

Effects of Psychological and Lifestyle Factors on Metabolic Syndrome Following the Fukushima Daiichi Nuclear Power Plant Accident: The Fukushima Health Management Survey

Atsushi Takahashi^{1, 2}, Tetsuya Ohira^{2, 3}, Kanako Okazaki^{2, 3}, Seiji Yasumura^{2, 4}, Akira Sakai^{2, 5}, Masaharu Maeda^{2, 6}, Hirooki Yabe^{2, 7}, Mitsuaki Hosoya^{2, 8}, Akira Ohtsuru^{2, 9}, Yukihiko Kawasaki², Michio Shimabukuro^{2, 10}, Junichiro Kazama^{2, 11}, Shigeatsu Hashimoto², Kazuyuki Watanabe^{2, 12}, Hironori Nakano^{2, 3}, Fumikazu Hayashi^{2, 3}, Hitoshi Ohto², Kenji Kamiya² and Hiromasa Ohira¹

¹Department of Gastroenterology, Fukushima Medical University School of Medicine, Fukushima, Japan

²Radiation Medical Science Center for the Fukushima Health Management Survey, Fukushima, Japan

³Department of Epidemiology, Fukushima Medical University School of Medicine, Fukushima, Japan

⁴Department of Public Health, Fukushima Medical University School of Medicine, Fukushima, Japan

⁵Department of Radiation Life Sciences, Fukushima Medical University School of Medicine, Fukushima, Japan

⁶Department of Disaster Psychiatry, Fukushima Medical University School of Medicine, Fukushima, Japan

⁷Department of Neuropsychiatry, Fukushima Medical University School of Medicine, Fukushima, Japan

⁸Department of Pediatrics, Fukushima Medical University School of Medicine, Fukushima, Japan

⁹Department of Radiation Health Management, Fukushima Medical University School of Medicine, Fukushima, Japan

¹⁰Department of Diabetology and Endocrinology, Fukushima Medical University School of Medicine, Fukushima, Japan

¹¹Department of Nephrology and Hypertension, Fukushima Medical University School of Medicine, Fukushima, Japan

¹²Department of Orthopaedic Surgery, Fukushima Medical University School of Medicine, Fukushima, Japan

Aim: The Fukushima Daiichi Nuclear Power Plant accident dramatically changed the lifestyle of residents who lived near the plant. We evaluated the association of metabolic syndrome (MetS) with specific lifestyle- and disaster-related factors in residents following the accident.

Methods: This cross-sectional study included 20,920 residents who underwent both the Comprehensive Health Check and the Mental Health and Lifestyle Survey from June 2011 to March 2012. Associations between MetS and lifestyle- and disaster-related factors, including psychological distress (post-traumatic stress disorder [PTSD]), were estimated using logistic regression analysis, adjusted for demographic and lifestyle factors, in 2019.

Results: MetS was present in 30.4% of men and 11.5% of women. There were significant differences in smoking, drinking status, and PTSD prevalence between subjects with and without MetS. Multivariable logistic regression analysis showed that age, quitting smoking, and low physical activity were significantly associated with MetS. Moreover, PTSD and light to moderate drinking were also significantly associated with MetS in women.

Conclusions: Lifestyle- and disaster-related factors, including PTSD, were associated with MetS among subjects who lived near the Fukushima Daiichi Nuclear Power Plant accident.

Key words: Metabolic syndrome, Lifestyle, Post-traumatic stress disorder, Disaster

Introduction

The Great East Japan Earthquake, and the asso-

ciated tsunami and accident at the Fukushima Daiichi Nuclear Power Plant, occurred in March 2011. The Japanese government designated the high-level radia-

Address for correspondence: Atsushi Takahashi, 1-Hikarigaoka, Fukushima City, Fukushima, 960-1295, Japan E-mail: junior@fmu.ac.jp

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tion exposure (>20 mSv/y) area around the Fukushima Daiichi Nuclear Power Plant as an evacuation zone, and more than 160,000 residents of Fukushima Prefecture were evacuated following the accident. Prolonged evacuation changed not only lifestyle factors for evacuees, such as physical exercise habits, diet, smoking status, and alcohol consumption, but also affected mental status.

Unhealthy lifestyle factors can contribute to metabolic syndrome (MetS) due to an increase in visceral obesity¹⁾. Moreover, mental status is also associated with MetS²⁻⁴⁾. In the Comprehensive Health Check of Fukushima Health Management Survey (FHMS), we showed that evacuation was associated with various health problems, including MetS⁵⁻¹¹⁾. Moreover, the Mental Health and Lifestyle Survey in FHMS reported changes in mental status and lifestyle factors following the disaster¹²⁾.

