pii: jc-18-00026 http://dx.doi.org/10.5664/jcsm.7272

JCSM Journal of Clinical Sleep Medicine

SCIENTIFIC INVESTIGATIONS

Association Between Sleep Duration, Quality and Body Mass Index in the Korean Population

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Study Objectives: Mounting evidence indicates that sleep disturbance contributes to the increased risk for cardiometabolic diseases. Obesity and underweight are also closely linked to cardiometabolic risk. Thus, the objective of this study was to examine the association between sleep duration, quality, and body mass index (BMI) categories.

Methods: Using data from a cohort of 107,718 Korean individuals (63,421 men and 44,297 women), we conducted cross-sectional analysis with sex subgroup analysis. Sleep duration was classified into 3 groups—short (< 7 hours), normal (7–9 hours) and long sleep (> 9 hours)—and Pittsburgh Sleep Quality Index (PSQI) score was used to divide sleep quality into 2 groups—poor (PSQI > 5) and good sleep (PSQI ≤ 5). Compared to normal sleep and good sleep quality, adjusted odds ratios of short and long sleep and poor sleep for BMI categories were calculated. BMI categories included underweight (BMI < 18.5 kg/m^2), overweight (BMI 23 to < 25 kg/m^2), obesity (BMI 25 to < 30 kg/m^2) and severe obesity (BMI ≥ 30 kg/m^2).

Results: Short sleep duration had the dose-dependent relationship with obesity categories from overweight to severe obesity, and inverse relationship with underweight (adjusted odds ratios [95% confidence intervals] for underweight, overweight, obesity, and severe obesity versus normal weight; 0.88 [0.82–0.94], 1.15 [1.11–1.20], 1.31 [1.26–1.37], 1.70 [1.54–1.85]). Poor sleep quality was significantly associated with severe obesity in male subgroup (1.16 [1.05–1.27]) and with obesity (1.18 [1.10–1.25]) and severe obesity in female subgroup (1.66 [1.40–1.98]).

Conclusions: Short sleep duration and poor sleep quality was more positively associated with obesity across BMI than underweight.

Keywords: obesity, sleep duration, sleep quality, underweight

Citation: Park SK, Jung JY, Oh CM, McIntyre RS, Lee JH. Association between sleep duration, quality and body mass index in the Korean population. *J Clin Sleep Med.* 2018;14(8):1353–1360.

BRIEF SUMMARY

Current Knowledge/Study Rationale: There has been accumulating evidence indicating the adverse influence of insufficient sleep and poor sleep quality on obesity. It is still under scrutiny in the association of sleep duration and quality with body weight including underweight.

Study Impact: Short sleep and poor sleep quality more closely link to obesity than underweight. The proper sleep duration and improving sleep quality are necessary to prevent obesity.

INTRODUCTION

Affecting approximately 20% of general population, short sleep duration and poor sleep quality is imposing a growing burden on public health.[1] With the steadily declined time devoted to sleep in working-aged adults for decades, accumulating evidence indicates that poor sleep quality is associated with a variety of cardiometabolic diseases.[2] Previous studies have suggested the significant relationship between sleep disturbance and insulin resistance, in which short sleep duration and poor sleep quality contributed to increasing risk for metabolic syndrome, impaired glucose tolerance and type 2 diabetes mellitus.[3–5] In particular, Koren et al. observed the U-shaped association between sleep duration and both HbA1c and serial glucose levels on oral glucose tolerance test and positive associations between slow-wave sleep duration and insulin secretory measures in 62 obese adolescents.[6] Their study indicates that sleep disturbance can have an adverse influence on glucose-insulin homeostasis, even in adolescence. In addition, an analysis of a nationally representative sample of 138,201 United States adults demonstrated that sleep disturbance was a significant risk factor for myocardial infarction, stroke, and coronary artery disease even after adjustment for other confounding factors.[7]

It is established that obesity is closely associated with the pathogenesis of aforementioned cardiometabolic disease. Epidemiologic studies have also provided evidence that insufficient sleep can cause obesity and weight gain.[8,9] Thus, it can be postulated that the developed obesity and related adverse metabolic condition in individuals suffering sleep disturbance may trigger pathophysiologic processes contributory to various cardiometabolic diseases. However, despite the mounting data suggesting the adverse influence of sleep disturbance on obesity, the association between sleep disturbance and underweight is still controversial and inconclusive. A cross-sectional population-based study in the United States reported that short sleep duration was significantly associated with all categories of abnormal body weight including underweight, overweight, and obesity, whereas longitudinal observation in a large national cohort of Thai adults did not identify any significant association of short sleep duration with underweight.[10,11] This discrepancy may be attributable to the heterogeneity in ethnics, characteristics of study population, and derangement of other confounding factors.

