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ORIGINAL RESEARCH

# PM$_{10}$ increases mortality risk in rheumatoid arthritis-associated interstitial lung disease

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## ABSTRACT

**Objectives** The effect of air pollution on the prognosis of rheumatoid arthritis-associated interstitial lung disease (RA-ILD) remains poorly understood. We aimed to evaluate the effect of long-term exposure to particulate matter with an aerodynamic diameter of ≤10 μm (PM$_{10}$) and nitrogen dioxide (NO$_2$) on mortality in patients with RA-ILD.
**Methods** We included 309 patients (mean age, 61.7 years; male, 44.3%) with RA-ILD. Individual-level long-term exposures to PM$_{10}$ and NO$_2$ at their residential addresses were estimated using a national-scale exposure prediction model. The effect of the two air pollutants on mortality was estimated using a Cox-proportional hazards model adjusted for individual-level and area-level characteristics.
**Results** The median follow-up period was 4.8 years, and 40.8% of patients died or underwent lung transplantation. The annual average concentrations of PM$_{10}$ and NO$_2$ were 56.3 μg/m$^3$ and 22.4 ppb, respectively. When air pollutant levels were stratified by quartiles, no association was observed between air pollutant concentration and mortality in patients with RA-ILD. However, when stratified by two groups (high exposure (top 25th percentile) vs low exposure (bottom 75th percentile)), we observed a significant association between high PM$_{10}$ exposure and mortality (HR 1.68; 95% CI 1.11 to 2.52; p=0.013) but no association between NO$_2$ exposure and mortality. In the subgroup analyses, the effect of high PM$_{10}$ exposure on mortality was significant in patients aged <65 years (HR 1.98; 95% CI 1.02 to 3.85; p=0.045).
**Conclusions** Our results indicated that high PM$_{10}$ exposure may be associated with mortality in patients with RA-ILD.

### WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Air pollution was previously reported to be positively associated with the incidence of rheumatoid arthritis (RA). However, the effect of air pollution on the prognosis of patients with RA-associated interstitial lung disease (RA-ILD) remains poorly understood.

### WHAT THIS STUDY ADDS

⇒ When air pollutant levels were categorized into two groups (high exposure (top 25th percentile) vs low exposure (bottom 75th percentile)), we observed a significant association between mortality and high exposure to particulate matter with an aerodynamic diameter of ≤ 10 μm (HR 1.68; 95% CI 1.11 to 2.52; p=0.013) but not in terms of exposure to nitrogen dioxide.

### HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our results indicate that the reduction of air pollution exposure could be helpful in improving the prognosis of patients with RA-ILD.

## INTRODUCTION

Rheumatoid arthritis (RA) is a systemic autoimmune disorder characterised by the progressive destruction of the joints and a variety of extra-articular manifestations, including pulmonary involvement.[1] Interstitial lung disease (ILD) is one of the most common extra-articular manifestations in patients with RA and has an estimated prevalence of 6%–30%.[2 3] The development of ILD was reported to be responsible for 13% of all-cause mortality in patients with RA[4] and showed a median survival of 3 years after diagnosis.[5] Previous studies reported that several risk factors were associated with mortality in patients with RA-associated ILD (RA-ILD), including old age (>60 years old),[6] high titres of rheumatoid factor (RF; >3 * upper limit of normal),[7] lower baseline or a 10% decrease from baseline in forced vital capacity (FVC),[8] and a usual interstitial pneumonia (UIP) pattern on high-resolution CT (HRCT).[9] Air pollution is associated with mortality in chronic respiratory diseases, such as asthma,[10] chronic obstructive pulmonary disease[11] and lung cancer.[12] Moreover, recent studies have reported the associations between air pollution and the clinical course of idiopathic pulmonary fibrosis (IPF) in terms of incidence,[13] acute exacerbation,[14] hospitalisation[15] and mortality.[16 17] However, the effect of air pollution on the prognosis of patients with RA-ILD remains poorly understood.