Previous studies in the FHMS⁶⁻¹²⁾ were evaluated independently, and thus lifestyle factors associated with MetS were limited to items assessed during an ordinary health check-up. Consequently, the association between MetS and disaster-related factors has not been estimated.

The present study's aim was to elucidate factors associated with MetS following the Fukushima Daiichi Nuclear Power Plant accident by connecting the results of the Comprehensive Health Check of the FHMS and the Mental Health and Lifestyle Survey of the FHMS. Our hypothesis is that disaster-related factors, including mental status, influenced MetS in residents who experienced the disaster.

Methods

Study Population

The subjects were residents of evacuation-designated areas near the Fukushima Daiichi Nuclear Power Plant. They were evacuated from all areas of Hirono-machi, Naraha-machi, Tomioka-machi, Okuma-machi, Futaba-machi, Namie-machi, Kawachi-mura, Katsurao-mura, Iitate-mura, and part of Tamura City, Minamisoma City, Kawamata-machi, and Date City, with total populations of 260,749 in 2011. Within these communities, residents aged 40-74 years have had annual health check-ups for MetS. The number of participants aged 40-74 years who completed the Comprehensive Health Check of the FHMS from June 2011 through March 2012 was 34,265 participants (14,397 men and 19,868 women), and 44,045 participants (20,127 men and 23,918 women) completed the Mental Health and Lifestyle Survey of the FHMS. A total of 24,527 participants (10,321 men and 14,206 women) completed

both the Comprehensive Health Check and the Mental Health and Lifestyle Survey. We excluded 3,607 participants due to insufficient data on diagnoses of MetS, lifestyle- and disaster-related factors, or psychological distress. Ultimately, 20,920 participants (8,810 men and 12,110 women) were eligible for our analyses.

The Ethics Committee of Fukushima Medical University approved this study (#29064). Informed consent was obtained from community representatives to conduct an epidemiological study based on guidelines of the Council for International Organizations of Medical Science. All participants in the FHMS provided written informed consent.

Definitions and Data Collection

Body weight (kg) and height were measured without shoes and in light clothing. Body mass index (BMI) was calculated as weight (kg)/height (m)², and overweight was defined as BMI ≥ 25 kg/m². Waist circumference was measured above the navel at minimal respiration. Blood pressure was measured by trained technicians.

The following laboratory data were collected under overnight fasting conditions: high-density lipoprotein cholesterol (HDL-C); low-density lipoprotein cholesterol (LDL-C); triglycerides (TG); fasting plasma glucose (FPG); and hemoglobin A1c (HbA1c).

MetS was diagnosed based on the definition of the Japanese diagnostic criteria¹³⁾: visceral obesity (waist circumference ≥ 85 cm in men and ≥ 90 cm in women) in addition to the presence of at least two of the following three abnormalities: (1) TG ≥ 150 mg/dL and/or HDL-C < 40 mg/dL, or being treated for dyslipidemia; (2) systolic blood pressure ≥ 130 mmHg and/or diastolic blood pressure ≥ 85 mmHg, or being treated with antihypertensive drugs; (3) FPG ≥ 110 mg/dL or being treated for diabetes (if the participant was not fasting, HbA1c $> 5.6\%$ was used instead).

Diabetes and dyslipidemia were defined as previously reported⁶⁾. Evacuation was defined by residential area and housing status, as previously reported¹⁴⁾. In the Mental Health and Lifestyle Survey, the Japanese versions of the Kessler 6-item scale (K6)¹⁵⁾ and Post-traumatic Stress Disorder Checklist (PCL-S)¹⁶⁾ were used to assess participants' mental health. The K6 consists of six brief questions about depressive and anxiety symptoms during the past 30 days, with overall scores ranging from 0 to 24. We defined psychological distress as corresponding to a K6 score ≥ 13 ¹⁷⁾. The PCL-S is a tool to evaluate symptoms of post-traumatic stress disorder (PTSD) during the past 30 days. The PCL-S consists of 17 items, and the overall score ranges from 17 to 85. We classified participants