To identify the influence of sleep disturbance on body weight across sexes, we analyzed the association of short sleep duration and poor sleep quality with body mass index (BMI) in a cohort from a large Korean population. In addition, considering the potential links between sleep duration and quality and body weight, we evaluated the difference of BMI according to sleep duration and sleep quality.

METHODS

Study Design and Participants

Relevant clinical data were obtained from the Kangbuk Samsung Health Study (KSHS). Most study participants were Korean men and women partaking in a medical health checkup program at the Health Promotion Center of Kangbuk Samsung Hospital, Sungkyunkwan University. The study participants came from all regions in South Korea, but most of our study participants were residents of the Seoul metropolitan area (population > 20 million) because the two sites of the Health Promotion Center of Kangbuk Samsung Hospital are in Seoul and Suwon. Family members of Korean employees also participate in this regular health checkup program.

Among the KSHS study participants, a total of 175,970 men and women, aged 18 to 91 years, who received a regular health checkup between January 2014 and December 2014 were initially enrolled in this study. All participants were asked to complete the Korean-validated version of the Pittsburgh Sleep Quality Index (PSQI) and a questionnaire related to sleep; 63,480 individuals who did not complete the PSQI and the other questionnaire were excluded from the study. Further exclusions totaled 4,772 for the following reasons: 153 participants were missing BMI data and 4,619 had serious medical conditions that can affect BMI and sleep duration and quality (eg, history of cancer, myocardial infarction, chronic obstructive lung disease). Finally, the total number of study participants was 107,718. Ethics approvals for the study protocol and analysis of the data were obtained from the institutional review board of Kangbuk Samsung Hospital. The informed consent requirement was waived by the Institutional Review Board because the researchers only retrospectively accessed a de-identified database for analytical purposes.

Clinical and Laboratory Measurements

Study data included medical history, a physical examination, echocardiographic data, self-administered questionnaires, anthropometric measurements and laboratory measurements. Data on medical and drug prescription history were assessed by examining physicians. All study participants were asked to respond to a health-related behavior questionnaire, which included questions on alcohol consumption (eg, frequency and amount), smoking, and exercise. Participants who exercise more than three times a week, moderate to vigorous intensity are classified as having regular exercise. Presence of diabetes mellitus was operationalized using fasting serum glucose levels (ie, ≥ 126 mg/dL), serum hemoglobin A1c (HbA1c) levels (ie, ≥ 6.5%), the current use of any blood glucose-lowering medications, or prior history of diabetes. Hypertension was defined as either the current use of an antihypertensive medication, past history of hypertension, or having a measured blood pressure (BP) ≥ 140/90 mmHg at initial examination. Trained nurses obtained sitting BP levels using automatic BP equipment (53000-E2, Welch Allyn, Skaneateles Falls, New York, United States) after a 5-minute rest. BMI was calculated using the formula of weight (kg) divided by height squared (m^2).

Blood samples were collected after more than 12 hours of fasting, and were drawn from an antecubital vein. The fasting serum glucose was measured using the hexokinase method. Total cholesterol and triglyceride were measured using enzymatic colorimetric tests, low-density lipoprotein (LDL) cholesterol was measured using the homogeneous enzymatic colorimetric test, and high-density lipoprotein (HDL) cholesterol was measured using the selective inhibition method (Advia 1650 Autoanalyzer; Bayer Diagnostics, Leverkusen, Germany).

Fasting insulin concentration was measured by immunoradiometric assay (Biosource; Nivelles, Belgium) and HbA1c was measured using an immunoturbidimetric assay with a Cobra Integra 800 automatic analyzer (Roche Diagnostics; Basel, Switzerland). High sensitivity C-reactive protein (hsCRP) was analyzed by particle-enhanced immunonephelometry with the BNII System (Dade Behring; Marburg, Germany). The clinical laboratory has been accredited and participated annually in inspections and surveys by the Korean Association of Quality Assurance for Clinical Laboratories.

