HEI

STATEMENT

Synopsis of Research Report 161

HEALTH EFFECTS INSTITUTE

Assessment of the Health Impacts of Particulate Matter Characteristics

BACKGROUND

Over the past several decades, epidemiologic studies in diverse locations across the United States and other parts of the world have reported associations between daily increases in low levels of ambient particulate matter (PM) mass and daily increases in morbidity and mortality. On the basis of these and other findings, many governmental agencies have set regulatory standards or guidelines for PM based on the concentration of its mass in ambient air.

However, scientists have long known that ambient PM is actually a complex mixture of solid and liquid airborne particles whose size, chemical composition, and other physical and biological properties vary with location and time. They have hypothesized that if the chemical components of PM most responsible for its associated health effects could be identified, it might then be possible to target their sources more cost effectively.

Until relatively recently, the large-scale epidemiologic studies necessary to explore associations between PM composition and health effects have not been possible. Data on particle composition were not collected systematically across the United States until 1999, when the U.S. Environmental Protection Agency began monitoring components of PM ≤ 2.5 µm in aerodynamic diameter ($PM_{2.5}$) in what has come to be known as the Chemical Speciation Network. Dr. Michelle L. Bell of Yale University sought to take advantage of this new source of composition data and proposed to evaluate the effects of short-term (that is, daily) exposures to various components of the $PM_{2.5}$ mixture on short-term morbidity and mortality, building on statistical methods established by the National Morbidity, Mortality, and Air Pollution Study and related research. The HEI Research Committee recommended funding her work under HEI's Walter A. Rosenblith New Investigator Award.

APPROACH

Bell's approach to investigating the relationship between the chemical components of PM and human health involved three broad steps. She began by characterizing how the chemical composition of $PM_{2.5}$ varies regionally and seasonally in the United States. Next, she evaluated whether the associations between short-term exposure to PM total mass and health effects followed regional and seasonal patterns. Finally, she evaluated whether the observed regional and seasonal variation in the health effects associated with PM total mass could in turn be explained by regional and seasonal variations in the chemical composition of $PM_{2.5}$.

The investigator obtained data on $PM_{2.5}$ total mass and on the mass of 52 chemical components of $PM_{2.5}$ for 187 counties in the continental United States for the period 2000 through 2005. She collected data on daily admissions to hospitals for cardiovascular- and respiratory-related illnesses for the period 1999 through 2005 for Medicare enrollees aged 65 years or older. Her analysis of the influence of $PM_{2.5}$ composition on associations between PM ≤ 10 µm in aerodynamic diameter (PM_{10}) and total nonaccidental mortality had to rely on associations reported from a previous study using earlier mortality data (from 1987 through 2000).

Bell focused her analysis of the regional and seasonal variation of components on seven components that made up 1% or more, on average, of $PM_{2.5}$ total mass on an annual or seasonal basis: ammonium, elemental carbon, organic carbon matter, nitrate, silicon, sodium, and sulfate. Together, these seven components made up more than 80% of annual average $PM_{2.5}$ mass.

Bell explored variations in the statistical associations between exposures to $PM_{2.5}$ mass and hospital admissions across regions and seasons using

This Statement, prepared by the Health Effects Institute, summarizes a research project funded by HEI and conducted by Dr. Michelle L. Bell of the School of Forestry & Environmental Studies and School of Public Health, Yale University, New Haven, Connecticut. The complete report, *Assessment of the Health Impacts of Particulate Matter Characteristics* (© 2012 Health Effects Institute), can be obtained from HEI or our Web site (see last page).

three different, but related, statistical models:

- The main model is based on the approach used in the National Morbidity, Mortality, and Air Pollution Study, in which a regression model is used to predict the percentage change in the daily rate of hospitalizations (from cardiovascular or respiratory disease) as a function of $PM_{2.5}$ concentrations on the same day, the previous day, or two days before. The relationship is assumed to be constant throughout the year.
- The seasonal model has essentially the same structure as the main model, with the exception that the relationship is allowed to vary by season — defined as four discrete 3-month periods — but to be constant within each season.
- The harmonic model essentially allows the $PM_{2.5}$ and hospitalization association to vary smoothly and continuously throughout the year.

Relationships between PM_{10} and mortality were estimated using only the main model. Each of the models included common approaches to controlling for other factors that might also influence rates of hospitalizations or mortality.

The last step of the analysis was to explore whether differences in levels of $PM_{2.5}$ components could explain any regional and seasonal variations in health effects associated with PM total mass. In addition to the seven key chemical components of $PM_{2.5}$ evaluated in the first part of her study, Bell examined 13 other components that either covaried with $PM_{2.5}$ or had been associated with adverse health outcomes in previous studies: aluminum, arsenic, calcium, chlorine, copper, iron, lead, magnesium, nickel, potassium, titanium, vanadium, and zinc. Note that her approach does not estimate the direct effect of individual component mass concentrations on rates of hospitalizations or mortality as is done for $PM_{2.5}$ or PM_{10}; instead, it evaluates how much the PM total mass–related health effect estimates change for each unit of variation, expressed as the interquartile range, in each component's fraction of PM in ambient air.

Finally, Bell explored the sensitivity of her main findings about the effects of individual components to some key variables in her model. She evaluated the sensitivity of the elemental carbon, nickel, and vanadium effects on the associations of PM total mass with hospital admissions and mortality to removal of individual counties from the data set, to adjustment for the presence of one or more of the other components, and to various characteristics of the communities (socioeconomic status and education level of its residents, racial composition, and degree of urbanization). She also assessed whether rates of hospitalization or of mortality could be partly explained by the prevalence of air conditioning.

