



Effects of particulate matter on respiratory disease and the impact of meteorological factors in Busan, Korea



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ABSTRACT

Background: Both air pollution and weather impact hospitalization for respiratory diseases. However, few studies have investigated the contribution of weather to hospitalization related to the adverse effects of air pollution. This study analyzed the effects of particulate matter (PM) on daily respiratory-related hospital admissions, taking into account meteorological factors.

Methods: Daily hospital admissions for respiratory diseases (acute bronchitis, allergic rhinitis, and asthma) between 2007 and 2010 were extracted from the National Health Insurance Corporation, Korea. Patients were divided into three age-based groups (0–15, 16–64, and ≥65 years). PM levels were obtained from 19 monitoring stations in Busan.

Results: The mean number of patients admitted for acute bronchitis, allergic rhinitis, and asthma was 5.8 ± 11.9 , 4.4 ± 6.1 , and 3.3 ± 3.3 , respectively. During that time, the daily mean PM₁₀ and PM_{2.5} concentrations were 49.6 ± 20.5 and $24.2 \pm 10.9 \mu\text{g}/\text{m}^3$, respectively. The mean temperature anomaly was $7.0 \pm 2.3^\circ\text{C}$; the relative humidity was $62.0 \pm 18.0\%$. Hospital admission rates for respiratory diseases increased with increasing PM and temperature, and with decreasing relative humidity. A multivariate analysis including PM, temperature anomaly, relative humidity, and age showed a significant increase in respiratory-related admissions with increasing PM levels and a decreasing relative humidity. Higher PM_{2.5} levels had a greater effect on respiratory-related hospital admission than did PM₁₀ levels. Children and the elderly were the most susceptible to hospital admission for respiratory disease.

Conclusions: PM levels and meteorological factors impacted hospitalization for respiratory diseases, especially in children and the elderly. The effect of PM on respiratory diseases increased as the relative humidity decreased.

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Abbreviations: PM, particulate matter; COPD, chronic obstructive pulmonary disease; PM₁₀, particulate matter with aerodynamic diameters <10 μm; PM_{2.5}, particulate matter with aerodynamic diameters <2.5 μm; SD, standard deviation; IRR, incidence rate ratio.

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1. Introduction

Air pollution is increasing as urbanization and industrialization processes expand worldwide. The adverse effects of air pollution on health, especially that of the cardiovascular and respiratory systems, have been confirmed in several studies [1–3]. In children, air pollution increases the prevalence and incidence of asthma [4–6]; in all age groups, it is associated with acute exacerbations of asthma, bronchitis, chronic obstructive pulmonary disease (COPD), and hospital admissions for respiratory diseases [7–10].

Climate factors can also affect the development and severity of respiratory diseases. Both hyperthermia and hypothermia have been linked to respiratory morbidity and mortality, and relative humidity have been related to aggravation of respiratory diseases [11–14]. Relative humidity is thought to reduce the number of total suspended particulates contained in air [15]. Particulate matter (PM), a major component of air pollution, consists of a mixture of solid and liquid particles suspended in air [16,17]. Among the major sources of PM release are traffic, industry, biomass burning, and long-range transport. However, whether the effects of PM on health vary in response to climate has not been investigated, except in a few recent studies [13,18,19].

Busan is the second largest city in the Republic of Korea. Its high concentration of PM is due to automobile exhaust and the presence of mid-to small-level industries, such as chemical and shipbuilding industries, and to its active ports [20]. Because the southern end of Busan meets the sea and the northern end is surrounded by mountains, the city's weather is relatively warm and humid. In this Busan-based study we investigated the effect of PM on hospital admission rates for respiratory diseases and asked whether they varied depending on meteorological factors.

2. Materials and methods

2.1. Hospital admissions for respiratory disease

Data on daily hospital admissions for respiratory diseases in Busan were extracted from the National Health Insurance Corporation, Republic of Korea, for the period 2007–2010. The data included the admission date, diagnostic code (International Classification of Diseases, ICD-10) of each admission, and the age and sex of the patient. Respiratory diseases analyzed in this study were acute laryngotracheobronchitis (J05), influenza (J10–J11), pneumonia (J18), acute bronchitis (J20–J21), allergic rhinitis (J30), chronic bronchitis (J40–J42), chronic obstructive pulmonary disease (COPD, J44), asthma (J45–J46), and hypersensitivity pneumonitis (J67). Patients were categorized in three age-based groups, I (0–15 years), II (16–64 years), and III (≥ 65 years), to assess the relative frequency of respiratory diseases with respect to age. Hospital admission rates were calculated as:

$$\text{Rate}_{(c,d)} = \frac{\text{Hospitalization}_{(c,d)} \times 1,000,000}{\text{Freq}_{(c,d)} \times \text{POP}_d}$$

where hospitalization_(c,d) is the number of patients with respiratory disease by age group, Freq_(c,d) is the frequency of hospital admission by age group, and POP_d is the size of the population in Busan.