Sleep Duration and Sleep Quality Measurements

Sleep duration measured by self-rated questionnaire. All participants were asked to answer for their habitual sleep duration (hours and minutes) and divided into three groups according to their sleep duration: short sleep duration (< 7 hours), normal sleep duration (7 to < 9 hours), and long sleep duration (≥ 9 hours).[12] Sleep quality evaluated by the Korean-validated version of the PSQI.[13,14] The PSQI is a self-rated questionnaire that is widely used to assess sleep duration and sleep quality during the previous month. Nineteen individual items generate seven component scores (range 0–3, with higher scores indicating worse sleep) on subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. The sum of the scores for the seven components yields one sleep quality score (range 0–21). A global PSQI score greater than 5 yielded a diagnostic sensitivity of 89.6% and specificity of 86.5% (kappa = 0.75, $P < .001$) in distinguishing between good and poor sleepers.[13] The Korean version of PSQI showed that Cronbach α coefficient for internal consistency of the total score of the PSQI was .84, and the test-retest correlation coefficient was .65 for the total score ($P < .001$).[14] We described a detailed method in our previous study.[15,16]

Statistical Analysis

All statistical analyses were performed using R software 3.3.3 (R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was considered as $P < .05$ or 95% confidence interval (CI). Data are presented as mean ± standard deviation (SD) within sleep duration groups for continuous variables and as numbers and proportions for categorical variables. Between-group clinical characteristics and echocardiographic parameters were compared using analysis of variance (ANOVA) for continuous variables and chi-square test for categorical variables. The reference groups in categorical analyses were the 7 to 9 hours of sleep duration. We also showed a demographic and clinical data according to the sleep quality.

The odds ratios (ORs) of underweight, overweight, obesity, and severe obesity based on sleep duration and sleep quality were compared using multinomial logistic regression analysis. All study participants were divided into five groups according to Asian-specific BMI cutoff points; underweight (BMI < 18.5 kg/m^2), normal weight (BMI 18.5 to < 23 kg/m^2), overweight (BMI 23 to < 25 kg/m^2), obesity (BMI 25 to < 30 kg/m^2), and severe obesity (BMI ≥ 30 kg/m^2). We also used conventional BMI cutoff point in analyses; underweight (BMI < 18.5 kg/m^2), normal weight (BMI 18.5 to < 25 kg/m^2), overweight (BMI 25 to < 30 kg/m^2), and obesity (BMI ≥ 30 kg/m^2). The covariates of the adjusted model were checked for the presence of multicollinearity and overdispersion, and the fitting model was then selected. The selected potential confounders were age, sex, regular exercise, alcohol intake, HDL-cholesterol, triglyceride, smoking, hsCRP, diabetes mellitus, and systolic blood pressure (sex excluded in sex subgroup analysis). In order to investigate the difference between men and women, we also conducted sex subgroup analysis. However, we excluded male participants with long sleep duration in multinomial logistic regression analysis of sleep duration because of too-small sample size (n = 281) and the presence of overdispersion.

RESULTS

Clinical Characteristics of Study Participants

A total number of study participants was 107,718 (63,421 men and 44,297 women), and their mean age was 39.7 ± 7.1 years. Clinical characteristics of study participants according to sleep duration are shown in **Table 1**. Short sleeper (< 7 hours) was more prevalent in men than women, whereas long sleeper (≥ 9 hours) is predominant in women. In particular, the proportion of long sleeper was very low in men (0.4%). Long sleepers had the more favorable clinical characteristics such as lower homeostasis model assessment of insulin resistance (HOMA-IR), fasting glucose, total cholesterol, and BMI than short sleeper. The proportions of overweight, obesity, and severe obesity were higher in short sleepers than long sleepers, and only 7% of short sleepers were underweight.

The clinical characteristics of study participants according to sleep quality are presented in **Table S1** in the supplemental material.

Sleep Duration, Sleep Quality and BMI

Table 2 shows the association between sleep duration and BMI categories. Short sleep duration had the inverse relationship with underweight and dose-dependent relationship with obesity categories from overweight to severe obesity. In an unadjusted model, short sleep duration had decreased ORs for underweight and increased ORs for overweight, obesity, and severe obesity (versus normal weight). Even in a fully adjusted model, despite the attenuated association, short sleep duration had statistically significant adjusted ORs for BMI categories including underweight, overweight, obesity, and severe obesity (adjusted ORs for underweight, overweight, obesity, and severe obesity versus normal weight; 0.88 [95% CI 0.82–0.94], 1.15 [95% CI 1.11–1.20], 1.31 [95% CI 1.26–1.37], 1.70 [95% CI 1.54–1.85]). This association was consistently observed in both male and female subgroups.

