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Short-Term Exposure to Outdoor Pollutants and Loss of Pulmonary Function in the Elderly

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1. Introduction

The reduction of pulmonary function has come to be considered one of the most important health effects of air pollution because it not only affects individual respiratory health status but also predicts cardiovascular morbidity and mortality in the general population (1-3). Although numerous studies have provided an understanding of air pollution's general effects on pulmonary function, the length of the lag period for the effects of short-term exposure to air pollution has not been well elucidated.

In addition, most of the information about the pulmonary effects of air pollution has come from studies of children and adults, whereas pulmonary effects in the elderly are less well understood. Because of the considerable increase in the prevalence of respiratory diseases in the elderly population and this population's known susceptibility to toxic chemicals in the environment, the effect of air pollution on pulmonary function in the elderly has emerged as a serious concern in both public health and clinical medicine.

Although the diminution of pulmonary function because of exposure to air pollutants has been reported in previous studies (4-6), most of these reports were time-series or cross-sectional analyses that did not capture within-subject changes. To account for within-subject changes in pulmonary function, a longitudinal study, such as a cohort or panel study, is required. A cohort study would be more appropriate for evaluating the long-term health effects of air pollution, while a panel study is better suited for evaluating the short-term effects (7). Because each subject can be used as his or her own control in a panel study with repeated measurements, only rapidly changing covariates for each given subject have to be considered in a statistical analysis.

Therefore, we conducted a longitudinal panel study using repeated measurements to evaluate the effects of air pollutants on pulmonary function in the elderly, who are known to be especially susceptible to air pollution (8-10).

2. Methods

2.1 Subject population

The study population consisted of 560 elderly people (all 60 years old or older) living in Seoul, Korea. Up to 5 spirometric tests were performed on different days for each subject.

During each subject's first visit, demographic data and information, such as medical history, dietary habits, smoking and alcohol consumption were gathered using a questionnaire. Written informed consent was obtained from every subject; this study was approved by the institutional review board of the Seoul National University College of Medicine.

2.2 Air pollution and meteorological data

Air pollution data were collected from the Research Institute of Public Health and Environment; values from the monitoring site nearest to each subject's residence were used as the dataset for that subject's exposure to ambient pollutants. Daily average values for concentrations of particulate matter with a diameter of 10 μm or less (PM_{10}), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and ozone (O_3) were computed for each site. Data on the daily average temperature (°C) and relative humidity (%) for each day of the study period were obtained from the Korean Meteorological Administration.

2.3 Spirometric measurements

Spirometric testing was conducted at each health evaluation visit according to the 2005 European Respiratory Society/American Thoracic Society recommendations. All tests were performed at the same hour of the morning by one trained technician, using a Microlab® (Sensormedic, USA) spirometer. The spirometric measurements used in our analyses were forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), FEV_1 as a percentage of FVC (FEV_1/FVC), and forced expiratory flow between 25 and 75% of the FVC (FEF_{25-75}).

2.4 Statistical analysis

Linear mixed-effect models were used to estimate the effects of the air pollutants on the pulmonary function test parameters, which controlled for temperature, relative humidity, smoking, dietary habits, alcohol consumption, and individual characteristics. We treated age, sex, height, weight, dietary habits, alcohol consumption, date, temperature, relative humidity, smoking and pollutant levels as fixed effects. Participant identity was treated as a random effect in the models. We examined the ongoing effects of air pollution on lung-function parameters over a lag time of 7 days after exposure. We counted the day of the air-pollutant exposure as lag day 0; lag day 7 was therefore defined as an exposure the 7 days prior. We also evaluated the cumulative lag effects of air pollution using a lag-distribution model.

3. Results

The mean age of the participants was 70.7 years old; 26.1% were male and 73.9% were female. Subjects underwent a mean of 3.3 health examination visits out of 5 possible visits. The male participants were more likely to be smokers than the female Participants (Table 1). Table 2 presents the levels of air pollutants and the meteorological data for the time periods preceding each health examination visit. The mean levels of PM_{10}, SO_2, O_3, NO_2 and CO were 42.6 μg/m³, 3.9 ppb, 19.2 ppb, 35.6 ppb and 0.6 ppm, respectively.

