HEALTH EFFECTS INSTITUTE

STATEMENT

Synopsis of Research Report 137

The Influence of Improved Air Quality on Mortality Risks in Erfurt, Germany

BACKGROUND

In 2002, as part of the Accountability Research program of the Health Effects Institute, HEI solicited research proposals to evaluate the effectiveness of measures intended to improve air quality, including proposals for research that focused on "real world experiments or measurement of the health impact of planned or unplanned actions that improve air quality." When East and West Germany were reunified, in October 1990, the city of Erfurt, in the former East Germany, underwent sweeping changes in its economy and energy use as a result of stricter environmental controls and the modernization of industry, transportation, and household heating. Over the next 11 years, the resulting changes in the sources and emissions of air pollution in the city affected its ambient air quality, and the mixture of pollutants changed from that associated with widespread coal combustion to one more similar to that of most Western European countries. However, the resulting changes in health impacts were difficult to predict, as there had been little published research on the consequences for mortality when pollution sources or emissions change so dramatically. However, data on mortality and measurements of pollution concentrations in Erfurt were available for this transition period, making it possible to evaluate the health impacts of such sweeping changes in air quality.

APPROACH

Dr. Annette Peters of the Institute of Epidemiology at Germany's GSF–National Research Center for Environment and Health (which, as of 2008, is now the Helmholtz Zentrum München–German Research Center for Environmental Health) with her colleagues performed a study of daily mortality and pollutant concentrations in Erfurt spanning the period of modernization that followed German reunification. Peters and colleagues had previously studied data from Erfurt on air pollution and health effects as part of an HEI-funded study of ultrafine particles (UFP) and mortality conducted by Dr. H.-Erich Wichmann and colleagues (HEI Research Report 98, 2000).

For the current study, Peters and her colleagues used daily measurements of concentrations of various air pollutants, available from 1990 to 2002, to study how the association between air pollution and risk of death (toxicity per unit of air pollutant) in Erfurt changed as the city's air quality changed. They presented relative risk (RR) results from Poisson models for each pollutant, as was done in Wichmann et al.'s time-series study, but the primary innovation of the study was the use of a complex statistical method known as time-varying coefficient modeling. Time-varying coefficient models were originally used to track insurance and investment risks and are at their most effective when used to study a series of changes that occur over a period of time rather than as a single event. The investigators used time-varying coefficient models to calculate the RR of death from various causes for a fixed change in the concentration of a pollutant in ambient air over the study period as a whole, thus providing a picture of how the unit toxicity of complex pollutants, such as $PM_{2.5}$ (particulate matter [PM] less than or equal to 2.5 μm in aerodynamic diameter) or gaseous mixtures, might have changed as fuels and pollutant sources changed and overall pollution levels declined.

This Statement, prepared by the Health Effects Institute , summarizes a research project funded by HEI and conducted by Dr. Annette Peters of the Institute of Epidemiology at the GSF–National Research Center for Environment and Health in Neuherberg, Germany and colleagues. The complete report, *The Influence of Improved Air Quality on Mortality Risks in Erfurt, Germany,* can be obtained from HEI or on our Web site (for contact information see last page).

RESULTS AND INTERPRETATION

Overall air-pollution concentrations in Erfurt decreased during the study period, with the largest reduction occurring for sulfur dioxide (SO_2; from 64 µg/m^3 in 1992 to 4 µg/m^3 in 2001). PM less than or equal to 10 µm (PM_{10}) or $PM_{2.5}$ and carbon monoxide (CO) concentrations decreased by more than 50%. High degrees of correlation were found between concentrations of nitric oxide (NO), nitrogen dioxide (NO_2), CO, and ultrafine particles—pollutants commonly associated with combustion in motor vehicles.

Results from the study's Poisson time-series models for individual pollutants are somewhat puzzling. Over the study period as a whole, RRs for all-cause mortality varied substantially from little or no association at some lags (the number of days between exposure and death) to significant associations at selected lags with an interquartile range (IQR) change in pollutant concentrations. All-cause mortality was associated with ultrafine particles (RR at lag 4 = 2.9%; 95% confidence interval [CI], 0.3% to 5.5%), CO (RR at lag 4 = 1.9%; 95% CI, 0.2% to 3.6%), and ozone (O_3; RR at lag 2 = 4.6%; 95% CI, 1.1% to 8.3%) and was marginally associated with NO_2 (RR at lag 3 = 1.6%; 95% CI, −0.4% to 3.5%). The investigators concluded that the results for ultrafine particles, NO_2, and CO, taken together, pointed to an association between mortality and local combustion sources. The lack of association between these pollutants and mortality at other lags is noteworthy, given the substantial drop in SO_2 and predominance of emissions from the combustion of coal in the early years of the study.