Anticitrullinated protein antibodies (ACPAs) are a marker for RA autoimmunity, which are produced against citrullinated proteins (CPs) with autoantigenicity,[18] and involved in the development of ILD in patients with RA.[19] CPs are known to be produced in the lungs via inhaled toxic stimuli, such as smoking, in individuals carrying the human leucocyte antigen DR-shared epitopes, which are associated with the risk of ACPA-positive RA.[20] Furthermore, CPs were found in the lung lavage fluid of smokers and the lung parenchymal tissues and synovium of patients with RA-ILD.[21] Considering that ACPAs are often detected before joint symptoms appear, the lung may be the origin of ACPA production.[22] Air pollution was known to be associated with ACPA positivity,[23] which is a risk factor for RA-ILD progression.[6] Furthermore, air pollution was reported to be positively associated with the incidence of RA-ILD,[24] as well as incidence and hospital readmissions of RA.[25 26] On the basis of these findings, we hypothesised that the prognosis of RA-ILD may be associated with exposure to air pollution. Therefore, we aimed to evaluate the effect of long-term exposures to particulate matter with an aerodynamic diameter of ≤10 μm ($PM_{10}$) and nitrogen dioxide ($NO_2$) on the mortality in patients with RA-ILD. $PM_{10}$ and $NO_2$ were estimated at an individual level by using a national-scale air pollution prediction model based on residential addresses.

## METHODS
### Study population
A total of 313 patients diagnosed with RA-ILD between June 1995 and August 2018 at the Asan Medical Center, Seoul, Republic of Korea, were screened for this study. After excluding participants whose data on baseline characteristics or survival status were not available (n=4), 309 patients were included in this study. A diagnosis of RA was made according to the 2010 American College of Rheumatology/European league against rheumatism criteria by a rheumatologist,[27] and the presence of ILD was confirmed on the basis of HRCT imaging and/or pathological findings.

### Clinical data
Clinical and survival data for all patients were retrospectively obtained from medical records and/or the records of the National Health Insurance of Korea. FVC, diffusing capacity of the lungs for carbon monoxide, and total lung capacity were evaluated by spirometry or plethysmography according to the recommendations of the American Thoracic Society/European Respiratory Society.[28–30] The results were expressed as percentages of the normal predicted values. The residential addresses were obtained on the basis of the patients' statements.

### HRCT assessment
HRCT scan images were reviewed by a radiologist (JC) and a pulmonologist (SHK) who were blinded to clinical and pathological information. Overall, HRCT patterns were classified as a UIP-like or non-UIP-like pattern on the basis of the HRCT classification of the Fleischner Society Guidelines for the diagnosis of IPF[31] and adjustments were made to allow applicability for patients with RA-ILD.[32] In summary, a UIP-like pattern was defined as a reticular pattern accompanied by honeycombing with or without traction bronchiectasis (or bronchiolectasis) and without considering the distribution or presence of mosaic attenuation, which was suggested by Jacob *et al*.[32] Any disagreements between the two readers were resolved by a third reader (JWS).

### Individual-level exposure assessment for $PM_{10}$ and $NO_2$
On the basis of geo-coded residential addresses, we estimated the individual-level concentrations of $PM_{10}$ and $NO_2$ by using the validated air pollution prediction model of South Korea (figure 1 A and B). This national-scale pointwise exposure prediction model was developed to estimate the annual average concentrations of $PM_{10}$ and $NO_2$ at any location in South Korea, and further details can be found in online supplemental appendix S1.[33 34]

The long-term exposure to $PM_{10}$ and $NO_2$ was assessed by the annual average concentrations estimated in 2006 (1 year before the first event of death in our cohort). The fixed-year exposure could prevent the possible overestimation of air pollution effect on mortality resulting from a substantial decrease in air pollutant concentration over time.[35] In South Korea, $PM_{10}$ concentrations decreased from 51 to 41 μg/m³, whereas $NO_2$ concentrations decreased from 23 to 20 parts per billion (ppb) between 1999 and 2018 (https://www.airkorea.or.kr). We considered the average concentrations in 2006 as the long-term average exposure on the basis of the results that the annual average concentrations in 2006 correlated well with those in each year during the 2001–2018 period ($PM_{10}$: r=0.38–0.84; $NO_2$: r>0.8) from regulatory monitoring sites. This implied a relatively consistent spatial distribution over time (online supplemental figure S1 and online supplemental figure S2). Furthermore, to overcome bias regarding changes in the residential addresses of each patient, we calculated the individual exposure by estimating the mean concentration in 2006 to reflect all the available addresses of each patient during the study period.

