

Effect of Short-Term Exposure to Fine Particulate Matter and Temperature on Acute Myocardial Infarction in Korea

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Research

Keywords: Fine particulate matter, Temperature, Acute myocardial infarction, National Health Information Database, Time-series study

Posted Date: April 2nd, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-342630/v1>

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Abstract

Background/Aim: Previous studies have suggested that the short-term ambient air pollution and temperature are associated with myocardial infarction. In this study, we aimed to conduct a time-series analysis to assess the impact of fine particulate matter (PM_{2.5}) and temperature on acute myocardial infarction (AMI) among adults over 20 years of age in Korea by using the data from the Korean National Health Information Database (KNHID).

Methods: Daily data of 197,940 AMI cases in Seoul were collected from the nationwide, population-based KNHID from 2005 to 2014. Monitoring data of ambient PM_{2.5} from the Seoul Research Institute of Public Health and Environment were also collected. A generalized additive model (GAM) that allowed for a quasi-Poisson distribution was used to analyze the effects of PM_{2.5} and temperature on the incidence of AMI.

Results: The models with PM_{2.5} lag structures of lag 0 and 2-day averages of lag 0 and 1 (lag 01) showed significant associations with AMI (Relative risk [RR]: 1.011, CI: 1.003–1.020 for lag 0, RR: 1.010, CI: 1.000–1.020 for lag 01) after adjusting the covariates. Stratification analysis conducted in the cold season (October–April) and the warm season (May–September) showed a significant lag 0 effect for AMI cases in the cold season only.

Conclusions: In conclusion, acute exposure to PM_{2.5} was significantly associated with AMI morbidity at lag 0 in Seoul, Korea. This increased risk was also observed at low temperatures.

Introduction

Acute myocardial infarction (AMI) is a leading cause of death worldwide. (1, 2) Similar to other countries, the incidence of AMI in Korea has increased over the last few decades. (3, 4) Therefore, it is important to prevent the occurrence of AMI and identify the risk factors of AMI.

Many environmental factors have been suggested as risk factors for AMI. Air pollution has been repeatedly associated with increased risks of hospital admissions and deaths due to cardiovascular disease. Specifically, particulate matter (PM) has been identified as a risk factor for cardiovascular disease in studies performed throughout the industrialized world (5–8). Air pollution is increasing as urbanization and industrialization processes expand worldwide.

Recently, growing evidence has shown that fine particulate matter (PM_{2.5}), which is $\leq 2.5\mu\text{m}$ in aerodynamic diameter, may play a role in the development of cardiovascular diseases and that different sizes of particulate matter affect cardiovascular health differently. (9–11) A prior study suggested that although smoking is a more important risk factor for cardiovascular mortality, exposure to PM_{2.5} is also a risk factor for the disease via mechanisms including pulmonary and systemic inflammation. (5) Some studies also have shown that PM_{2.5} air pollution is a specific trigger of myocardial infarction (MI). A prospective cohort study that examined the increased risk of ischemic heart disease (IHD) associated with occupational exposure to PM found that PM_{2.5} was a stronger predictor of IHD risk than total particulate matter (TPM). (7)

In addition to the PM_{2.5}, temperature can also be a risk factor for adverse cardiovascular outcomes. Previous studies suggested that high or low temperatures are associated with the AMI mortality and morbidity. For instance, studies conducted in Cuba, Sweden, Massachusetts and Denmark reported an increased AMI risk at low temperatures (12–15). Other studies conducted in South Korea and England identified that both low and high temperatures are associated with an increased AMI risk (16, 17).

South Korea has a serious air pollution concerns due to the frequent haze events and PM_{2.5} concentrations in recent years (18, 19). Especially, Seoul is the largest city in South Korea and it is a highly urbanized area with many emission sources, such as automobile exhaust, industrial factories, and power-generating facilities. (20) Furthermore, because of local and regional emission and meteorological and chemical interactions, there is a high concentration of PM_{2.5} in Seoul.

The temperature of South Korea is also unique when it is compared to the other countries. This is because South Korea has four distinctive seasons and a relative wide temporal variation in climate. The weather of South Korea is different between the central and southern parts of the Korean peninsula, and the central part including Seoul is colder than the southern parts (16).

Therefore, it is very important to identify the effect of PM_{2.5} and temperature on acute myocardial infarction (AMI) events in Seoul, Korea, one of the areas highly polluted by PM_{2.5}. However, nationwide research regarding these relationships are still limited. We

conducted a nationwide, population-based study designed to investigate the impact of PM_{2.5} and temperature on acute myocardial infarction (AMI) among adults over 20 years of age in Seoul, Korea, by using the data from the Korean National Health Information Database (KNHID).

Methods

Data Source

This study used data from the Korean National Health Information Database (KNHID) collected between January 1, 2002, and December 31, 2014. The KNHID contains information about participants who visited hospitals under the Korean National Health Insurance Service (NHIS) program. (21) Since this National Health Insurance Service in Korea is a single-payer program and is mandatory for all residents, the KNHIS represents the entire Korean population and can be utilized as a population-based database. (22) The KNHID includes five databases (an eligibility database, a national health screening database, a healthcare utilization database, a long-term care insurance database, and a medical institution database) and contains public data on the diagnosis and status of outpatients and inpatients (22).