To determine the length of the effective time period for pulmonary impact, we assessed the effects of air pollutants on lung function from the day of exposure (lag day 0) through lag day 7 (Figure 1). To estimate the effects of the air pollution, we calculated the estimated values of lung function parameters assuming average values for age, sex, height, weight, smoking, dietary habits, alcohol consumption, outdoor temperature and humidity. We

found that the effective time period for an air pollution-induced reduction of pulmonary function was from the day of exposure through the following 2 days. Compared to other air pollutants, O_3 did not show a significant association in reducing pulmonary function. We specifically calculated changes in pulmonary function due to exposure to air pollution within the past one day, because the calculated reduction in pulmonary function was most prominent for most air pollutants at lag day 1. Table 3 shows that the levels of PM_{10}, SO_2, NO_2 and CO were negatively associated with FEV_1/FVC and FEF_{25-75} but that O_3 levels were not significantly associated with changes in pulmonary function parameters.

	Male	Female	Total
No. of participants (%)	146 (26.1)	414 (73.9)	560 (100)
No. of visits [mean ± SE]	3.1 ± 0.1	3.4 ± 0.1	3.3 ± 0.1
Age [mean (range)]	71.4 (62-84)	70.5 (60-87)	70.7 (60-87)
Height [mean ± SE (cm)]	164.3 ± 0.4	151.3 ± 0.2	154.7 ± 0.3
Weight [mean ± SE (Kg)]	65.7 ± 0.8	57.1 ± 0.4	59.3 ± 0.4
No. of smokers (%)	64 (43.4)	5 (1.2)	67 (12.2)
Lung-function indicators:			
FVC [mean ± SE (L)]	2.86 ± 0.05	20.4 ± 0.02	2.27 ± 0.03
FEV_1 [mean ± SE (L)]	2.31 ± 0.04	1.74 ± 0.02	0.92 ± 0.02
FEV_1/FVC [mean ± SE (%)]	81.37 ± 0.64	86.70 ± 0.35	85.21 ± 0.33
FEF_{25-75} [mean ± SE (L/sec)]	2.31 ± 0.07	2.10 ± 0.04	2.16 ± 0.03

FVC: forced vital capacity; FEV_1: forced expiratory volume in one second; FEF_{25-75}: forced expiratory flow between 25% and 75% of forced vital capacity.

Table 1. Subject characteristics at first health evaluation visit

Pollutant	Number of measurements	Mean (SD)	Selected percentiles				
			10th	25th	50th	75th	90th
PM_{10} (μg/m³)	1850	42.6 (17.6)	21.9	29.3	39.7	53.1	63.0
SO_2 (ppb)	1850	3.9 (1.5)	2.4	2.7	3.4	4.5	6.0
O_3 (ppb)	1850	19.2 (8.4)	8.1	10.9	19.3	26.9	30.2
NO_2 (ppb)	1850	35.6 (9.1)	24.0	29.3	35.8	39.7	45.3
CO (ppm)	1850	0.6 (0.2)	0.4	0.5	0.6	0.7	0.9
Temperature (°C)	1915	17.3 (9.0)	4.0	10.1	19.1	25.1	27.0
Humidity (%)	1915	63.2 (12.8)	47.9	53.0	63.6	72.5	80.4

Levels of air pollutants for the health-examination day and the seven preceding days; meteorological data for the health examination day.

