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Long-term air pollution exposure is associated with higher incidence of ST-elevation myocardial infarction and in-hospital cardiogenic shock

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Previous studies have reported the association between myocardial infarction (MI) and air pollution (AP). However, limited information is available regarding the long-term effects of AP on the relative incidence rates of ST-elevation MI (STEMI) and Non-ST-elevation MI (NSTEMI). We investigated the association between long-term exposure to AP and the incidence of STEMI. Between January 2006 and December 2015, a total of 45,619 eligible patients with Acute Myocardial Infarction (AMI) were enrolled in the Korea Acute MI Registry (KAMIR) and KAMIR-National Institutes of Health. Mixed-effect regression models were used to examine the association between the annual average ambient AP before MI onset and the incidence of STEMI, and to evaluate the association of AP with the incidence of in-hospital cardiogenic shock. After mixed-effect regression model analysis, particulate matter (PM) 10 µm or less in diameter (PM₁₀) was associated with increased incidence of STEMI compared with NSTEMI (odds ratio [OR] 1.009, 95% Confidence Interval [CI] 1.002–1.016; $p = 0.012$). For in-hospital cardiogenic shock complication, PM₁₀ and SO₂ were associated with increased risk, PM₁₀ (OR 1.033, 95% CI 1.018–1.050; $p < 0.001$), SO₂ (OR 1.104, 95% CI 1.006–1.212; $p = 0.037$), respectively. Policy-level strategies and clinical efforts to reduce AP exposure are necessary to prevent the incidence of STEMI and severe cardiovascular complications.

Ischemic heart diseases (IHD), including acute myocardial infarction (AMI), constitute a significant global public health burden, being a leading cause of mortality and morbidity worldwide. AMI, in particular, is a major contributor to mortality in the Asia–Pacific region^{1–4}. Patients with coronary artery disease (CAD) may experience complications related to air pollution (AP), such as increased hospitalization, re-admission, and early mortality^{5–7}. Exposure to highly polluted air is one of the environmental factors that triggers AMI⁸. While both short and long-term effects of AP exposure have been investigated, the long-term consequences appear to outweigh the cumulative impact of short-term exposure⁹. Most studies have primarily focused on examining the association between short-term AP exposure and AMI^{8,10,11}. However, only a few studies have reported on long-term AP exposure and compared the relative incidence of ST-elevation myocardial infarction (STEMI) and

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Non-ST-elevation myocardial infarction (NSTEMI). Particularly, the incidence of cardiogenic shock—a critical complication predominantly associated with STEMI—within the context of long-term AP exposure, has not been integrally investigated. Our previous studies demonstrated that AP exposure was associated with overall adverse clinical outcomes, including mortality, in AMI patients, considering both short and long-term exposure durations and follow-up periods^{12,13}. As an extension of our prior findings, this study aims to further investigate the association between long-term average AP concentration and the relative risk of developing STEMI compared to a NSTEMI. Additionally, we aim to clarify the relationship between annual average AP concentration and the occurrence of cardiogenic shock, a complication observed to be more prevalent in STEMI patients.

Methods

Study protocols and population

The study subjects were enrolled in the Korea AMI registry (KAMIR) and KAMIR-National Institutes of Health (NIH). The KAMIR study protocol has been introduced previously¹⁴. KAMIR and KAMIR-NIH are nationwide prospective multicenter registration study series that aim to establish treatment guidelines and derive risk factors through the analysis of various clinical characteristics and follow-up of Korean AMI patients since October 2005 onwards. A flowchart of the study is shown in Fig. 1. A total of 50,130 patients with AMI were enrolled in the KAMIR and KAMIR-NIH between January 2006 and December 2015. The exclusion criteria were as follows: (1) date of symptom onset before 2006, (2) missing date of symptom onset, (3) age < 18 years, and (4) no final diagnosis of myocardial infarction (MI) at discharge.

Ethical approval

This study was approved by the Institutional Review Board (IRB) of Korea University Guro Hospital (KUGH, #2016GR0740) and was conducted in accordance with the principles of the Declaration of Helsinki. Prior to giving written consent to participate, the participants or their legal guardians received a thorough and detailed explanation of the study procedures, both in written and verbal form.

