The Relationship Between Lead Exposure and Homicide

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Context: Previous studies have suggested that excessive lead exposure is related to aggressive and violent behavior.

Objective: To evaluate the association between estimated air lead concentrations and homicide rates.

Design: Cross-sectional ecological study.

Setting: All counties in the contiguous 48 states of the United States.

Exposure Measure: Estimated air lead concentrations and blood lead levels.

Main Outcome Measure: The homicide rate in each county.

Results: Negative binomial regression was used to examine the relationship between air lead concentrations and the incidence of homicide across counties in the United States (N=3111). After adjusting for sociologic confounding factors and 9 measures of air pollution, the only indictor of air pollution found to be associated with homicide rates was air lead concentration. Across all counties, estimated air lead concentrations ranged from 0 to 0.17 µg/m^3. The adjusted results suggest that the difference between the highest and lowest level of estimated air lead is associated with a homicide incidence rate ratio of 4.12 (95% confidence interval, 1.02-16.61).

Conclusion: The results of this study support recent findings that there is an association between lead exposure and violent behavior.

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NUMEROUS behavioral, neuropsychological, and biological studies suggest that sufficient exposure to lead, a metallic neurotoxin, can promote brain dysfunction.[1] Called the *neurotoxicity hypothesis*, this position states that lead exposure alters neurotransmitter and hormonal systems and may induce aggressive and violent behavior.[2-5] Two studies have drawn specifically on the neurotoxicity hypothesis to examine the relationship between lead exposure and criminal behavior.[2,5] Denno[2] traced the behavioral patterns of 987 African American youth from birth to age 22 years. She found that among the dozens of sociologic and biologic correlates of delinquency, lead poisoning was among the strongest for male subjects.

Needleman et al[5] studied bone lead levels and self-reported antisocial behavior among 301 grade school students as part of the Pittsburgh Youth Study. Using the Child Behavior Checklist, they found that parents and teachers were more likely to rate the behavior of children with high bone lead levels as delinquent and aggressive, and that these children reported engaging in more delinquent acts than children with low bone lead levels. The authors concluded that lead exposure "should be included when considering the many factors contributing to delinquent behavior."[5(p369)]

Additional research examining a variety of settings and behaviors is needed if the relationship between lead exposure and aggression is to be considered more than speculative. One alternative is to examine the association between air lead levels, blood lead levels, and homicide through the use of ecological data. We focus on homicide as the most extreme outcome associated with expressions of aggression that lead exposure might generate.[6]

Lead exposure occurs through a variety of sources, but has most often been associated with the ingestion of lead-

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METHODS

Data on potential lead exposure were drawn from the Environmental Protection Agency's Cumulative Exposure Project (CEP).[14] The CEP provides estimated concentrations of various air pollutants covered under the Clean Air Act.[15] Estimated air lead concentrations, reflecting the average amount of air lead in micrograms per cubic meter, for 1990 were available for all 3111 contiguous counties in the United States. Long-term, large land tract air lead estimates were modeled using the Assessment System for Population Exposure Nationwide (ASPEN). These estimates were based on the amount of lead generated at fixed sources (eg, large waste incinerators and factories), small, dispersed emitters (eg, gas stations and machine repair shops), and mobile sources (eg, cars and off-road equipment). The ASPEN model accounts for various meteorological conditions (eg, wind speed and direction, atmospheric stability, decay, and secondary formation) to adjust lead estimates to more closely mirror actual environmental levels. The pollution estimates of ASPEN are highly correlated with actual levels of environmental pollution.[14]

Research on the association between air lead concentrations and blood lead levels indicates that air lead is an important source of levels of lead in the body.[9-13] To determine if CEP estimates of air lead concentrations were correlated with blood lead levels at the county level, we obtained data from the Ohio Department of Health on children younger than 6 years who had blood lead levels greater than 10 µg/dL during 1998. The Centers for Disease Control and Prevention (CDC) (Atlanta, Ga) identify the data from Ohio as more valid than data from most states because a large proportion of children across all Ohio counties are tested for lead poisoning. We found that across Ohio's counties, CEP-estimated air lead concentrations were positively and significantly correlated with the percentage of children (of those children screened) who had elevated blood lead levels (Pearson correlation coefficient, 0.44; $P<.001$; n=88). That relationship persisted (Pearson correlation coefficient, 0.48; $P<.001$; n=88) despite adjustments in the percentage of houses built before the 1950s (1990 census estimate), reinforcing previous findings that suggest that lead exposure may result from a variety of contamination sources, including lead-contaminated air.

The National Center for Health Statistics mortality files at the CDC contain homicide counts for each of the 3111 counties in the contiguous United States for 1990. A death was counted as a homicide if it was coded in the International Cause of Death classification as E960 to E969. We followed the CDC procedures and averaged the number of homicides during a 3-year period (1989-1991) to minimize random year-to-year fluctuations.[16]

We included 15 additional variables that may have potentially confounded the relationship between air lead concentrations and the incidence of homicides. Because homicide rates and air pollution are high in urban areas, we were concerned that an association between atmospheric lead and homicide incidence might reflect an association with air pollution in general. Therefore, we included 9 additional air pollutants drawn from CEP data in our cross-sectional homicide models. All air pollutants were measured in micrograms per cubic meter. Four air pollutants included in the analysis (toluene, benzene, ethylene dibromide, and ethylene dichloride) are or have been constituents of gasoline (as was lead prior to its discontinued use in that capacity); 1 pollutant (ethylene glycol) is used in antifreeze and brake fluids; and 4 pollutants (cyanide, trifluralin, naphthalene, and ethylbenzene) were estimated by the CEP to be most highly concentrated in urban areas.

