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Sleep duration and dietary macronutrient consumption can modify the cardiovascular disease for Korean women but not for men

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Abstract

Background: Although the association between cardiovascular disease (CVD) and sleep duration is generally recognized, the results are inconsistent, and investigations examining the effects of seep duration and diet on CVD are rare.

Methods: The gender-difference in the effect of the sleep duration on Framingham risk score (FRS)-related factors, 10-year predicted CVD risk, and dietary consumption was analyzed in 14,111 subjects (Men $n = 5,727$; Women $n = 8,384$) aged ≥20 from the Korean National Health and Nutrition Examination Survey.

Results: The gender difference in the CVD risk factors according to sleep duration was observed. Only women with short sleep durations (<7 h/day) exhibited elevated FRS factors, such as systolic blood pressures (SBP) ($P < 0.001$), diastolic blood pressures (DBP) ($P = 0.008$), and the proportion of hypertension (HTN) treatments ($P < 0.001$), but not for men. Moreover, the 10-year predicted CVD risk, as evaluated with the FRS, was higher in women with short sleep durations ($P < 0.001$). Women with short sleep durations consumed significantly more dietary carbohydrates (CHO) than those with normal sleep durations ($P < 0.001$). Additionally, the ORs for intermediate and high 10-year predicted CVD risks and CVD–related factors, such as high age, elevated SBP, and HTN treatment, significantly increased with short sleep durations among women [OR (95 % CI) = 1.709 (1.359–2.149) for CVD risk, 1.976 (1.756–2.224) for high age, 1.535 (1.291–1.826) for elevated SBP, and 1.515 (1.320–1.739) for HTN treatment].

Conclusions: Short sleep duration influenced dietary carbohydrate consumption and elevated FRS-related factors as well as 10-year predicted CVD risk. Our findings demonstrated that the CVD risk has been potentially modified by short sleep durations and greater CHO consumptions.

Keywords: Cardiovascular disease, Dietary consumption, Framingham risk score, Sleep duration

Background

Cardiovascular diseases (CVDs) are a group of heart and blood vessel disorders and are among the leading causes of death [1]. Recently, the incidence and prevalence of CVD have dramatically increased in Korea as they have worldwide [1, 2]. The risk factors for CVD include metabolic risk factors, such as hypertension, diabetes, hypercholesterolemia, and obesity, behavioral risk factors, such as smoking, an unhealthy diet, physical inactivity, heavy alcohol consumption, and gender, age, genetic disposition, and other factors [1].

Sleep duration is associated with adverse health outcomes, such as obesity [3], type 2 diabetes [4], hypertension [4], total mortality [5], and poor self-rated health [5]. Furthermore, it has generally been recognized that normal sleep durations decrease the risk of CVD events [6–12]. Although previous studies have reported results regarding CVD and sleep duration, these results are not consistent, and the associations of the risk of CVD with variations in sleep durations differ according to gender. Short sleep duration could cause a raise in total quantity and quality of dietary consumption [13, 14], then those change could eventually influence degree of the CVD [14]. However, studies of the relationship between CVD and sleep duration in Asian population are very rare.

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The Framingham risk score (FRS) was used because its ease of application and superior equations for assessing 10-year predicted CVD risks [15]. Therefore, the aim of this study was to examine how FRS -related factors and 10-year predicted CVD risks are affected by different sleep durations among Korean adults who participated in the Korean National Health and Nutrition Examination Survey (KNHNES).

Methods

Study population and study protocol

Our study was based on data from the 5th KNHANES (2010–2012), which is a national cross-sectional survey that has been conducted periodically since 1998 by the Korea Centers for Disease Control and Prevention (KCDC) [16, 17]. The KNHANES has been performed to investigate health and nutritional statuses of the non-institutionalized civilian Korean population through systematic sampling with a multi-stage clustered probability design. The KNHANES consisted of a health interview, a health examination, and a dietary survey. From the total of 25,534 participants of the KNHANES over the age of 20 years, those who reported implausible daily energy consumptions (≤500 kcal or ≥ 5,000 kcal), those with incomplete sleep duration data, and those with FRS-related factors such as gender, age, systolic blood pressure (SBP), total cholesterol (TC), high density lipoprotein-cholesterol (HDL-C), smoking status, and hypertension (HTN) treatment were excluded. Finally, the remaining 14,111 participants were included in the analysis. The KCDC Institutional Review Board approved the survey protocol, and all participants provided written informed consent. However, this study did not require any ethics approval, because the KNHANES data are publicly available.