AP measurement

Hourly AP concentrations were provided by the Korean Ministry of Environment (<http://www.airkorea.or.kr>). In 2001, 329 monitoring stations nationwide began measuring the concentration of air pollutants. Measurement of air pollutants involved the β -ray absorption method for particulate matter (PM) 10 μm or less in diameter (PM₁₀), the non-dispersive infrared method for carbon monoxide (CO), the pulse ultraviolet fluorescence method for sulfur dioxide (SO₂), the chemiluminescence method for nitrogen dioxide (NO₂), and the ultraviolet photometric method for ozone (O₃). The concentration measurement of PM 2.5 μm or less in diameter (PM_{2.5}) began in January 2015; therefore, annual average concentration values were not available during the patient enrollment period (2006–2015) and was excluded.

We transformed collected data into the daily average value, and then, the annual average value of air pollutants before the symptom day was calculated the way previous research was performed¹³. Each monitoring station

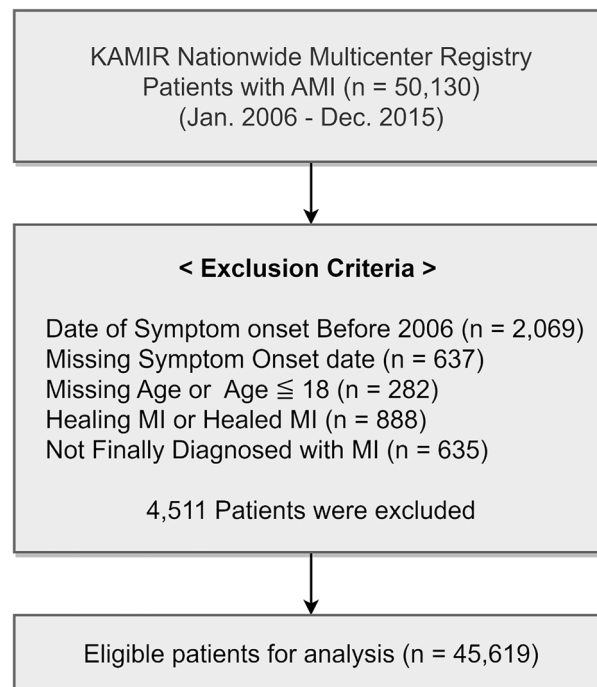


Figure 1. Study flow chart of patient enrollment. AMI = acute myocardial infarction; KAMIR = Korea Acute Myocardial Infarction Registry; MI = myocardial infarction.

was matched by the closest distance in a straight line to 68 hospitals registered in KAMIR to measure individual exposure concentration of air pollutants. Monitoring stations were selected based on hospital admission addresses for the following reasons: (1) Patient addresses were not included in the multicenter registry data. (2) As AMI is an emergency, it is assumed that the patient was admitted to an emergency room close to the workplace and residence at the time of symptom onset. If a pollutant measurement was missed due to a connection error with a monitoring station, the measurement of the next-nearest monitoring station was assigned. Symptom date was defined as the first occurrence of MI-related symptoms such as chest pain or dyspnea.

Study definitions

The diagnosis of AMI was defined as an elevation in cardiac biomarkers (creatinine kinase-MB, and troponin I, or T) with typical changes on 12 leads electrocardiogram (ECG) or clinical symptoms. STEMI was diagnosed as a new ST-elevation segment measuring ≥ 1 mm from ≥ 2 contiguous leads on ECG. Patients with positive cardiac biomarkers but without ECG findings of STEMI were defined as NSTEMI. Cardiogenic shock was defined as a systolic blood pressure < 90 mmHg for > 30 min, the need for supportive management to maintain systolic blood pressure > 90 mmHg, and clinical signs of pulmonary congestion. A complication of cardiogenic shock is defined as its new onset after admission.

Individual cardiovascular risk factors, including hypertension (HTN), dyslipidemia (DL), diabetes mellitus (DM), prior cardiovascular disease, heart failure (HF), prior cerebrovascular disease (CVA), family history of CAD, and smoking history, were based on self reports by the patient.

