Invited Commentary

Invited Commentary: Heterogeneity of Particulate Matter Health Risks

Paige E. Tolbert

From the Department of Environmental and Occupational Health, Rollins School of Public Health, Emory University, Atlanta, GA.

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Ambient particulate matter varies in composition and toxicity; therefore, some heterogeneity in risk per unit mass can be anticipated. In this issue of the Journal (Am J Epidemiol 2007;166:880–888), Dominici et al. explore temporal and spatial effect modification of particulate matter potency with the goal of gaining insights about how differences in the mixture may affect toxicity of the particulate matter, and they propose that it may be a useful tool in assessing the net impact of regulatory activity. Their approach is fresh and creative and yields provocative results. Such assessments will, of course, be constrained by limited power to detect the expected small degree of effect modification, as well as an abundance of possible explanations for observed differences in risk per unit mass. The utility for accountability assessment is further limited because regulatory actions impacting particulate matter levels do not necessarily target the most toxic species within the mixture and may confer benefits by reducing population exposure to particles and components of lesser toxicity. Used cautiously, however, this new methodology may provide a complementary approach to more direct assessments in shedding light on the characteristics of ambient particulate matter predictive of health effects.

Abbreviations: PM$_{2.5}$, particulate matter with an aerodynamic diameter of $<$2.5 μm; PM$_{10}$, particulate matter with an aerodynamic diameter of $<$10 μm.

Particulate matter is not particulate matter is not particulate matter . . . . The variable composition and differential toxicity of its components undoubtedly explain some of the variability in health risk per unit mass observed across studies of ambient particulate matter. Particulate matter comprises a variety of constituents including sulfates, nitrates, carbon compounds, and crustal materials such as soil dust, some emitted directly by sources such as vehicles, power plants, and vegetative burning and others formed through atmospheric reactions. The etiology of the health effects of particulate matter is complex, with various physical attributes and chemical constituents operating and interacting along a variety of interrelated mechanistic pathways to elicit distinct health outcomes (1). Ambient particulate matter has been consistently associated with cardiorespiratory morbidity and mortality, but little is understood about characteristics of particulate matter that may be driving these associations. Given that composition varies across geographic areas and over time, the following question arises: Can spatial or temporal differences in observed risk per unit mass provide insight into the relative potency of the mixture present in the particulate matter in different settings and reveal attributes of particulate matter predictive of health outcomes?

In this issue of the Journal, Dominici et al. (2) explore effect modification of associations of particulate matter with an aerodynamic diameter of $<$10 μm (PM$_{10}$) over time and space and posit that such effect modification may be studied to assess the health benefits of air quality regulations. They compare the short-term associations of PM$_{10}$ with mortality for the periods 1987–1994 and 1995–2000, using the National Morbidity, Mortality, and Air Pollution Study database covering approximately 100 US counties, to assess the overall
impact of regulations that went into effect during this time period. The premise is that if the net impact of the regulatory actions was to decrease harmful components of PM$_{10}$, the potency of PM$_{10}$ per unit mass would decrease. A comparison of changes in PM$_{10}$ potency in the eastern and western regions of the United States, where regulatory activities likely resulted in different impacts on particulate matter composition, is presented as well. The authors report a "weak indication" that 1) the per-unit impact of PM$_{10}$ has decreased over the time period in question, and 2) this action occurred to a greater degree in the east than the west. They report "strong evidence" that PM$_{10}$ continues to be associated with mortality, as well as new evidence that particulate matter with an aerodynamic diameter of $<2.5$ $\mu$m (PM$_{2.5}$) is also associated with mortality (1999–2000).

The findings regarding continued mortality impacts of PM$_{10}$ and evidence of similar impacts of PM$_{2.5}$ (for which measurements began being conducted nationally in 1999) are important and warrant the attention of policy makers and public health providers. The findings regarding effect modification are provocative but less convincing, and the accountability framework is not entirely compelling. The questions posed are difficult to tackle for many reasons, and the authors are to be commended for developing a fresh way to approach them indirectly by using available data. The authors’ findings weakly support the hypothesis that particulate matter toxicity has decreased overall and that this reduction has occurred to a greater degree in the eastern United States, where impacts of certain regulatory activities, such as the Acid Rain Program, were likely more pronounced.