### Statistical analyses
The primary outcome of this study was death, and lung transplantation was considered an equivalent event to death. The duration of follow-up was estimated from the date of ILD diagnosis to the date of death, lung transplantation, or time of censoring (31 December 2019). The annual average air pollutant concentrations were categorised into four groups on the basis of quartiles (Q1–Q4). Furthermore, air pollutant concentrations were categorised into two groups to evaluate the effect of high exposure to air pollutants (denoted as Q4, top 25th percentile) compared with low exposure to air pollutants (denoted as Q1–Q3, bottom 75th percentile).[36] The Kaplan-Meier survival curve analysis was used to evaluate
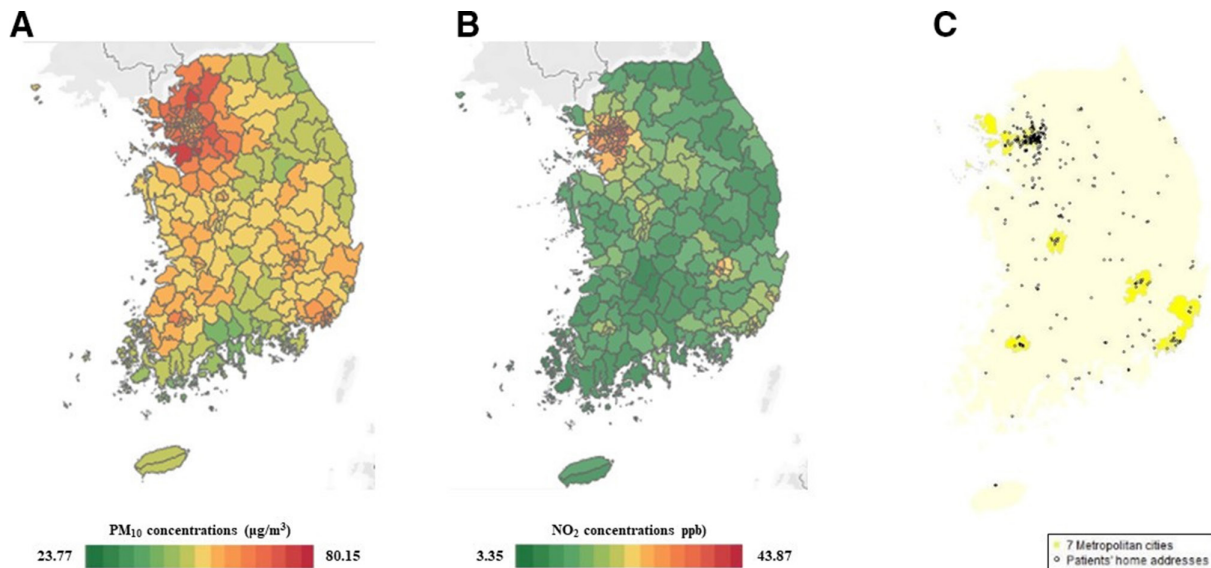
**Figure 1** Spatial distribution of air pollutants and the residential addresses of patients with RA-ILD. The map of estimated concentration of $PM_{10}$ (µg/m³) (A) and $NO_2$ (ppb) (B) in 2006. The map of the distribution of the residential addresses of patients with RA-ILD (C). RA-ILD, rheumatoid arthritis-associated interstitial lung disease; $PM_{10}$, particulate matter ≤10 µm; $NO_2$, nitrogen dioxide.

the survival probability over time, and a log-rank test was used to identify the difference in survival. The Cox-proportional hazards model was used to evaluate the effect of air pollution on the mortality in patients with RA-ILD.

To evaluate the effect of air pollution on mortality according to progressive adjustment, four models with different sets of confounders were used. Model 1 was an unadjusted model that only included $PM_{10}$ or $NO_2$ concentrations (quartiles; high vs low exposure). In model 2, we adjusted for age, sex and date of ILD diagnosis. In model 3, we added individual-level variables at the time of ILD diagnosis, including smoking status (ever-smokers vs non-smokers), baseline lung function (FVC), and HRCT patterns (UIP-like vs non-UIP-like patterns). In model 4, which was our primary model, we added area-level variables, the proportion of educational attainment equal to or higher than high school, and gross regional domestic product (GRDP) (top 50th percentile vs bottom 50th percentile) in each residential district; these were the most common indicators reflecting socioeconomic status.[37] In the current study, data on the proportion of high school graduates were obtained from the 2000 census (Korean Statistical Information Service (KOSIS) 2000, http://kosis.kr), whereas data on GRDP were collected from the 2005 general statistics (KOSIS 2005).

