Nutrition, Metabolism & Cardiovascular Diseases (2019) **29**, 144–151

Available online at www.sciencedirect.com

Nutrition, Metabolism & Cardiovascular Diseases

journal homepage: www.elsevier.com/locate/nmcd

Association between long-term exposure of ambient air pollutants and cardiometabolic diseases: A 2012 Korean Community Health Survey

J. Shin*, J. Choi, K.J. Kim

Department of Family Medicine, Konkuk University School of Medicine, Konkuk University Medical Centre, Seoul, South Korea

Received 11 May 2018; received in revised form 18 September 2018; accepted 19 September 2018
Handling editor: A. Siani
Available online 26 September 2018

KEYWORDS
Air pollution;
Hypertension;
Diabetes mellitus;
Dyslipidemia;
Obesity

Abstract *Background and aim:* The associations of long-term exposure to particulate matter <10 μm in size (PM_{10}), nitrogen dioxide (NO_2), carbon monoxide (CO), sulfur dioxide (SO_2), and ozone (O_3) with cardiometabolic diseases (CMD) remain uncertain in the Korean population. Therefore, we sought to examine the associations between PM_{10}, NO_2, CO, SO_2, and O_3 and CMD using data collected from the Korean Community Health Survey.

Methods and results: We selected 100,867 adults aged 19 years or older who had lived in the same domicile for ≥10 years and surveyed them to collect data on socioeconomic characteristics; health-related behaviors; obesity; and physician-diagnosed CMD history, including hypertension, diabetes mellitus, dyslipidemia, stroke, myocardial infarction, and ischemic heart disease. We calculated interquartile ranges for PM_{10}, NO_2, CO, SO_2, and O_3 from the 10 year average concentrations (2003–2012). Hypertension, diabetes mellitus, and dyslipidemia were positively associated with PM_{10}, NO_2, CO, SO_2, and O_3 after adjusting for confounding factors. Obesity was positively associated with PM_{10}, NO_2, SO_2, and O_3. On the other hand, we found no associations between stroke, myocardial infarction, and ischemic heart disease and exposure to PM_{10}, NO_2, CO, SO_2, and O_3 in these subjects. In subjects aged ≥65 years, the risk of dyslipidemia was markedly increased under exposure to NO_2 and CO compared to subjects aged <65 years. The risk of obesity was also significantly increased under exposure to PM_{10} and NO_2. However, sex differences in these associations were not found.

Conclusion: Long-term exposure to PM_{10}, NO_2, CO, SO_2, and O_3 may be a risk factor of CMD in Korean adults.

Introduction

Since the 1990s, intriguing epidemiological evidence has suggested that air pollutants such as particulate matter <10 μm in size (PM_{10}), nitrogen dioxide (NO_2), carbon monoxide (CO), sulfur dioxide (SO_2), and ozone (O_3), are adverse risk factors of cardiac and respiratory diseases [1,2]. A growing body of evidence has linked air pollutants with obesity and cardiometabolic diseases (CMD) such as

* Corresponding author. Department of Family Medicine, Konkuk University School of Medicine, Konkuk University Medical Centre, 120-1 Neungdong-ro, Gwangjin-gu, Seoul 05030, South Korea. Fax: +82 2 2030 7749.

E-mail address: jyshin@kuh.ac.kr (J. Shin).

https://doi.org/10.1016/j.numecd.2018.09.008
0939-4753/

hypertension, diabetes mellitus, dyslipidemia, stroke, myocardial infarction, and ischemic heart disease [3–5]. A meta-analysis of 17 studies suggested that exposure to the mentioned air pollutants may increase the risk of hypertension, regardless of exposure duration [4]. In a meta-analysis of 10 studies, the effects of NO_2 and $PM_{2.5}$ on the occurrence of type 2 diabetes mellitus were studied [5].

However, there have been several discrepant findings in the association between PM_{10}, NO_2, CO, SO_2, and O_3, and other CMD according to the duration of exposure [6–9]. Short-term exposure to the pollutants PM_{10}, NO_2, CO, SO_2, and O_3 increased hospital admissions owing to myocardial infarction in 1837 Brazilians [6] and in 302,283 Stockholm County subjects [7]. However, long-term exposure to PM_{10}, NO_2, CO, SO_2, and O_3 did not significantly increase the risk of incident myocardial infarction in a California female teachers' cohort from 1996 to 2005 [8]. Exposure to PM_{10} did not significantly increase the intima-media thickness of the common carotid artery in four European cohort studies [9]. Long-term exposure to PM_{10} and NO_2, in particular, was associated with hypertension; however, associations between hypertension and exposure to CO, SO_2, and O_3 lacked statistical significance, although the exposure was for a long term [4]. These mixed associations between air pollutant levels and CMD may be due to demographic characteristics of different study populations as well as dose and time duration of exposure [3].

To improve the supporting evidence for long-term exposure with heterogeneous outcomes, we sought to examine the association between air pollutants, namely, PM_{10}, NO_2, CO, SO_2, and O_3, and CMD in Korean adults from the Korean Community Health Survey, thereby accounting for health-related behaviors and socioeconomic status.

