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Association of skipping breakfast and short sleep duration with the prevalence of metabolic syndrome in the general Japanese population: Baseline data from the Japan Multi-Institutional Collaborative cohort study

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ABSTRACT

Abbreviations: BMI, Body mass index; CI, Confidence interval; CVD, Cardiovascular diseases; FFQ, Food-frequency questionnaire; HDL, High-density lipoprotein; MET, Metabolic equivalent; MetS, Metabolic syndrome; OR, Odds ratio; SD, Standard deviation.

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The purpose of the study was to investigate sex-specific associations of skipping breakfast and short sleep duration with metabolic syndrome (MetS) and their interaction. We analyzed baseline data of 14,907 men and 14,873 women aged 35–69 years, who participated in the Japan Multi-Institutional Collaborative Cohort Study from 2005. MetS was diagnosed using a modification of the National Cholesterol Education Program Adult Treatment Panel III revised definition (NCEP-R 2005), using body mass index instead of waist circumference. Breakfast consumption was classified into two categories: ≥6 days/week (consumers) or <6 days/week (skippers). Sleep duration was classified into three categories: <6h, 6 to <8 h, and ≥8 h/day. Multivariate logistic regression analysis was performed to estimate odds ratios (ORs) and 95 % confidence intervals (CIs) and examine the presence of interaction. In men, skipping breakfast and short sleep duration were independently associated with an increased prevalence of MetS (OR 1.26, 95%CI 1.12–1.42 and OR 1.28, 95%CI 1.12–1.45, respectively), obesity, and components of MetS. However, no significant interaction was observed between skipping breakfast and short sleep duration. In women, skipping breakfast and short sleep duration were associated with an increased prevalence of obesity, but not with MetS. These findings indicate that breakfast consumption and moderate sleep duration may be associated with a lower risk of MetS, particularly in men.

1. Introduction

Metabolic syndrome (MetS) is a condition characterized by a clustering of risk factors for cardiovascular diseases (CVD), such as large waist circumference, high blood pressure, elevated serum triglyceride and blood glucose levels, and low serum levels of high-density lipoprotein (HDL) cholesterol. MetS is known to increase the risk of developing type 2 diabetes, CVD, stroke, myocardial infarction, and all-cause mortality (Mottillo et al., 2010; Sattar et al., 2003). Therefore, early prevention of MetS is important for public health.

Breakfast is an important source of energy required for daily activities, and it is associated with the regulation of the circadian rhythm (Wehrens et al., 2017). In Japan, the National Health and Nutrition Survey of 2016 showed that 15.4% of men and 10.7% of women skipped breakfast. Several studies have shown an association between skipping breakfast and MetS (Chung et al., 2015; Odegaard et al., 2013; Uzhova et al., 2017); however, the results are not always consistent (Deshmukh-Taskar et al., 2013; Kutsuma et al., 2014).

Recently, modern lifestyles have led to a reduction in habitual sleep duration. In *meta*-analyses on the association between sleep and MetS, short sleep duration was shown to be positively associated with MetS, whereas long sleep duration was not (Hua et al., 2020; Xi et al., 2014). Meanwhile, a U-shaped relationship between sleep duration and adverse health outcomes, including obesity, cardiovascular disease and all-cause mortality, has been reported (Kim et al., 2017; Liu et al., 2017; Magee et al., 2012).

There are not many studies that assessed the sex-specific association between skipping breakfast or sleep duration and MetS (Kim et al., 2018; Kutsuma et al., 2014; Suliga et al., 2017; Wu et al., 2015; Wu et al., 2012). The purpose of this study was to investigate the sex-specific effects of breakfast consumption and sleep duration on MetS and their interaction. Our report may be the first to observe gender differences in the association between skipping breakfast and MetS.

2. Methods

2.1. Study subjects

The Japan Multi-Institutional Collaborative Cohort (J-MICC) Study was designed to detect and confirm gene-environment interactions for lifestyle-related diseases; the details of this cohort have been previously described (Hamajima and J-MICC Study Group, 2007; Takeuchi et al., 2020; Wakai et al., 2011). Briefly, the J-MICC Study was started in 2005 except for 2 areas where the survey began earlier (in 2004). Subjects aged 35–69 years were enrolled from 14 areas of Japan through 2014. Written informed consent was obtained from each participant, and the study protocol was approved by the ethics committees of Nagoya University Graduate School of Medicine (the affiliation of the present principal investigator Kenji Wakai) (IRB No. 2010–0939-8), Tokushima University Hospital (IRB No. 466–2), and each participating institution.