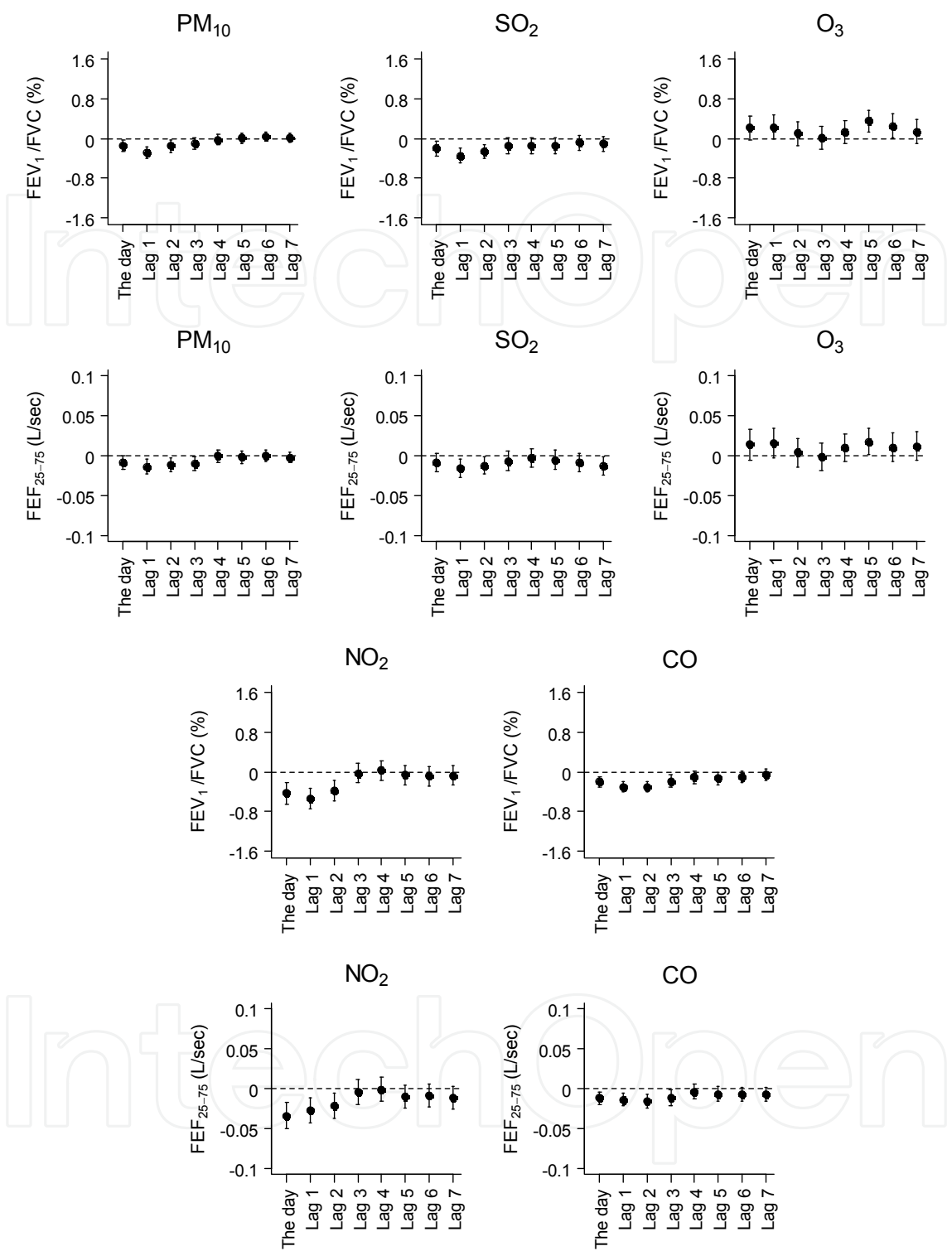Table 2. Air-pollutant levels and meteorological data

Fig. 1. The effect of PM_{10}, SO_2, O_3, NO_2, and CO on FEV_1/FVC and FEF_{25-75} by single lag days. Changes in FEV_1/FVC (%) and FEF_{25-75} (L/sec) were calculated per 10 μg/m³ of change in PM_{10} levels, per 1 ppb of change in SO_2, per 10 ppb of change in O_3, per 10 ppb of change in NO_2, and per 0.1 ppm of change in CO, adjusted for age, sex, body mass index (BMI), smoking status, alcohol consumption, dietary habits, temperature and relative humidity.