Methods

Study participants

This study was performed using data collected from the Korean Community Health Survey (KCHS). The KCHS conducted by the Korea Centers for Disease Control and Prevention is a nationwide survey that is carried out annually through computer-assisted personal interviews. Study participants aged 19 years or older were selected among every 900 people in 254 community units by the probability proportional sampling method and the systematic sampling method [10]. From a total of 228,921 adults surveyed in 2012, we selected subjects who had lived in the same domicile for $\geq$10 years after excluding the residential variance (<10 years, n = 29,317). After matching the participant's residence codes and the location of the air pollution surveillance station (unmatched n = 69,012) while excluding missing data (n = 408), we ultimately analyzed 100,867 subjects.

The Institutional Review Board (IRB) at Korean Centers for Disease Control and Prevention approved the study protocol, and all participants provided a written informed consent. The IRB at Konkuk University Medical Center approved this study (IRB File Number: KUH1230027).

Air pollutant variables

We obtained data of average concentrations of hourly measured PM_{10}, NO_2, CO, SO_2, and O_3 from Korean Air Pollutants Emission Service during 2003–2012. Air pollutants were measured at 268 nationwide surveillance stations, which were placed in the residential areas and covered the majority of the living area (Supplement Figure). We then calculated the interquartile ranges of 10 year average concentrations. PM_{10} was measured by beta attenuation monitoring (PM-711D, DONGIL GREENSYS, Seoul, Korea). NO_2 was measured using a chemiluminescence instrument (CM2041, APM ENGINEERING CO., LTD, Gyeonggi-do, Korea). CO was measured using a nondispersive infrared sensor (ZKJ, DONGIL GREENSYS, Seoul, Korea). SO_2 was measured with a UV fluorescence spectrometer (CM2050, APM ENGINEERING CO., LTD, Gyeonggi-do, Korea). O_3 was measured using an ultraviolet photometer (202, TOTAL ENGINEERING CO., LTD, Gyeonggi-do, Korea). These air pollutant measurements were measured following the standard reference protocol of the Korean Air Pollutants Emission Service [11]. Table 1 presents meteorological data of mean temperature, rainfall, wind speed, and air pollutant levels from 2003 to 2012.

Other variables

The KCHS surveyed personal health-related outcomes including health status and diagnosed diseases [12]. CMD was defined as the physicians' diagnosis of hypertension, diabetes mellitus, dyslipidemia, any type of stroke, myocardial infarction, and ischemic heart disease. Obesity was defined as a body mass index (BMI) greater than 25 kg/m^2 based on the World Health Organization

Table 1 Air pollutants and meteorological data in Korea from 2003 to 2012.

	Mean ± Standard deviation	Median	Range	Interquartile range
PM_{10} (μg/m^3)	52.7 ± 8.6	53.2	34.0 to 77.7	11.9
SO_2 (ppb)	5.6 ± 1.7	5.3	2.6 to 17.7	1.8
NO_2 (ppb)	24.2 ± 7.9	23.0	8.3 to 42.1	13.6
CO (10 ppm)	5.7 ± 1.3	5.8	3.0 to 9.4	1.7
O_3 (ppb)	23.4 ± 4.5	22.6	15.4 to 37.0	6.2
Temperature (°C)	12.5 ± 10.1	13.5	−2 to 26	12.0
Rainfall (mm)	112.1 ± 112.8	65.0	22 to 348	34.8
Wind speed (m/s)	3.6 ± 0.3	3.6	3.3 to 3.9	0.3

Particulate matter <10 μm (PM_{10}); Sulfur dioxide (SO_2); Nitrogen dioxide (NO_2); Carbon monoxide (CO). Temperature, rainfall, and wind speed were shown at Seoul (Lat.(N) 3734′, Long.(E) 12657′). Korea Meteorological Administration, Seoul, Korea http://www.weather.go.kr/weather/climate/average_world_monthly.jsp.

Table 2 Baseline characteristics of whole KCHS (n = 228,921) and enrolled population (n = 100,867).

Variables	Population		Enrolled population	
	KCHS (n = 228,921)	Enrolled (n = 100,867)	Male (n = 50,333)	Female (n = 50,534)
Age, years	46.8 ± 0.09	47.8 ± 0.06	46.6 ± 0.07	49.1 ± 0.07
Smoking (%)				
Current	23.5	23.1	44.4	3.0
Never/former	76.5	76.9	55.5	37.0
Alcohol consumption (%)				
Never/Less than one time per week	87.9	88.3	84.4	92.2
More than one time per week	12.1	11.7	15.6	7.8
Physical activity (%)				
Active	43.4	43.7	48.9	36.2
Inactive	56.6	56.3	51.1	63.8
Education, years (%)				
<9	27.2	28.0	19.1	35.7
≥9	72.8	72.0	80.9	64.3
Marital status (%)				
Married/with partner	66.2	65.0	67.4	62.7
Divorced/widowed/unmarried	33.8	35.0	32.6	37.3
Household income, wons/month (%)				
<1,000,000	16.1	17.7	15.2	20.1
≥1,000,000	83.9	81.3	84.8	79.9
Residence of urban (%)	81.2	79.5	79.5	79.5
Length of residence				
10–15 years	16.7	16.3	15.4	17.1
15–20 years	12.3	13.6	13.3	13.9
≥20 years	71.0	70.1	71.3	69.0
Hypertension (%)	19.5	20.0	19.4	20.5
Diabetes mellitus (%)	7.6	7.6	8.0	7.2
Dyslipidemia (%)	11.3	11.1	10.4	11.8
Obesity (%)	24.0	23.4	29.0	17.7
Stroke (%)	1.4	1.5	1.6	1.3
Myocardial infarction (%)	1.2	1.2	1.5	0.9
Ischemic heart disease (%)	1.4	1.5	1.5	1.5