Monitoring data of ambient PM_{2.5} from the Seoul Research Institute of Public Health and Environment were also collected. In Korea, the city of Seoul has recognized the importance of exposure to PM_{2.5} and began measuring PM_{2.5} in early 2000. Daily exposure measurements during the study period between January 1, 2005, and December 31, 2014, were taken from 25 monitoring sites installed in the administrative districts of Seoul using the SPM-613D beta gauge method (23). The daily PM_{2.5} values in Seoul were computed by averaging the daily mean concentration of PM_{2.5} at all monitoring stations.

To estimate other co-pollutants including CO, SO₂, NO₂, we obtained complete air pollution data from local district air quality fixed-site monitoring stations in Korea managed by the National Ambient Air Monitoring System(24). Because data on air pollution were not available at all administrative sites in Seoul, we applied interpolation techniques using geographic information systems (GIS) tools (ArcGIS Version 9.3, ESRI, Redlands, CA, USA) to estimate air pollution levels in unmonitored districts. Three air pollutants were interpolated using ordinary kriging models to derive the exposure assessments. Daily values were computed by averaging the daily mean concentration of air pollutants at all administrative districts in Seoul.

Weather condition data, including daily average temperature, daily maximum temperature, daily minimum temperature, daily mean relative humidity, and dew-point temperature were acquired from the database of the Korea Meteorological Administration (KMA), which runs 76 automated weather stations in the Seoul metropolitan area.

Ethic Approval

This study was approved by the Institutional Review Board of Ewha Womans University Hospital, Seoul, Republic of Korea (IRB number: EUMC 2019-12-009).

Ami Events And Exposure Definition

We obtained the study population data from the KNHID between the years January 1, 2005 to December 31, 2014. AMI patients were defined as persons who were newly diagnosed under a diagnostic code for AMI. Only the day of first diagnosis of AMI was designated as a day with an AMI event. We identified the AMI diagnosis from the patient's medical treatment based on the Korean Classification of Diseases, 6th revision (KCD-6), which is a modified version of the International Classification of Disease, 10th revision (ICD-10). We set the criteria of AMI patients based on the KCD-6 code for acute myocardial infarction (codes I21). Data regarding 192,567 AMI events in Seoul were collected during the study period.

To figure out the relationship between PM_{2.5} exposures and AMI morbidity, we fitted the models with different lag structures from lag 0 day (at the day of the AMI diagnosis) to lag 3 days. To consider the exposure effects of the average over the same and previous days, we used the 2-day to 4-day moving averages of PM_{2.5} to estimate the association between PM_{2.5} exposure and AMI morbidity. (25) We also explored the effect of three daily temperatures including daily mean temperature, daily maximum temperature and daily minimum temperature on AMI morbidity in adults.

A time-series design was used to analyze the daily data of AMI cases, PM2.5 concentration and weather variables that were linked by date. Since the variance of daily AMI cases is greater than the mean, the daily AMI cases assumed a quasi-Poisson distribution (Supplementary Table 1). We fit a generalized additive model (GAM) to identify the association between PM2.5 and AMI cases:

$$\text{Log}[E(Y_t)] = \text{intercept} + \beta \times \text{PM}_{2.5} + \text{s}(\text{Calendar time}, df = 4 * 10) + \\ \text{s}(\text{Temperature}, df = 6) + \text{s}(\text{Dew point temperature}, df = 3) + \\ \text{s}(\text{relative humidity}, df = 5) + \text{day of week}$$

Where $E(Y_t)$ represents the number of AMI cases or death at day t ; s shows smoothing spline and β represents the log-relative risk of AMI morbidity associated with a unit increase of PM2.5. Relative risks (RR) of AMI morbidity with a $10\mu\text{g}/\text{m}^3$ increase in PM2.5 concentration was calculated. To control for the seasonal patterns and long-term trends, we considered smoothing spline for calendar time with 4 degrees of freedom per year to control for seasonal trends, temperature with 6 degrees of freedom, dew point temperature with 3 degrees of freedom and relative humidity with 5 degrees of freedom (26). Day of week was controlled as a categorical variable. We used the value of temperature, dew point temperature and relative humidity at lag 0 as a covariate. Degrees of freedom (df) were further tested by the sensitivity analyses.

In the main model, we assumed that the relationship between exposure variables (i.e., $\text{PM}_{2.5}$) and AMI events was linear. However, the exposure-response relationship may also indicate non-linearity. Therefore, we visualized the exposure-response relationship between the exposure variables ($\text{PM}_{2.5}$ and temperature) and the AMI events.

The stratified analysis of $\text{PM}_{2.5}$ concentration and daily AMI events was further carried out in the cold months (October–April) and warm months (May–September) separately (27,28). We also defined the daily mean temperature strata in four levels (<3.70 , 3.70 – 14.30 , 14.30 – 22.40 , and ≥ 22.40) by using quartiles and examined the relationship within each group.

All P values were 2-sided, and those less than .05 were considered to be significant. The statistical analyses were performed using the R (version 3.5.2) 'mgcv' package.

Results

Summary statistics of air pollutant and weather conditions

Table 1 shows the summary statistics of air-pollutant concentrations and meteorological indicators including daily temperature, relative humidity and dew point temperature. During the 10 years under study, the mean daily PM2.5 concentration was $25.7\mu\text{g}/\text{m}^3$. The mean daily average temperature was 12.7°C and the average daily maximum temperature was 17.1°C . The average relative humidity was 60.6% during the study period. The concentrations of PM2.5 were higher in the cold season. The daily average temperature was 22.8°C in the warm season and 5.39°C in the cold season (Supplementary Table 2).