Sleep duration assessment

Sleep duration was assessed using the following question: "How long do you usually sleep per day?'. Sleep duration of 7 h per day was taken as the reference point in accordance with previous studies [18, 19]; short sleep durations were defined as < 7 h per day, and normal sleep durations were defined as ≥ 7 h a day.

FRS-related factors and definitions of the 10-year predicted coronary vascular disease risk

The 10-year predicted CVD risk was evaluated according to the FRS. The FRS was calculated according to the following seven factors: gender, age, SBP, TC, HDL-C, smoking status, and HTN treatment. Blood pressure (BP) was measured with a mercury manometer with the subjects in a sitting position, and the average of two blood pressure readings was used for the analyses. Venous blood samples were collected after overnight fasting and used to measure the TC and HDL-C levels with an automatic analyzer 7600 (Hitachi, Tokyo, Japan). Smoking status and the medical history regarding HTN treatment were self-reported based on the health interview. To adjust for potential confounding variables, body mass indices (BMIs) were calculated by dividing the participants' weights (kg) by their heights squared (m^2) as measured according to a standardized procedure, also physical activity was assessed using the following question: "Do you experienced hard breath after moderate or high intensive exercise?"

The FRS was calculated using the following cutoffs after classification by age and gender [15]: SBP: < 120, 120–129, 130–139, 140–159, and ≥ 160 mmHg (also dependent on HTN treatment); TC: < 160, 160–199, 200–239, 240–279, and ≥ 280 mg/dl; HDL-C: < 40, 40–49, 50–59 and ≥ 60 mg/d; and smoking status: non-smoker and smoker. The 10-year predicted CVD risk (%) was calculated according to the total points from the FRS, and we also defined an intermediate/high 10-year predicted CVD risk as ≥ 10 %.

Age (≥50 years), SBP (>140 mmHg), TC (>200 mg/dl), HDL-C (<40 mg/dl), smoking status (smoker), and HTN treatment (yes) were used as CVD-related factors,.

Dietary macronutrient consumption

The dietary survey was conducted by dietitians using the face-to-face interview method. In the dietary survey, the consumption of dietary macronutrients was assessed using a food frequency questionnaire that was developed and validated for the KNHANES [20].

Statistical analysis

The statistical analyses were performed using the SPSS (version 21.0; IBM Corporation, Armonk, NY, USA) software for Windows. Sample weights form the KNHANES were used in all analyses to obtain the resulting estimates, which were representative of the entire Korean population. To evaluate general characteristics by gender, we used the *Pearson's chi-square* test to examine the categorical variables such as smoking status, HTN treatment, and physical activity, and the independent *t*-test to examine the continuous variables such as age, BMI, SBP, DBP, TC, HDL-C, 10-year predicted CVD risk, sleep duration, and dietary macronutrient intake. To analyze the effects of sleep duration on the 10-year predicted CVD risk factors and dietary macronutrients intake, we used generalized linear models or multivariable logistic regression models after adjusting for covariates. BMI and physical activity were adjusted as covariate because they were reported to be associated with sleep duration and CVD, respectively [20, 21]. Moreover, multivariable logistic regression models were used to estimate the odds ratios (ORs) and 95 % confidence intervals (CIs) for the intermediate/high 10-year predicted CVD risk and CVD-related

factors in reference to sleep duration ≥ 7 h per day after adjustments for covariates.

Results

General characteristics

The general characteristics stratified by gender are shown in Table 1. The average age and sleep duration per day were 44.85 years and 6.87 h, respectively. However, no difference was observed in the distributions of sleep duration by gender. SBP, DBP, smoking status, HTN treatment, 10-year predicted CVD risk, and physical activity were significantly higher in the men, but HDL-C was significantly higher in the women. The consumptions of all dietary macronutrients were significantly different according to gender.