Pollutant	Outcome	No.	Estimated Change	SE	p-Value	Lower 95% CI	Upper 95% CI
PM_{10}	FEV_1 (L)	1146	0.003	0.002	0.1541	-0.001	0.008
	FEV_1/FVC (%)	1146	-0.287	0.063	<0.0001	-0.410	-0.164
	FEF_{25-75} (L/sec)	1146	-0.014	0.005	0.0034	-0.023	-0.005
SO_2	FEV_1 (L)	1146	0.003	0.026	0.8972	-0.047	0.054
	FEV_1/FVC (%)	1146	-3.447	0.718	<0.0001	-4.856	-2.037
	FEF_{25-75} (L/sec)	1146	-0.157	0.055	0.0047	-0.266	-0.048
O_3	FEV_1 (L)	1146	0.004	0.004	0.3123	-0.004	0.013
	FEV_1/FVC (%)	1146	0.228	0.124	0.0671	-0.016	0.472
	FEF_{25-75} (L/sec)	1146	0.016	0.009	0.0968	-0.003	0.034
NO_2	FEV_1 (L)	1146	0.002	0.004	0.6592	-0.006	0.009
	FEV_1/FVC (%)	1146	-0.542	0.102	<0.0001	-0.743	-0.341
	FEF_{25-75} (L/sec)	1146	-0.027	0.008	0.0005	-0.043	-0.012
CO	FEV_1 (L)	1143	0.001	0.002	0.4677	-0.002	0.005
	FEV_1/FVC (%)	1143	-0.300	0.053	<0.0001	-0.403	-0.197
	FEF_{25-75} (L/sec)	1143	-0.014	0.004	0.0005	-0.022	-0.006

Change in lung-function indicators per 10 μg/m³ of change in PM_{10} levels; per 10 ppb of change in SO_2; per 10 ppb of change in O_3; per 10 ppb of change in NO_2; per 0.1 ppm of change in CO.
The effect of each air pollutant on lung function was adjusted for age, sex, body mass index (BMI), smoking status, alcohol consumption, dietary habits, temperature and relative humidity.

Table 3. The relationship between air pollutants and lung-function indicators on lag day one.

To evaluate the cumulative effect of air pollutants on pulmonary function, we performed a lag-distribution model analysis and found that a significant reduction in pulmonary function occurred when subjects had been exposed to air pollutants during the previous 2 days, as in the single-day lag model analysis (Figure 2).