This study was approved by the Institutional Review Board of Pusan National University Hospital (H-1508-007-033).

2.2. Air pollution and meteorological data

Hourly levels of PM with aerodynamic diameters $<10 \mu\text{m}$ (PM₁₀) and $<2.5 \mu\text{m}$ (PM_{2.5}) were obtained from 19 monitoring stations in Busan (Fig. 1). The data were collected and made available by the Korean Ministry of Environment. Meteorological observation data were provided by the Korean Meteorological Administration and included temperature and relative humidity.

2.3. Statistical analysis

Descriptive data are presented as the means $\pm$ standard deviation (SD), minimum, lower quartile, median, upper quartile, and maximum. The relative risk of hospitalization was estimated using

Poisson regression analysis, which is appropriate for analyzing rare events in subjects followed for variable lengths of time. Hospitalization for respiratory diseases as a function of PM₁₀ and PM_{2.5} levels, temperature anomalies, and relative humidity were estimated adjusting for age. PM-specific incidence rates were then adjusted for the covariates temperature anomaly, relative humidity, and age. The regression results are presented as the incidence rate ratio (IRR) and the 95% confidence interval. *P* values < 0.05 were considered to indicate statistical significance.

3. Results

3.1. Daily hospital admissions for respiratory diseases as a function of air pollution

Daily hospital admissions for respiratory diseases, air pollution levels, and weather variables in Busan for the period 2007–2010 are presented in Table 1. The mean daily admission for respiratory diseases was 58.3 ± 36.2 patients. Because acute bronchitis, allergic rhinitis, and asthma accounted for the majority of the underlying diseases, they were the focus of this study.

The mean daily hospital admission rates for acute bronchitis, allergy rhinitis, and asthma were 5.8 ± 11.9 , 4.4 ± 6.1 , and 3.3 ± 3.3 patients, respectively. During the study period, air quality, as measured by the mean PM₁₀ and PM_{2.5} levels, were normal (as defined by the daily exposure limits set by the World Health Organization: $50 \mu\text{g}/\text{m}^3$ and $25 \mu\text{g}/\text{m}^3$ for PM₁₀ and PM_{2.5}, respectively), with a daily mean of $49.6 \pm 20.5 \mu\text{g}/\text{m}^3$ and $24.2 \pm 10.9 \mu\text{g}/\text{m}^3$, respectively. The mean temperature was $15.1 \pm 4.9^\circ\text{C}$ (range: -4.3 – 30.1°C), the mean temperature anomaly was $7.0 \pm 2^\circ\text{C}$ (range: 1.0 – 13.6°C), and the mean relative humidity was $62.0 \pm 18.0\%$ (range: 16.5 – 97.3%).

The number of patients admitted with respiratory disease and PM level showed a seasonal variation, with a maximum in spring (Fig. 2). Therefore, we used the temperature anomaly rather than the mean temperature to assess the effects of air pollution, to avoid a potential confounding effect of mean temperature on the effects of air pollution. Respiratory-related admissions showed an increasing trend as the PM₁₀, PM_{2.5}, and temperature anomaly increased and the relative humidity decreased (Figs. 3 and 4). Admission rates were higher in groups I and group III than in group II (Fig. 4).

3.2. Age-adjusted daily hospital admission rates for respiratory diseases according to air pollution and weather factors

The age-adjusted IRR for respiratory-related admissions was significantly associated with increases in PM₁₀, PM_{2.5}, and temperature anomaly and with a decrease in relative humidity (Table 2). An increase in the PM₁₀ or PM_{2.5} of $10 \mu\text{g}/\text{m}^3$ corresponded to an increase in the total respiratory-related hospital admission rate of 6% and 12%, respectively. A higher temperature anomaly or a lower relative humidity increased hospital admissions for all three respiratory diseases examined in this study (Table 2).

3.3. The effect of air pollution on hospital admission for respiratory diseases with respect to meteorological factors

Weather was previously shown to impact hospital admissions for respiratory diseases [13], and the same was demonstrated in this study. Since weather may alter the impact of air pollution, we analyzed the relationship between these two factors. Table 3 shows the adjusted IRR for PM₁₀ and relative humidity. An analysis adjusting for the effects of temperature anomaly, relative humidity, and age group showed that PM₁₀ levels greatly affected hospital