Of the 14 research sites, two did not collect biochemical data from the study participants, two did not measure fasting plasma glucose levels, and two used different questionnaires. Excluding these six research sites, 43,444 individuals (20,510 men and 22,934 women) from the remaining eight research sites were initially included in the current study (Version 2020.12.21 data set). Of the 43,444 participants, 13,664 were excluded due to the following reasons (with overlapping): (i) history of ischemic heart disease (n = 1,082) and cerebrovascular disease (n = 699); (ii) lack of data on breakfast consumption (n = 291) and sleep duration (n = 25); (iii) receiving anti-insomnia medication (n = 1,742); (iv) implausible high or low estimated total energy intake (<1,000 kcal/day or greater than 4,000 kcal/day, n = 848); (v) lack of data on the following items: body mass index (BMI), blood pressure, serum triglycerides, HDL cholesterol, fasting plasma glucose, or medical histories essential for the diagnosis of MetS (8,197 individuals); and (vi) lack of data on smoking status, alcohol drinking status, daily life activity, leisure-time exercise, or menopausal status (2,633 individuals). A total of 29,780 participants (14,907 men and 14,873 women) were ultimately eligible for the present analyses. Women made up a higher proportion of the excluded participants than of included participants. Excluded men were older, more educated, and had lower total energy intake. Excluded women had shorter duration of education and lower total energy intake (Supplementary Table 1).

2.2. Questionnaire

Lifestyle factors, including smoking and drinking habits, physical activity, current medication, disease history, breakfast consumption, sleep duration, and education level were investigated using a self-administered questionnaire, and the data were checked by trained staff. Smoking habit was asked as three categories: never, former, and current smokers. Drinking habit was also asked as three categories: never, former, and current drinkers (≥one time/month), and was re-categorized them into two (never and former, and current drinkers). Daily life activity was estimated by multiplying each metabolic equivalent (MET) level (≥2.0 METs): behaviors that require muscle power (4.5 METs); walking (3.0 METs); and standing (2.0 METs) by the average duration (hours). The MET-h/week of daily life activity was calculated by summing the three levels of activities. The leisure-time exercise was estimated using a questionnaire, similar to a short format of the International Physical Activity Questionnaire (Craig et al., 2003) and was estimated by multiplying the frequency (five categories from none to ≥5 times/week) and the average duration (six categories from ≤30 min to ≥4 h) of light (e.g., walking, hiking; 3.4 METs), moderate (e.g., jogging, swimming; 7.0 METs), and vigorous-intensity exercise (e.g., marathon running, combative sports; 10.0 METs). The MET-h/week of leisure-time exercise was calculated by summing the three levels of exercises.

A validated food-frequency questionnaire (FFQ), which was developed by the Nagoya City University Graduate School of Medical Sciences, asked about the intake frequency of 47 foods and beverages over

the past year (Imaeda et al., 2007; Tokudome et al., 2004; Tokudome et al., 2005). The daily total energy and nutrient intake were calculated using an original program based on the Standard Tables of Food Composition in Japan. Nutrient patterns were considered as dietary quality (Iwasaki et al., 2019). Nutrient patterns were extracted by factor analysis from 26 nutrient intakes. Factor 1 (nutrient pattern 1, like prudent dietary pattern) had the high factor loadings for folate, insoluble dietary fiber, carotene, iron, soluble dietary fiber, and vitamin C. Thus, nutrient pattern 1 was used as a potential confounding factor.

The participants' last education background was also obtained and educational level was classified into four categories: (≤9 years, 10–15 years, ≥16 years, and unknown).

2.3. Breakfast consumption and sleep duration

For breakfast consumption, participants were asked to fill in a numerical value (0–7) as the frequency of habitual breakfast intake (per week) during the past year. Habitual breakfast consumption was classified into five categories: every day, 6 days, 3–5 days, 1–2 days, and none/week. A uniform definition of breakfast skipping has not been established. Thus, based on the previous reports and the fact that more than 85% of both men and women ate breakfast ≥6 days/week, participants were divided into breakfast consumers (≥6 days/week) and breakfast skippers (0–5 days/week). The average sleep duration was classified into three categories based on the response to the question "What is the average amount of sleep you usually get in a day?": <6h/day (short sleep), 6 to <8 h/day, and ≥8 h/day (long sleep).

2.4. Anthropometric and biochemical measurements

Anthropometric and biochemical measurements were conducted in each research site at the health screening using standardized protocols. Height (to the nearest 0.1 cm) and weight (to the nearest 0.1 kg) were measured with shoes off. BMI was calculated as weight (kg)/[height (m)]^2. Systolic and diastolic blood pressure (mmHg) were measured while participants were in a sitting position at rest. Plasma glucose (mg/dL), serum triglycerides (mg/dL) and serum HDL cholesterol levels (mg/dL) were measured using overnight fasting venous blood.

