Health Effects of Acid Aerosols on North American Children: Pulmonary Function

Mark Raizenne,1,2 Lucas M. Ness,3,4 Andrew I. Damokosh,1 Douglas W. Dockery,1,4 John D. Spengler,1 Petros Koutrakis,1 James H. Ware,5 Frank E. Speizer1,4

1Department of Environmental Health, Harvard School of Public Health, Boston, MA 02115 USA; 2Environmental Health Directorate, Health Canada, Ottawa, K1A0L2 Canada; 3Department of Epidemiology, Harvard School of Public Health, 4Channing Laboratory, Brigham and Women's Hospital, Harvard Medical School, 5Department of Biostatistics, Harvard School of Public Health, Boston, MA 02115 USA

We examined the health effects of exposure to acidic air pollution among children living in 24 communities in the United States and Canada. Parents of children between the ages of 8 and 12 completed a self-administered questionnaire and provided consent for their child to perform a standardized forced expiratory maneuver at school in 22 of these communities. Air quality and meteorology were measured in each community for the year preceding the pulmonary function tests. Forced vital capacity (FVC) and forced expiratory volume in 1 sec (FEV1) measurements of 10,251 white children were examined in a two-stage regression analysis that adjusted for age, sex, height, weight, and sex-height interaction. In this study, a 52 nmol/m3 difference in annual mean particle strong acid was associated with a 3.5% (95% CI, 2.0–4.9) decrement in adjusted FVC and a 3.1% (95% CI, 1.6–4.6) decrement in adjusted FEV1. The FVC decrement was larger, although not significantly different, for children who were lifelong residents of their communities (4.1%, 95% CI, 2.5–5.8). The relative odds for low lung function (that is, measured FVC less than or equal to 85% of predicted), was 2.5 (95% CI, 1.8–3.6) across the range of particle strong acid exposures. These data suggest that long-term exposure to ambient particle strong acid may have a deleterious effect on lung growth, development, and function.

Key words: acid aerosols, air pollution, children, pulmonary function. Environ Health Perspect 104:506–514 (1996)

Experimental studies of sulfur dioxide and particulate pollutants have indicated adverse health effects in both animals (1) and human subjects (2). Epidemiologic studies of acute health effects have found decreased lung function (3), increased respiratory symptoms and illnesses (4), increased hospitalizations (5,6), and increased mortality (7) to be associated with current levels of particulate air pollution in many urban areas. Particle strong acid is found in the fine-size fractions of suspended particulates, raising the possibility that the observed chronic health effects associated with respirable particulate pollution may be attributable at least in part to the acidity of the particles (8,9). However, previous population-based studies lacked direct measures of particle acidity; investigators used surrogate measurements to assess the possible effects of particle acidity on health. Improvements in atmospheric monitoring have resulted in the direct measurement of particle acidity in various locations throughout North America (10). Because of the widespread distribution of the exposure and the toxicological and clinical data suggesting potential effects, concern has been raised regarding the possible adverse health effects resulting from exposures to particle acidity (11,12).

Previous population-based studies have relied on measurements of pollutants that were only indirectly related to particle acidity. The Harvard Six Cities Study of 5422 children demonstrated that particulate matter <15 μm in diameter was associated with reported bronchitis in the past year, but no statistically significant associations were observed for pulmonary function (13,14). A later analysis suggested that the annual mean of particle strong acidity was associated with reported bronchitis in the past year [odds ratio (OR) = 2.4, 95% confidence interval (CI), 1.9–3.2] among a separate cohort of 12,302 children in six communities plus Charleston, West Virginia (15), but the measurements of particle acidity were made after the collection of the health data. Authors of earlier studies suggested that the power of an epidemiologic study to detect the health effects of particle acidity would be enhanced by increasing the number of communities (16) and by selecting communities at the extremes of the continental scale range of aerosol acidity exposures (17). The present study (18) was specifically designed to examine the adverse health effects resulting from repeated intermittent, long-term exposures to directly measured particle strong acidity on pulmonary function and respiratory symptoms [reported in an accompanying paper (19)] of schoolchildren.

Methods

Air monitoring. We selected 24 communities on the basis of previously measured sulfate and ozone concentrations and demographic characteristics (20). We included 18 sites in the United States and 6 sites in Canada to provide a wide range of expected acid aerosol and ozone levels. Communities were predominantly suburban or rural with homogeneous, relatively stable populations and no major local sources of air pollution. Each site was monitored for approximately 12 months, and pulmonary function tests were conducted at the end of the year in all but two of the communities. Eight sites were monitored during the first year, nine sites in the second year, and seven sites in the third year of the study.