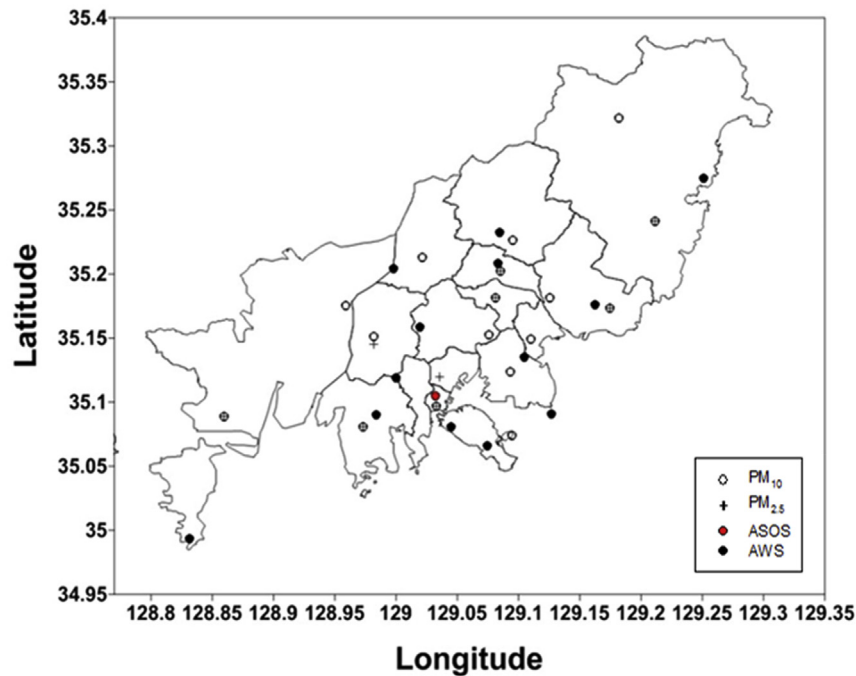


Fig. 1. Locations of meteorological observation sites and air-quality monitoring stations in Busan. Abbreviations: PM₁₀, particulate matter with aerodynamic diameters <10 μm ; PM_{2.5}, particulate matter with aerodynamic diameters <2.5 μm ; ASOS, Automated Synoptic Observing System; AWS, Automated Weather Station.

Table 1

Summary of daily hospital admissions for respiratory diseases, air pollution, and weather variables in Busan.

Variable	Mean $\pm$ SD	Min	Percentile			Max
			25th	Median	75th	
Daily admissions for respiratory diseases (N/day)						
Total respiratory admissions	58.3 $\pm$ 36.2	0.0	37.0	59.0	77.0	394.0
Acute bronchitis (J20-21)	5.8 $\pm$ 11.9	0.0	1.0	3.0	5.0	157.0
Allergic rhinitis (J30)	4.4 $\pm$ 6.1	0.0	1.0	3.0	5.0	79.0
Asthma (J45-46)	3.3 $\pm$ 3.3	0.0	1.0	3.0	5.0	47.0
Air pollution and weather						
PM ₁₀ (μg/m ³)	49.6 $\pm$ 20.5	13.0	34.5	44.5	60.7	122.0
PM _{2.5} (μg/m ³)	24.2 $\pm$ 10.9	4.5	15.7	22.0	30.8	55.0
Tavg (°C)	15.1 $\pm$ 7.9	-4.3	8.7	15.9	21.9	30.1
Tmax (°C)	19.1 $\pm$ 7.6	-0.3	12.9	19.7	25.4	34.1
Tmin (°C)	12.1 $\pm$ 8.5	-8.1	5.3	12.7	19.6	27.3
ΔT (°C)	7.0 $\pm$ 2.3	1.0	5.5	7.0	8.5	13.6
Relative humidity (%)	62.0 $\pm$ 18.0	16.5	47.6	64.4	76.8	97.3

Abbreviations: PM₁₀, particulate matter with aerodynamic diameters < 10 μm ; PM_{2.5}, particulate matter with aerodynamic diameters < 2.5 μm ; Tavg, mean temperature; Tmax, maximum temperature; Tmin, minimum temperature; Δ , T, temperature anomaly (Tmax–Tmin).

admissions for acute bronchitis, allergic rhinitis, and asthma, as did a lower relative humidity (Table 3). Similar results were obtained for PM_{2.5} (Table 4). Thus, an increase in the PM_{2.5} level by 10 $\mu\text{g}/\text{m}^3$ increased admission rates for acute bronchitis, allergic rhinitis, and asthma increased by 25%, 14%, and 1%, respectively (Table 4). In addition, a higher PM and a lower relative humidity together aggravated the effects of PM on respiratory-related hospital admissions.

In the PM-specific analysis, asthma admission rates were strongly associated with an increase in PM_{2.5}, when PM₁₀ levels, temperature anomaly, and relative humidity were held constant (Table 5). Thus, the effect of PM_{2.5} on respiratory disease aggravation was stronger than that of PM₁₀.

3.4. Age-related susceptibility to air pollution and weather variables

Adjusting the IRR for air pollution, weather, and age group (Table 6) showed that total hospital admission rates for respiratory diseases were highest in elderly patients (group III), whereas the relative risk of the three respiratory diseases was highest in children (group I), followed by the elderly (group III). Thus, children and the elderly were more susceptible to the effects of PM concentration and weather.