Long sleep duration was significantly associated with only severe obesity in all participants (adjusted OR; 1.46 [95% CI 1.02–2.10]), but sex subgroup analysis did not show any significant finding. In the male subgroup, the proportion of long sleepers was too low to conduct statistical analysis, and the female subgroup did not show any significant association between long sleep duration and BMI categories.

The association between sleep quality and BMI categories was also examined in all participants and sex subgroups (**Table 3**). Poor sleep quality tended to be associated with obesity, which was more dominant in the female subgroup than the male subgroup. Poor sleep quality was significantly associated with only severe obesity in all participants and the male subgroup (adjusted OR in all participants and male subgroup; 1.29 [95% CI 1.19–1.40], 1.16 [95% CI 1.05–1.27]), the female subgroup showed a stronger association between poor sleep quality and obesity and severe obesity (adjusted OR for obesity and severe obesity; 1.18 [95% CI 1.10–1.25], 1.66 [95% CI 1.40–1.98]). Additionally, the male subgroup showed an inverse relationship between poor sleep quality and obesity.

Table 4 presents the adjusted mean value of BMI according to five groups stratified by sleep duration (hour) and sleep quality (PSQI score). Short sleepers tended to have an increased adjusted mean value of BMI. Compared to normal sleepers (7–9 hours), male short sleepers (less than 7 hours) had a higher adjusted mean value of BMI without overlapped CI, and female short sleepers (less than 6 hours) had a higher adjusted mean value of BMI without overlapped CI. Regarding sleep quality, there was no statistically significant difference in the adjusted mean value of BMI among the five groups stratified by PSQI score. Although the female subgroup showed a higher adjusted mean value of BMI in groups with PSQI score > 5 than groups with PSQI ≤ 5, widely dispersed CI banished the statistical significance.

We analyzed the relationship of sleep duration and quality with BMI categories defined by the conventional BMI cutoff. In this analysis, short sleep duration less than 7 hours

Table 1—Main demographic characteristics according to the sleep duration.

	Sleep Duration			
	< 7 hours (n = 66,786)	7 to < 9 hours (n = 39,261)	≥ 9 hours (n = 1,671)	*P*
Men (n, %)	44,400 (70.0%)	18,740 (29.5%)	281 (0.4%)	< .001
Women (n, %)	22,386 (50.5%)	20,521 (46.3%)	1,390 (3.1%)	< .001
Age (year)	40.2 ± 7.1	39.0 ± 7.0	36.0 ± 7.8	< .001
Glucose (mg/dL)	96.1 ± 15.4	94.4 ± 13.5	91.8 ± 123	< .001
HOMA-IR	1.64 ± 1.25	1.56 ± 1.10	1.46 ± 1.01	< .001
Total cholesterol (mg/dL)	196.3 ± 34.0	192.3 ± 33.5	186.4 ± 32.7	< .001
Triglyceride (mg/dL)	123.7 ± 87.1	111.3 ± 77.5	94.2 ± 64.7	< .001
HDL-cholesterol (mg/dL)	57.8 ± 15.4	60.1 ± 15.6	63.6 ± 15.1	< .001
hsCRP (mg/dL)	0.10 ± 0.30	0.09 ± 0.28	0.10 ± 0.34	< .001
Height (cm)	168.9 ± 8.1	166.8 ± 8.3	162.8 ± 6.9	< .001
Weight (kg)	68.4 ± 12.8	64.1 ± 12.7	58.2 ± 11.0	< .001
BMI (kg/m^2)	23.8 ± 3.3	22.9 ± 3.3	21.9 ± 3.3	< .001
BMI category, n (%)				< .001
Underweight	2,451 (3.7)	2,479 (6.3)	191 (11.4)	
Normal	25,682 (38.5)	18,971 (48.3)	984 (58.9)	
Overweight	16,348 (24.5)	8,346 (21.3)	239 (14.3)	
Obese	19,533 (29.2)	8,440 (21.5)	214 (12.8)	
Severe obese	2,772 (4.2)	1,025 (2.6)	43 (2.6)	
Male				< .001
Underweight	352 (0.8)	249 (1.3)	6 (2.1)	
Normal	12,002 (27.0)	5,805 (31.0)	93 (33.1)	
Overweight	13,005 (29.3)	5,514 (29.4)	79 (28.1)	
Obese	16,787 (37.8)	6,437 (34.3)	82 (29.2)	
Severe obese	2,254 (5.1)	735 (3.9)	21 (7.5)	
Female				< .001
Underweight	2,099 (9.4)	2,230 (10.9)	185 (13.3)	
Normal	13,680 (61.1)	13,166 (64.2)	891 (64.1)	
Overweight	3,343 (14.9)	2,832 (13.8)	160 (11.5)	
Obese	2,746 (12.3)	2,003 (9.8)	132 (9.5)	
Severe obese	518 (2.3)	290 (1.4)	22 (1.6)	
Waist circumference (cm)	83.4 ± 9.5	80.8 ± 9.4	77.5 ± 9.0	< .001
SBP (mmHg)	109.9 ± 12.6	107.3 ± 12.5	103.1 ± 11.3	< .001
DBP (mmHg)	71.6 ± 10.1	69.5 ± 9.8	66.1 ± 8.8	< .001
Hypertension (%)	12.8	9.2	5.1	< .001
Diabetes (%)	4.5	3.0	2.6	< .001
Current smoker (%)	22.3	16.1	8.5	< .001
Average alcohol use (g/day)	14.5 ± 21.7	10.6 ± 18.0	8.1 ± 17.1	< .001
Regular exercise (%)	21.7	21.6	18.0	< .001
Employment (%)	76.5	67.5	46.7	< .001
Sleep duration (minute)	342.8 ± 38.3	438.3 ± 26.8	557.9 ± 37.0	< .001
Global PSQI score	5.7 ± 2.4	3.7 ± 1.8	3.3 ± 1.8	< .001
Poor sleep quality (%)	48.1	15.6	10.9	< .001