The subgroup analyses were performed according to age (≥65 years vs <65 years), sex (male vs female) and autoantibody positivity. For sensitivity analysis, the two-pollutant model was used; this model simultaneously included both pollutants ($PM_{10}$ and $NO_2$) in the analysis to adjust for influences between the two air pollutants. Furthermore, we calculated the individual exposures to air pollution by using single residential addresses close to

the year 2006, which reflected the exposure in 2006 more accurately. All statistical analyses were performed using the Statistical Package for the Social Sciences V.24.0 (IBM Corp.). Statistical significance was set at a p value (two-tailed) less than 0.05 (p<0.05).

## RESULTS

### Baseline characteristics

Among the patients, the mean age was 61.7 years, 44.3% were male, and 65.4% had a UIP-like pattern on HRCT (table 1). The annual average concentrations of $PM_{10}$ and $NO_2$ were 56.3 µg/m³ and 22.4 ppb, respectively. Among the 309 patients, 148 (47.9%) lived in 7 metropolitan cities (figure 1C). During the follow-up period (median, 4.8 years (IQR 2.8–8.5 years)), 125 (40.5%) patients died, and 1 (0.3%) patient underwent lung transplantation (median survival period, 9.8 years; 5-year survival, 68.6%; online supplemental figure S3–A).

### Association between air pollution and mortality

$PM_{10}$ exposure concentrations were divided into four quartiles: Q1 (≥42.10 and <52.67 µg/m³), Q2 (≥52.67 and <56.86 µg/m³), Q3 (≥56.86 and <59.64 µg/m³) and Q4 (≥59.64 and ≤77.7 µg/m³). No significant differences were observed in the mortality of patients with RA-ILD between the quartiles of $PM_{10}$ exposure concentrations (p=0.799) (online supplemental figure S3-B). $NO_2$ exposure concentrations were also classified as Q1 (≥3.83 and <14.78 ppb), Q2 (≥14.78 and <22.25 ppb), Q3 (≥22.25 and <29.68 ppb) and Q4 (≥29.68 and ≤44.10 ppb). No significant differences were observed in the mortality of patients with RA-ILD between the quartiles of $NO_2$ exposure concentrations (p=0.559) (online supplemental figure S3-C). In both unadjusted and adjusted models, $PM_{10}$ and

**Table 1** Baseline characteristics of patients with rheumatoid arthritis-associated interstitial lung disease

| | Total |
|---|---|
| Number | 309 |
| Age | 61.7±10.3 |
| Male | 137 (44.3) |
| Ever smokers | 139 (45) |
| BMI, kg/m$^2$ | 23.5±3.1 |
| Pulmonary function test | |
| FVC, % predicted | 74.2±18.0 |
| DLco, % predicted | 63.4±19.5 |
| A UIP-like pattern on HRCT | 202 (65.4) |
| Treatment status | |
| Corticosteroid with/ without IS | 198 (64.3) |
| None | 110 (35.7) |
| RF positive (n=305) | 250 (82) |
| ACPA positive (n=289) | 237 (82) |
| Rate of educational attainment equal to or higher than high school, % | 56.6±9.9 |
| GRDP, one million dollars | 7689.73 (3018.52–9282.67) |
| Air pollutants | |
| PM$_{10}$, µg/m$^3$ | 56.3±5.1 |
| NO$_2$, ppb | 22.4±9.0 |

Data are presented as mean±SD, median (IQR), or number (%).
USD 1=KRW 1086.50 (15 January 2021).
ACPA, anticitrullinated protein antibodies; BMI, body mass index; DLco, diffusing capacity of the lungs for carbon monoxide; FVC, forced vital capacity; GRDP, gross regional domestic product; HRCT, high-resolution CT; ILD, interstitial lung disease; IS, immunosuppressant; NO$_2$, nitrogen dioxide; PM$_{10}$, particulate matter≤10 µm; RF, rheumatoid factor; UIP, usual interstitial pneumonia.