4. Discussion

Our study showed increases in respiratory-related hospital admission rates with increasing PM and temperature anomaly as well as with a decreasing relative humidity. We found that, taking into account both the effect of PM and meteorological factors, with a decreasing relative humidity, higher PM values had a greater impact on hospitalization rates. PM_{2.5} levels had an especially strong effect on increasing admission rates, regardless of the PM₁₀. Children and the elderly were found to be particularly susceptible to the effects of the PM concentration.

The relationship between PM levels and respiratory effects has been the focus of several studies. Meszaros et al. reported a significant association between daily PM₁₀ concentrations and hospital admissions for acute bronchitis and bronchiolitis, but not for acute exacerbations of asthma and COPD [19]. However, other studies have demonstrated the adverse effect of PM₁₀ levels on asthma as well as COPD. According to Weinmayr et al., an increase in the PM₁₀ of 10 $\mu\text{g}/\text{m}^3$ resulted in a 4% increase in asthma symptoms [21]. A meta-analysis showed that a 10 $\mu\text{g}/\text{m}^3$ increase in PM₁₀ resulted in a 1.47% increase in hospital admissions for COPD [22]. Even healthy individuals were shown to have a significant reduction in lung function after exposure to high PM_{2.5} levels [23], in accordance with another study in which a high PM_{2.5} was associated with a higher risk of incident asthma [24]. Similar results

