short sleep duration was associated with a higher prevalence of diabetes and this correlation was particularly strong in young adults.

Conflicts of interest: The authors have no conflicts of interest relevant to this article.

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http://dx.doi.org/10.1016/j.jfma.2016.01.013

Introduction

Diabetes is one of the most common pandemic diseases worldwide. A recent study projected that the number of diabetic patients under 20 years of age will increase from 36.6 million in 2011 to 55.2 million by the year 2030, with the prevalence expected to increase 50.7% in the following 19 years.[1] In Taiwan, the prevalence of diabetes in adults was 5.3% in 1996, and it increased to 9.1% in 2008.[2] Diabetes is a huge and growing problem, and the costs to society are high and escalating. The global health expenditure due to diabetes was $548 billion in 2013.[3] The data demonstrated that diabetes is a common chronic disease with tremendous social repercussions and economic impacts on medical spending and health care services.

Many known risk factors, including dietary pattern, obesity, physical exercise, and sedentary lifestyle, contribute to diabetes. However, a growing number of epidemic studies indicated that sleep duration was also associated with the incidence of diabetes and an increased rate of mortality.[4,5] Several studies have suggested that extremely short ($\leq$5 hours/per night) or exceedingly long ($\geq$9 hours/per night) sleep duration were associated with an increased risk of diabetes.[4,6,7] Furthermore, experimental results suggested that acute sleep deprivation can affect glucose metabolism, reduce insulin sensitivity, and increase insulin resistance.[8,9] Chao et al[10] have found that sleep duration was a potential risk factor for newly diagnosed type 2 diabetes from one hospital health examination center.

However, some observation studies reported no correlation between sleep duration and the risk of diabetes.[11,12] According to the conflicting reports of the correlation between sleep duration and diabetes, further studies are required to investigate this issue. In addition, there are few studies addressing the correlation between sleep duration and diabetes prevalence in the Taiwanese population. Therefore, the purpose of this study was to analyze the association between sleep duration and risk of diabetes in adults of the Taiwan community based on the Nutrition and Health Survey in Taiwan (NAHSIT) 2005–2008 database.

Participants, materials, and methods

NAHSIT 2005–2008 database

NAHSIT is a population-based cross-sectional study, involving a large-scale survey of the entire nation.[13,14] The sampling method used for NAHSIT was a stratified three-staged probability sampling design, and its target population was permanent residents of Taiwan. First, the geographical location, dietary habits, and population density were used to divide. 358 townships and city districts into five sampling strata: two in the northern stratum, the central stratum, the southern stratum, and the eastern stratum. Subsequently, a three-stage probability sampling method was used to select samples from each stratum. In the first stage, specific townships and city districts were selected. In the second stage, sampling blocks were selected from the chosen townships and city districts. In the third stage, individuals were selected among the permanent residents in each sampling block. Additionally, based on the population density of the townships and city districts, six townships and city districts were selected as the primary sampling units (PSUs) with the probabilities proportional to sizes approach.

A total of 48 PSUs were selected from the eight stratums, and 128 participants from each PSU were visited. The probability of being a selected participant was based on their registered area of residence, sex, and age.[13] The proper sample weight for each stratum was estimated by the total population for a stratum and the registered household population in Taiwan, divided by the selected sample size. The weights were used in all subsequent analyses of the characteristics of the participants in the questionnaire interview and health examination.[13]

The study design and evaluation tools were approved by the Institutional Review Board of Academia Sinica and Department of Health (DOH94-FS-6–4), and all participants agreed to participate in the study. The total survey response rate of NAHSIT was 65%, and the physical examination response rate was 59%.[13] The surveys were performed between January 1, 2005, and December 31, 2008. Data collection tools included a questionnaire-guided interview, anthropometric measurements, and blood tests. The questionnaire-guided interview was primarily based on structured questionnaires during home visits and included questions about the participant's age, sex, medical history, sleep duration, and whether they had sleep disturbances or not.

Anthropometric measurements included height, weight, and body mass index, which was calculated as weight (kg) divided by height (m^2). Waist circumference was quantified by placing a tape measure around the waist to measure the middle distance between the upper edges of the right and left iliac bones and the lower edges of the ribs. Blood pressure was measured using an Omega 1400 automatic electronic blood pressure meter (Non-Invasive blood pressure monitors, Invivo Research Laboratories Inc.), and an average value was determined from triplicate measurements. Measurements were performed in the seated position after 15 minutes of resting. Fasting sugar and total cholesterol levels were obtained using blood tests after 8 hours of fasting.