Values are mean (± standard deviation) unless otherwise indicated. BMI = body mass index, DBP = diastolic blood pressure, HDL = high-density lipoprotein cholesterol, HOMA-IR = homeostasis model assessment of insulin resistance, PSQI = Pittsburgh Sleep Quality Index, SBP = systolic blood pressure.

presented the positive association with overweight and obesity and negative association with underweight in all participants and both sex subgroups (**Table S2** in the supplemental material). Additionally, poor sleep quality was significantly associated with overweight and obesity in the female subgroup, and with obesity in all participants and male subgroup (**Table S3** in the supplemental material).

DISCUSSION

In this cross-sectional study based on working-aged Korean adults, sleep duration was significantly associated with body weight status across the spectrum of BMI. Individuals with short sleep duration < 7 hours had the significantly elevated adjusted ORs for all obesity categories including overweight,

Table 2—The odds ratios and 95% confidence interval of underweight, overweight, and obesity with respect to normal body weight according to the sleep duration.

	Underweight Versus Normal	Overweight Versus Normal	Obese Versus Normal	Severe Obese Versus Normal
All Participants				
Unadjusted				
< 7 hours	0.73 (0.69–0.77)	1.45 (1.40–1.49)	1.71 (1.66–1.76)	2.00 (1.86–2.15)
7 to < 9 hours	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
≥ 9 hours	1.49 (1.27–1.74)	0.55 (0.48–0.64)	0.49 (0.42–0.57)	0.81 (0.59–1.10)
Adjusted				
< 7 hours	0.88 (0.82–0.94)	1.15 (1.11–1.20)	1.31 (1.26–1.37)	1.70 (1.54–1.85)
7 to < 9 hours	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
≥ 9 hours	1.12 (0.94–1.34)	0.91 (0.77–1.08)	0.87 (0.72–1.06)	1.46 (1.02–2.10)
Male Participants				
Unadjusted				
< 7 hours	0.68 (0.58–0.81)	1.14 (1.09–1.19)	1.26 (1.21–1.32)	1.48 (1.36–1.62)
7 to < 9 hours	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
≥ 9 hours	–	–	–	–
Adjusted				
< 7 hours	0.68 (0.56–0.82)	1.18 (1.12–1.24)	1.32 (1.25–1.39)	1.66 (1.49–1.84)
7 to < 9 hours	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
≥ 9 hours	–	–	–	–
Female Participants				
Unadjusted				
< 7 hours	0.91 (0.85–0.97)	1.14 (1.07–1.20)	1.32 (1.24–1.40)	1.72 (1.49–1.99)
7 to < 9 hours	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
≥ 9 hours	1.22 (1.04–1.45)	0.83 (0.70–0.99)	0.97 (0.81–1.18)	1.12 (0.72–1.74)
Adjusted				
< 7 hours	0.91 (0.84–0.98)	1.09 (1.02–1.16)	1.30 (1.20–1.40)	1.82 (1.52–2.18)
7 to < 9 hours	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
≥ 9 hours	1.11 (0.92–1.33)	0.94 (0.78–1.16)	0.92 (0.73–1.17)	1.32 (0.82–2.14)