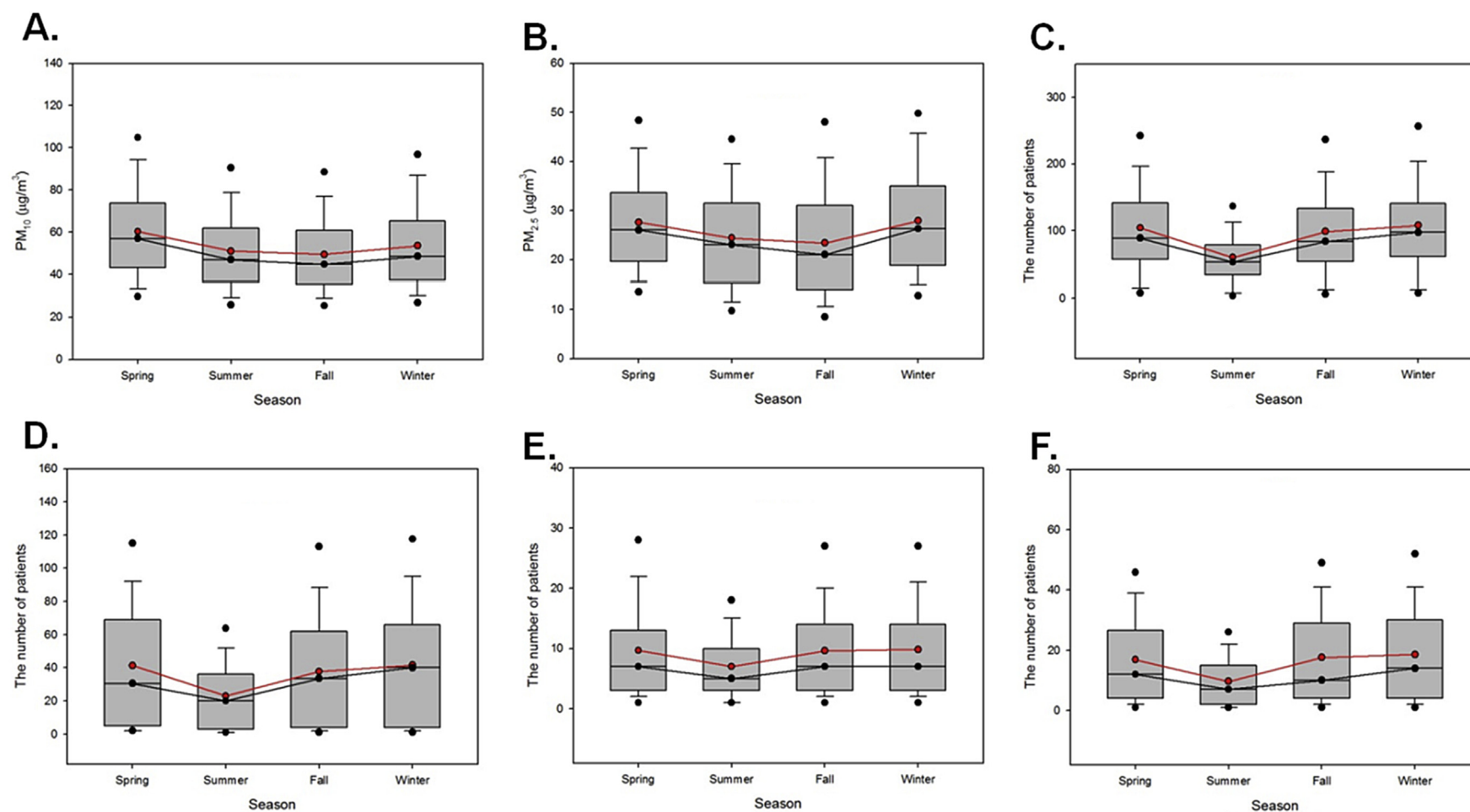


Fig. 2. Seasonal variations in particulate matter (PM) and the number of patients with respiratory disease in Busan. (A) PM_{10} concentration, (B) $PM_{2.5}$ concentration, and (C–F) number of patients admitted with (C) all respiratory diseases, (D) acute bronchitis, (E) allergic rhinitis, and (F) asthma. The box indicates the lower and upper quartiles; the red points show the mean value; the central line and black points, the median value; and the points at the ends of the whisker, the upper and lower extreme values. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

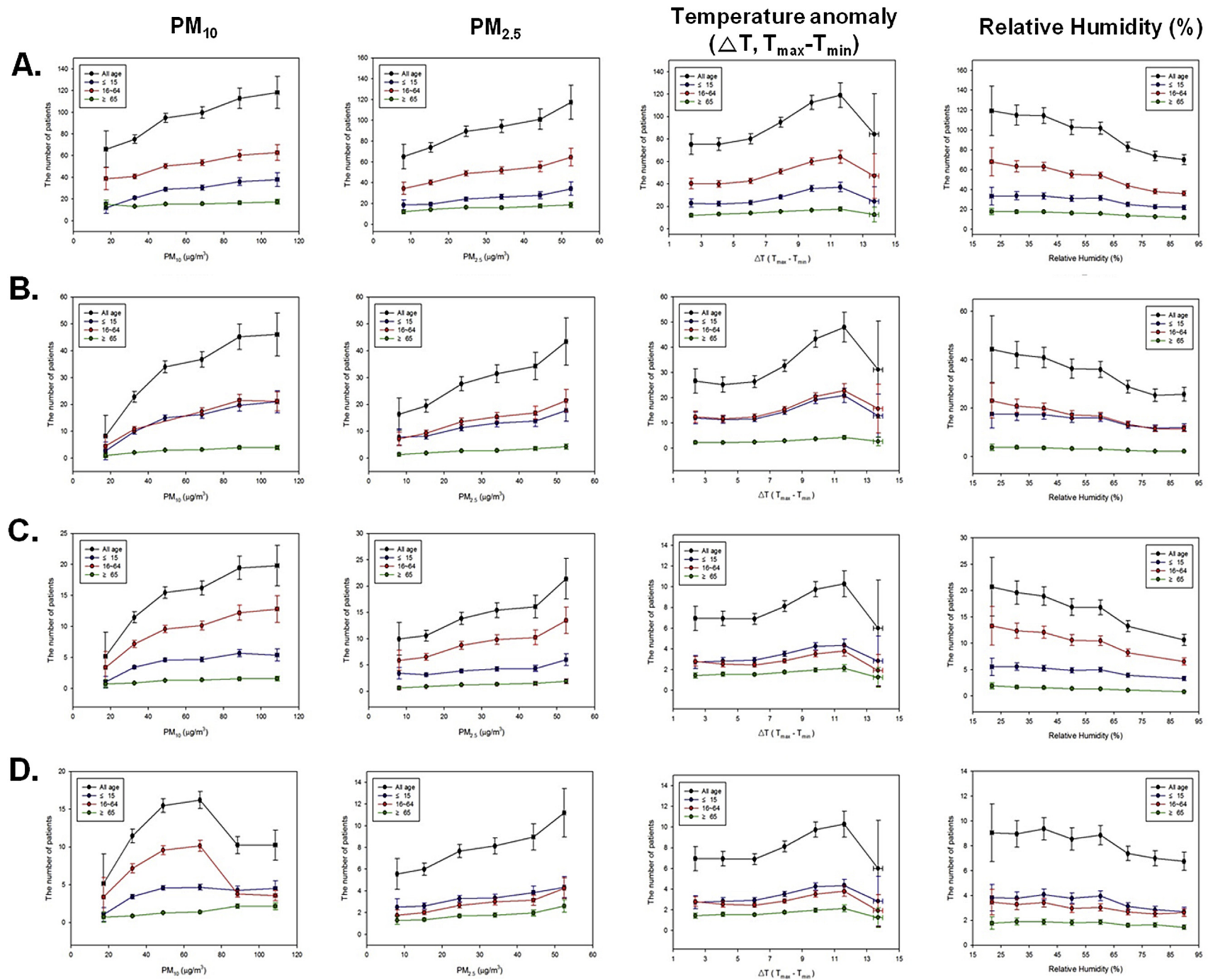


Fig. 3. Bidirectional error bars of the daily mean of the number of patients with respiratory diseases with respect to PM₁₀ concentration, PM_{2.5} concentration, daily temperature anomaly, and relative humidity. (A) Total respiratory diseases, (B) acute bronchitis, (C) allergic rhinitis, and (D) asthma.