Table 1. Clinical and biochemical characteristics of 20,920 participants

	Men			Women		
	Non-MetS	MetS	<i>p</i> value	Non-MetS	MetS	<i>p</i> value
Participants	6,132	2,678		10,719	1,391	
Age (years)	59.1 (9.2)	62.0 (8.2)	< 0.01	57.7 (9.4)	62.0 (8.0)	< 0.01
Body weight (kg)	64.7 (9.4)	73.3 (9.2)	< 0.01	53.7 (8.0)	66.5 (9.4)	< 0.01
BMI (kg/m ²)	23.5 (2.8)	26.7 (2.7)	< 0.01	22.7 (3.1)	28.6 (3.5)	< 0.01
Waist circumference (cm)	83.8 (7.8)	93.0 (6.2)	< 0.01	80.6 (8.4)	97.1 (6.3)	< 0.01
SBP (mmHg)	130.3 (15.3)	138.5 (14.1)	< 0.01	126.5 (16.1)	138.2 (14.8)	< 0.01
DBP (mmHg)	80.2 (10.0)	83.9 (9.6)	< 0.01	76.4 (10.1)	82.2 (9.8)	< 0.01
Triglycerides (mg/dL)	125.0 (93.3)	160.9 (124.6)	< 0.01	99.7 (54.8)	132.4 (67.4)	< 0.01
HDL-C (mg/dL)	57.6 (14.3)	50.6 (13.4)	< 0.01	65.2 (15.1)	57.0 (12.8)	< 0.01
LDL-C (mg/dL)	124.4 (32.4)	125.1 (32.9)	0.35	130.4 (32.3)	130.5 (33.2)	0.95
FPG (mg/dL)	97 (91-104)	110 (99-124)	< 0.01	93 (88-100)	104 (96-118)	< 0.01
HbA1c (%)	5.4 (0.7)	6.0 (0.9)	< 0.01	5.4 (0.6)	6.0 (0.9)	< 0.01
Overweight (BMI ≥ 25)	28.0	72.7	< 0.01	21.4	87.6	< 0.01
Hypertension (%)	45.7	79.3	< 0.01	36.2	80.5	< 0.01
Dyslipidemia (%)	51.4	80.6	< 0.01	54.3	83.7	< 0.01
Diabetes (%)	8.8	32.3	< 0.01	5.1	26.9	< 0.01

Values are expressed as mean (standard deviation), except for FPG, which is reported as median (25-75 percentile).

MetS, metabolic syndrome; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; HDL-C, high-density-lipoprotein-cholesterol; LDL-C, low-density-lipoprotein-cholesterol; FPG, fasting plasma glucose; HbA1c, hemoglobin A1c.

as having probable PTSD if their overall PCL-S score was ≥ 44 ¹⁶⁾. In addition to the K6 and PCL-S, the questionnaires included medical history and various lifestyle factors, such as physical activity, sleep dissatisfaction, cigarette smoking, alcohol intake, and job status. Job status included unemployment or a change in job after the accident.

Statistical Analysis

The data analysis was conducted in 2019. Participants with and without MetS were compared using the χ^2 test and Fisher's exact test for categorical variables and the Mann-Whitney *U*-test for continuous variables. We tested associations between MetS after the accident and other primary factors using simple and multivariable logistic regression analyses. The following variables were considered primary factors: age, sex, evacuation (yes or no), current smoking (yes or no), quitting smoking (yes or no), alcohol intake (non-drinker, light to moderate drinker [< 44 g/day] or heavy drinker [≥ 44 g/day]), physical activity (< 4 times a week or every day), change of job (yes or no), unemployment (yes or no), sleep dissatisfaction (yes or no), psychological distress (yes or no), and PTSD (yes or no). SAS version 9.3 (SAS Institute, Cary, NC, USA) was used for all statistical analyses. All probability values for statistical tests were two-tailed, and *p* values < 0.01 were considered statistically significant.

Results

Characteristics of Participants With and Without MetS

Overall, MetS was observed in 19.5% of the 20,920 participants. The prevalence of MetS was significantly higher in men than women (men 30.4% vs. women 11.5%, $p < 0.01$). For both sexes, the MetS group was significantly older than the non-MetS group. In addition, there were significant differences in laboratory data, such as HDL-C, TG, FPG, and HbA1c, between the non-MetS and MetS groups (Table 1).

Lifestyle Characteristics and Disaster-Related Factors of Participants With and Without MetS

Lifestyle characteristics and disaster-related factors are shown in Table 2. For both sexes, the prevalence of current smokers was significantly higher in the non-MetS group than in the MetS group. Among men, the prevalence of quitting smoking was significantly higher in the MetS group than in the non-MetS group ($p < 0.01$). The prevalence of quitting smoking among women also tended to be higher in the MetS group than in non-MetS group ($p = 0.06$). In addition, the prevalence of PTSD was significantly higher in the MetS group than in the non-MetS group in both sexes ($p < 0.01$).