10-year predicted CVD risk factors and dietary macronutrient consumption according to sleep duration

The 10-year predicted CVD risk factors and dietary macronutrient consumptions according to sleep duration after applying the adjustments for BMI and physical activity are shown in Tables 2 and 3. For both the men and women, the mean ages were higher among the subjects with short sleep durations than those with normal sleep durations after applying the adjustments for BMI and physical activity ($P = 0.011$ for the men and $P < 0.001$ for the women, Table 2). Gender-differences in the CVD risk factors according to sleep duration were observed. The SBP, DBP, HTN treatment, and 10-year CVD risk were significantly different for the women but not for the men. The women with short sleep durations exhibited elevated CVD risk factors, including SBP (117.3 ± 0.4 mmHg vs. 114.0 ± 0.3 mmHg, $P < 0.001$), DBP (74.2 ± 0.2 mmHg vs. 73.5 ± 0.2 mmHg, $P = 0.008$), and the proportion receiving HTN treatment (19.3 % vs. 12.6 %, $P < 0.001$). Moreover, the 10-year predicted CVD risk, which increased with the FRS, was higher for the women with short sleep durations (2.1 ± 0.1 % vs. 1.4 ± 0.1 %, $P < 0.001$).

The men with short sleep durations consumed less dietary protein compared to those with normal sleep durations (14.3 ± 0.1 % vs. 14.7 ± 0.1 %, $P = 0.009$ in Table 3). However, among the women, the consumption of dietary energy and fat were lower (1696.5 ± 16.4 kcal vs. 1739.3 ± 11.6 kcal, $P = 0.023$ and 17.2 ± 0.2 % vs. 18.5 ± 0.2 %, $P < 0.001$, respectively), but the consumption of dietary carbohydrate (CHO) was higher (68.5 ± 0.3 % vs. 67.2 ± 0.2 %, $P < 0.001$) in the subjects with short sleep durations.

Adjusted odds ratios for the 10-year predicted CVD risk and related factors according to sleep duration

Table 4 shows the ORs for the 10-year predicted CVD risk and related factors according to sleep duration after adjustments for BMI and physical activity. Only among the women with short sleep duration, the adjusted ORs for intermediate/high 10-year predicted CVD, which was defined by a FRS ≥ 10 %, and related factors, including old age, elevated SBP, and HTN treatment, were significantly increased ($P < 0.001$ for all). However, among the men, no significant differences were observed in the intermediate/high 10-year predicted CVD risk or the related factors according to sleep duration. After adjusting

Table 1 General characteristics in Koreans

	Total ($n = 14,111$)	Men ($n = 5,727$)	Women ($n = 8,384$)	P-value*
Age (years)	44.85 ± 0.24	44.02 ± 0.30	45.69 ± 0.25	<0.001
BMI (kg/m^2)	23.70 ± 0.05	24.10 ± 0.06	23.30 ± 0.06	<0.001
SBP (mmHg)	117.98 ± 0.22	120.22 ± 0.27	115.74 ± 0.27	<0.001
DBP (mmHg)	76.64 ± 0.14	79.54 ± 0.21	73.74 ± 0.15	<0.001
TC (mg/dl)	188.40 ± 0.43	187.10 ± 0.64	189.70 ± 0.50	0.241
HDL-C (mg/dl)	52.62 ± 0.15	49.89 ± 0.22	55.36 ± 0.17	<0.001
Smoking status (%)	18.7	39.0	4.8	<0.001
HTN treatment (%)	20.5	21.4	20.0	0.014
10-year CVD risk (%)[a]	4.05 ± 0.07	6.40 ± 0.12	1.70 ± 0.05	<0.001
Sleep duration (hrs/d)	6.87 ± 0.14	6.88 ± 0.21	6.85 ± 0.19	0.907
Energy intake (kcal)	2058.89 ± 10.45	2395.09 ± 16.14	1722.70 ± 10.28	<0.001
Dietary protein (E %)	14.43 ± 0.06	14.53 ± 0.08	14.33 ± 0.06	0.017
Dietary fat (E %)	18.27 ± 0.12	18.62 ± 0.16	17.92 ± 0.15	0.001
Dietary CHO (E %)	67.31 ± 0.15	66.86 ± 0.20	67.76 ± 0.19	0.001
Physical activity (%)	48.4	51.5	45.3	<0.001