There was no difference in demographics, socioeconomic characteristics, and health-related behaviors between whole KCHS and enrolled study population. Data are represented as mean and standard error or percentage. Physical active group was defined as moderate intense activity ≥3 times per week or vigorous activity ≥1 time per week. Inactive group did not meet these criteria. Length of residence with the same domicile was counted. Obesity was defined as a body mass index of more than 25 kg/m^2.

recommendation for an Asian population [13]. We adopted the original classification of KCHS as current smokers (smoking daily or intermittently at the time of the survey) and never/former smokers (smoked in the past but not currently). To account for alcohol consumption, we categorized patients as never/less than one time per week drinkers and more than one time per week drinkers. We defined physical activity by intensity and frequency and separated patients into an active group and an inactive group. The active group included patients who performed moderate intense activity ≥ three times per week or vigorous activity ≥ one time per week. Patients who did not meet these criteria were categorized into the inactive group. Vigorous physical activity included running (jogging), climbing, fast biking, fast swimming, soccer, basketball, jumping rope, squash, and singles tennis, as well as occupational activities such as carrying heavy objects [14]. We also obtained data on the following demographic information: years of education (<9 or ≥9), marital status (married/with partner and divorced/widowed/unmarried), household income (<1,000,000 wons/month or ≥1,000,000 wons/month), and place of residence (rural or urban). We excluded participants who lived in their area for <10 years and divided the remaining participants' lengths of residence into three groups: $10 \leq T1 < 15$ years, $15 \leq T2 < 20$ years, and $T3 \geq 20$ years.

Statistical analyses

We conducted all analyses considering the survey weight. For comparison of demographics, socioeconomic characteristics, and health-related behaviors between the KCHS and study population, continuous variables are represented as mean and standard error, and categorical variables are represented as percentage. We evaluated the odds ratios of CMD according to the per-interquartile increase of PM_{10}, NO_2, SO_2, CO, and O_3 by using the multiple logistic regression analysis. We adjusted for age, sex, smoking, drinking, physical activity, education, marital status, household income, residence, obesity, and medical history, except when the selected variable was the outcome. We conducted stratified analyses to investigate the possible effect of modification by age (divided by age