RESULTS AND INTERPRETATION

In this study, Bell has shown persuasively that concentrations of $PM_{2.5}$ components vary across counties and regions of the United States as well as over seasons. Her analysis of the seven components making up most of $PM_{2.5}$ mass found patterns similar to those in other studies. Organic carbon matter, nitrate, and elemental carbon were generally higher in the West than in the East, with some seasonal differences; sulfate was higher in the East, particularly in summer; and sodium ion appeared most prominently along the coasts.

Similarly, she has demonstrated that relationships between daily $PM_{2.5}$ total mass concentrations and hospitalizations for cardiovascular and respiratory disease also vary over season and region. Using the main model, statistically significant increases in cardiovascular admissions associated with same-day exposures to $PM_{2.5}$ total mass were observed in spring and fall, but were largest in winter. These increases were greatest across the 108 Northeast counties, followed by the 25 Southwest counties. With the seasonal model, positive and statistically significant increases in cardiovascular admissions were observed only for the Northeast region and in all seasons. Results from the harmonic model were similar to those of the seasonal model.

When hospitalizations for respiratory disease were examined, the main model results showed a pattern of increases in rates of hospitalization that were most pronounced on the second day after exposure to $PM_{2.5}$ total mass. With the seasonal model, the percentage increases nationwide in respiratory hospital admissions were largest in the winter with same-day $PM_{2.5}$ exposures. In her analysis of the influence of air conditioning prevalence, Bell found that counties with higher levels of central air conditioning had lower $PM_{2.5}$ total mass effects on cardiovascular hospital admissions, particularly in summer. PM_{10} total mass effects on mortality were unaffected by air conditioning.

The main question Bell's report set out to answer was whether or not the variation in the $PM_{2.5}$ components could explain any variation in the health effects associated with $PM_{2.5}$ or with PM_{10} total mass. Her results show that the observed variations in the relationships between PM and health effects could only partly be explained by variation in the chemical composition of $PM_{2.5}$. Of the components that made up the largest fractions of $PM_{2.5}$ total mass, only variability in elemental carbon explained variation in $PM_{2.5}$ mass effect estimates for hospitalization. For the remaining components studied, Bell reported that greater content of nickel and vanadium in $PM_{2.5}$ was associated with larger $PM_{2.5}$ total mass health effect estimates for both cardiovascular and respiratory hospitalizations. PM_{10} mass associations with total nonaccidental mortality were also larger in regions and seasons with higher fractions of vanadium and particularly nickel in $PM_{2.5}$. These relationships showed some sensitivity to the removal of either New York County or Queens County from the analysis, by declining in size and, in some cases, significance. They did not appear to be sensitive to socioeconomic status, race, or how urbanized the counties were.

In its independent review, the HEI Health Review Committee commented that Bell's well-conducted study had taken a careful and logical approach to the exploration of both $PM_{2.5}$ chemical speciation data and their implications for human health in the United States. Her work represents one of the largest efforts to take advantage of the $PM_{2.5}$ speciation data available for 52 chemical species and to analyze them in conjunction with data on hospital admissions and nonaccidental mortality from throughout the continental United States. In the spirit of the Rosenblith Award, her work bodes well for her development as an investigator.

However, the Committee concluded that a causal interpretation of the relationships between $PM_{2.5}$ composition and PM mass health effects observed in this study would be premature and agreed with Bell that more research is needed. Although some alternative explanations for spatial variation were considered (e.g., county, region, socioeconomic status, race, and degree of urbanization), the study ultimately could not rule out the possibility that other explanations might account for the observed influence of components on PM total mass health effects. No alternative explanations were considered for temporal variation. In view of these and other limitations discussed in the report (e.g., the absence of basic details about and evaluation of the implications of minimum detection limits for individual chemical species), the Committee concluded that the evidence from Bell's study implicating elemental carbon, nickel, and vanadium in the $PM_{2.5}$ impacts on hospitalizations and nickel and vanadium on mortality associated with PM_{10} should be considered only suggestive at this time. The Committee also thought that suggestions about specific sources for the influential components identified — whether in this report (e.g., traffic) or in Bell's related publications (e.g., power-generation, coal combustion, and residual oil, as in Bell 2008) — should also be viewed cautiously. That Bell's study has not led to more than very tentative and partial conclusions about the toxicity of PM components reflects the considerable complexity of the task, rather than deficiencies of her approach, which indeed offers important insights for future studies.

Bell's work now sits within a broader, rapidly growing body of epidemiologic literature that reports on associations between PM components and a range of health outcomes. Studies differ along many more dimensions — design, regional coverage, time period covered, study-population characteristics, PM size fraction, number of particles, components measured, copollutants measured, monitoring methods, health endpoints, and statistical methods applied. This current situation makes both simple comparisons and systematic reviews challenging. Bell's study, however, represents an early step in HEI's larger National Particle Component Toxicity initiative. The systematic toxicologic and epidemiologic studies in that multicenter effort are nearing completion and may help bring more consistent, comparable approaches to these important investigations going forward.

HEALTH
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INSTITUTE

101 Federal Street, Suite 500
Boston, MA 02110, USA
+1-617-488-2300 phone
+1-617-488-2335 fax

pubs@healtheffects.org
www.healtheffects.org

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