Air pollution measurement methods and results are described in an accompanying paper (20). We sampled particulate pollutants for 24 hr every other day for at least 11 months. Inhalable particulate matter with an aerodynamic diameter <10 μm (PM10) was sampled using a Harvard Impactor (21). Fine particulate matter with an aerodynamic diameter >2.1 μm (PM2.1) was sampled using a glass impactor/filter pack system. Fine particle strong acidity, fine particle sulfate, and gaseous acids (nitrous and nitric acids) were sampled using the Harvard EPA Annular Denuder System (HEADS) in 21 communities.
In three communities with low levels of gas-phase acidity, the simpler Harvard Impactors with ammonia condensers were used. Strong acidity was measured by pH analysis (24) and sulfate by ion chromatography of the extracted particles. Ozone was monitored continuously.

**Respiratory health questionnaire.** In communities with fewer than 750 children enrolled in the fourth and fifth grades of public schools, all schools were included in the study. In larger communities, schools were selected according to their proximity to the air monitoring sites or randomly, depending on geography of school district(s). A standard respiratory health questionnaire was distributed to each child for completion by a parent or guardian. All questionnaires were distributed in late September or early October. A return rate of more than 90% was attained for all but six communities, where the return rate was 84% or higher (25). The association between particle acidity and respiratory symptoms is reported elsewhere (25).

**Lung function testing.** Pulmonary function tests were administered by trained field technicians between October and May to those children with parental permission. Pulmonary function measurements were generally scheduled in each community to be completed with the end of the air monitoring sampling. The study protocol and methods were approved by the human subjects committee at the Harvard School of Public Health and separately by local health authorities and school boards in each community. The local school boards in two communities subsequently withdrew their permission to conduct the pulmonary function testing, although questionnaire data were collected.

The same centrally trained technicians administered a standard forced expiratory test throughout the study according to methods suggested by the American Thoracic Society (26) using a Spiroflow rolling seal spirometer system (PK Morgan, Andover, Massachusetts). All spirometers were calibrated each morning and afternoon on test days using a 3.0-I syringe and independently audited annually (27). Measurements were corrected to body temperature and pressure saturated with water (BTPS). Before testing, each child was asked a series of questions regarding present respiratory health, asthma and medication use, smoking habits, and recent exercise. After measurement of height and weight with shoes removed, each child performed at least five but not more than eight forced expiratory maneuvers while sitting with free mobility and with a noseclip to obtain three acceptable maneuvers.

Using a computer-assisted quantitative assessment, field technicians determined the acceptability of each maneuver according to the following criteria: the blow was a good effort with a maximal inspiration, a strong start, and continuous exhalation; the back-extrapolated volume was >100 ml or 5% of forced vital capacity (FVC); the exhalation had a duration of at least 3 sec; and the change in volume in the last 2 sec was less than 45 ml. Acceptable tests were considered to be reproducible if they had an FVC and an forced expiratory flow at 1 sec (FEV$_1$) within 5% of the maximum value on an acceptable test. During the first year of the study, children enrolled in the fifth grade also performed partial flow-volume maneuvers after the full forced expiratory test (28).

**Statistical methods.** Previously reported analyses of city-specific health outcomes demonstrated a larger between-city variation than would be predicted by individual variation (13,14). In the present study, a two-step analysis was used to correct for any excess between-city variability. In the first step, we calculated city-specific adjusted means by regressing the natural logarithm of the pulmonary function measurement on sex, age, height, weight, and an interaction term of sex and height. In the second step, we regressed these adjusted means against the city-specific annual mean air pollution concentrations using weights inversely proportional to the sum of the between-city and within-city variances of the adjusted means. Analyses were done using SAS software (SAS Institute, Inc., Cary, North Carolina). Results of the weighted regression coefficients and standard errors are summarized as the estimated relative changes in pulmonary function parameters scaled to the range in the city-specific annual mean of air pollution. Stratified and sensitive subgroup analyses were conducted in a similar fashion using the two-step approach.