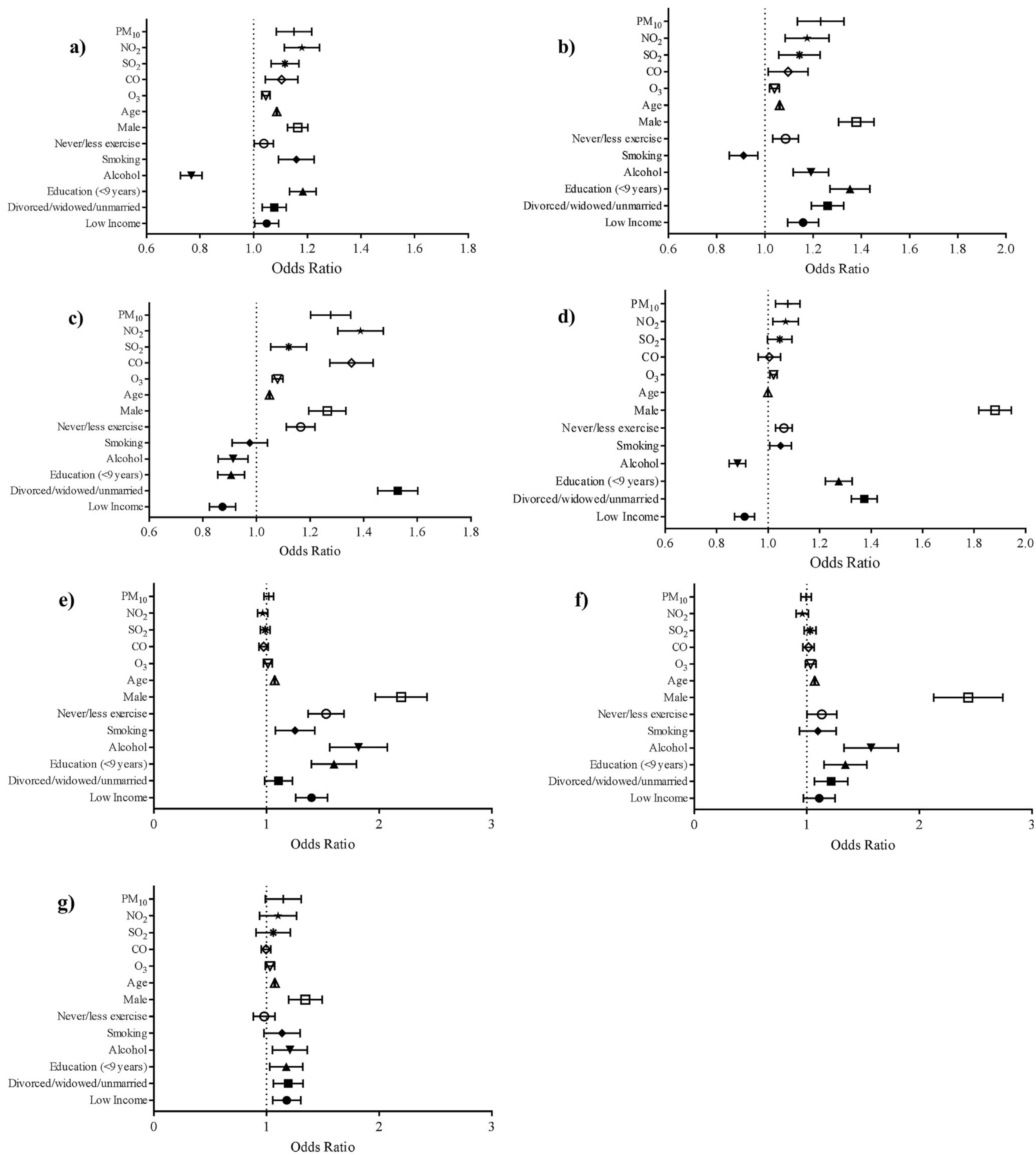

Figure 1 The odds ratios and 95% confidence intervals of CMD according to per-interquartile range of PM_{10}, NO_2, CO, SO_2, and O_3: (a) hypertension; (b) diabetes mellitus; (c) dyslipidemia; (d) obesity; (e) stroke; (f) myocardial infarction; and (g) ischemic heart disease. The odds ratios and 95% confidence intervals of CMD according to age, male sex, physical inactivity, current smoking, alcohol consumption (more than one time per week), education (<9 years), marital status (divorced/widowed/unmarried), and low income. All statistics were adjusted by age, sex, smoking, drinking, physical activity, education, marital status, household income, place of residence, hypertension, diabetes mellitus, dyslipidemia, obesity, stroke, myocardial infarction, and ischemic heart disease, except when the selected variable was the outcome.

65 years) and sex in subgroup analysis. All statistical analyses were conducted using SAS software 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

Data of demographics, socioeconomic characteristics, and health-related behaviors of the study population are summarized in Table 2. No differences in these characteristics between the KCHS population as a whole and the study population were observed. Approximately 70% of the participants lived in the same domicile for >20 years. We confirmed that the levels of measured pollutants from 2003 to 2012 had not changed significantly, although PM_{10} decreased slightly while O_3 increased (data are not shown).

After adjusting for confounding factors, hypertension, diabetes mellitus, and dyslipidemia showed a positive association with the per-interquartile increase in PM_{10}, NO_2, SO_2, CO, and O_3. Similarly, obesity showed a positive association with PM_{10}, NO_2, SO_2, and O_3 as shown in Fig. 1. On the contrary, we found no associations of stroke, myocardial infarction, and ischemic heart disease with PM_{10}, NO_2, SO_2, CO, and O_3. Additionally, Fig. 1 shows CMD risk according to age, sex, socioeconomic characteristics, and health-related behaviors of the study population. The odds ratios for PM_{10}, NO_2, SO_2, CO, and O_3 were similar to those of known CMD risk factors in hypertension, diabetes mellitus, and dyslipidemia. By contrast, the odds ratios for known CMD risk factors in stroke, myocardial infarction, and ischemic heart disease were much higher than those of PM_{10}, NO_2, SO_2, CO, and O_3.

The associations between CMD and air pollutants according to age (cut off, 65 years) are shown in Fig. 2. When we evaluated the modification effect exerted by age (cut off, 65 years), the risk of dyslipidemia and obesity in subjects of age ≥65 years significantly increased with exposure to all kinds of air pollutants compared to the risk in subjects of age <65 years ($P < 0.05$). The associations between other CMDs and air pollutants were not significantly different according to age. In analysis stratified by sex (Table 3), no significant differences were observed (all $P > 0.05$).

Discussion

In this nationwide Korean population-based study, long-term exposure to PM_{10}, NO_2, CO, SO_2, and O_3 was positively associated with hypertension, diabetes mellitus, and dyslipidemia. Exposure to PM_{10}, NO_2, SO_2, and O_3 was positively associated with obesity. Notably, we confirmed the associations between hypertension and long-term exposure to CO, SO_2, and O_3, which lacked statistical significance in a previous study [4].

In the study on PM_{10} and SO_2 by Sohn et al., Korean female citizens were associated with the risk of diabetes mellitus [12]. In addition to a study on $PM_{2.5}$ by Mazidi et al. [15], we confirmed the associations of diabetes mellitus with PM_{10}, NO_2, CO, SO_2, and O_3. Among the studies that investigated the association between lipid metabolism and air pollution, one study of 73,117 patients in Southern Israel found that the level of low-density lipoprotein increased by 1.54% (95% CI: 1.26–1.83) after 3 months of exposure to PM_{10} [16]. One year of exposure to PM_{10}, NO_2, and O_3 was associated with high lipid levels in 1023 subjects aged 54 years and older in Taiwan [17]. A study of natural exposure to Beijing air revealed that inflammatory activation and lipid oxidation in the lungs may systemically spill over, thus leading to dyslipidemia and weight gain [18].