Table 1
Average air-pollutant concentration and weather conditions during the study period (2005 to 2014)

Air pollutants	Mean ± SD	Min	P25	Median	P75	Max
PM2.5 ^a (µg/m ³)	25.7 ± 14.2	3.0	16.0	23.0	32.0	122
CO (ppb)	590 ± 241	218	427	529	683	1835
SO ₂ (ppb)	5.46 ± 2.26	2.30	3.86	4.87	6.45	22.0
NO ₂ (ppb)	33.98 ± 12.37	6.50	24.4	32.2	42.2	89.4
Meteorological indicators						
Daily average temperature (°C)	12.7 ± 10.6	-14.5	3.7	14.3	22.4	31.8
Daily maximum temperature (°C)	17.1 ± 10.8	-10.7	7.8	19.0	26.6	36.7
Daily minimum temperature (°C)	8.96 ± 10.7	-17.8	-0.2	9.9	18.7	28.7
Relative humidity (%)	60.6 ± 15.0	19.9	49.4	60.6	71.5	99.8
Dew point temperature (°C)	4.55 ± 12.1	-25.4	-5.20	5.15	15.1	25.3
^a PM2.5: particulate matter < 2.5µm in aerodynamic diameter; SD: standard deviation; Min: minimum; Max: maximum, P25: 25th percentile, P75: 75th percentile						

Ami Incidence

Supplementary Table 3 represents the newly diagnosed AMI patients and population number enrolled in the NHID in the overall cities and Seoul in Korea from 2005 to 2014. Of the 192,567 AMI cases that occurred during the study period, 17.27% of the data were cases that occurred in Seoul.

The crude incidence in Seoul was lower than overall crude incidence. In 2005, the incidence of AMI was the highest in Seoul. In 2005, the crude incidence per 100,000 was 46.4. In 2011, the crude incidence per 100,000 in Seoul was 39.3, which was the lowest incidence during the study period.

Relative Risk Estimates For Cases Of Ami Events

RR and 95% CI regarding the relationship between 10 µg/m³ increase in PM2.5 at different exposure days and daily cases of AMI are summarized in Table 2. In the single pollutant models, the models with lag structures of lag 0 and lag 01 showed significant associations with AMI (RR: 1.011, CI: 1.003–1.020 for lag 0, RR: 1.010, CI: 1.000–1.020 for lag 01). In the co-pollutant model which simultaneously included two pollutants (PM2.5 and alternatively NO₂, SO₂ or CO), we could observe significant associations between PM2.5 and AMI events in lag 0 model only.

Table 2

Adjusted relative risk estimates for daily cases of AMI event (95% CI) per 10 $\mu\text{g}/\text{m}^3$ increase in PM_{2.5} at single-lag (lag 0, lag 1, lag 2 and lag 3) and cumulative-lag (lag 01, lag 02 and lag 03) models.

Lag day	RR (95% CI)			
	None	+CO	+SO ₂	+NO ₂
Lag 0	1.011(1.003–1.020)*	1.018(1.005–1.031)*	1.013(1.000–1.025)*	1.013(1.001–1.024)*
Lag 1	1.004(0.995–1.012)	0.998(0.985–1.011)	1.005(0.992–1.017)	0.993(0.982–1.004)
Lag 2	1.000(0.991–1.009)	0.999(0.986–1.012)	1.000(0.988–1.013)	0.995(0.984–1.006)
Lag 3	0.997(0.989–1.006)	0.999(0.986–1.012)	1.003(0.991–1.015)	0.996(0.985–1.007)
Lag 01	1.010(1.000–1.020)*	1.012(0.997–1.027)	1.011(0.997–1.025)	1.004(0.991–1.017)
Lag 02	1.006(0.995–1.017)	1.004(0.987–1.021)	1.007(0.991–1.023)	0.994(0.979–1.009)
Lag 03	1.002(0.990–1.014)	1.001(0.982–1.019)	1.007(0.989–1.025)	0.989(0.972–1.006)

*P < 0.05; AMI, acute myocardial infarction; CI, confidence interval

^a Results adjusted for calendar time, daily mean temperature, dew-point temperature, relative humidity and day of week.

Figure 1 presents the average exposure-response curve between PM_{2.5} concentrations and the risk of daily AMI events. There were exposure-response relationships of the PM_{2.5} concentration and AMI at lag 0, lag 1, and the 2-day averages of lags 0 and 1 (lag 01). We also noted a broadly linear association for the 3-day average of lags 0, 1 and 2 (lag 02). A longer lag association show relatively flat or negative curves at lag3 and lag 03.

Figure 2 shows the nonlinear curve for the association between three different temperatures (mean temperature, minimum temperature and maximum temperature) and AMI. The results show a non-linear positive relationship between mean temperature and AMI. Furthermore, if the maximum temperature level increased, the log relative risk of AMI also increased nonlinearly. However, when we assumed the linear effect of the temperatures and identified the relationship between the three daily temperatures and daily cases of AMI events, the results showed no significant relationships between temperatures and AMI (Supplementary Table 4).