Statistical analysis

All statistical analyses were performed using R version 4.1.2. (R Core Team, 2021; R: Language and Environment for Statistical Computing; R Foundation for Statistical Computing, Vienna, Austria, URL: <https://www.R-project.org/>).

We compared the clinical and angiographic characteristics using a X^2 test or Fisher's exact test for categorical variables and Student's t-test or Mann–Whitney rank test for continuous variables. In our analysis, X^2 tests were used for categorical variables with expected cell frequencies of five or more; otherwise, Fisher's exact test was applied. Continuous variables were analyzed with Student's t-test if data were normally distributed (assessed by the Kolmogorov–Smirnov test) and with the Mann–Whitney rank test for non-normal distributions. Categorical data were expressed as percentages, and continuous variables were described as mean \pm standard deviation.

We used generalized logistic mixed effect models with a random effect term for hospitals to examine the associations of each air pollutant with the incidence rate of STEMI and cardiogenic shock complication rates, and to account for hospital and regional effects such as accessibility and treatment plans. All variables used in the models for the incidence of STEMI and cardiogenic shock complications are presented in Table 1.

Using a multivariable model, we adjusted for potential confounding factors for STEMI incidence, including age, sex, body mass index (BMI), smoking status, HTN, DM, DL, stroke, HF, previous IHD, and family history of CAD. To analyze the incidence of cardiogenic shock complications, we considered the factors previously mentioned, in addition to STEMI status, percutaneous coronary intervention (PCI), and left ventricular ejection fraction (LVEF).

To assess and mitigate the risk of collinearity, we conducted correlation analyses and variance inflation factor (VIF) assessments among the included air pollutants. The VIF values obtained were below the commonly used threshold of 4, indicating that collinearity was unlikely to significantly impact the results of our regression analyses.

In the subgroup analysis, we conducted several stratified analyses using interaction terms for each specified group. For the STEMI group analysis, we included the following terms respectively: age, sex, HTN, DM, DL, CVA, HF, prior IHD, smoking, family history of CAD. In the cardiogenic shock group, STEMI status, PCI, and LVEF were added. The results were presented as adjusted odds ratios (OR) for logistic regression with corresponding 95% confidence intervals (CI). Statistical significance was defined as a p -value < 0.05 .

Results

A total of 45,619 patients with AMI were enrolled in our study. Of these, 20,526 were patients with NSTEMI and 25,093 were patients with STEMI. In our study population, compared with patients with NSTEMI, patients with STEMI were younger, male, had a higher smoking status, and had fewer underlying chronic diseases, such as DM, HTN, and DL. Moreover, patients with STEMI had more Killip class IV and a low LVEF and those were less likely to have a history of cardiovascular diseases, such as HF, CVA, and previous IHD. Among the angiographic parameters, the STEMI group had more PCI as the initial treatment for MI, lower multivessel coronary artery

| Response variable | Fixed effects | Random effect |
|--|--|---------------|
| $\log\left(\frac{P_{STEMI}}{P_{NSTEMI}}\right)$ | Age, Sex, Body Mass Index, Smoking Status, Hypertension, Diabetes Mellitus, Dyslipidemia, Stroke, Heart Failure, Previous Ischemic Heart Disease, Family History of Coronary Artery Disease, Air Pollutant | Hospital |
| $\log\left(\frac{P_{Cardiogenic\ Shock}}{1 - P_{Cardiogenic\ Shock}}\right)$ | Age, Sex, Body Mass Index, Smoking Status, Hypertension, Diabetes Mellitus, Dyslipidemia, Stroke, Heart Failure, Previous Ischemic Heart Disease, Family History of Coronary Artery Disease, STEMI Status, Percutaneous Coronary Intervention, Left Ventricular Ejection Fraction, Air Pollutant | Hospital |

Table 1. Variables used in mixed-effects logistic regression models.

disease (MVD), and the left main artery as the culprit lesion. The cardiogenic shock complication rate during the index hospitalization was significantly higher in the STEMI group (Table 2).