CMD has been associated with abnormalities in vascular relaxation to insulin and acetylcholine and has been related to increased macrophage cells in the adipose tissue as well as increased inflammatory cells in microcirculation [19,20]. As strong inflammatory agents, air pollutants may induce hypoxia by binding to hemoglobin and damage blood vessels by promoting smooth muscle and endothelial proliferation [17]. Therefore, air pollutants may exaggerate insulin resistance and visceral adiposity [19].

On the contrary, we found no associations of stroke, myocardial infarction, and ischemic heart disease with exposure to PM_{10}, NO_2, CO, SO_2, and O_3 in these subjects. There may be several explanations for the null associations in multiple logistic regression analysis. First, known risk factors such as socioeconomic status, health-related behaviors, and medical history may show a significant effect on the development of stroke, myocardial infarction, and ischemic heart disease directly, compared to PM_{10}, NO_2, CO, SO_2, and O_3. The contribution of PM_{10}, NO_2, CO, SO_2, and O_3 was similar to that of age, sex, socioeconomic characteristics, health-related behaviors to hypertension, diabetes mellitus, and dyslipidemia, whereas their contribution to stroke, myocardial infarction, and ischemic heart disease was lower than that of established risk factors. Contrary to our findings, Kim et al. found that the risk of stroke and acute myocardial infarction in Seoul, Korea, increased with higher levels of PM, CO, NO_2, and SO_2; however, Kim et al. did not adjust for known CVD risk factors such as smoking, alcohol consumption, and socioeconomic status [21].

Second, differences in air pollution exposure level and duration may yield these results. The levels of air pollutants in the California female teachers' study, which showed null associations between air pollution and myocardial infarction, were lower than those in our study, with the exception of NO_2 and O_3 (PM_{10}: 29.21 $\mu g/m^3$ vs. 52.7 $\mu g/m^3$; NO_2: 33.59 ppb vs. 24.2 ppb; SO_2: 1.72 ppb vs. 5.6 ppb; CO: 1.05 ppm vs. 5.7 ppm; O_3:48.11 ppb vs. 23.4 ppb; mean values) [8]. Compared to the O_3 concentration in our study, a higher O_3 level of Ruidavets JB et al. study was associated with acute myocardial dysfunction (74.8 $\mu g/m^3$ [37.4 ppb] vs. 23.4 ppb, mean value) [22]. According to the exposure pattern, occupational exposure may affect CMD of subjects with ≥10 years of exposure. In subjects with occupational exposure to air pollution ≥10 years, an intima-media thickness of the common carotid