BMI Body mass index, *SBP* Systolic blood pressure, *DBP* Diastolic blood pressure, *TC* Total cholesterol, *HDL-C* High density lipoprotein cholesterol, *HTN* Hypertension, *CVD* Cardiovascular disease risk, *hrs/d* hours/day, *E %* percentage of energy, *CHO* Carbohydrate

The data were represented the means ± SE or *N* (%) about representative of the Korean population

*P-values were obtained using t-test or x^2-test

[a]10-year CVD risk was evaluated according to the FRS, which was calculated 7 factors such as gender, age, SBP, TC, HDL-C, smoking, HTN treatment

Table 2 Ten-year predicted CVD risk factors by sleep duration in Koreans

	Men ($n = 5,727$)			Women ($n = 8,384$)		
	<7 hrs/d ($n = 2,304$)	≥7 hrs/d ($n = 3,423$)	*P*-value*	<7 hrs/d ($n = 3,381$)	≥7 hrs/d ($n = 5,003$)	*P*-value*
BMI (kg/m^2)	24.23 ± 0.09	24.01 ± 0.08	-	23.72 ± 0.09	23.04 ± 0.08	-
Age (years)	44.98 ± 0.41	43.75 ± 0.36	0.011	48.98 ± 0.35	43.25 ± 0.29	<0.001
SBP (mmHg)	120.54 ± 0.39	120.79 ± 0.33	0.608	117.29 ± 0.37	113.98 ± 0.31	<0.001
DBP (mmHg)	79.68 ± 0.30	79.45 ± 0.25	0.543	74.16 ± 0.21	73.52 ± 0.18	0.008
TC (mg/dl)	188.02 ± 0.97	187.97 ± 0.78	0.968	189.53 ± 0.74	188.33 ± 0.65	0.220
HDL-C (mg/dl)	49.88 ± 0.31	49.30 ± 0.26	0.128	55.87 ± 0.24	55.64 ± 0.23	0.475
Smoking status (%)	37.6	40.0	0.523	4.8	4.8	0.987
HTN treatment (%)	23.4	20.0	0.120	24.6	16.9	<0.001
10-year CVD risk (%)[a]	6.42 ± 0.17	6.49 ± 0.15	0.732	2.08 ± 0.08	1.35 ± 0.05	<0.001

The data were represented the means ± s.e.m or *N* (%) about representative of the Korean population
CVD Cardiovascular disease, *hrs/d* hours/day, *BMI* Body mass index, *SBP* Systolic blood pressure, *DBP* Diastolic blood pressure, *TC* Total cholesterol, *HDL-C* High density lipoprotein cholesterol, *HTN* Hypertension
*P-values were obtained using general linear model or multivariate logistic model after adjustment for BMI and physical activity
[a]10-year CVD risk was evaluated according to the FRS, which was calculated 7 factors such as gender, age, SBP, TC, HDL-C, smoking, HTN treatment

for confounding variables, the women with short sleep durations exhibited a significantly increase the intermediate/high 10-year predicted CVD risk compared with those with normal sleep durations [OR (95 % CI) = 1.709 (1.359–2.149), $P < 0.001$]. The ORs for the 10-year predicted CVD risk-related factors of high age (>50 years), elevated SBP (>140 mmHg), and HTN treatment (yes) were increased among the women with short sleep durations compared with the women with normal sleep durations [ORs (95 % CIs) = 1.976 (1.756–2.224) for high age, 1.535 (1.291–1.826) for elevated SBP, and 1.515 (1.320–1.739) for HTN treatment].

Discussion

In a relatively large population of men and women, sleep duration was found to influence the 10-year predicted CVD risk and CVD-related factors after adjusting for BMI and physical activity; however, these findings were observed only in the women and not in the men. Moreover, these results were consistent with the effects of sleep duration on the ORs for the intermediate and high 10-year predicted CVD risk and CVD–related factors only among the women.