In Table 3, we observed the median value of annual average concentrations was 0.049 part per million (ppm) for SO₂, 0.6088 ppm for CO, 0.0211 ppm for O₃, 0.0259 ppm for NO₂, and 50.53 µg/m³ for PM₁₀.

| Variables | Total | NSTEMI (n = 20,526) | STEMI (n = 25,093) | P value |
|--|----------------|---------------------|--------------------|---------|
| Age (year) | 63.82 ± 12.77 | 65.10 ± 12.40 | 62.77 ± 12.97 | <0.001 |
| Sex (male) | 32,921 (72.2) | 14,042 (68.4) | 18,879 (75.2) | <0.001 |
| Body mass index (kg/m ²) | 23.98 ± 3.25 | 23.94 ± 3.27 | 24.01 ± 3.23 | 0.036 |
| Systolic blood pressure (mmHg) | 129.69 ± 28.25 | 133.71 ± 27.38 | 126.37 ± 28.53 | <0.001 |
| Diastolic blood pressure (mmHg) | 78.89 ± 16.66 | 80.18 ± 15.87 | 77.82 ± 17.22 | <0.001 |
| Heart rate (bpm) | 78.19 ± 19.90 | 79.70 ± 19.36 | 76.96 ± 20.25 | <0.001 |
| Left ventricular ejection fraction (%) | 51.96 ± 11.86 | 53.51 ± 12.20 | 50.66 ± 11.41 | <0.001 |
| Killip Class 4 | 2389 (5.2) | 552 (2.7) | 1837 (7.3) | <0.001 |
| Hypertension | 22,776 (49.9) | 11,203 (54.6) | 11,573 (46.1) | <0.001 |
| Diabetes mellitus | 12,596 (27.6) | 6418 (31.3) | 6178 (24.6) | <0.001 |
| Dyslipidemia | 5082 (11.1) | 2571 (12.5) | 2511 (10.0) | <0.001 |
| Cerebrovascular disease | 3030 (6.6) | 1659 (8.1) | 1371 (5.5) | <0.001 |
| Heart failure | 842 (1.8) | 582 (2.8) | 260 (1.0) | <0.001 |
| Smoking history | 26,337 (57.7) | 11,077 (54.0) | 15,260 (60.8) | <0.001 |
| Current smoker | 18,853 (41.3) | 7276 (35.4) | 11,577 (46.1) | <0.001 |
| Family history of heart disease | 3285 (7.2) | 1501 (7.3) | 1784 (7.1) | 0.404 |
| Previous ischemic heart disease | 7027 (15.4) | 4150 (20.2) | 2877 (11.5) | <0.001 |
| Previous PCI | 3346 (7.3) | 1968 (9.6) | 1378 (5.5) | <0.001 |
| Previous MI | 2164 (4.7) | 1265 (6.2) | 899 (3.6) | <0.001 |
| Previous CABG | 371 (0.8) | 268 (1.3) | 103 (0.4) | <0.001 |
| Previous angina | 2793 (6.1) | 1733 (8.4) | 1060 (4.2) | <0.001 |
| Initial treatment of MI | | | | |
| Thrombolysis | 990 (2.2) | 0 (0.0) | 990 (3.9) | <0.001 |
| CABG | 933 (2.0) | 556 (2.7) | 377 (1.5) | <0.001 |
| PCI | 39,847 (87.3) | 16,329 (79.6) | 23,518 (93.7) | <0.001 |
| Multi-vessel disease | 21,542 (47.2) | 9942 (48.4) | 11,600 (46.2) | <0.001 |
| Left main disease | 1661 (3.6) | 957 (4.7) | 704 (2.8) | <0.001 |
| Infarct-related artery | | | | |
| Left main | 886 (1.9) | 522 (2.5) | 364 (1.5) | <0.001 |
| Left anterior descending artery | 18,963 (41.6) | 6987 (34.0) | 11,976 (47.7) | <0.001 |
| Left circumflex artery | 6849 (15.0) | 4596 (22.4) | 2253 (9.0) | <0.001 |
| Right coronary artery | 13,489 (29.6) | 4719 (23.0) | 8770 (34.9) | <0.001 |
| Cardiogenic Shock Complications | 2317 (5.1) | 554 (2.7) | 1763 (7.0) | <0.001 |