2.5. Diagnosis of metabolic syndrome

We assessed the prevalence of MetS by using the National Cholesterol Education Program Adult Treatment Panel III revised definition (Grundy et al., 2005) with some modifications. Because waist circumference was not measured in all participants, we used BMI alternatively. BMI is closely correlated with abdominal circumference (Lauria et al., 2013). MetS was diagnosed when participants had at least three of the following five conditions: (i) Obesity: BMI ≥25 kg/m^2 instead of high waist circumference; (ii) High blood pressure: systolic blood pressure ≥130 mmHg and/or diastolic blood pressure ≥85 mmHg or receiving treatment for hypertension; (iii) Elevated triglycerides: serum triglyceride level ≥150 mg/dL; (iv) Low HDL cholesterol: serum HDL cholesterol level <40 mg/dL in men or <50 mg/dL in women; and (v) Elevated blood glucose: fasting plasma glucose level ≥100 mg/dL or receiving treatment for diabetes.

2.6. Statistical analyses

All analyses were separately conducted for both the sexes. For continuous variables of background characteristics, *t*-tests, and Wilcoxon's rank-sum tests were applied to assess the differences according to the presence or absence of MetS, and χ^2 tests were used for the categorical variables. To analyze the associations between breakfast consumption or sleep duration and MetS or its components, a multivariate logistic regression analysis was used. Model 1 was adjusted for age (continuous) and research site (7 categories); model 2 was adjusted for model 1 plus education level (4 categories), smoking habit (3 categories), drinking habit (2 categories), daily life activity (quartiles), leisure-time exercise (quartiles), total energy intake (quartiles), and menopause status (post-menopause or other) in women; model 3 was adjusted for model 2 plus nutrient pattern 1 (quartiles); and model 4 was adjusted for model 2 plus BMI (quartiles). Linear trends were assessed using ordinal categorical variables (1 to 4) in each statistical model, using a likelihood ratio test. Statistical significance for the interaction between skipping breakfast (2 categories) and sleep duration (3 categories) was also evaluated using a likelihood ratio test (degree of freedom = 2). All analyses were performed using the SAS software (Version 9.4; SAS Institute, Cary, NC, USA). Statistical significance was set at $P < 0.05$.

3. Results

The mean ± standard deviation (SD) of ages was 54.6 ± 9.7 years in men and 53.8 ± 9.5 years in women. We found that 14.6% of the men and 10.1% of the women skipped breakfast more than 2 days/week. As for the sleep duration, 10.1% of men and 13.3% of women slept <6 h, 68.0% of men and 70.8% of women slept from 6 to <8 h, and 21.9% of men and 14.6% of women slept ≥8 h.

Table 1 shows the sex-specific characteristics of the study participants according to MetS status. The prevalence of MetS was 22.6% in men and 10.5% in women. Among men, participants with MetS were slightly older (55.6 ± 9.0 years) than those without MetS (54.3 ± 9.8), had higher percentage of current drinkers, lower percentage of never smokers, higher percentage of breakfast skippers, shorter years of education, shorter sleep duration, and less daily life activity. Among women, participants with MetS were older (mean ± SD, 58.3 ± 7.9 vs. 53.3 ± 9.6), had high percentage of longer sleep duration, had low percentage of current drinker and shorter years of education. The characteristics of each research site are shown in Supplementary Table 2. The proportion of MetS in the Kagoshima site was relatively high compared to the other sites, but this was probably due to the higher average BMI.

When the study participants were divided into five categories by frequency of breakfast consumption, men who consumed breakfast 3–5 days or 1–2 days per week had a significantly higher prevalence of MetS compared with those who ate breakfast every day (Supplementary Table 3). There was a significant linear trend between the frequency of breakfast and MetS (*P* for linear trend = 0.022). Given more than 85% of both men and women ate breakfast ≥6 days/week, we divided the study participants into breakfast consumers (≥6 days/week) and breakfast skippers (0–5 days/week) (Table 2). In men, breakfast skipping was associated with a significantly higher prevalence of MetS (odds ratio [OR] 1.26, 95% confidence interval [CI] 1.12–1.42), obesity (OR 1.15, 95% CI 1.03–1.28), high blood pressure (OR 1.19, 95% CI 1.07–1.33), and elevated triglyceride levels (OR 1.21, 95% CI 1.09–1.36). When further adjusted for nutrient pattern 1 (like prudent dietary pattern), obesity was no longer significant (model 3). In women, skipping breakfast was significantly associated with obesity (OR 1.18, 95% CI 1.02–1.36), but not with MetS (OR 1.00, 95% CI 0.82–1.21). In women, meanwhile, obesity was no longer significant with additional nutrient pattern 1 adjustment, as in men (model 3). Further adjustment for BMI (instead of nutrient pattern 1) did not significantly alter the results in both sexes (model 4).