Table 2. Lifestyle characteristics of 20,920 participants

	Men			Women		
	Non-MetS	MetS	<i>p</i> value	Non-MetS	MetS	<i>p</i> value
Participants	6,132	2,678		10,719	1,391	
Evacuee (%)	2,750 (44.9)	1,214 (45.3)	0.67	4,751 (44.3)	621 (44.6)	0.82
Smoking status						
Current smoker (%)	1,927 (31.6)	647 (24.3)	<0.01	808 (7.8)	73 (5.5)	<0.01
Quit smoker (%)	2,659 (43.7)	1,391 (52.3)	<0.01	679 (6.5)	105 (7.9)	0.06
Drinking status						
< 44 g/day (%)	3,172 (51.9)	1,328 (49.7)	0.06	3,101 (29.4)	295 (21.7)	<0.01
≥ 44 g/day (%)	1,311 (21.5)	586 (22.0)	0.61	238 (2.3)	17 (1.3)	0.02
Physical activity						
< 4 times a week (%)	4,997 (82.2)	2,185 (82.6)	0.73	9,227 (87.2)	1,214 (88.7)	0.11
Change of job	3,558 (59.1)	1,502 (57.3)	0.13	5,777 (56.5)	701 (54.3)	0.14
Unemployment	1,403 (22.9)	644 (24.1)	0.23	2,813 (26.3)	339 (24.4)	0.13
Sleep dissatisfaction (%)	3,140 (60.1)	1,335 (59.2)	0.43	6,578 (72.7)	818 (71.5)	0.38
Psychological distress (K6 ≥ 13)	700 (11.4)	304 (11.4)	0.93	1,788 (16.7)	243 (17.5)	0.46
Post-traumatic stress disorder (PCL-S ≥ 44)	1,030 (16.8)	516 (19.3)	<0.01	2,486 (23.2)	394 (28.3)	<0.01

MetS, metabolic syndrome; K6, Kessler 6-item scale; PCL-S, Post-traumatic Stress Disorder Checklist.

Table 3. Logistic regression analysis of factors influencing metabolic syndrome after the disaster among 20,920 participants

	Men (8,810)		Women (12,110)	
	Odds ratio (95% CI)	<i>p</i> value	Odds ratio (95% CI)	<i>p</i> value
Age (1-year increase)	1.04 (1.03-1.05)	<0.01	1.06 (1.05-1.07)	<0.01
Evacuation (ref: non-evacuation)	1.07 (0.96-1.20)	0.19	1.00 (0.86-1.15)	0.94
Smoking (ref: non-smoker)				
Current smoker	0.97 (0.84-1.12)	0.65	1.04 (0.77-1.39)	0.81
Quit smoker	1.30 (1.14-1.48)	<0.01	1.60 (1.23-2.07)	<0.01
Alcohol intake (ref: non-drinker)				
< 44 g/day	0.86 (0.76-0.97)	0.01	0.71 (0.61-0.84)	<0.01
≥ 44 g/day	0.97 (0.84-1.12)	0.68	0.65 (0.37-1.14)	0.13
Physical activity (ref: every day)				
< 4 times a week	1.23 (1.07-1.41)	<0.01	1.42 (1.15-1.75)	<0.01
Change of job (ref: no change)	0.98 (0.87-1.10)	0.73	0.98 (0.83-1.15)	0.78
Unemployment (ref: no)	1.04 (0.91-1.20)	0.57	1.16 (0.97-1.40)	0.11
Sleep dissatisfaction (ref: yes)	1.02 (0.91-1.14)	0.75	0.94 (0.81-1.10)	0.45
Psychological distress (ref: K6 < 13)	0.93 (0.77-1.12)	0.46	0.89 (0.72-1.09)	0.25
Post-traumatic stress disorder (ref: PCL-S < 44)	1.12 (0.95-1.31)	0.17	1.29 (1.08-1.55)	<0.01

Logistic regression analysis was used (dependent variable: metabolic syndrome, independent variable of interest: presence versus absence of each lifestyle factor, adjustment variables: age and sex). CI, confidence interval; K6, Kessler 6-item scale; PCL-S, Post-traumatic Stress Disorder Checklist.