For this secondary analysis study, 1634 participants aged between 19 years and 64 years were selected from the NAHSIT 2005–2008 database and they completed the questionnaire and physical exam. Participants who had sleep duration outliers ($n = 25$) or did not report important questions ($n = 76$) were excluded; therefore, 1533 participants were eventually included in the analysis.

Definitions of sleep duration, diabetes, sleep disturbances, and hypertension

The participants self-reported average sleep duration during weekdays (Sunday to Thursday) and weekends (Friday to Saturday) over the past week. The final sleep duration value was obtained using the following weighted formula, as described by Hall et al[15] [(5 $\times$ weekday sleep duration) + (2 $\times$ weekend sleep duration)]/7. Based on self-reported sleep duration, we divided the entire sample into four groups using as cutoff points the 25th percentile, and relevance cutoff points from previous studies with

slight modification.[4,6,16] Thus, we created the following four sleep duration groups: the severely short sleep duration group consisted of those who sleep $\leq$ 5 hours; the moderately short sleep duration group consisted of those who sleep $>$ 5 hours to $<$ 7 hours; the normal sleep duration group consisted of those who sleep $\geq$ 7 hours to $<$ 9 hours; and the long sleep duration group consisted of those who sleep $\geq$ 9 hours.

To define sleep disturbances, we used a questionnaire to assess sleep disturbances over the previous month. Questions were asked concerning difficulty initiating sleep, difficulty in maintaining sleep, and waking up early in the morning. A five-point Likert scale was used to collect data, allowing participants to answer questions using the following categories: never, rarely, sometimes, often, and almost always. In this study, five categories were classified into two categories, absent (never, rarely) and present (sometimes, often, and almost always).

Diabetes was defined by an 8-hour fasting blood sugar level of $\geq$126 mg/dL or a person who took diabetes medication. Hypertension was defined by the Joint National Committee VII,[17] including an systolic blood pressure of $\geq$140 mmHg, a diastolic blood pressure of $\geq$ 90 mmHg, or participants who took hypertension medication.

Statistical analysis

Data collected between 2005 and 2008 from the NAHSIT were organized, and statistical analyses were performed using the SPSS software program (Version 21; SPSS Inc., Chicago, Illinois, USA). The descriptive statistics, such as percentages, averages, and standard deviations were calculated. Differences in sleep duration among the four groups were executed by one-way analysis of variance. Post-hoc analysis for multiple comparisons of means was performed using Scheffé's test. Chi-square analysis was employed to compare various sleep duration groups and categorical variable distributions (Table 1).

A logistic regression model was used to assess the odds ratio (OR) and 95% confidence interval (CI) values for independent variables over dependent variables. The related confounders were controlled, including the continuous variables age, body mass index, abdominal circumference, total cholesterol levels, and sample weights (Table 2), as well as the categorical variables sex and hypertension. Age, sex, and sleep disturbances were stratified, and the OR values of sleep duration over diabetes were determined (Table 3). A level of 0.05 was used to determine the significance of statistical results.

Results

In total, 1533 adults (733 men, 800 women, age ranging from 19 years to 64 years) were involved in the study, with a total average age of 43.2 $\pm$ 12.4, a male average age of 43.7 $\pm$ 12.4, and a female average age of 42.7 $\pm$ 12.3. The average sleep duration was 7.2 $\pm$ 1.4 hours for all adults, 7.1 $\pm$ 1.3 hours in men, and 7.3 $\pm$ 1.4 hours in women. Sleep duration was most commonly between 7 hours and 8 hours (54.6%), although 35.1% of participants had a sleep duration $<$ 7 hours, 6.1% of participants had a sleep duration $\leq$ 5 hours, and the remainder of the participants (10.1%) had a sleep duration $\geq$ 9 hours. Participants with sleep duration $\leq$5 hours were significantly older and had significantly higher fasting blood glucose levels compared with the other participants ($p < 0.05$). The participants with sleep duration between 7 hours and 8.9 hours had the highest prevalence of diabetes mellitus. In addition, this

Table 1 Characteristics of the study participants (N = 1533).