The time-varying coefficient models estimated RRs per IQR for pollutant exposures and all-cause and cause-specific mortality that had varied continuously across the study period. The models suggested that the RRs of mortality per unit of exposure to O_3, CO, ultrafine particles, and NO_2 varied during the period.

The investigators observed that the highest RRs per unit of pollutant concentrations occurred in the transition period and noted that this transient increase in risk occurred when pollutant sources were changing and the full benefits of the rapidly improving air quality had yet to be realized in mortality reduction. The HEI Health Review Committee noted that the observed variations in pollutant–mortality coefficients could also be due to chance, as the study had relatively low statistical power because of the low number of daily deaths in Erfurt. Methods for selecting the time lags between exposure and death were entirely based on a statistical analysis of the available data, rather than on any specific understanding of physiologic mechanisms linking exposure and death from various causes. The time lags between exposure and death were limited to the selection of a single day lag, as multi-day or distributed lags were not explored in this study. Other methodologic sources of uncertainty included the selection of confounders and methods for the control of confounding.

The observed pattern of variations over time in the toxicity per unit of the studied pollutants did not correspond to the known trends in the pollutants' concentrations or sources. Current scientific understanding is insufficient to predict what happens to unit toxicity as sources change from coal combustion to motor-vehicles emissions. Changes in risk over time might relate not only to changes in unit toxicity but also to changes in the effects of misclassification of exposure or in the vulnerability of the population. The extent or nature of exposure misclassification seems unlikely to have changed to a large extent over time in Erfurt, given the quality of the monitoring data, but the Review Committee noted that the report discussed variables associated with potential changes in the vulnerability of the population, such as its age structure and the prevalence of chronic cardiopulmonary disease and smoking; other potential variables could include diet and lifestyle. These variables were not explicitly included in the analysis, making epidemiologic inferences problematic.

Because of the limitations noted above — in particular the restricted power of the study — the Review Committee considered the investigation of dynamic risk by Dr. Peters et al. more valuable as an exploration of methods for tracking changes in unit toxicity during periods of changing air quality than as a source of substantive information on this issue.

A number of the study's conclusions were based on estimated effects on mortality of individual pollutants when analyzed over the study period as a whole. Considerable caution should be used in interpreting these overall effect estimates because of the factors mentioned above. The ongoing measurements of ultrafine particles by Dr. Peters and colleagues during a time of rapid change in Erfurt provided a unique opportunity to explore concurrent changes in mortality risks in this accountability study. The study's finding of an association between exposure to ultrafine particles and mortality may be important, given the paucity of other epidemiologic evidence on the health effects of ultrafine particles, despite intensive laboratory research. However, there is considerable uncertainty in the findings for ultrafine particles as the biologic basis for an association between mortality and exposure to ultrafine particles 3 or 4 days earlier (and not for other lag times) is not known, and previously reported associations between ultrafine particle exposure and mortality and nonfatal cardiac events from this research group are contradictory (Wichmann et al. 2000; Peters et al. 2005).

Given the extensive literature on associations between mortality and air pollution, it is puzzling that no consistent effects of $PM_{2.5}$ or PM_{10} were observed over the study period, although the null $PM_{2.5}$ results are consistent with an earlier report by the same investigators. Neither $PM_{2.5}$ nor PM_{10} daily mean concentrations were highly correlated with concentrations of ultrafine particles, which were associated with mortality risk. The investigators also observed effects on mortality of gaseous pollutants of vehicular origin (NO_2 and CO) at selected lags. Because of the high degree of correlation between the concentrations of ultrafine particles and the two gaseous pollutants, the effects were interpreted by the investigators as surrogates for particle effects, in particular the effects of ultrafine particles. The Review Committee noted that this interpretation was based on toxicologic grounds and was not strongly supported by the epidemiologic evidence presented in the report.

HEI considers this study to be an accountability study, in that it explores innovative, advanced methods to evaluate some subtle consequences of improving air quality. The situation in Erfurt differed from that in Dublin (which involved a ban on coal sales) or Hong Kong (which involved a regulation to reduce sulfur in motor fuel). In Dublin and Hong Kong, a permanent change in air quality enabled changes in health outcomes to be linked directly to the intervention. In the case of the slower, less well defined changes in air pollution seen in Erfurt, investigating changes in unit toxicity rather than overall changes in the risk of health outcomes clearly had interesting potential. However, the innovative methods that Dr. Peters and her colleagues used make severe demands on statistical power, as demonstrated in the report. Any future research that uses the methodologic work on time-varying coefficients developed by Peters and colleagues should first determine that the study population is of sufficient size to permit the methods to detect changes in unit toxicity over time with an appropriate degree of statistical certainty. The innovative methodologic work on time-varying coefficients carried out in this study could have an important part to play in a study of a sufficiently large population.

The Influence of Improved Air Quality on Mortality Risks in Erfurt, Germany

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