Lifestyle and Disaster-Related Factors Associated with MetS Following the Accident

Multivariable logistic regression was used to elucidate lifestyle- and disaster-related factors associated with MetS following the accident (Table 3). In both men and women, age, quitting smoking, and lack of physical activity were significantly associated with MetS ($p < 0.01$ for all). The association between MetS

and quitting smoking was somewhat greater in women than in men. The multivariable-adjusted odds ratio (OR) of MetS was 1.60 (95% confidence interval [CI]=1.23, 2.07) for women and 1.30 (95% CI=1.14, 1.48) for men. PTSD and light to moderate drinking were significantly associated with MetS in women.

Discussion

We previously reported that evacuation following the accident was associated with an increased incidence of MetS as well as obesity or other metabolic diseases, such as hypertension, diabetes, and dyslipidemia⁷⁻¹¹). However, the associations between various health problems and detailed lifestyle factors have not been elucidated except for our recent report about hepatobiliary enzyme abnormalities¹⁴). In this cross-sectional study, we first investigated the associations between MetS and detailed lifestyle- and disaster-related factors following the accident. After adjusting for potential confounders, we found significant associations between MetS and age, quitting smoking, light to moderate drinking, physical activity, and PTSD.

Subjects in the present study had strong post-traumatic responses related to the Fukushima Daiichi Nuclear Power Plant explosion and the following crisis. The proportion of PTSD in adults, based on the (PCL-S), was 21.6% at 10 months after the accident¹²), which was similar to 20.1% reported in study of workers after the 9/11 World Trade Center attacks in the United States¹⁸). PTSD is a risk factor for developing MetS through its impact on unhealthy factors such as a sedentary lifestyle, smoking, alcohol intake, consuming saturated fats and refined sugars, and consuming low amounts of fruit⁴). In the present study, the association between PTSD and MetS was found only in women, possibly because PTSD has a different impact on MetS-related lifestyle factors between men and women. Compared to participants without PTSD, those with PTSD had a higher prevalence of alcohol consumption of ≥ 44 g/day in women (**Supplement Table 1**). Moreover, we previously found that, following the disaster, PTSD was associated with changes in food intake, such as reduced vegetable intake or increased juice intake. These changes place people at a higher risk for MetS, and these associations are predominantly observed in women¹⁹). On the other hand, the sex differences of hypothalamic-pituitary-adrenal (HPA) axis²⁰) can support our results. HPA is a potential mechanism associated with both PTSD and metabolic disease²¹). Although psychological stress elevates cortisol levels²²), it could not be observed in only male samples²³). Moreover, estrogen activates HPA axis response to stress²⁴). Taken together, these results suggest that, following the disaster, PTSD was more likely to lead to MetS in women than in men.

Smoking is a risk factor for MetS development²⁵). On the other hand, the proportion of smokers among residents of evacuation-designated areas decreased after the disaster in spite of the increase in MetS²⁶).

Smoking cessation increases body weight²⁷⁻²⁸) or short-term risk of diabetes²⁹). Moreover, without educational instruction, stopping smoking could promote MetS development³⁰). These previous studies support present findings that quitting smoking, but not current smoking, is a risk factor for MetS. However, the association between smoking and MetS after the disaster needs future, long-term evaluation.

Alcohol intake increases the risk of hypertension³¹). On the other hand, moderate alcohol intake decreases the risk for diabetes³²) and increased TG levels³³). In the present study, alcohol intake < 44 g/day was associated with significantly lower MetS occurrence in women. This result is in accordance with a previous meta-analysis, which associated light alcoholic consumption with a reduced prevalence of MetS³⁴⁻³⁵). However, heavy alcohol consumption is a risk factor for developing MetS³⁵). Following the disaster, 9.6% of non-drinkers before the disaster began drinking, of which 18.4% were heavy drinkers. Moreover, post-disaster heavy drinkers were likely to continue heavy drinking³⁶). Therefore, intake of alcohol, and in particular the amount of alcohol, should be considered in the prevention of MetS following a disaster.

A low level of physical activity is associated with MetS³⁷). In the present study, this association was confirmed among residents of a disaster-affected region. Early evacuation after the accident decreased radiation exposure levels among residents living around the Fukushima Nuclear Power Plant. The United Nations Scientific Committee on the Effects of Atomic Radiation reported no distinct increases in the incidence of radiation-related health effects based on the during first-year data of residents exposed to low or very low doses of radiation³⁸). Therefore, the causes of MetS are unlikely to be due to direct radiation exposure. However, residents tended to avoid going out because of fears of radioactive exposure after Fukushima Daiichi Nuclear Power Plant accident. In fact, the proportion of residents who exercised was lower following the accident, especially for residents in the evacuation zone¹¹). Therefore, fear of radioactive exposure can potentially increase the risk for MetS by decreased physical activity. Moreover, relieving anxiety due to radioactive exposure may contribute to overcoming MetS in residents following the accident.

