Air Pollution and Daily Mortality in Seven Major Cities of Korea, 1991-1997

Jong-Tae Lee,
Institute of Environmental and Industrial Medicine, Hanyang University,
Seoul, Korea,
jlee@hanyang.ac.kr

Ho Kim,
Department of Environmental Health, School of Public Health,
Seoul National University, Seoul, Korea,
hokim@snu.ac.kr

Yun-Chul Hong,
Department of Preventive Medicine, Inha University College of Medicine,
Incheon, Korea,
ychong@inha.ac.kr

Ho-Jang Kwon,
Department of Preventive Medicine, Dankook University College of Medicine,
Cheonan, Choongnam, Korea,
hojang@anseo.dankook.ac.kr

Joel Schwartz,
Department of Environmental Health, Harvard School of Public Health,
Boston, Massachusetts, USA,
jschwrtz@hsph.harvard.edu

David C. Chistiani,
Department of Environmental Health, Harvard School of Public Health,
Boston, Massachusetts, USA

1. OBJECTIVES

Several time-series investigations have shown associations between daily mortality and ambient air pollution in the limited central area of Korea (1-3). The findings are consistent with study results conducted in various countries and have potential to be an important contribution to air pollution epidemiology. There are, however, many differenced between Korean and other western countries, as well as within Korea itself, which may perhaps influence the health effects of air pollution; these include emission sources, pollution mixtures, climate, lifestyle, and the underlying health of the population. The consistency of the results across studies conducted in populations with varying levels of potential confounders plays a critical role in assessing causality of the adverse health effects of air pollution (4). Cities included in this study vary in several aspects, such as the lifestyle of populations, emission sources, pollution mixtures, climate, and geographic characters. Whereas the amount of air pollution attributable to automobiles varies, automobiles were a major source of ambient air pollution in all the cities of this study. A multi-city analysis of the short-term health effects of air pollution on mortality was conducted. This study investigated the effects of several air pollutants in seven major cities in Korea. This paper reports results from both the meta-like combined and the pooled analyses using data from the seven cities of Korea that cover almost the entire southern half of the Korean peninsula.

2. MATERIALS AND METHODS

We selected seven major cities in Korea as a study area that covers half of the Korean population and almost all of the southern half of the Korean peninsula. The major air pollution sources in Seoul, Kwangju, and Taejeon are automobile exhaust and domestic heating, whereas the other cities are sites of larger industrial concentrations. The numbers of deaths occurring in the study area between 1 January 1991 and 31 December 1997, according to the day on which deaths occurred, were supplied by the National Statistics Office of Korea. Deaths due to accidents were excluded, as were all deaths of residents outside of the study area. The Ministry of Environment of the Republic of Korea supplied data on air quality. Exposure measurements during the study period are based on results from monitoring stations in each city. Each monitoring station provided hourly ambient air concentrations of total suspended particles (β-ray absorption method), SO_2 (ultraviolet fluorescence method), NO_2 (chemiluminescent method), O_3 (ultraviolet photometry method), and CO (nondispersive infrared photometry method). Information on the 24-h average temperature and relative humidity was provided by the National Meteorological Office. Daily mean pollution and weather levels were constructed and filed during the study period. For O_3, we took the highest hourly measured concentration as the representative level for the day.

Previous studies suggested that air pollution may affect mortality with some lags, and the appropriate average time for exposure may exceed 24 hours; therefore, we considered various lead-lag situations, such as concurrent exposure, lagged exposure (up to four days), and various moving averages (including the concurrent day or not). Based on preliminary explorations, we selected the average of the concentrations on the current and a prior day as the primary analytic variable for all pollutants. The statistical analysis was conducted in two steps: each city was separately handled and analyzed to estimate the relationship between air pollution and mortality; and all data were pooled and analyzed to derive an overall estimation of the relationship. In the latter step, each city was coded to a dummy variable so that the indicator variables can be included in the regression model. Generalized additive models (GAM) that use nonparametric smoothing were applied to allow for highly flexible fitting of seasonality and long-term time trends, as well as nonlinear associations with weather variables such as air temperature and relative humidity (5,6). Meanwhile, meta-like analysis was also applied to give a summary estimator for the mortality effects of air pollutants and to compare the data with the pooled analysis. The meta-like summary regression coefficients were estimated as the weighted means of the individual regression coefficients based on each city, with the weights being the reciprocal of the local variances (fixed effects model) (7).