Table 3 shows the adjusted RR for daily cases of AMI events per 10 $\mu\text{g}/\text{m}^3$ increase in PM_{2.5} at different lag days, which is stratified by the quartile level of daily mean temperature at lag0. The results showed when the daily mean temperature level at lag 0 was between 3.70–14.30°C, a 10 $\mu\text{g}/\text{m}^3$ increase in PM_{2.5} at lag 0, lag 01 and lag 02 were significantly associated with increased daily cases of AMI events. In the co-pollutant models at Supplementary Table 6, PM_{2.5} at Lag 0 were significantly associated with AMI events and Lag 01 was only associated with AMI in SO₂ adjusted model. In different temperature groups such as < 3.70°C, 14.30–22.40°C, and \geq 22.40, the results did not show any significant associations.

Table 3

Adjusted relative risk for daily cases of AMI event (95% CI) per 10 µg/m³ increase in PM_{2.5} at different lag days, stratified by quartiles of daily mean temperature levels at lag 0^{ab}

Temperature (°C)	Lag 0	Lag 1	Lag 2	Lag 3	Lag 01	Lag 02	Lag 03
< 3.70	0.983(0.964–1.002)	0.988(0.972–1.005)	0.989(0.973–1.005)	0.992(0.977–1.008)	0.985(0.965–1.004)	0.980(0.960–1.001)	0.977(0.956–0.999)
3.70–14.30	1.030(1.014–1.046)*	1.006(0.990–1.022)	1.002(0.986–1.019)	1.000(0.983–1.016)	1.024(1.006–1.042)*	1.022(1.002–1.042)*	1.018(0.996–1.041)
14.30–22.40	1.017(0.998–1.037)	1.007(0.998–1.025)	1.011(0.993–1.031)	1.002(0.984–1.020)	1.015(0.995–1.036)	1.019(0.997–1.042)	1.018(0.995–1.043)
≥ 22.40	1.003(0.984–1.023)	1.011(0.992–1.031)	1.000(0.981–1.019)	0.999(0.979–1.020)	1.008(0.986–1.030)	0.999(0.975–1.024)	0.994(0.967–1.022)
*P < 0.05							
<p>^a Results adjusted for calendar time, daily mean temperature, dew-point temperature, relative humidity and day of week.</p> <p>^b Using the quartile of temperature as the cut-off value.</p>							
^a Results adjusted for calendar time, daily mean temperature, dew-point temperature, relative humidity and day of week.							

Figure 3 shows the results of stratified analyses by season. The associations between PM_{2.5} concentration and the cases of AMI events varied by season. The stratified analysis carried out in the cold season (October–April) and warm season (May–September) showed a significant lag0 effect for AMI cases only in the cold season (RR: 1.012, CI: 1.002–1.023) after the adjustment for the covariates. Except for the lag0 effect, the other lag effects were not significant.

Discussion

This study suggests there is an evidence of an association between PM_{2.5} concentration and AMI morbidity in adults at lag 0 and lag 01 in Seoul, Korea. However, the adverse effect of PM_{2.5} at lag01 became insignificant after adjustment for other co-pollutant. Our results are mostly consistent with previous studies that reported detrimental heart effects from short-term exposure to PM_{2.5}. A cohort study performed in Beijing showed a significant association between PM_{2.5} concentration and ischemic heart disease (IHD) morbidity in lag 0 to lag 3 days. However, there was no significant lag association with IHD mortality. (29) Furthermore, a cross-sectional study of the adult National Health and Nutrition Examination Survey (NHANES) observed a significant effect of PM_{2.5} acutely at lag day 0 on the CRP level, which is a cardiovascular disease related inflammatory marker. (30)

In the stratified analyses by the season and daily mean temperature, the relationship was significant only in the cold season. Furthermore, when the daily mean temperature at lag 0 was between 3.70–14.30°C, the increase of PM_{2.5} at lag 0, lag 01 showed significant positive associations with the daily cases of AMI events. In the warm season, the PM_{2.5} concentration was not associated with the AMI morbidity. One possible reason for the significant association in the cold season is connected to a low temperature and increased blood pressure and viscosity in the cold season, which might be important causal factors in increasing winter morbidity due to heart attacks and strokes. (31, 32)

Our results indicate the effect estimates were higher in the cold season, but they did not show that if the temperature drops the risk increases since the daily mean temperature group < 3.70°C showed a negative relationship between PM_{2.5} increase and the risk of AMI. In very cold weather, people stay home or inside. This activity pattern might attenuate the effect of the lowest temperature group on AMI, and thus only the medium temperature group shows a significant positive association between PM_{2.5} and AMI events. A study of seasonal variations in hospital admissions with AMI in Korea also found that AMI events increased during October to December (daily mean temperature in October to December: -1.00 to 15.5°C) and it then reduced in January to February (daily mean temperature of January and February: -2.46 and 0.50°C) (33)