Limitations

Several limitations of the present study should be considered. First, subjects with bad mental health status were not included in the present study because mental status might affect the response rate to the sur-

vey³⁹). Therefore, it is impossible to deny the possibility of sample bias. Moreover, PTSD in the present study was based on a 12 month survey, 9 months after the Fukushima Daiichi nuclear power plant accident. The relation between PTSD and MetS, including elapsed time from the accident, should be examined in a future longitudinal survey. Second, food intake, which can affect MetS, was not estimated in the present study because of lack of information. The dietary effects on MetS following the disaster will be an important element of future investigations. Third, because there is no information about lifestyle factors before the Fukushima Daiichi Nuclear Power plant accident, we could not evaluate changes in these factors in the pre- and post-accident periods. Furthermore, the lifestyle itself before the accident may directly affect MetS in present participants. A future longitudinal study of changes in both MetS and lifestyle factors will help clarify the true associations between MetS and lifestyle factors after the Fukushima Daiichi Nuclear Power Plant accident. Despite these limitations, the strength of present study was that it was a large-scale survey of residents of evacuation-designated areas near the Fukushima Daiichi Nuclear Power Plant. Moreover, the present survey is the first report showing an association between MetS and PTSD related to the Nuclear Power Plant accident.

Conclusions

Several lifestyle- and disaster-related factors were associated with MetS after the Fukushima Daiichi Nuclear Power Plant accident. These findings could provide information relevant to the prevention of MetS, regardless of evacuation status.

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All authors participated in study conception and design. A. Takahashi, T. Ohira, and K. Okazaki performed statistical analysis of the data. H. Ohira supervised the project. All authors participated in interpretation of the results and drafting of the manuscript, and approved the final version.

Conflicts of Interest

All authors have no financial disclosures.

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Supplementary Table 1. Comparison of lifestyle characteristics between with and without post-traumatic stress disorder

	Men			Women		
	PCL-S < 44	PCL-S ≥ 44	<i>P</i> value	PCL-S < 44	PCL-S ≥ 44	<i>p</i> value
Participants	7,264	1,546		9,230	2,880	
Evacuees (%)	3,102 (42.7)	862 (55.8)	< 0.01	3,831 (41.5)	1,541 (53.5)	< 0.01
Smoking						
Current smoker (%)	2,143 (29.7)	431 (28.3)	0.29	624 (6.9)	257 (9.4)	< 0.01
Quit smoker (%)	3,342 (46.3)	708 (46.5)	0.87	593 (6.6)	191 (7.0)	0.50
Current drinker						
< 44 g/day (%)	3,760 (51.9)	740 (48.1)	< 0.01	2,616 (28.7)	780 (27.8)	0.36
≥ 44 g/day (%)	1,554 (21.5)	343 (22.3)	0.48	171 (1.9)	84 (3.0)	< 0.01
Physical activity						
< 4 times a week (%)	5,916 (82.3)	1,266 (82.7)	0.69	7,966 (87.4)	2,475 (87.3)	0.94
Change of job	3,925 (55.0)	1,135 (75.4)	< 0.01	4,649 (52.7)	1,829 (67.7)	< 0.01
Unemployment	1,500 (20.7)	547 (35.4)	< 0.01	2,225 (24.1)	927 (32.2)	< 0.01
Sleep dissatisfaction (%)	3,389 (54.7)	1,086 (84.7)	< 0.01	5,223 (67.0)	2,173 (91.0)	< 0.01
Psychological distress (K6 ≥ 13)	286 (3.9)	718 (46.4)	< 0.01	513 (5.6)	1,518 (52.7)	< 0.01

Logistic regression analysis was used (dependent variable: metabolic syndrome; independent variable of interest: presence versus absence of each life styles; adjustment variables: age, sex, evacuation, smoking, alcohol intake, physical activity, change of job, unemployment, sleep dissatisfaction, psychological distress, and post-traumatic stress disorder). CI, confidence interval; K6, Kessler 6-item scale; PCL-S, Post-traumatic Stress Disorder Checklist.