3. RESULT

The observed concentrations of sulfur dioxide (SO_2, mean=23.3 ppb), ozone (O_3, mean=23.7 ppb), and total suspended particulates (TSP, mean=77.9 ug/m^3) during the study period were at levels below Korea's current ambient air quality standards. Correlations between TSP, SO_2, NO_2, and CO tended to be moderately strong and positive (Pearson correlation coefficient, r = 0.49

~ 0.57). The correlations of O_3 with each of the other pollutants were very weak and negative (r = -0.24 ~ -0.11). The average daily death count was about 30 persons per day for these seven major cities in Korea. As we expected, the highest average daily death count was shown in Seoul and the lowest average daily death counts was shown in Ulsan. The death counts were linearly correlated with the size of the population in each city. The range of the daily mean temperature was –11~33 °C, which indicated there was a clear seasonal variation in this country.

Mortality rate ratios for air pollutants varied from one study city to another. One pollutant models for Seoul and Taegu were found to be significant in TSP and SO_2. In five cities (Kwangju, Pusan, Seoul, Taejeon, and Taegu), SO_2 was a significant predictor for all-cause deaths. An increase of 50 ppb of SO_2 corresponded to 1-12% more deaths, given a constant level of weather conditions. The highest effect of SO_2 on mortality was found in Taejeon (RR=1.13, 95% CI 1.05-1.21). The risk of all-cause mortality was estimated to increase by 0.5-4% with an increase in the two-day moving average of TSP levels equal to 100 $\mu g/m^3$. In multi-pollutant models with pooled data, we found that the estimated risk of death by SO_2 was notably unaffected by adding the other two pollutants (TSP and O_3) to the model and was statistically significant in various regression models. The rate ratio for SO_2 remained elevated, indicating an excess mortality of three percent per 50 ppb (RR=1.03, 95% CI 1.01-1.05). TSP's effect on mortality maintained its significance with O_3, but not with SO_2.

Table 1. Comparisons of analysis results from pooled data and combined meta-like analysis

Pollutant	Pooled analysis [1]	Meta-like combined analysis [2]		
	Relative risk (95% CI*)	Relative risk (95% CI)		p_{het}*
		Fixed effects model	Random effects model	
TSP* ($100\mu g/m^3$)	1.017 (1.008-1.026)	1.022 (1.012-1.030)	1.022 (1.012-1.030)[3]	0.581
SO_2* (50 ppb)	1.028 (1.016-1.040)	1.051 (1.038-1.064)	1.051 (1.028-1.075)	0.035

*CI, confidence intervals; p_{het}, p value from χ^2 for heterogeneity; TSP, total suspended particulates; SO_2, sulfur dioxide

[1]Data from all cities was pooled and analyzed in the same model that included indicator variables for all cities.

[2]Regression coefficients from each city were combined as followed by meta-analysis to calculate the summary estimate.

[3]The estimated between-city variation, τ^2, was a negative value. Thus, τ^2 was substituted to zero which meant that random effect model became the same as fixed effect model.

Table 1 shows both the pooled and meta-like combined estimates of relative risks and the tests for heterogeneity for TSP and SO_2. The RR and CI for the fixed effects model and random effects model for TSP are the same because the estimated between-city variation, τ^2, is a negative value (in this case, the estimated τ^2 should be substituted to zero, which means that the weights in both random effect model and fixed effect model are the same). Significant heterogeneity was found for the effect of sulfur dioxide. The estimated relative risks from meta-like analysis for TSP and SO_2 both increased by 29% and 82%, respectively, as we compared to those relative risks from pooled analysis.

4. SUMMARY

The findings of this study imply that there may be collinearity problems where TSP and SO_2 are included in the same model, or that TSP may function less than SO_2 as a surrogate for fine particles in the ambient air of Korea. In conclusion, increased mortality was associated with air pollution at SO_2 levels below the current recommendation for air quality. Further research is needed to clarify the relationship between SO_2 and fine particles in Korea.

REFERENCE

1. *Hong YC, Leem JH, Ha EH, Christiani DC. PM_{10} exposure, gaseous pollutants, and daily mortality in Inchon, South Korea. Environ Health Perspect 1999;107:873-878*
2. *Lee JT, Shin D, Chung Y. Air pollution and daily mortality in Seoul and Ulsan, Korea. Environ Health Perspect 1999;107:149-154*
3. *Lee JT, Schwartz J. Reanalysis of the effects of air pollution and daily mortality in Seoul, Korea: A case-crossover design. Environ Health Perspect 1999;107: 633-636*
4. *Bates DV. Health indices of the adverse effects of air pollution: The question of coherency. Envrion Res 1992;59:336-349*
5. *Pope CA III, Kalkstein LS. Synoptic weather modeling and estimates of the espoosure-response relationship between daily mortality and particulate air pollution. Environ Health Perspect 1996;104:414-420*
6. *Pope CA III, Schwartz J. Time series for the analysis of pulmonary health data. Am J Respir Crit Care Med 1996;154:S229-S233*
7. *Der Simonian R, Laird N. Meta-analysis in clinical trials. Control Clin Trials 1986;7:177-188*