NO$_2$ were not associated with mortality in patients with RA-ILD (online supplemental figure S4).

Furthermore, we evaluated the effect of high concentrations of air pollutants by dividing the PM$_{10}$ exposure concentrations on the basis of Q4 levels (high: PM$_{10}$≥59.64 µg/m$^3$ vs low: <59.64 µg/m$^3$); no significant difference was observed in the mortality of patients with RA-ILD between the two groups (median survival, 7.9 years (95% CI 4.9 to 10.8 years) vs 9.9 years (7.8 to 12.0 years); p=0.350) (figure 2A). High exposure to PM$_{10}$ showed an HR>1 for mortality in model 1 (HR 1.20; 95% CI 0.82 to 1.77; p=0.351) and model 2 (HR 1.45; 95% CI 0.98 to 2.16; p=0.065) without statistical significance. However, when individual-level and/or area-level covariates were adjusted, a statistically significant association was observed between high exposure to PM$_{10}$ and mortality in model 3 (HR 1.60; 95% CI 1.07 to 2.38; p=0.021) and our primary model (model 4: HR 1.68; 95% CI 1.11 to 2.52; p=0.013) (figure 3). In terms of NO$_2$, no significant difference was noted in the mortality of patients with RA-ILD between the high-concentration and low-concentration groups of NO$_2$ (median survival, 9.3 years (95% CI 7.9 to 10.8 years) vs 9.8 years (6.7 to 13.0 years); p=0.283) (figure 2B). We could not observe any evidence of association with mortality in both the unadjusted and adjusted models (figure 3).

### Subgroup analyses

In the analysis of the data stratified by age (≥65 years vs <65 years) using the primary model, high exposure to PM$_{10}$ was associated with mortality in patients with RA-ILD aged <65 years old (HR 1.98; 95% CI 1.02 to 3.85;
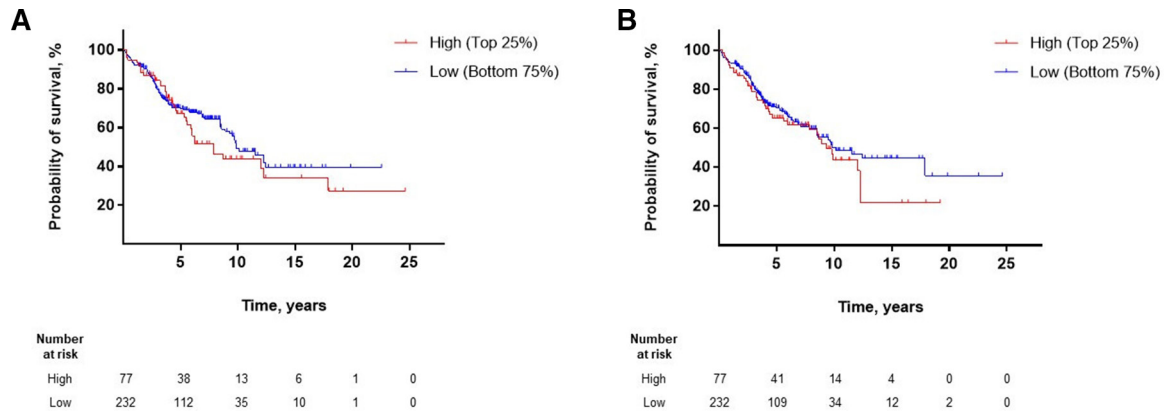
**Figure 2** Comparison of survival probability over time between the high-concentration group (top 25th percentile) and the low-concentration group (bottom 75th percentile) among patients with RA-ILD. (A) The Kaplan-Meier survival curve for $PM_{10}$. (B) The Kaplan-Meier survival curve for $NO_2$. RA-ILD, rheumatoid arthritis-associated interstitial lung disease; $PM_{10}$, particulate matter$\leq$10 μm; $NO_2$, nitrogen dioxide.

p=0.045) (figure 4A). By contrast, an association with $NO_2$ was not detected in either age group (figure 4B). When the data were stratified by sex (male vs female), high $PM_{10}$ exposures were not associated with RA-ILD mortality in either groups (figure 5A). Conversely, high exposure to $NO_2$ was significantly associated with mortality in female patients with RA-ILD (HR 2.01; 95% CI 1.02 to 3.96; p=0.044) (figure 5B).