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Analyses about effect modification by season or temperature was performed in other studies conducted in other countries and some results were consistent with our results. A previous time-series study conducted in Shanghai, China reported that the daily counts of coronary heart disease (CHD) morbidity in the cold season (November–April) were higher than those in the warm season (May–October).⁽³⁴⁾ They also found a significant association between the particulate matter concentration including PM_{2.5} and PM₁₀ at lag 01 and CHD outpatient and emergency department visits in all seasons. Although these significant particulate matter effects were observed in all seasons and in cold seasons, the association was not statistically significant in the warm season. Research conducted in Hong Kong also found detrimental effects of air pollution in cool and dry seasons. In cool and dry seasons, a 10 $\mu\text{g} / \text{m}^3$ increment of lag 03 exposure was associated with an increase in emergency IHD admissions. However, another study conducted in Belgium showed a steep linear association in summer whereas in winter the association was non-linear.⁽³⁵⁾ Studies conducted in U.S. cities also showed that for the 10 $\mu\text{g} / \text{m}^3$ increase in 2-day averaged PM_{2.5}, the percent increases in all mortality categories were greatest in the spring.⁽³⁶⁾

For the strengths of our study, although many studies have analyzed the association between PM_{2.5} concentration and heart diseases such as in the UK, US and other developed countries, those PM_{2.5} exposure levels are quite low. ^(37, 38) Therefore, it is important to identify the relationship regarding PM_{2.5} exposure and heart disease in a high polluted region. Our average PM_{2.5} level during the study period was 25.7 $\mu\text{g} / \text{m}^3$, which is over the World Health Organizations' Air Quality Guidelines (25 $\mu\text{g} / \text{m}^3$, 24-hour mean). ⁽³⁹⁾ We conducted the study in the Seoul, a highly polluted area with PM_{2.5} and found effects at higher levels of exposure. Another strength of our study is that we tried to avoid overestimating the effect of PM_{2.5} by constructing the co-pollutant models and therefore we constructed both single pollutant and co-pollutant models to consider the potential role of other gaseous air pollutants such as CO, SO₂ and NO₂. Finally, our study is a large-scale, nationwide, population-based study since we used the KNHID data, which includes health information about participants who visited hospitals under the Korean National Health Insurance Service Program, which covers all residents of South Korea. ⁽⁴⁰⁾We also used KCD codes to identify the AMI patients and this usage increased the accuracy of AMI diagnosis in our study since the diagnosis was confirmed by a physician.

For the limitations of this study, since our PM_{2.5} data from the Seoul Research Institute of Public Health and Environment were available only in Seoul, from January 1, 2005, we could not extend the analysis prior to 2005 or to other locations except Seoul. Secondly, the air pollution level of the day was estimated according to the average of all monitoring sites in Seoul, Korea. Therefore, the possible diversity of the exposure level of each patient such as in the working area, in-or out-door daily activity, or the distance from the monitoring station to the patients' home were not considered in the exposure estimation.

In conclusion, our results have demonstrated that the PM_{2.5} concentration was significantly associated with an increased AMI morbidity at lag 0 in Seoul, Korea. This increased association was also observed at low temperatures, suggesting that the temperature could modify the effect of air pollution on cardiovascular outcomes. Further studies from other countries that have different temperature trends examining the effect modification of PM and AMI association by temperatures are necessary.

Declarations

Ethical Approval and Consent to participate

This study was approved by the Institutional Review Board of Ewha Womans University Hospital, Seoul, Republic of Korea (IRB number: EUMC 2019-12-009).

Consent for publication

Not applicable.

Availability of supporting data

Not applicable.

Competing interests

The authors declare they have no actual or potential competing financial interests.

Funding

This study was funded by The Korean Society of Cardiology (201605-07).

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Authors' contributions

J.S. designed the study. E.H. and W.B. P. collected the data and take responsibility for the content of the manuscript, including the data and analyses. They interpreted the data, and approved the final version of the manuscript. J.S. prepared the draft of this manuscript. J.O. and I.S. K. advised the design of this study. J.S. performed the statistical analyses. All authors interpreted the data, read the manuscript, and approved the final manuscript.

Acknowledgements

This study was supported by The Korean Society of Cardiology (201605-07) and Seoul Research Institute of Public Health and Environment