Table 3 shows the association between sleep duration and MetS for both the sexes. In men, short sleep duration was significantly associated with MetS (OR 1.28, 95% CI 1.12–1.45), obesity (OR 1.40, 95% CI 1.25–1.57), and high blood glucose (OR 1.15, 95% CI 1.03–1.29). When further adjusted for nutrient pattern 1, the results were not greatly altered (model 3). After adjustment for BMI, short sleep duration was no longer significantly associated with high blood glucose (model 4). In women, short sleep duration was positively associated with obesity (OR 1.28, 95% CI 1.14–1.44), but not with MetS (OR 1.13, 95% CI

Table 1
Baseline characteristics of the participants according to metabolic syndrome status by sex.

	Men (n = 14,907)			Women (n = 14,873)		
	Metabolic syndrome (Yes)	Metabolic syndrome (No)	*P*-value	Metabolic syndrome (Yes)	Metabolic syndrome (No)	*P*-value
N (%)	3,371 (22.6)	11,536 (77.4)		1,562 (10.5)	13,311 (89.5)	
Age (years)[a]	55.6 ± 9.0	54.3 ± 9.8	<0.001	58.3 ± 7.9	53.3 ± 9.6	<0.001
Education level (years)[b]						
≤9	445 (13.2)	1,256 (10.9)	<0.001	347 (22.2)	1,367 (10.3)	<0.001
10–15	1,735 (51.5)	5,792 (50.2)		1,055 (67.5)	9,753 (73.3)	
≥16	1,065 (31.6)	4,110 (35.6)		92 (5.9)	1,708 (12.8)	
Unknown	126 (3.7)	378 (3.3)		68 (4.4)	483 (3.6)	
Smoking habit[b]						
Current	908 (26.9)	3,200 (27.7)	<0.001	80 (5.1)	737 (5.5)	0.28
Past	1,514 (44.9)	4,630 (40.1)		98 (6.3)	964 (7.2)	
Never	949 (28.2)	3,706 (32.1)		1,384 (88.6)	11,610 (87.2)	
Drinking habit[b]						
Current	2,672 (79.3)	8,857 (76.8)	0.002	468 (30.0)	5,255 (39.5)	<0.001
Past or Never	699 (20.7)	2,679 (23.2)		1,094 (70.0)	8,056 (60.5)	
Daily life activity (MET-h/week)[a]	136.1 ± 111.9	142.2 ± 114.1	0.01	160.7 ± 101.9	160.5 ± 98.5	0.96
Leisure-time exercise (MET-h/week)[a]	15.0 ± 22.7	16.7 ± 26.6	<0.001	14.5 ± 22.4	13.7 ± 21.8	0.16
Total energy intake (kcal/day)[a]	1,924 ± 358	1,929 ± 349	0.54	1,539 ± 229	1,555 ± 229	0.01
Body mass index (kg/m^2)[a]	26.6 ± 2.9	22.9 ± 2.6	<0.001	26.8 ± 3.6	21.9 ± 2.9	<0.001
Systolic blood pressure (mmHg)[a]	138 ± 16	125 ± 17	<0.001	139 ± 16	122 ± 18	<0.001
Diastolic blood pressure (mmHg)[a]	85 ± 10	78 ± 10	<0.001	82 ± 10.0	73.8 ± 10.7	<0.001
Triglycerides (mg/dL)[c]	178 (129, 240)	96 (71, 131)	<0.001	157 (105, 202)	77 (58, 104)	<0.001
HDL cholesterol (mg/dL)[a]	51 ± 14	61 ± 15	<0.001	54 ± 13	72 ± 16	<0.001
Fasting glucose (mg/dL)[c]	106 (100, 118)	95 (90, 101)	<0.001	103 (96, 113)	90 (85, 96)	<0.001
Obesity (%)[b]	2,605 (77.3)	1,857 (16.1)	<0.001	1,166 (74.7)	1,649 (12.4)	<0.001
High blood pressure (%)[b]	2,950 (87.5)	4,943 (42.9)	<0.001	1,373 (87.9)	4,638 (34.8)	<0.001
Elevated triglycerides (%)[b]	2,313 (68.6)	1,759 (15.3)	<0.001	867 (55.5)	866 (6.5)	<0.001
Low HDL cholesterol (%)[b]	736 (21.8)	346 (3.0)	<0.001	746 (47.8)	660 (5.0)	<0.001
Elevated blood glucose (%)[b]	2,620 (77.7)	3,453 (29.9)	<0.001	1,085 (69.5)	1,870 (14.1)	<0.001
Breakfast intake (days/week)[a]	6.3 ± 1.7	6.4 ± 1.7	0.016	6.6 ± 1.3	6.6 ± 1.3	0.69
Sleep duration (h/day)[a]	6.8 ± 1.1	6.7 ± 1.0	0.23	6.6 ± 1.0	6.5 ± 1.0	<0.001
Breakfast intake (days/week)[c]						
≥6	2,866 (85.0)	10,059 (87.2)	0.001	1,414 (90.5)	11,958 (89.8)	0.39
<6	505 (15.0)	1,477 (12.8)		148 (9.5)	1,353 (10.2)	
Sleep duration (h/day)[c]						
<6	375 (11.1)	1,134 (9.8)	<0.001	224 (14.3)	1,944 (14.6)	0.001
6 to <8	2,200 (65.3)	7,930 (68.7)		1,061 (67.9)	9,471 (71.2)	
≥8	796 (23.6)	2,472 (21.4)		277 (17.7)	1,896 (14.2)	

MET, metabolic equivalent.
Data are presented as mean ± SD[a], number (%)[b], or median (25%, 75%)[c].