A second analysis assessed the prevalence of children whose pulmonary function was less than 85% of the value predicted by the analysis performed in stage one. We calculated city-specific logits of the fraction of children with FVCs <85% of predicted. The stage-two analysis was conducted as described above, but using the sum of the between-city and within-city variances of the adjusted logits as the weights. The logistic regression coefficients and their standard errors are expressed as odds ratios scaled to the range in the city-specific annual means of air pollution.

**Results**

A total of 15,523 questionnaires were returned, of which 14,103 had complete...
information on selected covariates for white children age 8–12 years. We excluded 736 children because of significant medical conditions unrelated to air pollution: children with a history of cystic fibrosis, chest operations, heart conditions, or who received oxygen for more than 2 weeks after birth or at home. A total of 1537 children did not attempt the pulmonary function test, mainly due to lack of parental permission. In addition, 82 children were excluded who smoked more than five cigarettes in their lifetime, 10 children with missing heights or weights, 133 children (1%) with extreme heights (<120 cm or >160 cm), and 133 children (1%) with extreme weights (<50 lbs or >150 lbs). After eight attempts, 721 children (6%) had no acceptable pulmonary function test, and an additional 502 children (5%) failed to have two acceptable tests. These restrictions left a data set of 10,251 children in 22 communities with at least 2 acceptable pulmonary function tests.

The communities had similar means for gender, age, height, and weight as well as similar numbers of children excluded from the analysis with the exception of Newtown, Connecticut (Table 1). Newtown was the first community examined, and a technical error led to a higher exclusion rate. Due to the restrictions on height and weight, the children were of similar stature across the 22 communities, with city-specific means ranging from 140 to 144 cm for height and from 79 to 91 lbs for weight (36–41 kg). The communities also had similar proportions of children in subgroups considered potentially sensitive to air pollutant health effects (Table 2). Approximately three-fourths of the children had lived in their current community since at least age 6, and most had lived in their current community since birth. The proportion of children in each community who were exposed to environmental tobacco smoke in the home ranged from 28% to 63%.

The ranges in the city-specific annual means (Table 3) for particulate pollutants were 51.9 nmol/m³ for particle strong acidity, 6.8 μg/m³ for sulfate particles, 14.9 μg/m³ for respirable particulate matter (PM₁₀), and 17.3 μg/m³ for inhalable particulate matter (PM₂·₅). City-specific mean particle strong acidity was moderately correlated with PM₁₀ [Pearson's correlation coefficient (r) = 0.47], strongly correlated with sulfate (r = 0.90) and PM₂·₅ (r = 0.82), and essentially uncorrelated with gaseous acids (r = 0.07). Three exposure parameters were considered for the annual mean ozone concentration: the average maximum 1-hr mean, the average daytime 8-hr (1000–1800 hr local time) mean, and the average daily 24-hr mean. All three ozone parameters were highly correlated across the 24 communities, with Pearson correlation coefficients ranging from 0.74 to 0.98. By design, city-specific mean particle strong acidity was correlated only weakly with the three ozone parameters; the strongest correlation was with the average 1-hr maximum ozone concentration (r = 0.37). A more complete description of air monitoring results can be found in an accompanying article (20).

We calculated city-specific mean pulmonary function values adjusted for sex,
Age, height, weight, and the interaction of sex with height (Table 4). Adjusted FVC ranged from a low of 2.38 l in Charlottesville, Virginia, to a high of 2.52 l in Penticton, British Columbia, and Yorkton, Saskatchewan. The coefficients of variation for these city-specific pulmonary function values were small (range 0.4-0.6% for FVC) because of the narrow age range of the children studied in each community. The city-specific adjusted means of the five pulmonary function parameters were highly correlated, with Pearson correlation coefficients ranging from 0.99 for the association of FEV1,0 with forced expiratory volume at three-quarters of a second (FEV1,75) to 0.50 for the association of forced expiratory flow between 25% and 75% of FVC (FEF25-75%) with peak expiratory flow rate (PEFR). The ratio of FEV1,0 and FVC was only weakly correlated with the basic pulmonary function measurements across the 22 communities, with the strongest correlation shown for FEF25-75% (r = 0.37). The proportion of children with an FVC <85% of predicted ranged from 2.0% in Yorkton, Saskatchewan to 8.9% in Charlottesville, Virginia.