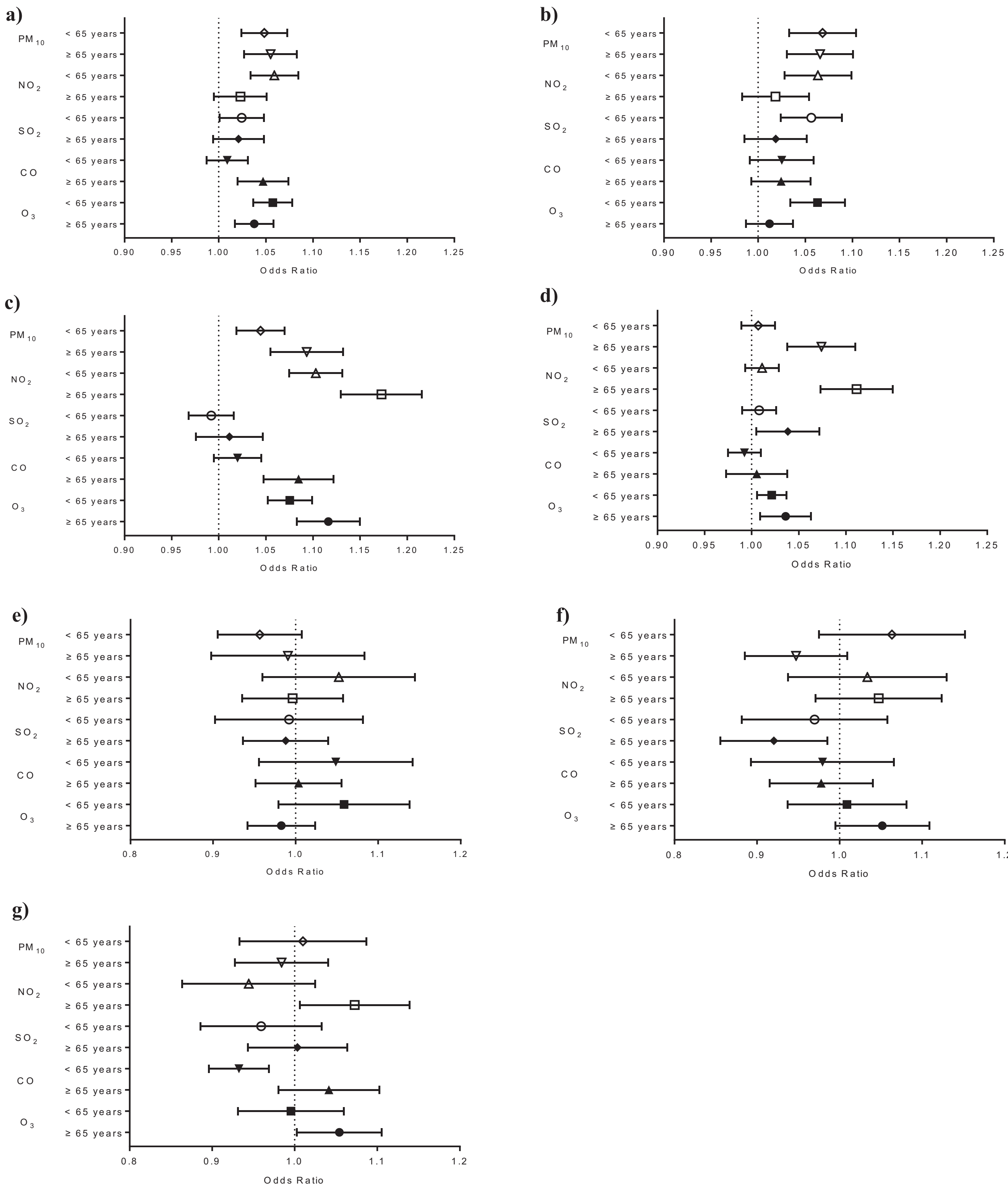

Figure 2 The odds ratios and 95% confidence intervals of CMD and risk factors according to per-interquartile range of PM_{10}, NO_2, CO, SO_2, and O_3 according to age (cut off, 65 years): (a) hypertension; (b) diabetes; (c) dyslipidemia; (d) obesity; (e) stroke; (f) myocardial infarction; and (g) ischemic heart disease. Age, sex, smoking, drinking, physical activity, education, marital status, household income, place of residence, hypertension, diabetes mellitus, dyslipidemia, obesity, stroke, myocardial infarction, and ischemic heart disease were adjusted except for the selected variable itself. c) and d) represent $P < 0.05$.

Table 3 The odds ratios (95% confidence intervals) of cardiometabolic disease for the long-term exposure of PM_{10}, NO_2, CO, SO_2, and O_3 according to sex.

	Hypertension		Diabetes		Dyslipidemia		Obesity		Stroke		Myocardial infarction		Ischemic heart disease	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
PM_{10}	1.14 (1.06, 1.23)	1.13 (1.05, 1.22)	1.18 (1.06, 1.31)	1.22 (1.09, 1.35)	1.29 (1.19, 1.40)	1.26 (1.16, 1.36)	1.07 (1.01, 1.13)	1.06 (1.00, 1.12)	1.04 (0.97, 1.12)	1.07 (0.99, 1.16)	1.05 (0.98, 1.14)	0.92 (0.83, 1.01)	1.07 (0.99, 1.16)	0.97 (0.90, 1.04)
NO_2	1.17 (1.09, 1.26)	1.17 (1.09, 1.16)	1.12 (1.02, 1.22)	1.19 (1.07, 1.33)	1.27 (1.16, 1.39)	1.42 (1.31, 1.55)	1.03 (1.00, 1.07)	1.08 (1.02, 1.14)	0.95 (0.88, 1.03)	1.04 (0.96, 1.13)	1.00 (0.92, 1.08)	0.92 (0.83, 1.02)	1.03 (0.94, 1.12)	1.02 (0.95, 1.11)
SO_2	1.08 (1.00, 1.16)	1.13 (1.04, 1.22)	1.15 (1.04, 1.28)	1.20 (1.08, 1.33)	1.03 (0.95, 1.13)	1.23 (1.13, 1.33)	1.01 (0.95, 1.06)	1.14 (1.07, 1.22)	0.96 (0.90, 1.03)	1.09 (1.01, 1.18)	1.08 (0.99, 1.17)	0.99 (0.89, 1.10)	1.06 (0.98, 1.15)	0.98 (0.91, 1.06)
CO	1.09 (1.03, 1.18)	1.07 (1.00, 1.15)	1.05 (0.95, 1.16)	1.05 (0.95, 1.17)	1.32 (1.21, 1.45)	1.40 (1.29, 1.53)	0.97 (0.91, 1.02)	1.06 (0.99, 1.13)	0.94 (0.88, 1.01)	1.06 (0.99, 1.14)	1.00 (0.93, 1.08)	1.04 (0.94, 1.14)	1.07 (0.99, 1.16)	1.01 (0.94, 1.09)
O_3	1.04 (1.01, 1.07)	1.00 (0.92, 1.08)	0.93 (0.85, 1.02)	1.15 (1.04, 1.28)	1.08 (1.05, 1.10)	1.07 (1.03, 1.09)	0.98 (0.93, 1.04)	1.03 (1.00, 1.06)	1.04 (0.96, 1.12)	0.95 (0.87, 1.04)	0.99 (0.91, 1.07)	1.07 (0.96, 1.19)	1.03 (0.95, 1.12)	0.99 (0.92, 1.08)

All statistics were adjusted with age, smoking, drinking, physical activity, education, marital status, household income, place of residence, hypertension, diabetes mellitus, dyslipidemia, obesity, stroke, myocardial infarction, and ischemic heart disease, except when the selected variable was the outcome.

artery was higher than those with <10 years of occupational exposure [23]. Therefore, the level and duration of exposure must be considered when investigating the association between CMD and air pollution.