Adjusted for age, sex, regular exercise, alcohol intake, HDL cholesterol, triglyceride, smoking, hsCRP, diabetes mellitus, systolic blood pressure (sex excluded in sex subgroup analysis). Underweight (BMI < 18.5 kg/m^2), normal weight (BMI 18.5 to < 23 kg/m^2), overweight (BMI 23 to < 25 kg/m^2), obese (BMI 25 to < 30 kg/m^2), and severe obese (BMI ≥ 30 kg/m^2). BMI = body mass index, HDL = high-density lipoprotein, hsCRP = high-sensitivity C-reactive protein.

obesity, and severe obesity, which proportionally increased according to the degree of obesity. These findings suggest that individuals with short sleep duration are more likely to be obese. Previous studies have also demonstrated that short sleep duration could contribute to weight gain.[8–11] Thus, it is postulated that short sleep duration < 7 hours may induce adverse metabolic milieu associated with obesity. Current evidence also supports the general recommendation for obtaining 7 or more hours of sleep per night on a regular basis to promote optimal health among adults aged 18 to 60 years.[17]

Recent studies have highlighted the clinically adverse effect of underweight as well as obesity. In collaborative analyses of 57 prospective studies and population-based studies including an Asian cohort and National Cancer Institute cohort, U-shaped relationship between all-cause mortality and BMI was found.[18–20] Moreover, this phenomenon was more prominent in the elderly, smoker, and patients with major cardiovascular diseases and chronic kidney disease.[18,21–24] Thus, evaluating the association between underweight and sleep disturbance may be important in identifying the clinical significance of sleep disturbance. Nonetheless, in contrast to the evident association between sleep curtailment and obesity and weight gain, there have been inconsistent and conflicting results in terms of underweight and weight loss.

Epidemic studies performed in Western countries showed that short sleep duration was significantly associated with underweight as well as overweight and obesity in United States adults and Norwegian adolescents.[10,25] However, a 4-year longitudinal analysis for a national cohort of Thai adults indicated only significant association between short sleep duration and the risk for obesity.[11] Moreover, cross-sectional analysis for Chinese longevity did not identify any difference in sleep duration among categories of BMI.[26] Interestingly, our study showed the statistically significant inverse relationship between short sleep duration and underweight. This finding is different from previous results showing only significant or insignificant association between short sleep duration and underweight. Our result suggests that individuals with short sleep duration have the lower likelihood of weight loss, which expands to a hypothesis that sleep curtailment tends to have an effect on weight gain. This influence of short sleep duration on weight gain is supported by laboratory studies that showed the increased hunger and appetite and relevant hormonal changes such as increased levels of ghrelin and

Table 3—The odds ratios and 95% confidence interval of underweight, overweight, and obesity with respect to normal body weight according to the sleep quality.

	Underweight Versus Normal	Overweight Versus Normal	Obese Versus Normal	Severe Obese Versus Normal
All Participants				
Unadjusted				
Good	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Poor	1.12 (1.05–1.19)	0.96 (0.93–0.99)	0.98 (0.95–1.01)	1.23 (1.15–1.32)
Adjusted				
Good	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Poor	1.02 (0.96–1.10)	1.01 (0.97–1.05)	1.03 (0.98–1.07)	1.29 (1.19–1.40)
Male Participants				
Unadjusted				
Good	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Poor	0.91 (0.77–1.08)	0.99 (0.95–1.03)	0.99 (0.95–1.03)	1.21 (1.11–1.31)
Adjusted				
Good	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Poor	0.92 (0.75–1.12)	0.96 (0.92–1.01)	0.94 (0.90–0.99)	1.16 (1.05–1.27)
Female Participants				
Unadjusted				
Good	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Poor	1.11 (1.04–1.19)	1.00 (0.95–1.06)	1.18 (1.10–1.25)	1.60 (1.39–1.83)
Adjusted				
Good	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Poor	1.05 (0.98–1.13)	1.05 (0.98–1.12)	1.23 (1.14–1.33)	1.66 (1.40–1.98)