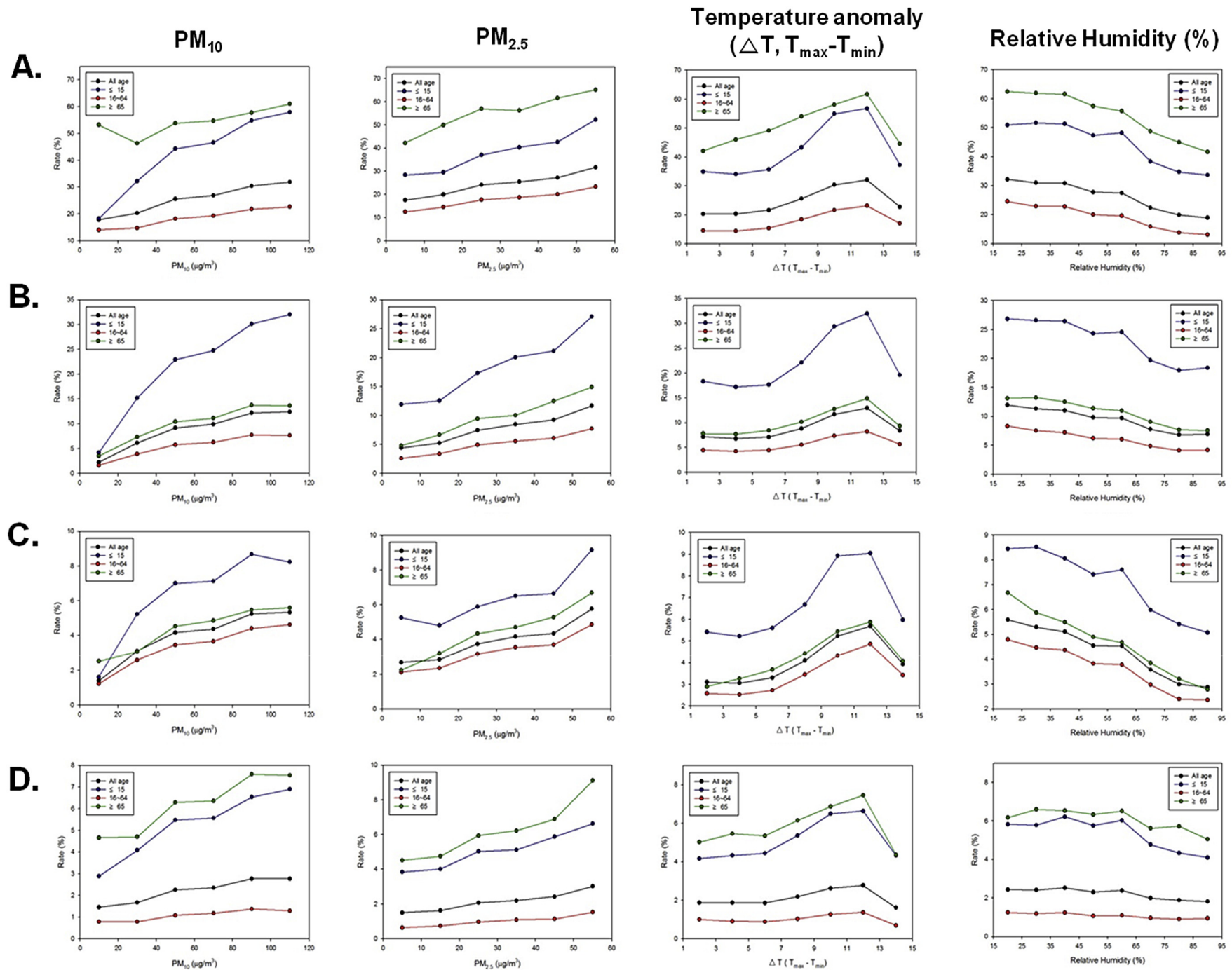


Fig. 4. Change in the rates of hospitalization for respiratory disease with respect to PM₁₀ concentration, PM_{2.5} concentration, daily temperature anomaly, and relative humidity. (A) Total respiratory diseases, (B) acute bronchitis, (C) allergic rhinitis, and (D) asthma.

Table 2

Age-adjusted incidence rate ratio (IRR) of air pollution and weather factors.

Respiratory disease	IRR			
	PM ₁₀	PM _{2.5}	Temperature anomaly	Relative humidity
Total respiratory diseases	1.006 (1.006–1.006)*	1.012 (1.011–1.012)*	1.064 (1.062–1.065)*	0.991 (0.99–0.991)*
Acute bronchitis	1.010 (1.009–1.010)*	1.020 (1.019–1.021)*	1.088 (1.085–1.091)*	0.990 (0.990–0.990)*
Allergic rhinitis	1.007 (1.007–1.008)*	1.016 (1.015–1.017)*	1.086 (1.082–1.090)*	0.989 (0.988–0.989)*
Asthma	1.007 (1.007–1.008)*	1.015 (1.013–1.016)*	1.056 (1.050–1.061)*	0.994 (0.993–0.995)*

*P < 0.001.