Table 2. Baseline characteristics. Data is expressed as number (percentage), mean ± standard deviation. CABG = coronary artery bypass grafting, NSTEMI = non-ST-elevation myocardial infarction, PCI = percutaneous coronary intervention, MI = myocardial infarction, STEMI = ST-elevation myocardial infarction.

| | SO ₂ (ppm) | CO (ppm) | O ₃ (ppm) | NO ₂ (ppm) | PM ₁₀ (µg/m ³) |
|--------|-----------------------|----------|----------------------|-----------------------|---------------------------------------|
| Min | 0.0014 | 0.2028 | 0.0037 | 0.0070 | 18.25 |
| Q1 | 0.0041 | 0.5312 | 0.0176 | 0.0218 | 44.65 |
| Median | 0.0049 | 0.6088 | 0.0211 | 0.0259 | 50.53 |
| Q3 | 0.0061 | 0.7211 | 0.0244 | 0.0342 | 58.67 |
| Max | 0.0136 | 1.4976 | 0.0437 | 0.0812 | 99.14 |
| IQR | 0.0020 | 0.1899 | 0.0068 | 0.0124 | 14.02 |
| Mean | 0.0053 | 0.6276 | 0.0210 | 0.0284 | 52.57 |

Table 3. Distribution for annual average air pollution concentration before symptom date. CO = carbon monoxide, IQR = interquartile range, NO₂ = nitrogen dioxide, O₃ = ozone, PM₁₀ = particulate matter 10 µm or less in diameter, ppm = part per million, Q1 = 1st quintile, Q3 = 3rd quintile, SO₂ = sulfur dioxide.

In the Spearman rank correlation analysis using the average annual concentrations after the symptom date, most air pollutants showed a positive correlation ($r = 0.178$ – 0.467); however, O_3 and other air pollutants, showed a negative correlation ($r = -0.265$ to -0.609 ; Fig. 2).

After mixed-effect regression model analysis, no difference was observed for most air pollutants except PM_{10} , which was associated with increased incidence of STEMI compared with NSTEMI for each $1 \mu\text{g}/\text{m}^3$ increase (OR 1.009, 95% CI 1.002–1.016; $p = 0.012$; Table 4). For in-hospital cardiogenic shock complication, each $1 \mu\text{g}/\text{m}^3$ increase of PM_{10} and each 1 part per billion (ppb) increase of SO_2 were associated with increased risk: PM_{10} (OR 1.033, 95% CI 1.018–1.050; $p < 0.001$), SO_2 (OR 1.104, 95% CI 1.006–1.212; $p = 0.037$), respectively. In contrast, for each 1 ppb increase in O_3 was negatively correlated with cardiogenic shock (OR 0.891; 95% CI 0.857–0.928; $p < 0.001$; Table 5).

When STEMI and each air pollutant were analyzed in subgroups, the results showed there was a significant association with a decrease in STEMI incidence for every 1 ppb increase of NO_2 in CVA patients. In the absence of HTN, there was an increase in STEMI incidence for every $1 \mu\text{g}/\text{m}^3$ increase PM_{10} (Supplementary Figs. 1–5). In subgroup analyses used to evaluate the risk of cardiogenic shock with AP exposure, it is shown that there was a significant association between increasing cardiogenic shock complication rate and for each 1 ppb increase of NO_2 in patients with no history of PCI, for each $1 \mu\text{g}/\text{m}^3$ increase of PM_{10} in patients with prior IHD or without PCI treatment, and for each 1 ppb increase in SO_2 with HF patients or prior IHD (Supplementary Figs. 6–10).