Particulate air pollutants, including measurements of particle strong acidity, were associated with decreased pulmonary function levels among the children in these communities (Table 5). Particle strong acidity across the 22 communities (range 52 mol/m³) was associated with a 3.5% decrement (95% CI, -4.9 to -2.0) in FVC (Fig. 1). Controlling for daytime ozone had little effect on the association between FVC and particle strong acidity (Fig. 1). Similar differences in FVC were seen for the other particulate pollutants (Table 5), with the smallest decrement in FVC (-2.4%, 95% CI, -4.3 to -0.5) associated with the 17.3 µg/m³ range in PM10 concentrations. The other measures of pulmonary function, including FEF25-75% and PEFR, showed decrements similar to that for FVC. The ratios of the pulmonary function measurements with FVC were not associated with any of the measured air pollutants.

All three ozone parameters were associated with a decrease in pulmonary function (Table 6); daytime mean ozone showed the strongest association (Fig. 2). Although the association with daytime mean ozone alone was statistically significant (-3.7% difference in FVC scaled to the range of 39.4 ppb in daytime ozone), adding particle strong acidity into the model (Fig. 2) resulted in a substantial attenuation of the daytime ozone effect (-2.2%, 95% CI, -4.2 to -0.2, difference in FVC scaled to the range of daytime mean ozone). This suggests that the association between daytime ozone and adjusted FVC is partially explained by the correlation of daytime mean ozone with particle strong acidity. However, the explained variation in FVC associated with particle strong acidity was independent of daytime mean ozone (Fig. 1).
Abbreviations: PM$_{2.5}$ respirable particulate matter; PM$_{10}$ inhalable particulate matter; FVC, forced vital capacity; FEV$_{1.0}$ forced expiratory volume (1.0 = in 1 sec; 0.75 = in three-quarters second); FEV$_{25-75%}$/FVC, forced expiratory flow between 25 and 75% FVC; PEFR, peak expiratory flow.

*Adjusted for age, sex, weight, height, and the interaction of sex and height.

*Confidence intervals in parentheses.
predicted was 2.5 (95% CI, 1.8–3.6) for the range of particle strong acidity.

**Consistency with Previous Studies**

Animal toxicological studies have demonstrated the additive and synergistic potential of particle strong acidity for different pulmonary endpoints. Amdur and Chen (29) exposed guinea pigs to varying concentrations of acidic aerosols in combination with zinc oxide and observed a dose–response relationship with bronchial reactivity. Schlesinger et al. (30,31) demonstrated the effects of inhaled acid sulfates on macrophage and mucociliary clearance of particles in rabbits.

Clinical controlled exposure studies have provided evidence of adverse responses in selected subjects after acid aerosol exposure, in some cases approaching concentrations observed in ambient settings.

Utell et al. (32) found a significant reduction in \( \text{FEV}_1 \) among 15 asthmatics after 20 min of exposure to 350 \( \mu \)g/m\(^3\) (equivalent to 7100 nmol/m\(^3\) of strong acidity) of a monodispersed sulfuric acid aerosol. Koenig et al. (33) examined the effects of acid exposures on asthmatic adolescents and demonstrated a modest decrement in lung function performance after exposure with moderate levels of exercise. Linn et al. (34) observed significant \( \text{FEV}_1 \) changes in 15 nonasthmatic subjects exposed to 2,272 \( \mu \)g/m\(^3\) of a sulfuric acid aerosol with a volume median droplet diameter of 1 \( \mu \)m, but at levels of 122 to 410 \( \mu \)g/m\(^3\) (equivalent to 2500 to 8400 nmol/m\(^3\) of strong acidity), the changes were not statistically significant (35).

The acute health effects of particle acidity on young people attending summer camps have been studied, with inconsistent results. Studies by Lippman et al. (36), Liou et al. (37), and Spektor et al. (38) did not reveal significant effects of acid aerosol exposures on the lung function of children. Raizenne et al. (39) reported that modest
Decrements in lung function were associated with periods of elevated particle strong acidity. Recently, Neas et al. (40) observed an association between elevated daytime levels of particle strong acidity with one episode exceeding 676 nmol/m³ and decreased evening peak expiratory flow measurements (-2.5 l/min for a 1.2-hr exposure to a 125 nmol/m³ increment in particle strong acidity) among 86 children in Uniontown, Pennsylvania.

The magnitude of the effect on lung function observed in this study is comparable to the results observed by other researchers. Stern et al. (17) observed statistically significant differences of 1.7% in mean FVC and 2.1% in mean FEV₁,₀ between the children in two Canadian regions whose annual mean sulfate concentrations differed by 6.0 μg/m³.