When the data were stratified by autoantibody positivity (RF, ACPA) (online supplemental table S1–S2), high $PM_{10}$ exposure showed a numerical trend towards a positive association with RA-ILD mortality in the RF (+) (HR 1.54; 95% CI 0.98 to 2.42; p=0.060) and ACPA (+) (HR 1.58; 95% CI 0.99 to 2.51; p=0.054) groups; but with marginal significance. High $PM_{10}$ exposure was also associated with mortality in RA-ILD in the RF (−) group (HR 18.81; 95% CI 2.91 to 121.61; p=0.02). Conversely, high $NO_2$ exposure was not associated with RA-ILD mortality in either autoantibody (+) group.
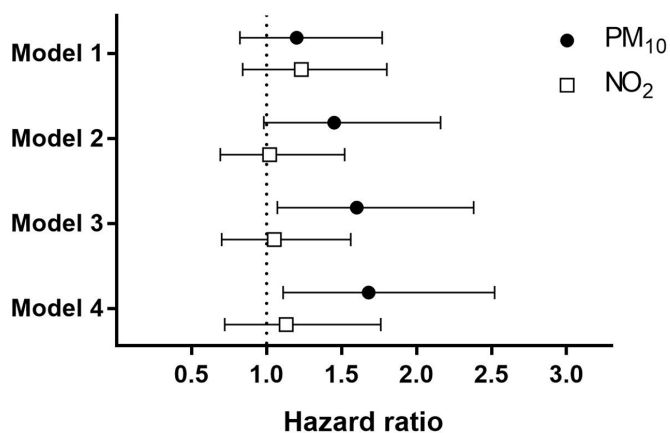


**Figure 3** The effect of high (top 25th percentile) air pollutant concentrations on the mortality in patients with RA-ILD. Symbols and error bars represent HRs and 95% CIs, respectively. RA-ILD, rheumatoid arthritis-associated interstitial lung disease; $PM_{10}$, particulate matter ≤10 μm; $NO_2$, nitrogen dioxide.

### Sensitivity analysis
When both $PM_{10}$ and $NO_2$ were included in the primary model (two-pollutant model), high $PM_{10}$ exposure was significantly associated with mortality in patients with RA-ILD (HR 1.67; 95% CI 1.10 to 2.52; p=0.015) (online supplemental figure S5). In the analysis using the average concentrations for single residential addresses close to 2006, high $PM_{10}$ exposure demonstrated a numerical trend of positive association with RA-ILD mortality; however, this was not statistically significant (HR 1.32; 95% CI 0.88 to 1.99; p=0.183) (online supplemental figure S6). High exposure to $NO_2$ was not associated with RA-ILD mortality in both of these analyses (online supplemental figures S5 and S6).

### DISCUSSION
To the best of our knowledge, this is the first study to report the association between air pollution and mortality in patients with RA-ILD by using spatially resolved estimates for individual exposures to air pollution. When data were analysed based on quartiles, we could not observe any association between air pollutant concentrations and mortality in patients with RA-ILD. In contrast, we observed that high $PM_{10}$ exposure significantly increased the risk of mortality in the multivariable analysis adjusted by the individual-level and/or area-level covariates. The subgroup analyses demonstrated a significant association between high $PM_{10}$ exposure and mortality in patients with RA-ILD aged <65 years, as well as between high exposure to $NO_2$ and mortality in the female group.