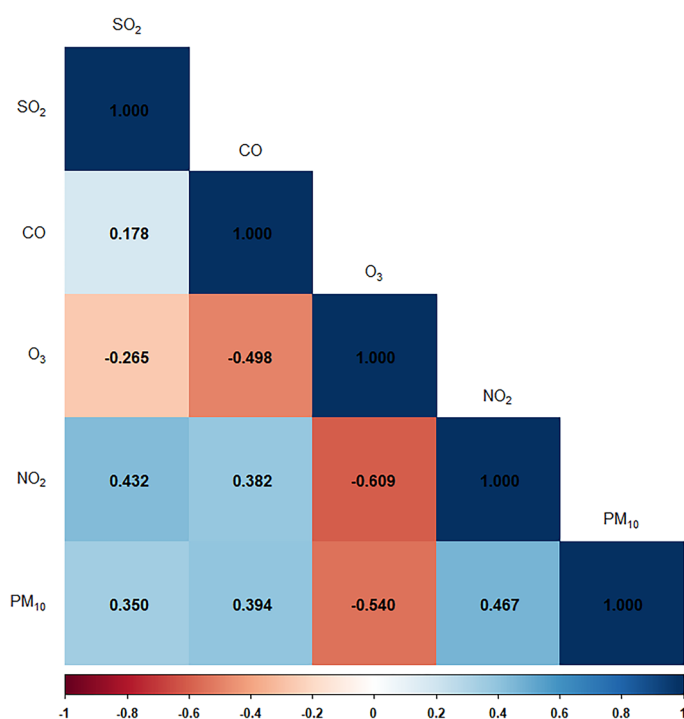


Figure 2. Spearman correlation coefficients for annual average concentrations of air pollutants. CO = carbon monoxide; NO_2 = nitrogen dioxide; PM_{10} = particulate matter 10 μm or less in diameter.

| | Univariate | | Multivariate | |
|--|---------------------|---------|---------------------|---------|
| | OR (95% CI) | P value | OR (95% CI) | P value |
| SO_2 (ppb) | 1.044 (0.998–1.093) | 0.060 | 1.041 (0.995–1.089) | 0.084 |
| CO (ppm) | 1.037 (0.978–1.100) | 0.225 | 1.036 (0.977–1.099) | 0.236 |
| O_3 (ppb) | 0.990 (0.972–1.009) | 0.293 | 0.989 (0.971–1.007) | 0.239 |
| NO_2 (ppb) | 1.000 (0.987–1.012) | 0.943 | 0.999 (0.987–1.012) | 0.914 |
| PM_{10} ($\mu\text{g}/\text{m}^3$) | 1.008 (1.001–1.014) | 0.027 | 1.009 (1.002–1.016) | 0.012 |

Table 4. Univariate and multivariate regression analysis of the incidence of STEMI compared with NSTEMI regarding annual average concentration of each air pollutant before symptom date. Adjusted for Age, body mass index, diabetes mellitus, dyslipidemia, heart failure, hypertension, previous ischemic heart disease, sex, smoking status, stroke, and family history of CAD. CI = confidence interval, CO = carbon monoxide, NO_2 = nitrogen dioxide, O_3 = ozone, OR = odds ratio, PM_{10} = particulate matter 10 μm or less in diameter, ppb = part per billion, ppm = part per million, SO_2 = sulfur dioxide.

| | Univariate | | Multivariate | |
|---------------------------------------|---------------------|---------|---------------------|---------|
| | OR (95% CI) | P value | OR (95% CI) | P value |
| SO ₂ (ppb) | 1.122 (1.021–1.234) | 0.017 | 1.104 (1.006–1.212) | 0.037 |
| CO (ppm) | 1.090 (0.960–1.238) | 0.182 | 1.076 (0.949–1.219) | 0.254 |
| O ₃ (ppb) | 0.889 (0.853–0.926) | <0.001 | 0.891 (0.857–0.928) | <0.001 |
| NO ₂ (ppb) | 1.013 (0.985–1.041) | 0.365 | 1.015 (0.988–1.042) | 0.269 |
| PM ₁₀ (µg/m ³) | 1.036 (1.019–1.053) | <0.001 | 1.033 (1.018–1.050) | <0.001 |

Table 5. Univariate and multivariate regression analysis between the incidence of cardiogenic shock events and the annual average concentration of each air pollutant before the symptom date of myocardial infarction. Adjusted for age, body mass index, diabetes mellitus, dyslipidemia, heart failure, hypertension, left ventricular ejection fraction, percutaneous coronary intervention, previous ischemic heart disease, sex, smoking status, STEMI status, stroke, and family history of CAD. CI = confidence interval, CO = carbon monoxide, NO₂ = nitrogen dioxide, O₃ = ozone, OR = odds ratio, PM₁₀ = particulate matter 10 µm or less in diameter, ppb = part per billion, ppm = part per million, SO₂ = sulfur dioxide.