0.96–1.32). Longer sleep duration was not associated with MetS or obesity in either sex. However, longer sleep was positively associated with high blood pressure in men (OR 1.12, 95% CI 1.03–1.23), elevated triglycerides in both men and women (OR 1.13, 95% CI 1.03–1.24; OR 1.16, 95% CI 1.01–1.33, respectively), and low HDL cholesterol in women (OR 1.22, 95% CI 1.05–1.42).

With regard to the interaction between breakfast consumption (2 categories) and sleep duration (3 categories) on MetS (Table 4), the ORs were significantly higher in the group with short sleep or skipping breakfast in men when the breakfast eaters/sleeping 6 to < 8 h were used as reference. *P*-values for interaction were greater than 0.05 in both sexes. When we performed the subgroup analysis as short sleep duration (<6h) vs. others (≥6h), we found that the highest OR was found in the group of men who had short duration of sleep and skipping breakfast (data not shown). *P* values for interaction were also not significant.

4. Discussion

In this study, skipping breakfast and short sleep duration was associated with MetS only in men. However, some components of MetS were associated with skipping breakfast and sleep duration in women.

In a cohort study, Odegaard et al. reported a hazard ratio of 0.82 (95% CI 0.69–0.98) for MetS among daily breakfast eaters compared with those who consumed breakfast 0–3 days per week (Odegaard et al., 2013). Although Chung et al. and Uzhova et al. defined skipping breakfast by 24-hour recall or dietary records, both cross-sectional studies reported that skipping breakfast was associated with a higher OR for MetS (Chung et al., 2015; Uzhova et al., 2017). Conversely, several cross-sectional studies have reported no significant associations (Deshmukh-Taskar et al., 2013; Kutsuma et al., 2014). In our study, skipping breakfast was associated with MetS and high blood pressure only in men, but with obesity in both sexes. A *meta*-analysis of 19 cross-sectional studies reported that skipping breakfast was associated with a higher prevalence of obesity (Horikawa et al., 2011). Blom et al. reported that intake at lunch as well as hunger ratings were significantly increased after skipping breakfast (by 144 kcal) (Blom et al., 2005), this may lead to increased insulin response and fat storage. Owing to poor diet quality in the breakfast skipping group as previously reported (Cappuccio et al., 2008), we adjusted for nutrient pattern 1 (like prudent dietary pattern). Consequently, skipping breakfast was no longer significantly associated with obesity in both sexes. In our previous study, nutrient pattern 1 was inversely associated with MetS and its components (Iwasaki et al., 2019). Results of the present study suggest that diet quality may intermediate the association between skipping breakfast and obesity. Regarding components of MetS other than obesity/abdominal obesity, positive associations between breakfast skipping and high blood pressure (Odegaard et al., 2013; Uzhova et al., 2017), high triglycerides, low HDL cholesterol, and high fasting glucose (Uzhova et al., 2017) have been reported. In most previous studies, skipping breakfast was associated with obesity/overweight, but the results were not always consistent for MetS or other components. Moreover, few reports have examined the association between skipping breakfast and MetS by gender, and our report may be the first to observe gender differences.

Table 2
Multivariate-adjusted odds ratios of metabolic syndrome and each components according to breakfast consumption by sex.