The authors point out that there are a number of alternative explanations for the observed differences in risk per unit mass of PM$_{10}$, as there would be in any investigation using this approach. First, the results may simply represent chance fluctuations or noise, particularly since the differences do not approach statistical significance. Second, nonlinearities in the associations could lead to apparent differences in potency as a reflection of examining a different part of the dose-response curve. If the curve were sublinear in the observed range of particulate matter levels, the overall reduction in particulate matter levels over the time period in question could lead to a reduced apparent potency. The authors have previously shown that the dose response is consistent with a linear pattern (3, 4); however, this is not the same as demonstrating that the pattern is not nonlinear. Unlike other contexts, the present analysis depends strongly on the dose response being linear in the range of the observed values. Another possible alternative explanation is differing degrees of exposure misclassification (defining true exposure as personal exposure to particulate matter of ambient origin) during the two periods, for example, if people were using air-conditioning more often or if new houses were being built to be more airtight. Susceptibility of the underlying populations may differ between the two periods. Finally, one must reserve some caution for other commonly cited potential limitations of air pollution studies of this type, such as uncontrolled confounding and model misspecification. Clearly, many alternative explanations for the observed patterns are possible, leading to concerns about potential overinterpretation of the results.

Moreover, the amount of effect modification that is realistic to expect in these types of comparisons may be small. Particularly if mortality is the outcome—the end result of a number of different health-effect pathways—one might anticipate that multiple components may be relevant in the association and that the differential toxicity of components may be less extreme than for a single, specific outcome. The changes in chemical composition are not likely to be so striking that they would lead to dramatic changes in the potency of particulate matter at the midpoints of the two study periods (1990 vs. 1997). Because there is little information on specific changes in composition over the study period and a limited understanding of the relative roles and interactions of different particulate matter components in the association with mortality, it is difficult to hypothesize the degree of expected effect modification. Therefore, this undertaking is necessarily more of a descriptive, exploratory exercise.

The authors have proposed this methodology as one way to assess whether the regulations that went into effect over the study period had a beneficial impact on health, motivated by the recent interest in accountability assessments (5). The question posed is quite narrow: Was the net impact of the regulations over this time period a reduction in the risk per unit of PM$_{10}$? The assumption is that regulations seek to differentially target the most toxic PM$_{10}$ species. Clearly, regulations impacting particulate matter components can exert public health benefits without leading to a change in the apparent potency of particulate matter mass. In the simplest case, if all components are reduced proportionally, there would be a health benefit to the population in terms of reduced mortality attributable to PM$_{10}$ and its constituents, but there would be no change in the risk per unit mass; in other words, the overall risk would be reduced, but the risk ratio would be unchanged. If less toxic agents were reduced proportionally more than the more toxic agents, there would still be a health benefit, but in this case the risk per unit mass would actually increase. In a third scenario, if components of moderate toxicity are reduced more than other species, increasing the proportion of species of low toxicity and high toxicity, there would be a health benefit, and the apparent potency could either increase or decrease depending on the relative toxicities of the various fractions and their proportions. In each of these scenarios, the regulatory actions would have produced health benefits to society that would be better assessed by measures that account for the change in particulate matter levels and particulate matter components experienced by the population, rather than the risk per unit mass. For instance, the pre-to-postintervention change in population attributable risk (or the impact fraction) could be a useful measure, even for examination of short-term effects of acute exposure.

An interesting angle on the assessment of particulate matter potency warrants consideration. The US National Ambient Air Quality Standards address PM$_{10}$ and PM$_{2.5}$ mass. If, for instance, states achieve attainment largely by reducing less toxic or inert components because this action happened to be easier or less costly, the overall health benefit of the reduction in particulate matter levels could be less than anticipated, and the overall health risk associated with the allowable ambient levels could be greater than intended. The potency assessment could be useful in elucidating these types of issues.

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In the future, more studies will be able to directly assess component effects and the impact of regulatory actions on levels of specific components, for example, by using speciated particle data that have been collected since 1999 by the Speciation Trends Network (6, 7). The tool presented by Dominici et al. in this issue of the Journal (2) provides a complementary approach even if speciated data are lacking. Power considerations will be paramount in these types of assessments. Typical studies will have difficulty attaining sufficient sample size, as evidenced by the calculations presented by Dominici et al. (2), even for detection of dramatic effect modification (reduction of particulate matter effect by 75 percent or 100 percent). Thus, the utility of this approach will be best realized when a sufficiently long record with ample daily counts is available. Finally, caution must be exercised in interpreting such results as impacts of regulatory actions. For example, particulate matter composition is influenced by a variety of factors, including short- and long-term variation in meteorologic conditions that can affect the formation of secondary components. Assessment of effect measure modification of particulate matter risks per unit mass will likely reveal more about characteristics of the particulate matter mix responsible for adverse health effects than it will about the overall accountability of regulatory actions.

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REFERENCES