3.1 Discussion

Our study demonstrates that exposure to outdoor air pollutants exerts harmful effects on lung function in the elderly and that the lag period for this effect is from the day of exposure to 2 days later.
All of these effects were observed at pollution levels within the current air-quality standard in Korea, which sets the maximum 24-hour average at 100 μg/m³ for PM_{10}, 50 ppb for SO_2, and 60 ppb for NO_2 and the maximum 8-hour average at 60 ppb for O_3 and 9 ppm for CO.
Spirometry provides a simple, convenient and reproducible measure of pulmonary function. We examined the association between exposure to ambient air pollutants and lung function test results and found statistically significant correlations between air pollutant levels of PM_{10}, NO_2, SO_2 and CO and results of FEV_1/FVC and FEF_{25-75} measurements. In contrast, FVC and FEV_1 results did not show any association with air pollutant levels. Though declines in FVC and FEV_1 have been found to be associated with occupational exposure to air pollutants, these two parameters do not change quickly during the early stages of disease (11). This stasis suggests that the primary site affected by air pollutants might be the airways, especially the small airways, rather than the pulmonary parenchyma.
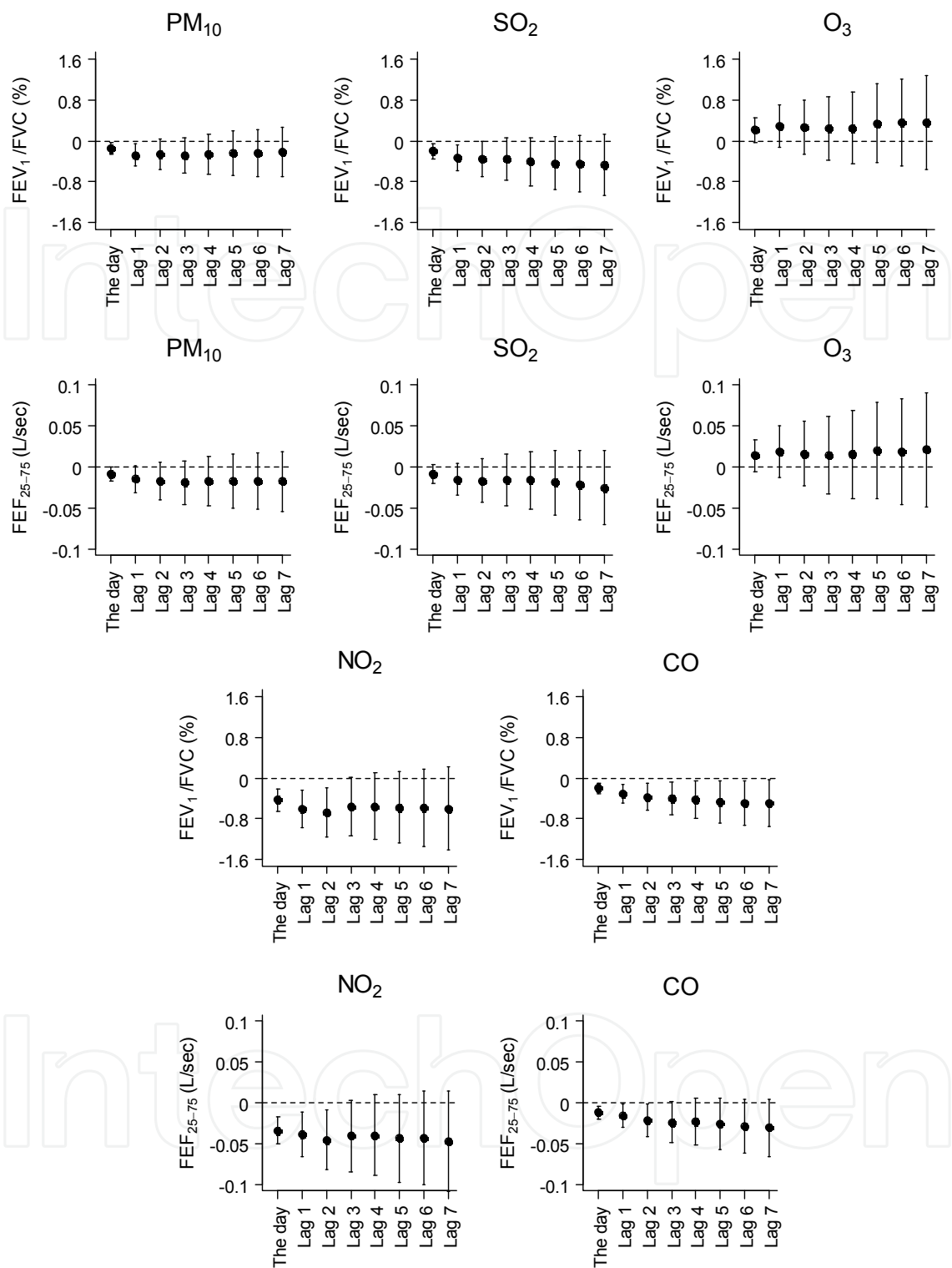
Fig. 2. The effect of PM_{10}, SO_2, O_3, NO_2, and CO on FEV_1/FVC and $FEF_{25\text{-}75}$ by distributed lag days. Changes in FEV_1/FVC (%) and $FEF_{25\text{-}75}$ (L/sec) were calculated per 10 μg/m³ of change in PM_{10} levels, per 1 ppb of change in SO_2, per 10 ppb of change in O_3, per 10 ppb of change in NO_2, and per 0.1 ppm of change in CO, adjusted for age, sex, body mass index (BMI), smoking status, alcohol consumption, dietary habits, temperature and relative humidity.