Table 3Adjusted incidence rate ratio (IRR) of PM₁₀ and weather factors for hospitalization.

Respiratory disease	IRR	
	PM ₁₀	Relative humidity
Total respiratory diseases	1.003 (1.003–1.004)*	0.990 (0.990–0.991)*
Acute bronchitis	1.009 (1.008–1.010)*	0.977 (0.976–0.978)*
Allergic rhinitis	1.006 (1.005–1.007)*	0.981 (0.979–0.983)*
Asthma	1.003 (1.002–1.005)*	0.992 (0.990–0.994)*

The analysis included PM₁₀, temperature anomaly, relative humidity, and age group.

*P < 0.05.

Table 4Adjusted IRR of PM_{2.5} and weather factors for hospitalization.

Respiratory disease	IRR	
	PM _{2.5}	Relative humidity
Total respiratory diseases	1.008 (1.007–1.009)*	0.991 (0.990–0.991)*
Acute bronchitis	1.025 (1.023–1.027)*	0.978 (0.977–0.980)*
Allergic rhinitis	1.014 (1.012–1.017)*	0.982 (0.980–0.984)*
Asthma	1.010 (1.007–1.013)*	0.992 (0.990–0.994)*

The analysis included PM_{2.5}, temperature anomaly, relative humidity, and age group.

*P < 0.05.

Table 5Adjusted IRR of PM₁₀ and PM_{2.5} for hospitalization.

Respiratory disease	IRR	
	PM ₁₀	PM _{2.5}
Total respiratory diseases	0.997 (0.996–0.998)*	1.013 (1.012–1.015)*
Acute bronchitis	0.981 (0.978–0.983)*	1.055 (1.050–1.059)*
Allergic rhinitis	0.990 (0.987–0.993)*	1.031 (1.026–1.036)*
Asthma	0.991 (0.988–0.995)*	1.023 (1.018–1.029)*

The analysis included PM₁₀, PM_{2.5}, temperature anomaly, relative humidity, and age group.

*P < 0.05.

Table 6

Adjusted IRR of age group for hospitalization.

Respiratory disease	IRR		
	0–15 years	16–64 years (ref)	≥65 years
Total respiratory diseases	1.636 (1.606–1.667)*	1.000	3.118 (3.067–3.170)*
Acute bronchitis	2.547 (2.420–2.681)*	1.000	1.884 (1.767–2.009)*
Allergic rhinitis	2.346 (2.214–2.485)*	1.000	1.253 (1.153–1.362)*
Asthma	7.685 (7.178–8.229)*	1.000	6.245 (5.782–6.746)*

This analysis included PM_{2.5}, temperature anomaly, relative humidity, and age group.

*P < 0.05.

were obtained in our study, in which hospitalizations for acute bronchitis, allergic rhinitis, and asthma were associated with increases in PM₁₀ and PM_{2.5}. PM originates from traffic, industry, biomass burning, or pollen, and consists of a carbon core with

various chemicals and reactive metals on its surface [17,25]. Their ability to penetrate the lung depends on the size of the particles. PM₁₀ are usually trapped in the upper airways, while PM_{2.5} can penetrate the alveolar portions of the lung, allowing water-soluble particle components to translocate through the alveolar capillaries into the circulation [25]. This might explain our finding of a greater effect of PM_{2.5} than of PM₁₀ on hospital admissions.

The relationship between PM and lung injury has been examined with respect to diesel exhaust particles and residue oil fly ash [26,27]. Other studies have documented the role of PM in innate and adaptive immunity. For example, Kumar et al. showed that ambient PM₁₀ injures airway epithelial cells, leading to the production of the pro-inflammatory cytokines interleukin 6 and chemokine ligand 1 [28]. Gehring et al. described the adverse effects of air pollution on asthma, rhinitis, allergic sensitization, and lung function in schoolchildren. They demonstrated an increased risk of PM with iron, copper, and zinc constituents [17]. Exposure to PM and their surface chemical and metal components could induce an oxidative stress response in macrophages and bronchial epithelial cells [29] and, in turn, a pro-inflammatory effect [30]. The impact on allergic sensitization of PM is less clear but ambient PM could act as an adjuvant in this process. Brandt et al. suggested that the increased prevalence of asthma in children exposed to high levels of traffic-related diesel exhaust particles was due to the accumulation of allergen-specific Th2 and Th17 cells in the lungs following co-exposure to these particles and house dust mite allergens [31]. Exposure to complex mixtures of pollutants from different sources in the environment may have additive toxic effects, including an increase in the bioavailability of airborne pollen allergens. Airway mucosal damage may facilitate the access of these inhaled allergens to the immune system [16]. While these findings would seem to be relevant to the pathogenesis of asthma, further research is needed to elucidate the mechanisms by which pollutants induce respiratory diseases.