Adjusted for age, sex, regular exercise, alcohol intake, HDL cholesterol, triglyceride, smoking, hsCRP, diabetes mellitus, systolic blood pressure (sex excluded in sex subgroup analysis). Underweight (BMI < 18.5 kg/m^2), normal weight (BMI 18.5 to < 23 kg/m^2), overweight (BMI 23 to < 25 kg/m^2), obese (BMI 25 to < 30 kg/m^2), and severe obese (BMI ≥ 30 kg/m^2). BMI = body mass index, HDL = high-density lipoprotein, hsCRP = high-sensitivity C-reactive protein.

Table 4—The adjusted mean value with 95% confidence interval of BMI according to the sleep duration and sleep quality.

	Sleep Duration				
	< 5 hours	5 to < 6 hours	6 to < 7 hours	7 to < 9 hours	≥ 9 hours
All participants	24.28 (24.17–24.38)	24.20 (24.14–24.27)	23.95 (23.90–24.00)	23.71 (23.66–23.77)	22.58 (23.43–23.73)
Male participants	25.50 (25.38–25.63)	25.40 (25.33–25.47)	25.12 (25.06–25.18)	24.88 (24.82–24.95)	24.85 (24.48–25.22)
Female participants	22.92 (22.72–23.12)	22.94 (22.78–23.10)	22.75 (22.60–22.90)	22.52 (22.37–22.67)	22.43 (22.22–22.64)
	Pittsburgh Sleep Quality Index Score				
	≤ 5	6	7	8	≥ 9
All participants	23.87 (23.81–23.93)	23.97 (23.89–24.05)	23.97 (23.87–24.06)	23.94 (23.83–24.05)	23.99 (23.89–23.09)
Male participants	25.12 (25.07–25.18)	25.14 (25.05–25.23)	25.13 (25.02–25.24)	25.15 (25.00–25.30)	25.09 (24.95–25.23)
Female participants	22.54 (22.38–22.70)	22.77 (22.59–22.95)	22.76 (22.57–22.95)	22.67 (22.47–22.88)	22.77 (22.59–22.95)

Adjusted for age, sex, regular exercise, alcohol intake, HDL cholesterol, triglyceride, smoking, hsCRP, diabetes mellitus, systolic blood pressure (sex excluded in sex subgroup analysis). BMI = body mass index, HDL = high-density lipoprotein, hsCRP = high-sensitivity C-reactive protein.

decreased levels of leptin induced by quantitatively insufficient sleep.[27,28]

We also found the increased likelihood of severe obesity (BMI ≥ 30 kg/m^2) in long sleepers (> 9 hours). This finding is accordance with previous studies, in which a U-shaped association between sleep duration and BMI categories was observed. In an analysis among Norwegian children aged 10–12 years old, Danielsen et al. observed U-shaped associations between sleep duration and overweight/obesity as well as BMI.[29] Additionally, a survey in Chinese adolescents showed a clear U-shaped association between sleep duration and overweight/obesity.[30] Also in studies for adults, long sleep duration was more significantly associated with obesity than normal sleep duration. In a study using 2004–2005 United States National Health Interview Survey data (n = 56,507 observations, adults age 18–85 years), short sleep (< 7 hours) and long sleep (> 8 hours) are positively associated with the risk of obesity, diabetes, hypertension, and cardiovascular disease.[31] A Thai cohort study also showed the increased risk for obesity and overweight in long sleepers (≥ 9 hours).[11] Nonetheless, our sex subgroup analysis did not show any statistically significant association between long sleep duration and severe obesity. This finding may be attributable to the proportion of severe obesity and long sleeper in our study participants. Despite a large sample size, most of our study participants were Korean employees working in Korean companies. Thus, the proportion of men who can sleep longer than 9 hours was too low to conduct statistical analysis. Moreover, the proportion of women with severe obesity (BMI $\geq$ 30 kg/m^2) was also too low to show the statistically significant result in analysis. Thus, this limitation of our study should be considered in interpreting our results.