In an analysis of the second National Health and Nutrition Examination Survey (NHANES), Schwartz (16) found that total suspended particulate levels across 44 geographic sampling units were associated with decrements in FVC, FEV₁,₀, and PEFR among nonsmoking adults. Chestnut et al. (41), using data from the first NHANES, also found that exposure to total suspended particulates was associated with decrements in FVC and FEV₁,₀ among nonsmoking adults living in 49 cities, but not with FEF₂₅-₇₅% or with the FEV₁,₀/FVC ratio.

Several ozone exposure metrics were used in the assessment including 8-hr daytime mean, 24-hr mean, and 1-hr maximum. For all of these parameters, the magnitudes of the associations between ozone and lung function for both FVC and FEV₁,₀ were similar (Table 6). In analyses with two pollutants, ozone did not alter the association between the pulmonary function measurements and particle strong acidity, but particle strong acidity reduced the associations with ozone. This reduction in the ozone association after controlling for particle strong acidity indicates that the observed ozone association is produced in part by confounding by particle strong acidity. However, the instability in the observed ozone association may be due to the limited variance of the mean ozone measurements across the 22 communities. The present data may not be sufficiently heterogeneous to reliably assess the chronic pulmonary effects of ozone in children.

Potential Limitations

Epidemiologic studies are vulnerable to selection, information, and confounding biases. In this cross-sectional study, the observed associations with acid aerosols may be confounded by other pollutants or by other city-specific characteristics.

The site selection process provided a range of particle strong acidity exposures with little correlation with ozone exposures. The 22 communities were selected to be demographically similar to the communities in the Harvard Six Cities Study and to cover the range of exposures to particle strong acidity across the United States and Canada. No prior information on respiratory health was used in the site selection process. Across these 22 communities, the children had similar mean levels of selected covariates (Tables 1 and 2), and the effect of any differences in the distributions of sex, age, height, and weight were controlled in the first stage of the analysis by an individual level regression model.

The influence of covariates was examined and revealed no substantial effects on the observed association either as confounding or effect modification. The pulmonary function tests were administered by trained technicians, and no consistent technician effect was observed. The test protocol did not vary between communities, aside from the performance of partial flow-volume curves by a portion of the children during the first year. These tests were performed on separate occasions after the full expiration tests and thereby would not influence the pattern of data collection used in the analysis. The year of study was not a significant predictor of pulmonary function level, and the association of particle strong acidity with FVC and FEV₁,₀ revealed consistent negative slope estimates across the 3 years of testing (Fig. 3). The influence of exercise less that 30 min before the examination was determined to have a small effect, similar to that found in other studies (42), but the adjustment for exercise did not alter the observed relationship. Although dampness of the home was associated with respiratory symptoms (43), there was no evidence of a stronger association between particle strong acidity and FVC among children living in damp homes nor among asthmatic children. The association between higher levels of particle strong acidity and decrements in FVC was unrelated to asthma: asthmatic children showed the same decrement in FVC as nonasthmatic children, the prevalence of an FEV₁,₀ to FVC ratio <85% of predicted was not associated with the particle strong acidity, and the prevalence of asthma and asthmatic symptoms was not associated with particle strong acidity among these children (25). The child’s sex did not alter the observed response to pollution.

Chronic air pollution exposure in each community was estimated by the long-term mean concentration based on at least 11 months of monitoring. It is possible that the year of air monitoring in each community was not representative of previous years of exposure. Brook and Spengler (44) have reviewed available historical aeroetric and meteorologic data available in several regions and have concluded that the exposure measure assigned to each community was relatively stable and that no factors were observed that altered the relative ranks of the communities for particle strong acidity, ozone, or PM₁₀. The effect of length of residence in the community was examined using the questionnaire data. More than half of the subjects had lived in their respective communities from birth, and there is some evidence that the association of particle strong acidity with FVC was greater.
among those children who were lifelong residents of the communities (4.1%, 95% CI, -2.5 to -5.8).

Personal activity and exposure patterns could have affected the lung function of individuals within each community. This effect cannot be determined within the design of the present study, but it is unlikely that there were significant activity pattern differences across the communities that would be directly correlated with annual exposures. Exposure misclassification cannot be excluded as a potential factor that could affect the magnitude of the observed association; however, nondifferential misclassification of exposure would tend to bias the association towards the null hypothesis.