	Men		Women	
	Breakfast eaters	Breakfast skippers	Breakfast eaters	Breakfast skippers
	(6–7 days/week, n = 12,925) OR (reference)	(0–5 days/week, n = 1,982) OR (95% CI)	(6–7 days/week, n = 13,372) OR (reference)	(0–5 days/week, n = 1,501) OR (95% CI)
Metabolic syndrome				
Model 1	1.00	1.29 (1.15–1.45)	1.00	1.15 (0.95–1.38)
Model 2	1.00	1.26 (1.12–1.42)	1.00	1.00 (0.82–1.21)
Model 3	1.00	1.20 (1.06–1.35)	1.00	0.96 (0.79–1.17)
Obesity (BMI ≥25 kg/m^2)				
Model 1	1.00	1.13 (1.01–1.25)	1.00	1.20 (1.05–1.37)
Model 2	1.00	1.15 (1.03–1.28)	1.00	1.18 (1.02–1.36)
Model 3	1.00	1.10 (0.99–1.23)	1.00	1.14 (0.99–1.32)
High blood pressure				
Model 1	1.00	1.11 (1.00–1.23)	1.00	0.94 (0.84–1.07)
Model 2	1.00	1.19 (1.07–1.33)	1.00	0.94 (0.82–1.06)
Model 3	1.00	1.13 (1.01–1.26)	1.00	0.92 (0.81–1.04)
Model 4	1.00	1.16 (1.03–1.30)	1.00	0.88 (0.77–1.00)
Elevated triglycerides				
Model 1	1.00	1.34 (1.21–1.49)	1.00	1.23 (1.04–1.45)
Model 2	1.00	1.21 (1.09–1.36)	1.00	1.05 (0.88–1.25)
Model 3	1.00	1.18 (1.05–1.31)	1.00	1.02 (0.85–1.21)
Model 4	1.00	1.18 (1.05–1.32)	1.00	0.98 (0.82–1.18)
Low HDL cholesterol				
Model 1	1.00	1.41 (1.18–1.67)	1.00	1.20 (1.00–1.44)
Model 2	1.00	1.20 (0.99–1.43)	1.00	1.08 (0.89–1.31)
Model 3	1.00	1.18 (0.98–1.42)	1.00	1.05 (0.86–1.28)
Model 4	1.00	1.16 (0.96–1.39)	1.00	1.02 (0.84–1.24)
Elevated blood glucose				
Model 1	1.00	1.08 (0.98–1.20)	1.00	1.21 (1.05–1.39)
Model 2	1.00	1.08 (0.96–1.20)	1.00	1.17 (1.00–1.35)
Model 3	1.00	1.04 (0.94–1.16)	1.00	1.14 (0.98–1.32)
Model 4	1.00	1.05 (0.94–1.17)	1.00	1.12 (0.96–1.30)

OR, odds ratio; 95% CI, 95% confidence interval.
Model 1: Adjusted for age and research site.
Model 2: Adjusted for age, research site, education level, smoking habit, drinking habit, daily life activity, leisure-time exercise, total energy intake, and menopause status (women only).
Model 3: Adjusted for variables in model 2 plus nutrient pattern 1.
Model 4: Adjusted for variables in model 2 plus BMI (quartiles).

The association between short sleep duration and MetS has been reported in *meta*-analyses of prospective and cross-sectional studies (Hua et al., 2020; Xi et al., 2014). Hua et al. reported short sleep duration was positively associated with MetS in cohort studies (relative risk 1.15, 95% CI 1.05–1.25) and for cross-sectional studies (OR 1.12, 95% CI 1.08–1.18). Short sleep duration could lead to endocrine changes, by affecting carbohydrate metabolism, the hypothalamic-pituitary adrenal axis, and sympathetic activity (Hua et al., 2020). Additionally, the association between short sleep duration and obesity has been reported in *meta*-analyses and reviews (Nielsen et al., 2011; Patel and Hu, 2008; Taheri et al., 2004). In our analysis, short sleep duration was significantly associated with elevated blood glucose in men, albeit not significantly after additional BMI adjustment. This result suggests that obesity may intermediate the association between short sleep duration and elevated blood glucose. Previous reports (Hua et al., 2020; Xi et al., 2014) and our results suggest that obesity is the main contributor to the association between shorter sleep duration and MetS. Some previous studies that investigated the association between sleep duration and Mets conducted gender-stratified analyses (Hua et al., 2020), but most of the authors did not insist on gender difference. In our study, there were no differences in the number of subjects or mean age between sexes, but the prevalence of MetS was lower in women than in men. Lower statistical power because of the lower prevalence might be one of the reasons why a significant association between short sleep duration and MetS was not detected in women. However, the gender difference between short sleep duration and MetS is still open to discussion.

Long sleep duration was associated with elevated blood pressure (men), elevated triglycerides (both sexes), and low HDL cholesterol (women) in our study. Xi et al. reported that a *meta*-analysis of 13 cross-sectional studies found a significant positive association between prolonged sleep and elevated blood pressure in adults (Xi et al., 2014), but a *meta*-analysis of 5 cohort studies did not (Kaneita et al., 2008). A positive association between long sleep duration and elevated triglyceride levels has also been reported (Grandner and Drummond, 2007; Kim et al., 2018; Zheng et al., 2015). All significant associations between long sleep duration and MetS components were independent of obesity in our study; thus, pathways other than obesity could be involved in these relationships. This mechanism is unclear because the negative effects of prolonged sleep have not been investigated widely. In this study, only 55 were being treated for depression, and so this effect could not be considered. A positive association between long sleep duration and low HDL cholesterol levels has been reported in women (Kim et al., 2018; Zheng et al., 2015). The underlying mechanism has not been elucidated, but it has frequently been observed that people with high triglycerides have low HDL cholesterol (Kim et al., 2018; Zheng et al., 2015). In addition, a female-specific hormonal balance could also affect lipoprotein metabolism (Kim et al., 2018).