Consistent with previous studies [6–12], this study revealed that sleep duration was related to CVD. However, the associations between sleep duration and the CVD risk reported in previous studies are inconsistent. Some previous studies [9, 10] have reported that CVD is significantly elevated in longer sleepers, whereas other studies [11, 12] have found that only shorter sleep durations are associated with CVD or that both shorter and longer sleep durations are independently associated with CVD [6–8]. In contrast, some studies [23] have reported no association of sleep duration with CVD risk. Moreover, although this study did not directly examine the role of sleep duration on the incidence of CVD events, the women with short sleep durations exhibited elevations in the FRS–related factors and the 10-year predicted CVD risk. These results extend the observations of two studies [6, 23] that found that poor sleep duration is related to the 10-year predicted CVD risk as calculated with the FRS. As mentioned previously, the FRS is easier to apply and uses better equations to assess the

Table 3 Dietary macronutrients intake by sleep duration in Koreans

	Men ($n = 5,727$)			Women ($n = 8,384$)		
	<7 hrs/d ($n = 2,304$)	≥7 hrs/d ($n = 3,423$)	*P*-value*	<7 hrs/d ($n = 3,381$)	≥7 hrs/d ($n = 5,003$)	*P*-value*
Energy (kcal)	2415.80 ± 24.04	2381.43 ± 20.14	0.250	1696.49 ± 16.39	1739.33 ± 11.62	0.023
Protein (E %)	14.31 ± 0.10	14.68 ± 0.10	0.009	14.31 ± 0.10	14.33 ± 0.07	0.875
Fat (E %)	18.82 ± 0.26	18.42 ± 0.18	0.199	17.15 ± 0.21	18.46 ± 0.19	<0.001
CHO (E %)	66.87 ± 0.31	66.91 ± 0.24	0.919	68.54 ± 0.26	67.21 ± 0.23	<0.001

The data were represented the means ± s.e.m or *N* (%) about representative of the Korean population
hrs/d hours/day, *E %* percentage of energy, *CHO* Carbohydrate
*P-values were obtained using general linear model or multivariate logistic model after adjustment for BMI and physical activity

Table 4 Adjusted odds ratio for intermediate/high 10-year predicted CVD risk and related factors by sleep duration in Koreans

	Men (n = 5,727)	Women (n = 8,384)
	OR (95 % CI)	OR (95 % CI)
High age (>50 years)	1.007 (0.882–1.150)	1.976 (1.756–2.224)[a]
Elevated SBP (>140 mmHg)	1.053 (0.863–1.284)	1.535 (1.291–1.826)[a]
High TC (>200 mg/dl)	0.988 (0.855–1.143)	1.092 (0.973–1.226)
Low HDL-C (<40 mg/dl)	1.061 (0.895–1.257)	1.071 (0.904–1.270)
HTN treatment (yes)	1.141 (0.966–1.349)	1.515 (1.320–1.739)[a]
Smoking status (smoker)	0.957 (0.838–1.094)	1.002 (0.783–1.283)
10-year predicted CVD risk (intermediate and high risk)	0.995 (0.871–1.136)	1.709 (1.359–2.149)[a]

OR Odds ratio, *CI* confidence interval, *CVD* Cardiovascular disease, *FRS* Framingham risk score, *SBP* Systolic blood pressure, *TC* Total cholesterol, *HDL-C* High density lipoprotein cholesterol, *HTN* Hypertension

ORs (95 % CI) were calculated in reference to sleep duration ≥ 7 h per day using multivariate logistic regression after adjustment for BMI and physical activity ([a]< 0.0001)

10-year predicted CVD risk [14]. Additionally, this study revealed that the ORs for an intermediate/high 10-year predicted CVD risk and CVD–related factors, such as old age, elevated SBP, and HTN treatment, were significantly elevated with short sleep durations.