In some studies, a decrease in air temperature was suggested to

worsen asthma symptoms [32–34]. By contrast, Marco et al. showed an increased in the prevalence of asthma with an increase in the annual mean temperature and a decrease in the temperature range [35]. According to Wu et al., in healthy adults PM_{2.5} had

stronger effects on lung function under weather conditions of high vs. low temperature [23]. Decreasing relative humidity [36] was also suggested to be a predictor of increased respiratory-related hospital admissions [14]. Low humidity may cause the dehydration of airway epithelial cells, as water moves from these cells to the airway surface. This would, in turn, cause a significant increase in the osmolarity of airway surface liquid and induce mucosal injury [37]. Humidity may also influence the atmospheric levels of aeroallergen [38], as suggested by the reduction in total suspended particulates in response to a higher relative humidity [15]. Furthermore, the composition of PM can vary depending on meteorological conditions [25]. Although these observations suggest meteorological factors as confounding factors of the effect of air pollution, this possibility has largely been ignored in studies of the health impact of air pollution. In our study, respiratory-related hospital admissions were significantly associated with a temperature anomaly and a decrease in the relative humidity, with the latter strengthening the contribution of PM.

The effect on admission rates of an increasing PM was more prominent in children and the elderly, consistent with age as a modifier of the association between PM exposure and hospitalization, especially in older individuals [39]. In this population, the physiological changes that accompany age, differences in activity patterns, and occupational exposures probably contribute to the higher vulnerability. In children, the higher risks may be due to the immaturity of their biological systems and the fact that their air-intake per body weight is higher than that of adults [39].

Our study had several limitations. Data on hospital admissions for respiratory diseases were extracted from the National Health Insurance Corporation, based on the diagnostic code. Thus, the accuracy of the diagnoses could not be confirmed. We used the mean value of PM levels obtained from the monitoring stations in Busan. Therefore we couldn't reflect the actual exposure of the population according to their residence. It might have led to either an overestimation or underestimation of the impact on respiratory diseases. However, as the analysis was based on the population living in Busan, we think there was no significant difference in the results. Also, we used the mean daily value of outdoor PM levels, whereas hourly values or indoor levels may have been more informative. Kim et al. showed an association in Korean patients between hourly differences in air pollution and asthma exacerbation [40]. However, in most studies, as in our study, daily PM levels were used to examine their impact on respiratory disease [6,41–43]. In contrast, some studies showed temporal difference between exposure to environmental pollutants and hospital admission, or assessed the cumulative effect of PM exposure [22,24]. Our study was conducted without lag time because it was aimed to evaluate the impact of PM with meteorological factors. Our study showed the importance of meteorological factors on the impact of PM on hospital admission, so we are planning further study to investigate when it represents the greatest risk for lag time. Moreover, the similar relationship between indoor and outdoor exposure to PM_{2.5} and asthma symptoms has been well established [44–46]. Another consideration is that PM contains a variety of aeroallergens, but we did not include pollen or mold, associated with atopic diseases, as confounders. Nevertheless, the strength of our study was its inclusion of meteorological factors to investigate the adverse effect of air pollution on respiratory diseases. The World Health Organization has set daily exposure limits for PM_{2.5} and PM₁₀ of 25 µg/m³ and 50 µg/m³, respectively. Our study suggests that, even if PM levels are low, in the presence of a lower relative humidity, respiratory admission rates can greatly increase. Thus, the effects of PM may be compounded by the influence of meteorological factors.

5. Conclusion

PM and meteorological factors are known to affect respiratory diseases, but our study showed the change in meteorological factors, especially humidity, further amplified the effects of PM. Thus, we should consider the possibility of aggravation of the diseases by considering it with meteorological change rather than simply observing the concentration of air pollution.

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Author contributions

Eun-Jung Jo: conception and design of the study, interpretation of the data, and preparation and drafting the submitted article.

Woo-Seop Lee, Hyun-Young Jo: acquisition of data, analysis, and interpretation of the data.

Chang-Hoon Kim: conception and design of the study, acquisition of data, analysis, and interpretation of the data.

Jung-Seop Eom, Jung-Ha Mok, Mi-Hyun Kim, Kwangha Lee, Ki-Uk Kim, and Min-Ki Lee: conception and design of the study, and interpretation of the data.

Hye-Kyung Park: conception and design of the study, interpretation of the data, and final approval of the version to be submitted.

Conflicts of interest

This manuscript has not been published or presented elsewhere in part or in entirety, and is not under consideration by another journal. All the authors have approved the manuscript and agree with submission to your esteemed journal. There are no potential conflicts of interest related to this article or the research described.

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