This study has some limitations. First, owing to the study's cross-sectional design, the temporal relationship between the exposure and the outcome is not ensured. Second, because data on waist circumference were lacking, BMI was alternatively used for the diagnosis of MetS.

Table 3
Multivariate-adjusted odds ratios of metabolic syndrome and each component according to sleep duration by sex.

	Men			Women		
	Sleep duration (<6h)	Sleep duration (6 to <8 h)	Sleep duration (≥8h)	Sleep duration (<6h)	Sleep duration (6 to <8 h)	Sleep duration (≥8h)
	(n = 1,509)	(n = 10,130)	(n = 3,268)	(n = 2,168)	(n = 10,532)	(n = 2,173)
	OR (95% CI)	OR (reference)	OR (95% CI)	OR (95% CI)	OR (reference)	OR (95% CI)
Metabolic syndrome						
Model 1	1.27 (1.12–1.44)	1.00	1.02 (0.93–1.13)	1.15 (0.99–1.34)	1.00	1.10 (0.95–1.27)
Model 2	1.28 (1.12–1.45)	1.00	1.02 (0.92–1.12)	1.13 (0.96–1.32)	1.00	1.07 (0.92–1.24)
Model 3	1.27 (1.12–1.45)	1.00	1.01 (0.91–1.11)	1.13 (0.97–1.33)	1.00	1.07 (0.93–1.24)
Obesity (BMI ≥25 kg/m^2)						
Model 1	1.40 (1.24–1.56)	1.00	0.91 (0.83–1.00)	1.31 (1.16–1.47)	1.00	1.03 (0.91–1.16)
Model 2	1.40 (1.25–1.57)	1.00	0.92 (0.84–1.00)	1.28 (1.14–1.44)	1.00	1.02 (0.90–1.14)
Model 3	1.40 (1.25–1.57)	1.00	0.91 (0.83–1.00)	1.28 (1.14–1.44)	1.00	1.02 (0.90–1.14)
High blood pressure						
Model 1	1.08 (0.97–1.21)	1.00	1.13 (1.03–1.23)	1.05 (0.95–1.16)	1.00	1.04 (0.94–1.15)
Model 2	1.10 (0.98–1.23)	1.00	1.12 (1.03–1.23)	1.05 (0.95–1.16)	1.00	1.03 (0.93–1.14)
Model 3	1.09 (0.97–1.22)	1.00	1.11 (1.02–1.21)	1.05 (0.95–1.17)	1.00	1.03 (0.93–1.14)
Model 4	1.01 (0.90–1.14)	1.00	1.20 (1.09–1.31)	1.01 (0.91–1.13)	1.00	1.06 (0.95–1.17)
Elevated triglycerides						
Model 1	1.04 (0.92–1.17)	1.00	1.14 (1.05–1.25)	0.92 (0.79–1.07)	1.00	1.17 (1.02–1.34)
Model 2	1.04 (0.92–1.18)	1.00	1.13 (1.03–1.24)	0.91 (0.78–1.06)	1.00	1.16 (1.01–1.33)
Model 3	1.04 (0.92–1.18)	1.00	1.13 (1.03–1.23)	0.91 (0.78–1.06)	1.00	1.16 (1.01–1.34)
Model 4	0.96 (0.85–1.09)	1.00	1.21 (1.10–1.33)	0.87 (0.75–1.02)	1.00	1.20 (1.04–1.38)
Low HDL cholesterol						
Model 1	0.99 (0.80–1.22)	1.00	0.97 (0.83–1.14)	1.13 (0.96–1.33)	1.00	1.24 (1.07–1.43)
Model 2	0.98 (0.79–1.21)	1.00	0.99 (0.84–1.16)	1.11 (0.93–1.30)	1.00	1.22 (1.05–1.42)
Model 3	0.98 (0.79–1.21)	1.00	0.99 (0.84–1.16)	1.11 (0.94–1.30)	1.00	1.22 (1.05–1.42)
Model 4	0.90 (0.73–1.12)	1.00	1.04 (0.88–1.23)	1.05 (0.89–1.24)	1.00	1.26 (1.08–1.47)
Elevated blood glucose						
Model 1	1.15 (1.02–1.28)	1.00	0.94 (0.87–1.03)	0.97 (0.86–1.10)	1.00	1.07 (0.95–1.20)
Model 2	1.15 (1.03–1.29)	1.00	0.93 (0.86–1.01)	0.97 (0.85–1.09)	1.00	1.06 (0.94–1.19)
Model 3	1.15 (1.02–1.29)	1.00	0.93 (0.85–1.01)	0.97 (0.85–1.09)	1.00	1.06 (0.94–1.19)
Model 4	1.09 (0.97–1.23)	1.00	0.96 (0.88–1.05)	0.93 (0.82–1.06)	1.00	1.08 (0.96–1.22)

OR, odds ratio; 95% CI, 95% confidence interval.
Model 1: Adjusted for age and research site.
Model 2: Adjusted for age, research site, education level, smoking habit, drinking habit, daily life activity, leisure-time exercise, total energy intake, and menopause status (women only).
Model 3: Adjusted for variables in model 2 plus nutrient pattern 1.
Model 4: Adjusted for variables in model 2 plus BMI (quartiles).