CMD risk factors, including those of ambient air pollution, must be considered individually and collectively. Interestingly, we found that the effect of air pollutants on dyslipidemia and obesity were particularly attributable to age. PM_{10}, NO_2, CO, SO_2, and O_3 may act markedly to increase the risk of dyslipidemia and obesity to those aged $\geq$65 years. In accordance with this assumption, an increased coronary artery calcium score was reported for participants aged $\geq$65 years after the exposure of air pollution in a 10 year prospective cohort study with 6795 participants [24]. These findings are indicative of associations between air pollution and CMD because dyslipidemia and obesity are the most prevalent cardiometabolic risk factors in the general population [25]. In contrast to the findings of our study (increased odds ratios of hypertension regardless of age and sex), 24 months of exposure to PM was associated with an increase in incident hypertension, particularly among females aged <65 years rather than females aged $\geq$65 years in the Nurses' Health Study (Hazard ratio [95% CI]: 1.07 [1.02, 1.12] vs. 0.99 [0.93, 1.04], $P = 0.02$) [26]. Therefore, further investigation is needed to evaluate the associations between the exposure duration to air pollution and CMD according to age.

This study has several limitations. First, it was not possible to establish causality because this was a cross-sectional study. Moreover, obtaining data on CMD on a self-reporting basis may bias study findings. Owing to the lack of information about the time of diagnosis, not sharing their medical records between different medical institutions, we could only estimate the risk of CMD development after long-term exposure to air pollutants. Second, because we could not obtain data regarding the attainment of treatment goals for hypertension, diabetes, or dyslipidemia, treatment-related factors could not be considered [27]. Third, we matched the community of residence and local air pollutant levels using participant's residence codes. Therefore, if participants worked at a distant location from their domiciles, our system of matching would not have accurately reflected the exposed air pollutant levels. Further, we could not consider residential proximity to major roadways from the KCHS data [28]. Fourth, air pollutants rarely occurred in isolation to each other. Nevertheless, the independent or potentially additive risks by these multiple exposures could not be considered [3]. Fifth, we could not obtain measurements of long-term exposure to $PM_{2.5}$; therefore, the association between $PM_{2.5}$ and CMD could not be evaluated in this study. Finally, the prevalence of hypertension (20.0%) may be underestimated in this study compared to a 2012 report of Koreans (males: 32.2%, females: 25.4%) and a 2013–2014 Chinese (27.8%) report [29,30]. The prevalence of diabetes mellitus (7.6%) may also be underestimated when compared to that reported in a Korean study (males: 10.1%, females: 8.0%) [30].

Therefore, we may have underestimated the prevalence of CMD in KCHS.

Conclusively, long-term exposure to PM_{10}, NO_2, CO, SO_2, and O_3 is associated with the risk of hypertension, diabetes mellitus, dyslipidemia, and obesity in South Korea. Future investigations have to examine the effect of demographic characteristics. This information is helpful in making a policy to control air pollution as a risk factor of the cardiometabolic disease.

Acknowledgement

The authors would like to thank the Korea Centres for Disease Control and Prevention for the data obtained from the 2012 Community Health Survey and the National Institute of Environmental Research. This paper was supported by Konkuk University. We thank Dyanne Ahn to proofread.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.numecd.2018.09.008.