Discussion

In the population of AMI patients, we performed a large registry-based analysis to evaluate the association between long-term exposure to AP. In this study, using a nationwide prospective clinical registry, we found associations between elevated levels of AP and a higher incidence of STEMI relative to NSTEMI. Additionally, our findings suggest an association between increased AP concentrations and a heightened incidence of cardiogenic shock complications, which have been linked to increased overall mortality. The results of this study showed that long-term exposure to high levels of PM₁₀ is associated with an increased risk of STEMI. Moreover, this study demonstrates that PM₁₀ and SO₂ may impact on the development of cardiogenic shock complication in patients with AMI.

Air pollutants comprise complex mixtures that are compounded with gases, including SO₂, NO₂, CO, O₃, and PM, including PM₁₀ and PM_{2.5}¹⁵. Although it may intuitively seem that AP poses a health risk mostly in the form of respiratory disease, many epidemiological and clinical studies have suggested that the majority of the adverse effects of AP are associated with the cardiovascular system^{16–18}. Previous studies demonstrated that AP exposure is associated with endothelial injury and inflammation, indicating that it can trigger cardiovascular events^{19–21}. Moreover, recent study demonstrated that air pollution may induce plaque rupture and is associated with macrophage infiltrates in coronary plaques and it is well reported that plaque rupture portends a worse prognosis in MI patients²². By integrating these insights with the concept of the exposome—defined as the totality of environmental exposures—this discussion broadens to highlight the need to assess the cumulative impact of such exposures, particularly key inflammation drivers like air pollution, on cardiovascular risk and outcomes²³.

Regarding the association between AP and CVD, many studies have demonstrated that short-term exposure to AP increases the incidence of an acute coronary syndrome (ACS)^{24–26}. In contrast, the present study investigated the effects of long-term exposure to AP, which was the major novelty of our research. The number of studies on the long-term effects of AP exposure are increasing. The ESCAPE (European Study of Cohorts for Air Pollution Effects) study, the increase in PM₁₀ and PM_{2.5} during the long-term follow-up period increases the risk of ACS²⁷. However, these studies mainly focus on mortality or overall clinical outcome^{17,27–29}. Researchers have rarely compared the risk of developing STEMI with that of NSTEMI. To the best of our knowledge, this is the first study to demonstrate a long-term association between AP exposure and the relative incidence of STEMI compared with that of NSTEMI in the Asia-Pacific region.

Our present study was shown that the risk of developing STEMI increased compared to NSTEMI according to the 1-year average PM₁₀ concentration before symptom onset. These results indicate that STEMI contributes more than NSTEMI to an increased risk of MI according to the AP concentration. Studies on short-term exposure have reported that elevated AP exposure highly triggers the development of STEMI compared with that of NSTEMI^{30,31}. However, some studies have also reported greater incidence of NSTEMI than that of STEMI due to AP exposure³². The inconsistent results can be attributed to differences in exposure periods, geographic location, pollutant concentration level, study population, and statistical methods used for analysis^{8,10}.

In addition, this study is meaningful in that we clarified the effect of AP exposure on the risk of severe complications of cardiogenic shock. Our main findings showed that an increased AP concentration was associated with an increase incidence of cardiogenic shock complication. Cardiogenic shock occurs in approximately 5–13% of AMI patients³³. Moreover, AMI itself was an important etiology contributing to 80% incidences of cardiogenic shock³⁴. Cardiogenic shock is associated with poor prognosis for high rate of adverse events even with appropriate treatment, with an in-hospital mortality of 20–40% and a 1-year mortality rate of up to 50%³³.