In association between sleep quality and obesity, prior studies have demonstrated that sleep quality evaluated by self-report was significantly associated with overweight, obesity, and increased fat mass.[32–35] We also observed the significant association of poor sleep quality with obesity categories. This finding was observed in both men and women, but a subtle difference was found between sex subgroups. Although the female subgroup showed a significant association between poor sleep quality and obesity and severe obesity, the male subgroup had a significant association of poor sleep quality with only severe obesity, showing an unexpected inverse relationship with obesity. Meanwhile, the adjusted mean value of BMI, despite the attenuated statistical significance by widely dispersed CI, was consistently higher in women with PSQI score > 5 than women with PSQI score ≤ 5. These findings suggest that the influence of poor sleep quality on obesity may be more powerful in women than men. Previous studies have implied that sex may make a difference in the influence of sleep deprivation and disturbance on adverse health outcomes.[36,37] In particular, several investigations observed that poor sleep quality may independently lead insulin resistance and subclinical inflammation only in women, suggesting sex difference in adverse influence of poor sleep quality on metabolic condition.[38,39] Further research should be conducted to identify the sex difference in the association between sleep disturbance and obesity.

One merit of this study is the large number of the participants with relevant clinical data including self-reported sleep duration and PSQI score that enabled us to investigate the association of sleep duration and sleep quality with BMI categories, adjusting for multiple demographic and clinical covariates. Additionally, our subgroup analysis provides additional information about sex differences in the influence of sleep on health outcomes.

Nonetheless, several limitations of this study should be considered. First, our results should be interpreted in light of the study's cross-sectional design. The association between short sleep duration, poor sleep quality and obesity is a significant clinical implication; however, a cross-sectional study cannot suggest the evident incidental risk for any health outcome.

Second, the evaluation of sleep duration and quality was based on self-reported data. Self-reported data has been shown to correlate with an objective measurement using actigraphy. However, several sleep studies have noted the problem of subjectivity in self-reporting sleep duration and quality.[9,40] Thus, it should be acknowledged that subjectivity of self-reporting may have an effect on results.

Third, we could not identify individuals with OSA in our study. It is well established that obesity is a leading cause of OSA related to poor sleep quality. Thus, identifying individuals with OSA is important in suggesting the potential mechanism accounting for the association between poor sleep quality and obesity. Nonetheless, because our data were collected from medical records of over 100,000 individuals who underwent periodic medical health check-ups, polysomnography to investigate OSA could not be conducted. Further studies should be conducted to show the interaction among OSA, poor sleep quality, and obesity.

In conclusion, our study demonstrated that short sleep duration was more closely linked to obesity categories across BMI. Additionally, poor sleep quality also showed a significant association with obesity, which was more prominent in women than men. Our observations provide epidemiologic evidence that identifies the influence of sleep status on cardiometabolic conditions including obesity.

ABBREVIATIONS

ANOVA, analysis of variance
BMI, body mass index
BP, blood pressure
CI, confidence interval
KSHS, Kangbuk Samsung Health Study
LDL, low-density lipoprotein
HDL, high-density lipoprotein
HOMA-IR, homeostasis model assessment of insulin resistance
hsCRP, high sensitivity C-reactive protein
OR, odds ratio
PSQI, Pittsburgh Sleep Quality Index

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ACKNOWLEDGMENTS

This study was based on medical data collected and arranged by Kangbuk Samsung Cohort Study (KSCS). Therefore, this study could only be done by virtue of the labor of all staff members working in KSCS and Total Healthcare Center, Kangbuk Samsung Hospital. The authors offer a special thanks to Jiin Ahn and professor Yoosoo Chang in Kangbuk Samsung Cohort Team.
Author contributions: Sung Keun Park coordinated the study, analyzed the data, and wrote the manuscript as a first author. Ju Young Jung made the study design, analyzed the data, and edited the manuscript. Chang-Mo Oh participated in the methodology and statistical analysis. Roger S. McIntyre and Jae-Hon Lee, MD participated in reviewing and editing manuscript.
Ju Young Jung is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

SUBMISSION & CORRESPONDENCE INFORMATION

Submitted for publication January 18, 2018
Submitted in final revised form March 14, 2018
Accepted for publication April 12, 2018
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DISCLOSURE STATEMENT

The authors report no conflicts of interest.