References

[1] Sun Q, Hong X, Wold LE. Cardiovascular effects of ambient particulate air pollution exposure. Circulation 2010;121:2755–65.
[2] Bourdrel T, Bind MA, Bejot Y, Morel O, Argacha JF. Cardiovascular effects of air pollution. Arch Cardiovasc Dis 2017;110:634–42.
[3] Brook RD, Newby DE, Rajagopalan S. Air pollution and cardiometabolic disease: an update and call for clinical trials. Am J Hypertens 2017;31:1–10.
[4] Cai Y, Zhang B, Ke W, Feng B, Lin H, Xiao J, et al. Associations of short-term and long-term exposure to ambient air pollutants with hypertension: a systematic review and meta-analysis. Hypertension (Dallas, Tex: 1979) 2016;68:62–70.
[5] Balti EV, Echouffo-Tcheugui JB, Yako YY, Kengne AP. Air pollution and risk of type 2 diabetes mellitus: a systematic review and meta-analysis. Diabetes Res Clin Pract 2014;106:161–72.
[6] Tuan TS, Venancio TS, Nascimento LF. Effects of air pollutant exposure on acute myocardial infarction, according to gender. Arq Bras Cardiol 2016;107:216–22.
[7] Bero Bedada G, Raza A, Forsberg B, Lind T, Ljungman P, Pershagen G, et al. Short-term exposure to ozone and mortality in subjects with and without previous cardiovascular disease. Epidemiology (Cambridge, Mass) 2016;27:663–9.
[8] Lipsett MJ, Ostro BD, Reynolds P, Goldberg D, Hertz A, Jerrett M, et al. Long-term exposure to air pollution and cardiorespiratory disease in the California teachers study cohort. Am J Respir Crit Care Med 2011;184:828–35.
[9] Perez L, Wolf K, Hennig F, Penell J, Basagana X, Foraster M, et al. Air pollution and atherosclerosis: a cross-sectional analysis of four European cohort studies in the ESCAPE study. Environ Health Perspect 2015;123:597–605.
[10] Seo J, Choi B, Kim S, Lee H, Oh D. The relationship between multiple chronic diseases and depressive symptoms among middle-aged and elderly populations: results of a 2009 Korean community health survey of 156,747 participants. BMC Publ Health 2017; 17:844.
[11] Kim Sun Taek. Quality control of air pollution monitoring system and establishment of data evaluation scheme(I). Korean Air Pollutants Emission Service; 2015.
[12] Sohn D, Oh H. Gender-dependent differences in the relationship between diabetes mellitus and ambient air pollution among adults in South Korean cities. Iran J Publ Health 2017;46:293–300.
[13] Committee S. The Asia-Pacific perspective: redefining obesity and its treatment. Melbourne: International Diabetes Institute; 2000. p. 11–2.
[14] Kim J, Kim H. Demographic and environmental factors associated with mental health: a cross-sectional study. Int J Environ Res Publ Health 2017;14.
[15] Mazidi M, Speakman JR. Ambient particulate air pollution (PM2.5) is associated with the ratio of type 2 diabetes to obesity. Sci Rep 2017;7:9144.
[16] Yitshak Sade M, Kloog I, Liberty IF, Schwartz J, Novack V. The association between air pollution exposure and glucose and lipids levels. J Clin Endocrinol Metabol 2016;101:2460–7.
[17] Chuang KJ, Yan YH, Chiu SY, Cheng TJ. Long-term air pollution exposure and risk factors for cardiovascular diseases among the elderly in Taiwan. Occup Environ Med 2011;68:64–8.
[18] Wei Y, Zhang JJ, Li Z, Gow A, Chung KF, Hu M, et al. Chronic exposure to air pollution particles increases the risk of obesity and metabolic syndrome: findings from a natural experiment in Beijing. FASEB J 2016;30:2115–22.
[19] Sun Q, Yue P, Deiuliis JA, Lumeng CN, Kampfrath T, Mikolaj MB, et al. Ambient air pollution exaggerates adipose inflammation and insulin resistance in a mouse model of diet-induced obesity. Circulation 2009;119:538–46.
[20] Hwang SH, Lee JY, Yi SM, Kim H. Associations of particulate matter and its components with emergency room visits for cardiovascular and respiratory diseases. PLoS One 2017;12, e0183224.
[21] Kim H, Kim J, Kim S, Kang SH, Kim HJ, Kim H, et al. Cardiovascular effects of long-term exposure to air pollution: a population-based study with 900 845 person-years of follow-up. J Am Heart Assoc 2017;6.
[22] Ruidavets JB, Cournot M, Cassadou S, Giroux M, Meybeck M, Ferrieres J. Ozone air pollution is associated with acute myocardial infarction. Circulation 2005;111:563–9.
[23] Erdogmus B, Yazici B, Annakkaya AN, Bilgin C, Safak AA, Arbak P, et al. Intima-media thickness of the common carotid artery in highway toll collectors. J Clin Ultrasound JCU 2006;34:430–3.
[24] Kaufman JD, Adar SD, Barr RG, Budoff M, Burke GL, Curl CL, et al. Association between air pollution and coronary artery calcification within six metropolitan areas in the USA (the Multi-Ethnic Study of Atherosclerosis and Air Pollution): a longitudinal cohort study. Lancet 2016;388:696–704.
[25] Shokeen D, Aeri BT. Prevalence of cardio-metabolic risk factors: a cross-sectional study among employed adults in urban Delhi, India. J Clin Diagn Res JCDR 2017;11. Lc01-lc4.
[26] Zhang Z, Laden F, Forman JP, Hart JE. Long-term exposure to particulate matter and self-reported hypertension: a prospective analysis in the Nurses' health study. Environ Health Perspect 2016; 124:1414–20.
[27] Nayor M, Duncan MS, Musani SK, Xanthakis V, LaValley MP, Larson MG, et al. Incidence of cardiovascular disease in individuals affected by recent changes to US blood pressure treatment guidelines. J Hypertens 2018;36:436–43.
[28] Brunekreef B, Beelen R, Hoek G, Schouten L, Bausch-Goldbohm S, Fischer P, et al. Effects of long-term exposure to traffic-related air pollution on respiratory and cardiovascular mortality in The Netherlands: the NLCS-AIR study. Research report (Health Effects Institute); 2009. p. 5–71. discussion 3-89.
[29] Li Y, Yang L, Wang L, Zhang M, Huang Z, Deng Q, et al. Burden of hypertension in China: a nationally representative survey of 174,621 adults. Int J Cardiol 2017;227:516–23.
[30] Korea Health Statistics. 2012: Korea national health and nutrition examination survey (KNHANES V-3). Ministry of Health Welfare: Korea Control for Desease Control and Prevention; 2013.