Characteristics[a]	Sleep duration (h)				F/χ^2	Scheffe's test
	$\leq$5 (G1)	>5 to <7 (G2)	$\geq$7 to <9 (G3)	$\geq$9 (G4)		
No. of participants (%)	93 (6.1)	444 (29.0)	841 (54.9)	155 (10.1)	—	
Age (y)	48.8 $\pm$ 10.9	45.8 $\pm$ 11.0	41.8 $\pm$ 12.2	39.8 $\pm$ 13.2	21.637***	G1 > G3, G4; G2 > G3, G4
BMI (kg/m^2)	24.5 $\pm$ 3.8	24.7 $\pm$ 4.1	24.0 $\pm$ 4.0	24.9 $\pm$ 4.8	3.933**	
FPG (mg/dL)	116.8 $\pm$ 50.2	107.9 $\pm$ 32.7	104.4 $\pm$ 29.5	106.0 $\pm$ 32.1	5.123**	G1 > G3, G4
WC (cm)	81.5 $\pm$ 11.0	82.5 $\pm$ 10.7	80.6 $\pm$ 10.6	81.7 $\pm$ 11.8	2.901*	G2 > G3
TCHOL(mg/dL)	194.0 $\pm$ 39.2	190.4 $\pm$ 37.2	187.3 $\pm$ 33.5	184.8 $\pm$ 44.1	1.968	
Female (%)	51.6	50.5	51.5	61.3	5.862	
HT (%)	1.4	5.2	6.7	1.8	13.887**	
DM (%)	1.1	3.2	4.1	0.8	14.307**	
Sleep disturbances (%)					42.297***	
Absent	36.6	58.8	68.4	65.8		
Present	63.4	41.2	31.6	34.2		

χ^2, Chi-square test was used to test categorical variables between groups.
F, one-way ANOVA (Scheffe's test) was used to test continuous variables between two or more groups.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.
BMI = body mass index; DM = diabetes mellitus; FPG = fasting plasma glucose; G = group; HT = hypertension; TCHOL = total cholesterol; WC = waist circumference.
[a] Data are presented as n (%) or mean $\pm$ standard deviation values.

Table 2 Multivariable adjusted odds ratio of diabetes associated with sleep duration ($N = 1533$).

Sleep duration (h)	Model 1[a]	Model 2[a]	Model 3[a]
≤5	2.76* (1.54–4.96)	1.86* (1.01–3.43)	2.04* (1.05–3.95)
>5 to <7	1.53* (1.04–2.27)	1.20 (0.80–1.81)	1.13 (0.74–1.73)
≥9	1.04 (0.55–1.97)	1.13 (0.58–2.21)	0.88 (0.44–1.77)

Data were analyzed as odds ratios (95% confidence intervals) for the "presence of diabetes mellitus" relative to "without diabetes mellitus" using logistic regression models using the 7–8.9 hours sleep duration as the reference group.
*$p < 0.05$.
[a] Model 1 was unadjusted; Model 2 was adjusted for age and sex; Model 3 was adjusted for age, sex, body mass index, waist circumference, total cholesterol, sleep disturbances, and hypertension.

After adjusting for potential confounding factors, participants between the ages of 19 years and 44 years with a sleep duration of ≤ 5 hours showed a 5.24-fold (95% CI, 1.17–23.47) higher prevalence of diabetes compared with the control group with sleep duration of 7 hours to 8.9 hours. In men, participants with a sleep duration of ≤ 5 hours had a diabetes prevalence 3.33-fold (95% CI, 1.42–7.80) higher than participants of the same sex in the control groups. Participants with sleep disturbances and of ≤ 5 hours and between 5 hours and 7 hours exhibited an OR of diabetes prevalence 2.76-fold (95% CI, 1.54–4.96) and 1.53-fold (95% CI, 1.04–2.27) higher, respectively, than the control group with sleep disturbances and sleep duration of 7 hours to 8.9 hours.

Discussion

This study performed on Taiwanese adults between the ages of 19 years to 64 years revealed that sleep duration ≤ 5 hours was significantly correlated with diabetes prevalence. Even after adjustment for confounders, the relationship between particular sleep duration group experienced significantly more sleep disturbances than other groups (Table 1).

Table 3 Multivariable adjusted odds ratio of diabetes associated with sleep duration in stratified analyses.

Variables	Sleep duration per night (h)[a]			
	No. of participants	≤5	>5 to <7	≥9
Age				
19–44	738	5.24 (1.17–23.47)*	2.22 (0.82–6.02)	0.79 (0.15–4.08)
45–64	795	1.85 (0.91–3.74)	1.01 (0.63–1.62)	0.96 (0.44–2.08)
Sex				
Men	733	3.33 (1.42–7.80)*	1.20 (0.67–2.15)	1.36 (0.57–3.23)
Women	800	1.04 (0.35–3.16)	0.97 (0.52–1.83)	0.52 (0.14–1.87)
Sleep disturbances				
Absent	972	1.77 (0.58–5.41)	0.65 (0.36–1.18)	0.97 (0.42–2.27)
Present	561	2.70 (1.06–6.88)*	2.29 (1.12–4.70)*	0.83 (0.24–4.93)

*$p < 0.05$.
[a] Data were analyzed as odds ratios (95% confidence intervals) for the "presence of diabetes mellitus" relative to "without diabetes mellitus" using logistic regression models using the 7–8.9 hours sleep duration group as the reference group. Analyses were adjusted for age, sex, body mass index, waist circumference, total cholesterol, sleep disturbances, and hypertension.