We did not observe a significant association between air pollutants and mortality in patients with RA-ILD as a whole. This is contrary to previous studies on the effect of air pollutants on mortality in patients with IPF.[16 17] Sese *et al* studied 192 patients with IPF and reported that the increased exposure levels of $PM_{10}$ were significantly associated with all-cause mortality (HR 2.01; 95% CI 1.07 to 3.77; p=0.03).[16] A possible explanation for the
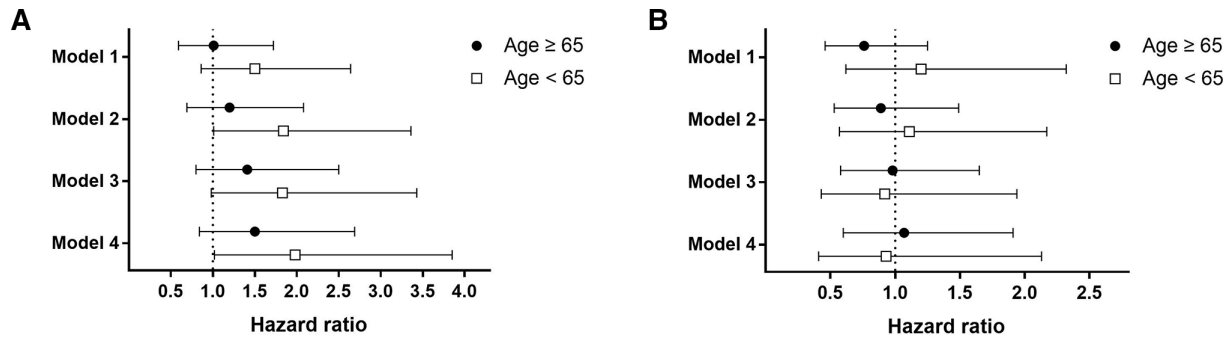
**Figure 4** Comparison of the effect of high (top 25th percentile) air pollutant concentrations on mortality in patients with RA-ILD stratified by age[*]. [*] ≥65 years (n=137) versus <65 years (n=172). The forest plot of (A) $PM_{10}$ and (B) $NO_2$. Symbols and error bars represent HRs and 95% CIs, respectively. RA-ILD, rheumatoid arthritis-associated interstitial lung disease; $PM_{10}$, particulate matter ≤10 µm; $NO_2$, nitrogen dioxide.

discrepancy could be physical inactivity due to painful arthritis, which may lead to lower exposure to outdoor air pollutants.[38] This is consistent with our results. When data were stratified according to age, high exposure to $PM_{10}$ was associated with an increased risk of mortality in patients with RA-ILD aged <65 years old, who were more physically active. Furthermore, chronic injuries to the alveolar epithelium by air pollution may lead to higher susceptibility to IPF, which is characterised by alveolar epithelium dysfunction.[39] In contrast, RA-ILD is characterised by local and systemic inflammation secondary to ACPA and inducible bronchus-associated lymphoid tissues.[19] Overall, our results suggested that patients with RA-ILD may be less affected by air pollutants than patients with IPF.

Interestingly, high exposure to $PM_{10}$ was significantly associated with an increased risk of mortality in patients with RA-ILD. The clinical effect of $PM_{10}$ has been mostly reported in patients with IPF.[16 40] In addition to its effect on mortality,[16] Winterbottom et al reported that each 5 µg/m³ increase in $PM_{10}$ was associated with a 46 cc/year decline in FVC (p=0.008).[40] Particulate matter is known to induce toxic effects by triggering free radical reactions causing oxidative stress and telomere shortening, leading to the development of chronic respiratory disease, such as ILD, and ultimately increasing mortality.[41] RA-ILD shares

some common features with IPF,[39] including a higher prevalence of UIP-like pattern on HRCT scans,[42] the presence of *MUC5B* promoter variant rs35705950,[43] and short telomere length.[44] Therefore, the effect of $PM_{10}$ on IPF could be reproduced in RA-ILD, particularly in those exposed to high concentration of $PM_{10}$. Furthermore, in contrast to our results, the long-term effect of $PM_{10}$ in the Korean National Health Insurance Service-National Sample Cohort, using the same prediction model as in our study, showed only a marginal association with non-accidental mortality in the general population (HR 1.05; 95% CI 0.99 to 1.11).[37] This suggests that patients with RA-ILD may be more susceptible to $PM_{10}$ than the general population.