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References

- (1) Mozaffarian D, Benjamin EJ, Go AS, Arnett DK, Blaha MJ, Cushman M, et al. Executive summary: heart disease and stroke statistics –2015 update: a report from the American Heart Association. *Circulation* 2015;131(4):434-441.
- (2) Ishihara M, Fujino M, Ogawa H, Yasuda S, Noguchi T, Nakao K, et al. Clinical Presentation, Management and Outcome of Japanese Patients With Acute Myocardial Infarction in the Troponin Era–Japanese Registry of Acute Myocardial Infarction Diagnosed by Universal Definition (J-MINUET)–. *Circulation Journal* 2015;79(6):1255-1262.
- (3) Kim JH, Chae S, Oh DJ, Kim H, Kim YJ, Ahn Y, et al. Multicenter Cohort Study of Acute Myocardial Infarction in Korea–Interim Analysis of the Korea Acute Myocardial Infarction Registry–National Institutes of Health Registry–. *Circulation Journal* 2016:CJ-16-0061.
- (4) Hong JS, Kang HC, Lee SH, Kim J. Long-term trend in the incidence of acute myocardial infarction in Korea: 1997-2007. *Korean Circ J* 2009 Nov;39(11):467-476.
- (5) Pope III CA, Burnett RT, Thurston GD, Thun MJ, Calle EE, Krewski D, et al. Cardiovascular mortality and long-term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease. *Circulation* 2004;109(1):71-77.
- (6) Anderson H, Atkinson R, Bremner S, Marston L. Particulate air pollution and hospital admissions for cardiorespiratory diseases: are the elderly at greater risk? *European Respiratory Journal* 2003;21(40 suppl):39s-46s.
- (7) Neophytou AM, Noth EM, Liu S, Costello S, Hammond SK, Cullen MR, et al. Ischemic heart disease incidence in relation to fine versus total particulate matter exposure in a US aluminum industry cohort. *PloS one* 2016;11(6):e0156613.
- (8) Ahn J. Fine Particulate Matter: a Threat to the Heart Rhythm. *Korean Circ J* 2021 Feb;51(2):171-173.
- (9) Pope III CA, Dockery DW. Health effects of fine particulate air pollution: lines that connect. *J Air Waste Manage Assoc* 2006;56(6):709-742.
- (10) Peng RD, Chang HH, Bell ML, McDermott A, Zeger SL, Samet JM, et al. Coarse particulate matter air pollution and hospital admissions for cardiovascular and respiratory diseases among Medicare patients. *JAMA* 2008;299(18):2172-2179.
- (11) Park H, Lim S, Lee S, Mun D, Kang J, Kim H, et al. High Level of Real Urban Air Pollution Promotes Cardiac Arrhythmia in Healthy Mice. *Korean Circ J* 2021 Feb;51(2):157-170.
- (12) Rivero A, Bolufé J, Ortiz PL, Rodríguez Y, Reyes MC. Influence of climate variability on acute myocardial infarction mortality in Havana, 2001-2012. *MEDICC review* 2015;17:14-19.
- (13) Wichmann J, Rosengren A, Sjöberg K, Barregard L, Sallsten G. Association between ambient temperature and acute myocardial infarction hospitalisations in Gothenburg, Sweden: 1985–2010. *PloS one* 2013;8(4):e62059.

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- (14) Madrigano J, Mittleman MA, Baccarelli A, Goldberg R, Melly S, von Klot S, et al. Temperature, myocardial infarction, and mortality: effect modification by individual- and area-level characteristics. *Epidemiology* 2013 May;24(3):439-446.
- (15) Wichmann J, Ketzel M, Ellermann T, Loft S. Apparent temperature and acute myocardial infarction hospital admissions in Copenhagen, Denmark: a case-crossover study. *Environ Health* 2012;11(1):1-12.
- (16) Lee S, Lee E, Park MS, Kwon BY, Kim H, Jung DH, et al. Short-term effect of temperature on daily emergency visits for acute myocardial infarction with threshold temperatures. *PLoS One* 2014;9(4):e94070.
- (17) Bhaskaran K, Hajat S, Haines A, Herrett E, Wilkinson P, Smeeth L. Short term effects of temperature on risk of myocardial infarction in England and Wales: time series regression analysis of the Myocardial Ischaemia National Audit Project (MINAP) registry. *BMJ* 2010 Aug 10;341:c3823.
- (18) Zhang Z, Zhang X, Gong D, Kim S, Mao R, Zhao X. Possible influence of atmospheric circulations on winter haze pollution in the Beijing–Tianjin–Hebei region, northern China. *Atmospheric Chemistry and Physics* 2016;16(2):561-571.
- (19) Zhang J, Sun Y, Liu Z, Ji D, Hu B, Liu Q, et al. Characterization of submicron aerosols during a month of serious pollution in Beijing, 2013. *Atmospheric Chemistry and Physics* 2014;14(6):2887-2903.
- (20) Lee D, Lee Y, Jang K, Yoo C, Kang K, Lee J, et al. Korean national emissions inventory system and 2007 air pollutant emissions. *Asian Journal of Atmospheric Environment* 2011;5(4):278-291.
- (21) Cheol Seong S, Kim Y, Khang Y, Heon Park J, Kang H, Lee H, et al. Data resource profile: the national health information database of the National Health Insurance Service in South Korea. *Int J Epidemiol* 2016;46(3):799-800.
- (22) Song SO, Jung CH, Song YD, Park C, Kwon H, Cha BS, et al. Background and data configuration process of a nationwide population-based study using the Korean national health insurance system. *Diabetes & Metabolism Journal* 2014;38(5):395-403.
- (23) Lee M. An analysis on the concentration characteristics of PM_{2.5} in Seoul, Korea from 2005 to 2012. *Asia-Pacific Journal of Atmospheric Sciences* 2014;50(1):585-594.
- (24) Korea Environment Corporation. Air Korea. 2018; Available at: <http://www.airkorea.or.kr/index>. Accessed 10 Jul 2018, 2018.
- (25) Bell ML, Samet JM, Dominici F. Time-series studies of particulate matter. *Annu Rev Public Health* 2004;25:247-280.
- (26) Bhaskaran K, Gasparrini A, Hajat S, Smeeth L, Armstrong B. Time series regression studies in environmental epidemiology. *Int J Epidemiol* 2013;42(4):1187-1195.
- (27) Zhang J, Liu Y, Cui L, Liu S, Yin X, Li H. Ambient air pollution, smog episodes and mortality in Jinan, China. *Scientific reports* 2017;7(1):11209.
- (28) Vicedo-Cabrera A, Olsson D, Forsberg B. Exposure to seasonal temperatures during the last month of gestation and the risk of preterm birth in Stockholm. *International journal of environmental research and public health* 2015;12(4):3962-3978.
- (29) Xie W, Li G, Zhao D, Xie X, Wei Z, Wang W, et al. Relationship between fine particulate air pollution and ischaemic heart disease morbidity and mortality. *Heart* 2015 Feb;101(4):257-263.
- (30) Dabass A, Talbott EO, Rager JR, Marsh GM, Venkat A, Holguin F, et al. Systemic inflammatory markers associated with cardiovascular disease and acute and chronic exposure to fine particulate matter air pollution (PM_{2.5}) among US NHANES adults with metabolic syndrome. *Environ Res* 2018;161:485-491.
- (31) Kyobutungi C, Grau A, Stieglbauer G, Becher H. Absolute temperature, temperature changes and stroke risk: a case-crossover study. *Eur J Epidemiol* 2005;20(8):693-698.
- (32) Neild PJ, Syndercombe-Court D, Keatinge WR, Donaldson GC, Mattock M, Counce M. Cold-induced increases in erythrocyte count, plasma cholesterol and plasma fibrinogen of elderly people without a comparable rise in protein C or factor X. *Clin Sci (Lond)* 1994 Jan;86(1):43-48.