Table 2 suggests that in Model 1 (confounders not adjusted), the groups with a sleep duration of ≤ 5 hours and between 5 hours and 7 hours exhibited OR diabetes prevalence 2.76-fold (95% CI, 1.54–4.96) and 1.53-fold (95% CI, 1.04–2.27) higher, respectively, than the control group with a sleep duration of 7 hours to 8.9 hours. After adjustment for the confounders of age, sex, body mass index, abdominal circumference, total cholesterol levels, sleep disturbances, and hypertension (Model 3), the group with sleep duration ≤ 5 hours exhibited OR of diabetes prevalence 2.04-fold (95% CI, 1.05–3.95) higher than the control group with a sleep duration of 7 hours to 8.9 hours.

In Table 3, age (19–44 years and 45–64 years old), sex (men and women), and sleep disturbances (yes and no) were stratified to determine the correlation between various sleep duration groups and prevalence of diabetes. short sleep duration and diabetes prevalence did not change (adjusted OR, 2.04). This result was consistent with previous studies showing a correlation between short sleep duration and increased risk of diabetes.[6,10,18]

Famous laboratory studies suggested that sleep deprivation affected blood glucose utilization and insulin regulation.[8,19] Prior physiological study supported the model that decreased sleep duration up-regulates the activity of the hypothalamic–pituitary–adrenal axis and increases the secretion of cortisol.[8] In addition, sleep curtailment also affected the homeostasis of appetite-regulating hormones, leading to a decrease in leptin levels and an increase in ghrelin levels, both of which are risk factors for obesity and diabetes.[20,21] McNeil and coworkers[22] suggested that sleep restriction not only resulted in changes to neuronal hormones but was also associated with irregular eating behaviors, including increased caloric consumption and favoring fats and high-carbohydrate/energy-dense foods.

Therefore, that study demonstrates that decreased sleep duration not only directly affected the regulation of specific hormones in the body but also indirectly changed the eating patterns of the participants.

There is growing evidence that sleep plays a major role in the regulation of glucose metabolism and neuroendocrine function in adults.[4,21] The follow-up studies showed that those who had $\leq$ 5 hours sleep resulted in a higher risk of diabetes symptoms, including excessive thirst, polyuria weight loss, and hunger compared with a sleep duration of 8 hours (adjusted relative risk, 1.37).[23] A previous study suggested that short sleep duration increased the risk of impaired glucose tolerance.[7] Our data found that the participants with a sleep duration of $\leq$ 5 hours showed higher fasting blood glucose levels; however, the present study was restricted to a cross-sectional research design such that the cause—effect relationship between short sleep duration and abnormal blood glucose levels could not be determined. Therefore, in future studies, changes in blood glucose levels might be monitored for long periods of time in participants with habitual short sleep durations. Alternatively, long-term sleep architecture might be evaluated in participants with abnormal blood glucose levels to determine the risk of diabetes. In addition, we found that participants with sleep duration of $\leq$ 5 hours showed a strong propensity for sleep disturbances, which was as high as 63.4% in this study. According to previous reports, these two factors showed a high co-occurrence.[6,16] Therefore, changes in sleep quality and sleep duration would be a predictor of diabetes development.[18]

This study revealed that participants between the ages of 19 years and 44 years who had a sleep duration of $\leq$ 5 hours showed a 5.24-fold increased risk for diabetes compared with participants of the same age who had a sleep duration of 7 hours to 8.9 hours. By contrast, in the 45—64 years age group, no correlation was observed between sleep duration and the risk of diabetes, indicating that this correlation was more prominent in young adults. In a cohort study, Lai et al[24] showed that sleep disorders increased the risk of diabetes by 1.42-fold in young adults $\leq$ 40 years of age, although there was no correlation between these two variables in other age groups (41—65 years and $>$65 years). These results also suggested a higher correlation between sleep disorders and the risk of diabetes in young adults—a fact that warranted more attention. The trend of chronic diseases in younger individuals has been associated with mortality due to subsequent diseases.[25]

In addition, this study revealed a 3.33-fold high risk for diabetes in male participants with a sleep duration of $\leq$ 5 hours compared with individuals of the same sex with a sleep duration of 7 hours to 8.9 hours. However, no correlation was observed for women, consistent with previous studies.[6,9] It has been suggested that the reason men with a short sleep duration are more at risk for diabetes than women could be due to lifestyle differences between the two sex groups. For example, the prevalence of alcohol use and smoking in the male population was likely higher than in the female population.[26,27] A long-term follow-up study by Yaggi et al[28] suggested that men reporting short sleep duration were twice as likely to develop diabetes and that the effects of sleep on diabetes could be mediated via changes in endogenous testosterone levels.