Particle acidity, sulfate, and fine particulate matter have a common origin in the combustion of fossil fuels and have similar long-range regional transport characteristics. Across the 22 communities in this study, particle strong acid was strongly correlated with sulfates ($r = 0.90$) and with PM$_{2.5}$ ($r = 0.82$), but less correlated with the PM$_{10}$ measurements ($r = 0.47$). This correlation limits the ability to attribute the observed decreased in lung function to any particular pollutant. Measurements of particle strong acidity were slightly better predictors of a pulmonary function decrement, but these differences are not significant and may only reflect differences in the precision of the various measurement techniques as indicators of a common unmeasured or poorly measured pollutant.

The evidence of an association between fine acidic particulates and lung function may have significant health implications. Three possible explanations for a decrement in pulmonary function include submaximal inspiration to less than total lung capacity, incomplete expiration to residual volume, and reduced total lung capacity. The first hypothesis suggests that inflammation of the airways results in a child’s inability to take a deep breath by either blockage of the airways or sensory inhibition stopping the child from taking a deep breath. While in adults this mechanism would tend to produce greater decrements in FVC than FEV$_{1.0}$ in children similar reductions in both measures would be anticipated, as occurred in this study. The second hypothesis suggests that peripheral airway inflammation would result in children not being able to expire to their true residual volumes due to airway closure. This was suggested by Becklake et al. (1972) in a study that directly measured increased closing volumes among children living in a polluted city. In this case, the peripheral airway inflammation would tend to reduce the measures of flow at lower lung volumes, such as FEF$_{25-75}$% more than FVC measurements. This was not seen in the associations with particle strong acidity, although the ozone associations suggested such a difference. The third hypothesis would propose that the growth rate of children’s lungs has been reduced with all measurements of pulmonary function level equally affected. Pulmonary function measurements obtained by this study do not permit the direct determination of each child’s true total lung capacity. The essentially symmetrical reductions in FVC, FEV$_{1.0}$, FEF$_{25-75}$%, and PEFR with no significant differences in any of the ratio measures is consistent with any of these hypotheses.

In summary, in this study we found a modest but significant reduction in pulmonary function level among children associated with living in communities with higher levels of respirable particulates, including directly measured particle strong acidity. If these children continue on this track in the growth of their lung function, as suggested by previous studies, exposure to particle acidity may put these children at a disadvantage in the future. Because of the cross-sectional nature of the current study, further studies will be necessary to determine if these outcomes are found in older children who have entered their adolescent growth phase. Whether these or other exposed children are at greater risk of both acute and chronic response to other ambient or respiratory pollutants such as occupational or personal exposures to environmental tobacco smoke or other pollutants will need to be explored.