- (33) Hong J, Kang H. Seasonal variation in case fatality rate in Korean patients with acute myocardial infarction using the 1997-2006 Korean National Health Insurance Claims Database. *Acta Cardiol* 2014;69(5):513-521.
- (34) Ye X, Peng L, Kan H, Wang W, Geng F, Mu Z, et al. Acute effects of particulate air pollution on the incidence of coronary heart disease in Shanghai, China. *PLoS One* 2016;11(3):e0151119.
- (35) Nawrot TS, Torfs R, Fierens F, De Henauw S, Hoet PH, Van Kersschaever G, et al. Stronger associations between daily mortality and fine particulate air pollution in summer than in winter: evidence from a heavily polluted region in western Europe. *J Epidemiol Community Health* 2007 Feb;61(2):146-149.
- (36) Dai L, Zanobetti A, Koutrakis P, Schwartz JD. Associations of fine particulate matter species with mortality in the United States: a multicity time-series analysis. *Environ Health Perspect* 2014 Aug;122(8):837-842.
- (37) Milojevic A, Wilkinson P, Armstrong B, Bhaskaran K, Smeeth L, Hajat S. Short-term effects of air pollution on a range of cardiovascular events in England and Wales: case-crossover analysis of the MINAP database, hospital admissions and mortality. *Heart* 2014 Jul;100(14):1093-1098.
- (38) Dominici F, Peng RD, Bell ML, Pham L, McDermott A, Zeger SL, et al. Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. *JAMA* 2006;295(10):1127-1134.
- (39) World Health Organization. Ambient air pollution: A global assessment of exposure and burden of disease. 2016.
- (40) Song SO, Jung CH, Song YD, Park CY, Kwon HS, Cha BS, et al. Background and data configuration process of a nationwide population-based study using the Korean national health insurance system. *Diabetes Metab J* 2014 Oct;38(5):395-403.