Specifically, the gender differences in the effect of sleep duration on CVD or the risk of CVD observed in this study agree with the findings of other studies [8, 24]. These discrepancies were likely partially explainable based on sleep quality, lifestyle, psychological and physical factors, etc. Generally, women tend to exhibit lower sleep quality, higher rates of insomnia, and more complaints about difficulty falling asleep than men [25] due to psychological factors such as anxiety and depression [26]. Moreover, the effect of sleep duration on CVD or the risk of CVD is weaker for men, among whom the percentage of smokers is higher, compared with women among whom the percentage of smokers is lower [27]. Because smoking strongly influences cardiovascular events, it is difficult to distinguish other effects; i.e., smoking exerts a 'mask effect'. Additionally, because physical activity is associated with sleep duration [28, 29] and cardiovascular events [28, 30] and could also be co-influence both of these factors, the association between short sleep duration and CVD or the risk of CVD was stronger in the women who engaged in relatively less physical activity than in the men [27].

Previous studies [14, 31] have reported that short sleep duration might lead to increased energy consumption via the consumption of energy-rich foods, particularly foods high in CHO. This study found that the women with short sleep durations exhibited increased CHO consumption and decreased fat consumption; this pattern is similar to those of the previous reports, although this report observed decreases in total energy consumption. These results may be partly explained by the fact that women tend to exhibit more emotional eating and are more likely to have sleep disorders causes by psychological factors compared with men.

Although interactions between dietary consumption and sleep duration with respect to CVD components and the 10-year predicted CVD risk were definitely not observed in this study, there are currently no plausible explanations for the mechanisms of these results. Several previous studies have suggested that short sleep durations are related to CVD risk via the following mechanisms: (a) obesity and disorders in glucose metabolism that are caused by changes in dietary consumption via alterations in circulating levels of leptin and ghrelin [4]; (b) low-grade inflammatory states due to increased levels of circulating leukocytes and cytokines [32]; and (c) HTN and dyslipidemia per se [34]. However, among the women in our study, short sleep durations and greater CHO consumptions were strongly associated with elevations in CVD components and the predicted 10-year CVD risk. Furthermore, it is reasonable to conclude that the women who consumed high proportions of CHO consumed relatively low proportions of protein and fat because dietary macronutrients were represented as proportions of the total energy consumed. One meta-analysis [34] reported that low-CHO diets reduce body weight and improve lipid profiles and that long-term low-CHO diets can decrease the incidence of CVD events in a manner comparable to that of low-fat diets. In contrast, a recent review [35] found that low-CHO diets have little or no influence on body weight and CVD risk. In agreement with other studies, only the absolute amount of CHO consumed was considered in the definition of a low-CHO diet. To explore the effect of low-CHO diets on CVD risk, dietary quality and type should be considered because the quality and type of the macronutrients consumed are very important. Generally, because CHO-rich foods are consumed as the main staples of the diets of the Korean population, the consumptions of specific CHO-rich foods and the overall dietary CHO consumption were higher than those of Americans, particularly among the women (50.5 % of the

total kcals consumed by American women are composed of CHO) [36]. Furthermore, the 10-year predicted CVD risk in this study was defined according to the intermediate risk level of a FRS ≥10 % because the proportion of participants with a high 10-year predicted CVD risk as defined by a FRS ≥ 20 % was very low. Therefore, the results of studies of Korean populations are difficult to generalize to the other populations. These results provide a foundation for investigations of the associations between sleep duration, dietary consumption, CVD risk and the differences in these associations according to gender. Moreover, future studies will need to consider the effects of the quality and type of consumed macronutrients on the interaction between sleep duration and CVD risk.

Conclusions

This study using KNHANE which is relatively large in sample size and a national representative, demonstrated that short sleep duration influenced with more consumed dietary carbohydrate and elevated FRS-related factors as well as 10-year predicted CVD risk. This findings demonstrated that the CVD risk has been potentially modified by short sleep durations and greater CHO consumptions.

Abbreviations

BMI: body mass index; BP: blood pressures; CHO: carbohydrate; CVD: cardiovascular disease; DBP: diastolic blood pressures; FRS: Framingham risk score; HDL-C: high-density lipoprotein cholesterol; HTN: hypertension; KNHNES: Korean National Health and Nutrition Examination Survey; SBP: systolic blood pressures; SE: standard error; TC: total cholesterol.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

The authors' responsibilities were as follows- YK and MD: study concept and design MD: data statistical analysis, interpretation and draft of the manuscript YK: review of the manuscript. All authors read and approved the final version of the manuscript.

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