Although the pathophysiology of cardiogenic shock is not fully understood, it is known that the systemic inflammatory response, release of inflammatory cytokines, and increase in the concentration of nitric oxide (NO) are involved in inappropriate vasodilation after peripheral vascular constriction to compensate for the reduction in myocardial contractility^{35,36}. Exposure to AP is related to oxidative stress and systemic inflammation^{14,16–18} and it adversely affects vascular homeostasis through the production of superoxide and the uncoupling of NO synthase³⁷. These results add evidence for the development of cardiogenic shock and its subsequent poor prognosis.

In our previously published study, the 1-year average AP concentration before the onset of symptoms was associated with an increase in 30-day short-term mortality¹³. Studies using the same registry reported that STEMI patients exhibited not only higher short-term mortality but also an elevated incidence of cardiogenic shock compared to NSTEMI patients³⁸. These results underline the critical need for a consolidated approach in research to further understand the mechanisms linking AP exposure, the differential impact on STEMI versus NSTEMI, and the subsequent risk of cardiogenic shock and cardiac death³³.

This study strongly suggests that reducing exposure to high concentrations of AP is crucial for reducing the occurrence of potential MI and mortality. This holds true not only for the high-risk group but also for the low-risk group of AMI. It is necessary to reduce the occurrence of potential MI and mortality, even if STEMI appears to be relatively safe because of its younger age and lower co-morbidity rates than NSTEMI (Table 1). These efforts should be accompanied by policy strategies and clinical practice.

This study has several limitations. First, because of the limited sampling data available for PM_{2.5}, the associations with clinical events may have been relatively low. PM_{2.5} data was only available for 2015, the final year of our study period, limiting longitudinal analysis. Evidence suggests that PM size is related to cardiovascular morbidity and mortality^{29,38,39}. Further studies with new data are needed to evaluate the impact of PM_{2.5} in AMI patients in the future with our KAMIR data with later than 2015 registry database. Second, because the patients' addresses were not available, the direct exposure level determined for the patients could be incorrect. It was assumed that patients were admitted to a nearby emergency room at the time of symptom onset. However, some patients who visited other local hospitals or were transferred may have been misclassified, requiring careful interpretation of the results. Third, because of the limitations of the study design, although confounding factors were adjusted for, the results for residential addresses and socioeconomic variables should be carefully considered. We aimed to assess adjusted adequate variables which could be potentially relevant factors using a multivariable model. Finally, although data used in this research were collected by the attending hospitals well-trained, multicenter registry is need to interpret with consideration for several characteristics such as a gap among each hospitals and data such as input errors and misclassification.

In conclusion, We observed that high concentration of air pollutants, particularly of PM₁₀, which is an environmental risk factor was associated with an increased incidence of STEMI. Moreover, PM₁₀ and SO₂ levels were risk factors for in-hospital cardiogenic shock complication after MI. This study emphasizes on the need of developing a policy-level strategy and clinical efforts to reduce AP exposure and prevent the incidence of STEMI and severe cardiovascular complications.

Data availability

Data and materials cannot be shared publicly because of the KAMIR group policy. Data are available from the Chonnam National University Hospital Institutional Data Access/Ethics Committee (contact via research manager) for researchers who meet the criteria for access to confidential data.

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Author contributions

J.C. analyzed the results and was a major contributor in writing the manuscript. S.Y.C. analyzed and interpreted the patient data regarding myocardial infarction with air pollution. S.-W.R. provided advice throughout the study and assisted in the design of the methodology. BGC provided expertise on the KAMIR-NIH dataset. J.K.B. provided advice throughout the study and redacted parts of the background section. S.H. provided advice throughout the study and redacted parts of the materials section. M.W.L. provided expertise on the air pollution data and revised the manuscript. J.K. and W.C. collected and analyzed the datasets. S.P., E.J.P., and D.O.K. provided advice throughout the study and revised the manuscript. C.U.C. provided advice throughout the study and revised the manuscript. S.W.K. analyzed the data and developed figures. M.H.J. provided advice throughout the study and administered the KAMIR project. All authors reviewed the manuscript.

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Competing interests

The authors declare no competing interests.

Additional information

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