The estimated changes for the FEV_1/FVC and FEF_{25-75} results were -0.287% and -14 ml/sec with a change in PM_{10} levels of 10 μg/m³. An increase of 10 ppb for SO_2 reduced FEV_1/FVC results by -3.447% and FEF_{25-75} results by -157 ml/sec. An increase of 10 ppb in NO_2 reduced FEV_1/FVC by -0.542% and FEF_{25-75} by -27 ml/sec, and an increase of 100 ppb in CO reduced FEV_1/FVC by -0.300% and FEF_{25-75} by -14 ml/sec. Although these levels of reduction do not seem to be clinically significant for young adults, the impact of such air pollution on the already declining lung function of the elderly could be considerable.

The effect of air-pollution exposure on lung function is not necessarily contemporaneous (7). When we examined the pattern of lag in the relationship between air pollutants and lung function using single-lag-day and distributed-lag-day models, we found that the adverse effects of exposure to air pollutants could be detected immediately on the day of the exposure and that these effects had a lag period of 2 days except in the case of O_3, which did not show any effect during the test period. Lag structures in relationships between air pollution and respiratory health outcomes have been discussed in several studies. Goldberg et al. reported that the effect on the rate of respiratory-related deaths in persons older than 65 years was greatest following the same-day exposure (12). Braga et al. reported that respiratory deaths were affected more by exposure in the previous 1 to 2 days (13). Peters et al. reported stronger cumulative effects than the same-day effects of air pollution for asthmatic symptoms and peak expiratory flow rates (14). Our results are consistent with the short-term lag effects found in previous studies, showing that the cumulative effects of air pollution exposure on lung function were greater than the single-day lag effects, although the effect was no longer significant after lag day 2 for most of the air pollutants.

In our study, O_3 levels were not associated with changes in pulmonary function, although other pollutants were significantly associated. Estimating the effects of O_3 on lung function is challenging because of the strong correlation between O_3 levels and outdoor temperatures. However, in our results, the estimated risk level resulting from O_3 was constant, whether or not temperature was analyzed as a confounding variable.

The strengths of the present study merit further discussion. First, the panel study design, with repeated measurements on spirometric tests for each participant, provided a good opportunity to evaluate the short-term effects of the changes in air pollutant levels over time. In this longitudinal study, the subjects served as their own controls because personal characteristics could be assumed to remain constant over the study period. We used mixed-effects models to assess the effects of visit-to-visit variations in ambient air pollution on lung function to account for inter- and intra-subject variability. Individual exposure to other pollutants or other confounding factors could have biased the results if they had increased concomitantly with the measured air-pollution levels; however, this scenario is not likely.

There were also some limitations to this study. We could not completely control for those environmental factors that could have changed concomitantly with the levels of air pollutants, which could have biased the results for air-pollution effects. For example, possible environmental factors that could have confounded the results were meteorological variables, such as temperature and humidity. However, the relationships between air pollutants and pulmonary function can be significantly maintained, even after controlling for these meteorological variables. In addition, we did not measure precisely each individual's exposure level to ambient air pollutants, but we used monitoring data for the nearest site to their home. However, the misclassification of exposure levels according to the monitoring data may have contributed to a null association. Although we adjusted for other

potential factors affecting lung function, such as smoking, in the statistical analyses, concomitant exposure to other pollutants, such as volatile organic chemicals or heavy metals, could also have had some impact on lung function.

In conclusion, our findings suggest that short-term exposure to air pollutants reduces lung function in the elderly for a period lasting from the day of exposure to 2 days after exposure. These results contribute to our understanding of how short-term exposure to air pollution affects lung function.

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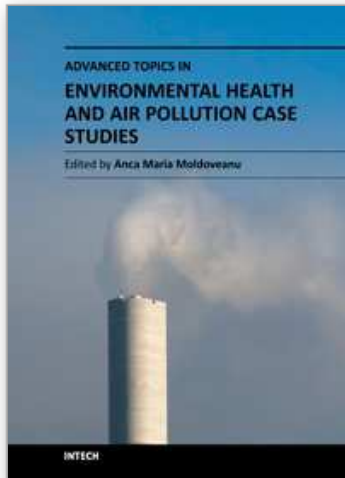
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