Sleep disturbance is a common sleep complaint and previous studies have confirmed that sleep disturbances are related to sympathetic stimulation[29] and activation of the stress system.[30] A recent study found that participants with both sleep disturbances and short sleep duration showed an increased risk for diabetes: the results were similar to prior studies.[16,31] However, we did not find the association between sleep duration and diabetes risk in participants without sleep disturbances. One possible explanation for this result was that short sleep duration was a reflection or marker of sleep disturbances. A previous study indicated that sleep duration in insomnia was possibly a useful indicator of biological severity, when the participant's combination of sleep disturbances and short sleep duration were considerate related to hyperarousal, and the risk of chronic diseases such as hypertension and diabetes.[16] In addiction, a previous study reported that the combination of sleep disturbance and short sleep duration was correlated with a 21% increase in mortality due to disease.[32]

It has been shown that type U sleep duration is correlated with an increased risk of diabetes;[6,7] however, we observed no such correlation between sleep duration of $\geq$ 9 hours and the risk of diabetes. Conflicting results have been reported concerning the link between long and the risk of diabetes,[11] and the pathological mechanism behind such a link remains unclear.[4,23] Gangwisch[33] suggested that long sleep duration was not the cause of diabetes but rather an effect of diabetes and other chronic diseases; however, more studies will be required to clarify this correlation. In our study, some of the 95% CIs had a large range, possibly due to the relatively small number of participants with diabetes in each subgroup.

Although adequate confounders were controlled for in our analyses, this study has several limitations. Firstly, this study used self-reported sleep duration values. Objective sleep measurement is certainly more accurate, although a recent study suggested that there was a strong agreement between reported sleep duration and objective actigraphy measurements.[34] Secondly, the original questionnaires were limited by the lack of questions addressing obstructive sleep apnea for the confounder control, although the prevalence of obstructive sleep apnea is only 1.9—2.6% in Taiwanese adults.[35] Thirdly, a previous study showed confounders on the association between sleep duration and risk of diabetes, such as socioeconomic factors, and unhealthy behaviors.[10] In this study, we adjusted for potential confounders, such as age, objective indicators (body mass index, waist circumference, total cholesterol), and other factors (sleep disturbances, hypertension); however, we did not comprehensively cover all the potential bias and could not exclude the possible confounding effect on the results. Furthermore, regular medication used for sleep problems may also alter sleep duration and predict diabetes risk.[36] In the present study, we did not evaluate hypnotics for sleep disturbances; therefore, the results may be affected by hypnotics effect on the association between sleep duration and diabetes. Fourthly, in this study, the definition of diabetes is not totally the same as suggested by the American Diabetes Association in 2012, which included oral glucose tolerance test and HbA1c. We had adapted single fasting plasma glucose and medication as the definition criteria of diabetes. The prevalence of diabetes may be the lack of use of more sensitive measures of glycemic

status, such as oral glucose tolerance test, and induced potential bias of results, suggesting that further studies should be conducted to address the issue of sleep problems and diabetes using more sensitive ways to diagnose diabetes in the future. Fifthly, as we know, type 2 diabetes is a chronic disease involving a complex combination of genetic, environment, and lifestyle. Family history of diabetes is considered to be an important risk for diabetes. However, it was not available in our dataset; this limitation might have influenced our study results. Finally, this study was limited to a cross-sectional survey that could not establish the cause—effect relationship between sleep duration and both the incidence and cumulative risk of diabetes.

In summary, the correlation between sleep duration and diabetes was found to be the strongest in participants with a sleep duration of $\leq$ 5 hours, suggesting that short sleep duration could be a serious risk factor. Therefore, people who engage in community health care practices should provide early education to the group described above concerning the role of sleep duration and sleep quality and the risk of diabetes to mitigate the potential harmful effects of these phenomena. This study suggested that short sleep duration should be regarded as a novel risk factor association with diabetes. Therefore, preventative strategies for reducing the incidence of diabetes should also focus on sleep duration and sleep quality, as well as conventional risk factors such as obesity, diet, and physical exercise.

Acknowledgments

The authors thank the Nutrition and Health Survey in Taiwan 2005—2008 for providing the data. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors. All authors conducted the research by recoding data, wrote and reviewed the manuscript, and contributed to the conclusion. All authors have read and approved the final manuscript.

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