Figures

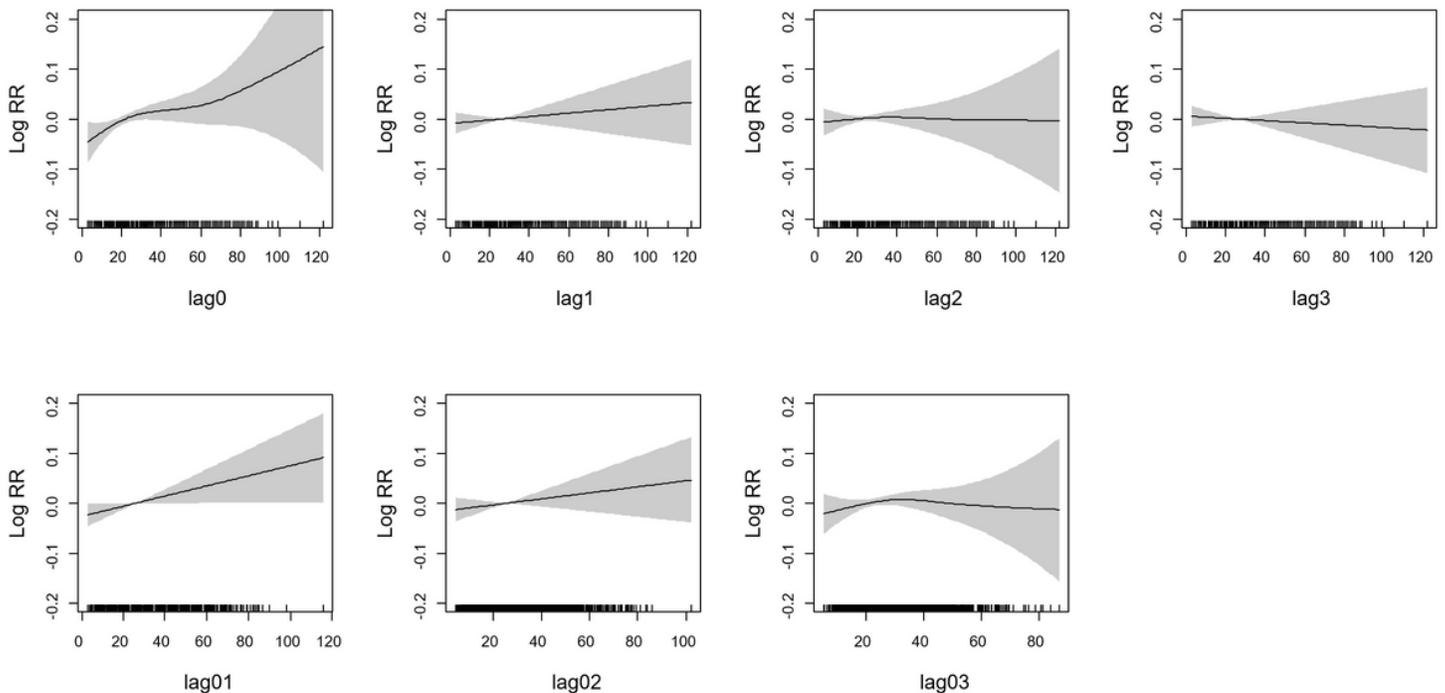


Figure 1

The nonlinear curve for the association between concentration of PM_{2.5} and AMI over lag days. The black line is the log relative risk, and the gray area is the 95% confidence intervals of the risk estimates.

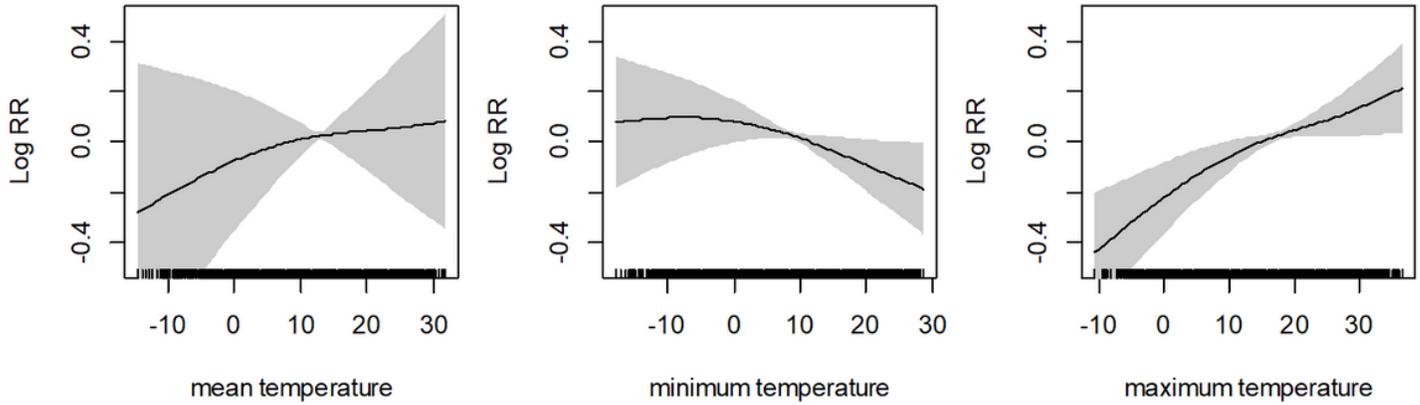


Figure 2

The nonlinear curve for the association between different temperatures and AMI. The black line is the log relative risk, and the gray area is the 95% confidence intervals of the risk estimates.

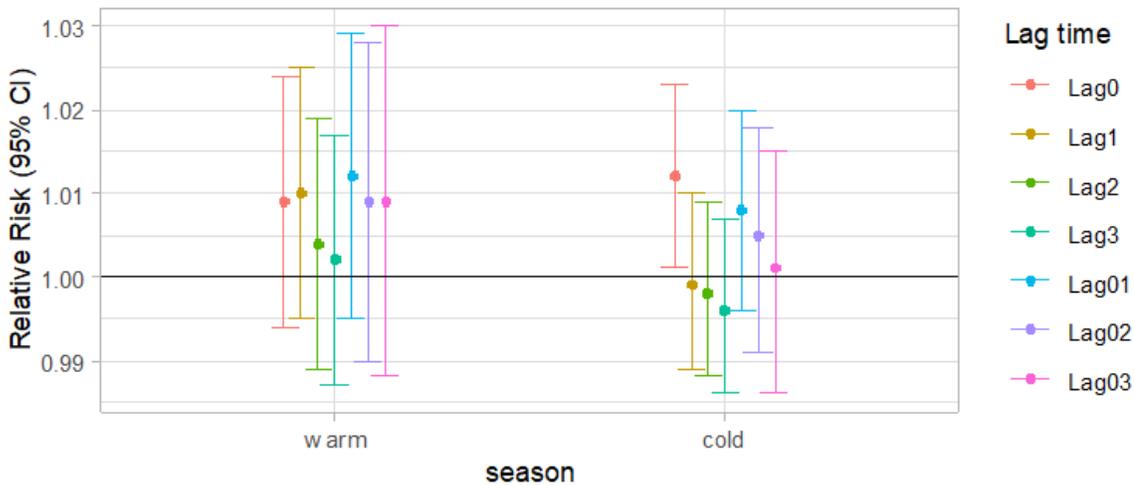


Figure 3

Adjusted relative risk for daily cases of AMI events (95% CI) per 10 $\mu\text{g}/\text{m}^3$ increase in PM2.5a at single-lag (lag 0, lag 1, lag2 and lag3) and cumulative-lag (lag 01, lag 02 and lag 03) models according to the season. Results adjusted for calendar time, daily mean temperature, dew-point temperature, relative humidity and day of week.

Supplementary Files

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