Although $NO_2$ exposure was not associated with mortality in patients with RA-ILD for the whole population in our study, high exposure to $NO_2$ was associated with an increased risk of mortality in female patients. Different health effects of $NO_2$ according to sex have been recently reported in the Canadian general population. Shin et al reported a significant association between $NO_2$ and all-cause mortality in women during the cold season (0.7% per 10 ppb increase; 95% CI 0.2 to 1.2) compared with that in men (0.1% per 10 ppb increase; 95% CI −0.8 to −0.9).[45] This may be due to sex-based biologic differences (eg, hormone and lung size), which can influence
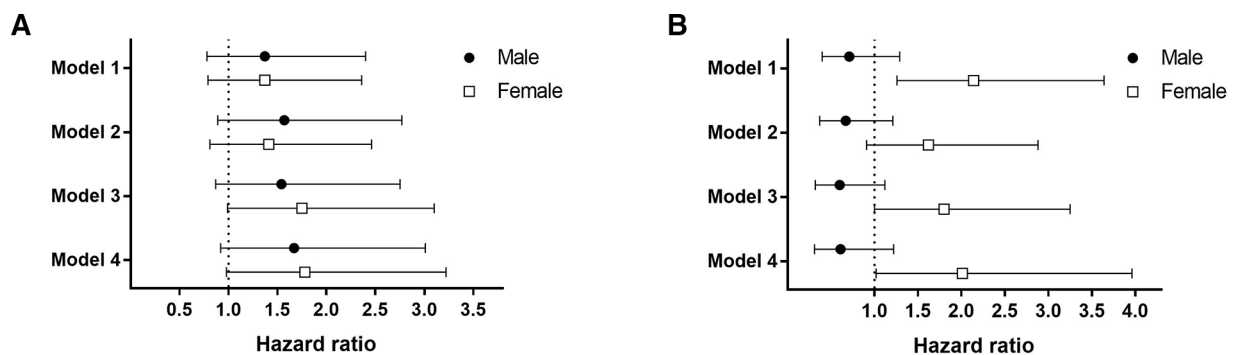


**Figure 5** Comparison of the effect of high (top 25th percentile) air pollutant concentrations on mortality in patients with RA-ILD stratified by sex[*]. [*]Male (n=137) versus female (n=172). The forest plot of $PM_{10}$ (A) and $NO_2$ (B). Symbols and error bars represent HRs and 95% CIs, respectively. RA-ILD, rheumatoid arthritis-associated interstitial lung disease; $PM_{10}$, particulate matter ≤10 µm; $NO_2$, nitrogen dioxide.

the deposition and transport of air pollutants.[46] In addition, gender-based differences in social roles, such as greater household responsibilities among women, could contribute to increased exposures to indoor $NO_2$ in women because indoor $NO_2$ levels may increase through the use of gas stoves in the kitchen and indoor ventilation, as well as exposure to outdoor $NO_2$.[47 48] Thus, women could be exposed to higher daily concentrations of $NO_2$ considering their social role, potentially increasing their susceptibility to high exposure to outdoor $NO_2$.

Our study had several limitations. First, this study was conducted in a single centre, using a retrospective design, which introduced a possibility of selection bias. However, the baseline characteristics of patients in our study were similar to those in previous studies,[7 8] and the residential address of patients with RA-ILD was distributed throughout the country (figure 1C). Second, the sample size was relatively small, which could lead to statistical insignificance. Future studies with a larger number of patients are warranted to confirm our findings. Third, we did not consider the other potential location of air pollutant exposures, such as workplaces, which may affect individual exposure, particularly in patients who spend less time in their homes. Future studies that consider these aspects should be performed to assess the individual effect of air pollution more precisely. Lastly, our approach may not reflect the exact exposures of each patient during years other than 2006. We estimated individual exposures by using annual averages for a fixed-year period to avoid the possible overestimation of mortality effects. However, the annual average concentrations demonstrated relatively consistent spatial patterns over time.

In conclusion, our results suggested that exposure to high concentrations of $PM_{10}$ may be associated with mortality in patients with RA-ILD, particularly in younger patients. Therefore, preventive measures to reduce exposure to high levels of $PM_{10}$ need to be considered to reduce the risk of mortality in patients with RA-ILD.

**Competing interests** None declared.

**Patient consent for publication** Not applicable.

**Ethics approval** The study was conducted in accordance with Good Clinical Practice guidelines and the provisions of the Declaration of Helsinki. This study was approved by the Institutional Review Board of the Asan Medical Center (2021-1266), and the requirement for informed consent was waived because of the retrospective nature of this study.

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**Data availability statement** Data are available upon reasonable request.

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