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Air Pollution Levels and Children's Lung Health
How Low Do We Need to Go?

During the 25 years since the last amendment to the Clean Air Act, ambient air pollution concentrations in the United States have decreased significantly. These reductions represent a major public health success of the regulations resulting from this law. This poses a question: Have we reached or are we approaching a point at which health effects are no longer attributable to the primary air pollutants? The existing body of evidence regarding respiratory health effects of air pollutants has largely been based on research conducted at higher concentrations than those now experienced in the United States.

Respiratory health effects of air pollutants occur throughout the lifespan, although children are considered an especially susceptible population. Children are exposed to a higher burden of pollutants because of their greater ventilatory rate and propensity to spend more time outdoors, engaged in physical activity. They are also exposed at a vulnerable stage, when the immune and metabolic systems are less mature and the lungs are rapidly developing (1).

Evidence has linked air pollutants to a variety of adverse respiratory outcomes in children, from higher rates of bronchitis to an increased incidence of asthma (2). Epidemiologic studies have also shown that air pollution is associated with lung function impairment in children (3–6). Although the full implications of this finding are unknown, it is postulated that even subclinical declines in lung function may portend subsequent cardiopulmonary morbidity (7).

Several cross-sectional and cohort studies have found long-term air pollution concentrations associated with a decline in spirometry in children. Some studies have shown a proportional decline in spirometry consistent with a restrictive ventilatory defect (4, 5, 8, 9), whereas others have observed more obstructive physiology (10, 11). A recent cohort study in Germany did not observe decreased pulmonary function in association with air pollutants; however, this study applied exposure models from the end of follow-up that did not account for changes in long-term air pollution concentrations that occurred over time (12). Importantly, the shape and slope of the exposure–effect relationship has been difficult to determine because of concerns over exposure misclassification, correlations between pollution levels during different stages of life, and residual confounding. Furthermore, it is uncertain whether these changes persist at lower levels of pollution.

In this issue of the *Journal*, Rice and colleagues (pp. 881–888) present an analysis within a well-designed prospective cohort to assess whether long-term ambient air pollution adversely affects lung function, even after policy changes that resulted in improvements in air quality (13). In contrast to other studies, the authors were able to characterize the cohort and potential confounders from birth, they used advanced modeling of exposures to air pollution within a city and over time, and they used robust measurements of lung function by including both pre- and post-bronchodilator spirometry. Their study suggests that even pollutant concentrations that are below current U.S. Environmental Protection Agency standards (12 $\mu g/m^3$ annual average) are associated with a decrease in spirometric measures.

The study followed 614 mother–child pairs that were born in Boston, Massachusetts, from 1999 to 2002 until lung function was measured at a middle-childhood visit (median age, 7 yr). The authors focus their analysis on three measurements of air quality: a model of particulate matter with aerodynamic diameter ≤ 2.5 μm ($PM_{2.5}$), a model of black carbon (BC), and a metric of distance to

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the nearest roadway. Their pollutant modeling estimates daily individual exposure at home addresses, using a combination of daily satellite-derived observations and land use regression. In their analyses, they are able to adjust for key potential confounders.

The authors found that all three air pollution metrics ($PM_{2.5}$, BC, and proximity to nearest major roadway) were associated with a reduction in FVC, but not as clearly with measurements of irreversible or reversible airflow obstruction. $PM_{2.5}$ was also associated with the clinically relevant cutpoint for reduced lung function ($FEV_1 < 80\%$). Their analysis suggests that exposures in the year before spirometric measurements were more important than exposures during the first year of life, which could lead to speculation that some effects of these air pollution effects are reversible. Also, although exposures in the first year of life were higher, the most recent $PM_{2.5}$ concentrations were estimated to be below 12 $\mu g/m^3$ for most of the cohort.

The findings of this study corroborate previous research of children exposed to higher levels of pollution, suggesting there is significant impairment of lung function even at current standards of air quality. We should note that epidemiologic studies to date, including this one, have not measured lung volumes, so any conclusions regarding lung "growth" are speculative. Here, Rice and colleagues postulate that the pattern of lung impairment they observed could be consistent either with restricted growth or with a pattern of small airway obstruction that results in proportional decline in forced expiratory volumes (13). This later hypothesis might be more in keeping with pollution's known effects of airway inflammation and radiographic evidence of lung hyperinflation and air trapping in exposed children (14).

The findings of Rice and colleagues provide compelling additional evidence that it is timely to reevaluate the effects of lower levels of air pollutants on human health (13). Although carefully conducted, there are limitations to the work that should be noted, in addition to the usual caveats regarding observational rather than experimental designs and the risk for residual confounding. The study was performed in a relatively homogenous population in Boston, and the findings may not be generalizable to a population in which other determinants of lung function may predominate. The outcome of lung function is only measured once in study participants, so the time course of effects is unknown, and it is uncertain whether these changes represent a reversible effect versus a permanent change in lung development that leads to a lower adult maximum in lung function (12).

These important findings are from a novel study combining modern modeling of exposures to air pollution with robust measurements of lung function, conducted in a community with pollutant levels now lower than Environmental Protection Agency standards. This adds to the urgency for more work to understand the effects of these low-level exposures on human health. Is there a safe level of exposure to air pollutants?

These findings appear even as communities in rapidly developing economies such as China and India are experiencing increasing and dramatic high levels of air pollutant exposure, with some locations reporting concentrations more than an order of magnitude greater than those observed in this study in Boston. Taken together, the questions about the "shape" of the relationship between exposure and health are urgent and important, with implications for research and public policy. It appears that benefits of pollution control accrue at all levels of exposure, and we do not yet know the levels that will avoid important impacts on health. ■

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Cora S. Sack, M.D.
Joel D. Kaufman, M.D., M.P.H.
Department of Medicine
Department of Environmental and Occupational Health Sciences
and
Department of Epidemiology
University of Washington
Seattle, Washington

ORCID ID: 0000-0003-4174-9037 (J.D.K.).

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