Table 4
Sex-specific odds ratios of metabolic syndrome according to breakfast consumption stratified by sleep duration (3 categories).

	Sleep duration (<6h)	Sleep duration (6 to <8 h)	Sleep duration (≥8h)	*P*-interaction
	OR (95% CI)	OR (95% CI)	OR (95% CI)	
Men				
Breakfast eaters	1.30 (1.13–1.50)	1.00 (reference)	1.00 (0.90–1.10)	0.47
Breakfast skippers	1.35 (1.02–1.75)	1.19 (1.03–1.37)	1.30 (1.02–1.66)	
Women				
Breakfast eaters	1.17 (0.98–1.38)	1.00 (reference)	1.07 (0.92–1.24)	0.66
Breakfast skippers	0.94 (0.62–1.38)	0.99 (0.77–1.25)	1.11 (0.69–1.70)	

95% CI, 95% confidence interval.
Adjusted for age, research site, educational level, smoking habit, drinking habit, daily life activity, leisure-time exercise, total energy intake, menopause status (women only), and nutrient pattern 1.

However, it has been reported that BMI is closely correlated with abdominal circumference. Third, as breakfast consumption status was self-reported, and there may be some degree of misclassification. However, the direction of the effect of misclassification could be non-differential. Fourth, no information on the food or the nutritional content of the breakfast was collected, thereby impossible to assess the effect of breakfast quality. However, the overall quality of the diet (nutrient pattern) could be adjusted. Nutrient pattern 1 (like prudent dietary pattern) scores of breakfast skippers were significantly lower than those of breakfast consumers in both sexes (data not shown). Fifth, sleep duration was evaluated using a self-administered questionnaire. However, a moderate positive correlation (r = 0.45–0.57) between self-reported and objectively measured sleep duration has been reported (Cespedes et al., 2016; Lauderdale et al., 2008). Sixth, no data on sleep quality was obtained, although positive associations have been reported between poor sleep quality (Lian et al., 2019) or obstructive sleep apnea syndrome (Castaneda et al., 2018) and MetS. Therefore, the possibility of confounding by sleep disorder cannot be denied. Seventh, we cannot eliminate the possibility of bias caused by measurement error of components of MetS, even if adjusted for research site. Finally, some characteristics between included and excluded participants were significantly different. Therefore, the generalizability of our findings may be limited.

5. Conclusions

Skipping breakfast and short sleep duration was independently

associated with a high prevalence of MetS in men. These lifestyle factors were positively associated with obesity, but not with MetS, in women. Further studies are needed to clarify the reason for differences in results between the sexes.

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CRediT authorship contribution statement

Sakurako Katsuura-Kamano: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Writing – original draft. **Kokichi Arisawa:** Data curation, Funding acquisition, Investigation, Methodology, Project administration, Validation, Writing – original draft. **Hirokazu Uemura:** Data curation, Investigation, Methodology, Writing – review & editing. **Tien Van Nguyen:** Investigation, Methodology. **Toshiro Takezaki:** Data curation, Investigation, Project administration. **Rie Ibusuki:** Data curation, Investigation. **Sadao Suzuki:** . **Takahiro Otani:** Data curation, Investigation. **Rieko Okada:** Data curation, Investigation. **Yoko Kubo:** Data curation, Investigation. **Takashi Tamura:** Data curation, Investigation. **Asahi Hishida:** Data curation, Investigation. **Teruhide Koyama:** Data curation, Investigation. **Daisuke Matsui:** Data curation, Investigation. **Kiyonori Kuriki:** Data curation, Investigation, Project administration. **Naoyuki Takashima:** Data curation, Investigation. **Naoko Miyagawa:** Data curation, Investigation. **Hiroaki Ikezaki:** Data curation, Investigation, Project administration, Writing – review & editing. **Yuji Matsumoto:** Data curation, Investigation. **Yuichiro Nishida:** Data curation, Investigation, Writing – review & editing. **Chisato Shimanoe:** Data curation, Investigation. **Isao Oze:** Data curation, Investigation. **Keitaro Matsuo:** Data curation, Investigation, Project administration. **Haruo Mikami:** Data curation, Investigation, Project administration. **Miho Kusakabe:** Data curation, Investigation. **Kenji Takeuchi:** Data curation, Investigation, Project administration. **Kenji Wakai:** Data curation, Funding acquisition, Investigation, Methodology, Supervision, Project administration, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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