REFERENCES

1. Graham JA. Review, discussion, and summary: toxicology. Environ Health Perspect 79: 191–194 (1989).
2. Gong H. Health effects of air pollution. A review of clinical studies. Clinics Chest Med 13:201–214 (1992).
3. Dassen W, Brunekeef B, Hoek G, Hofschreuder P, Staartsen B, deGroot H, Schouten E, Biensteke K. Decline in children’s pulmonary function during an air pollution episode. J Air Pollut Control Assoc 36:1223–1227 (1986).
4. Graham NMH. The epidemiology of acute respiratory infections in children and adults: a global perspective. Epidemiol Rev 12:49–178 (1990).
5. Bates DV, Baker-Anderson M, Sipko R. Asthma attack periodicity: A study of hospital emergency visits in Vancouver. Environ Res 51:51–19 (1991).
6. Pope CA III. Respiratory hospital admissions associated with PM10 pollution in Utah, Salt Lake, and Cache Valleys. Arch Environ Health 46:90–97 (1991).
7. Schwartz J. Particulate air pollution and daily mortality: a synthesis. Public Health Rev 19:39–60 (1991).
8. Lippmann M. Background on health effects of acid aerosols. Environ Health Perspect 79:3–6 (1989).
9. Spengler JD, Brauer M, Koutrakis P, Acidic air and health. Environ Sci Technol 24:946–956 (1990).
10. Spengler JD, Keeler GJ, Koutrakis P, Ryan PB, Raizenne M, Franklin CA. Exposures to acid aerosols. Environ Health Perspect 79:43–51 (1989).
11. American Thoracic Society. Health effects of atmospheric acids and their precursors. Am Rev Respir Dis 144:464–467 (1991).
12. U.S. EPA. An acid aerosols position paper: health effects and aerometrics. ECAO-R-0140. Research Triangle Park, NC:Environmental Protection Agency, 1987.
13. Ware JH, Ferris BG Jr, Dockery DW, Spengler JD, Strom DO, Speizer FE. Effects of ambient sulfur oxides and suspended particles on respiratory health of preadolescent children. Am Rev Respir Dis 133:834–842 (1986).
14. Dockery DW, Speizer FE, Strom DO, Ware JH, Spengler JD, Ferris BG Jr. Effects of inhalable particles on respiratory health of children. Am Rev Respir Dis 139:587–594 (1989).
15. Damokosh AI, Spengler JD, Dockery DW, Ware JH, Speizer FE. Effects of acidic particles on respiratory symptoms in 7 U.S. communities. Am Rev Respir Dis 147:A652 (1993).
16. Schwartz J. Lung function and chronic exposure to air pollution: A cross-sectional analysis of NHANES II. Environ Res 50:309–321 (1989).
17. Stern B, Jones L, Raizenne M, Burnett R, Meranger J-C, Franklin C. Respiratory health effects associated with ambient sulfates and ozone in two rural Canadian communities. Environ Res 49:20–39 (1989).
18. Speizer FE. Studies of acid aerosols in six cities and in a new multi-city investigation: design issues. Environ Health Perspect 79:61–67 (1989).
19. Dockery DW, Damokosh AI, Neas LM, Raizenne M, Spengler JD, Koutrakis P, Ware JH, Speizer FE. Health effects of acid aerosols on North American children: respiratory symptoms and illness. Am Rev Respir Dis 147:A653 (1993).
20. Spengler JD, Koutrakis P, Dockery DW, Raizenne M, Speizer FE. Health effects of acid aerosols in North American children: air pollution exposures. Environ Health Perspect 104:492–499 (1996).
21. Marple VA, Rubow KL, Turner W, Spengler JD. Low flow rate sharp cut impactors for indoor air sampling: design and calibration. J Air Pollut Control Assoc 35:1203–1307 (1987).
22. Koutrakis P, Wbolson JM, Slater JL, Brauer M, Spengler JD, Stevens RK. Evaluation of an annular denuder/filter pack system to collect acidic aerosols and gases. Environ Sci Technol 22:1463–1468 (1988).
23. Keeler GJ, Spengler JD, Castillo RA. Acid aerosol measurements at a suburban Connecticut site. Atmos Environ 25A:681–690 (1991).
24. Koutrakis P, Wbolson JM, Spengler JD. An improved method for measuring aerosol strong acidity: Results from a nine-month study in St. Louis, Missouri and Kingston, Tennessee. Atmos Environ 22:157–162 (1988).
25. Dockery DW, Cunningham J, Damokosh AI,
Tenure-Track Position

NATIONAL INSTITUTE OF ENVIRONMENTAL HEALTH SCIENCES

Cell Cycle Regulation and Molecular Carcinogenesis

A position is available in the Laboratory of Environmental Carcinogenesis and Mutagenesis for an outstanding scientist to develop an independent program of basic research in the area of cell cycle control alterations during the process of carcinogenesis. Applications are invited from candidates with a strong research record in molecular cell cycle control and carcinogenesis as demonstrated by having significant impact in the field. Priority will be to applicants whose expertise includes genetic and molecular approaches to investigate the impact on cell cycle regulation in mammalian cells of exposure to environmental carcinogens. Minimum qualifications are a doctoral degree in the biomedical sciences, a minimum of three years' postdoctoral experience and research publications in prestigious peer-reviewed journals. Desirable additional qualifications include demonstrated expertise in the following areas: cell biology of neoplastic transformation; molecular consequence of proto-oncogene activation on cell cycle regulation; inactivation of tumor suppressor genes; cell cycle checkpoint mechanisms and genetic alterations of cell cycle control that predispose to cancer.

The position is available to citizens or permanent residents of the United States. Salary will be commensurate with experience and qualifications of the candidate. Applications from women and minority groups are particularly welcome. Interested individuals should provide a curriculum vitae with bibliography, a brief statement of research interests, and arrange for three letters of recommendation to be sent by June 1, 1996 to:

Lisa Rogers (HNV96-7), Human Resource Management Branch, National Institute of Environmental Health Sciences, PO Box 12233 Research Triangle Park, NC 27709 (919) 541-3316

NIEHS/NIH is an Equal Opportunity Employer