We included 6 sociological confounding factors that have been hypothesized to be related to potential lead exposure and homicide rates.[5,17,18] These were derived from the Bureau of Census Summary Tape File 3C for 1990 and include area of county (square kilometers); number of persons aged 16 to 29 years; number of persons living beneath the Social Security Administration's determined poverty level; number of African-Americans; a census-defined urban indicator; number of individuals aged 18 years and older who have not completed high school; and whether or not the county is located in a southern state.

To investigate the association between estimated air lead concentrations and the incidence of homicides we used negative binomial regression.[19] All statistical computations were performed using statistical software (SAS Institute, Cary, NC). The natural logarithm of the 1990 population (eg, the midpoint between 1989 and 1991) was entered as an offset term. All of the pollutants entered into the model were scaled so that a 1-unit change represented the difference between the highest and lowest levels across all counties.

based paint by children.[7,8] Empirical research, however, suggests that airborne lead is an important exposure pathway.[9,10] Seventy percent of inhaled lead less than 1 µm in size is absorbed directly into the bloodstream, while larger lead particles may be trapped in mucous and swallowed. Numerous studies have documented a strong positive association between air lead levels and blood lead levels.[9,11-13] Following the ban on leaded gasoline, the Environmental Protection Agency determined that most air lead comes from smelters, battery plants, and industrial facilities that process lead. Given the importance of airborne lead as one potential source of lead exposure, this study tested the hypothesis that a positive, statistically significant association exists between estimated air lead concentrations and the incidence of homicide across US counties in 1990.

RESULTS

Descriptive statistics and bivariate correlations for all of the variables in this analysis are presented in **Table 1**. The mortality data indicate that many counties (992 [34%]) did not report a homicide between 1989 and 1990. A few counties (eg, Los Angeles County [Los Angeles, Calif] and Cook County [Chicago, Ill]), however, reported a large number of homicides. Fewer than 1% of all counties reported more than 100 homicides annually. Estimated air lead concentrations and other measures of pollution were also skewed (Table 1), indi-

Table 1. Characteristics of 3111 Counties Analyzed*

Variable	Mean	Median	SD	Minimum Value	Maximum Value	Pearson Correlation to Lead
Lead, μg/m³	0.001	0.001	0.004	0	0.172	. . .
Toluene, μg/m³	1.142	0.628	1.432	0.003	18.971	0.333
Benzene, μg/m³	0.978	0.766	0.677	0.481	14.323	0.288
Ethylene dibromide, μg/m³	0.008	0.008	0.002	0.008	0.068	0.016
Ethylene dichloride, μg/m³	0.075	0.061	0.094	0.061	3.660	0.062
Ethylene glycol, μg/m³	0.101	0.051	0.149	0	2.420	0.346
Cyanide, μg/m³	0.024	0.013	0.030	0	0.319	0.345
Trifluralin, μg/m³	0.252	0.139	0.307	0.001	3.248	0.336
Naphthalene, μg/m³	0.044	0.025	0.053	0	0.576	0.344
Ethylbenzene, μg/m³	0.122	0.070	0.145	0	1.405	0.334
No. of homicides	7.828	1.000	51.537	0	1857	0.195
No. of persons†	79.412	22.254	264.648	0.052	8863.164	0.226
Area, square miles†	2.464	1.583	3.374	0.005	51.961	–0.076
Urban (1 = urban)	0.154	0	0.361	0	1.000	0.214
South (1 = south)	0.458	0	0.498	0	1.000	–0.009
No. of African Americans†	9.605	0.435	49.738	0	1314.859	0.232
No. of persons at poverty level†	1.733	0.047	16.864	0	744.383	0.120
No. of persons aged 16-29 y†	10.526	2.689	36.523	0.002	1298.700	0.218
No. of persons aged ≥18 y without a high school education†	1.807	0.034	20.699	0	986.179	0.109

**Ellipses indicate not applicable.*
†Measured in thousands.

Table 2. The Relationship Between Estimated Air Lead Concentrations and Homicide Rates Across US Counties, 1990*

	Unadjusted Estimate		Adjusted Estimate	
Air Pollutant†	IRR	95% CI	IRR	95% CI
Lead	14.094	3.676-53.990	4.119	1.021-16.615
Toluene	. . .	. . .	0.866	0.297-2.519
Benzene	. . .	. . .	0.648	0.129-3.250
Ethylene dibromide	. . .	. . .	1.346	0.614-2.950
Ethylene dichloride	. . .	. . .	3.111	0.739-13.111
Ethylene glycol	. . .	. . .	0.637	0.265-1.536
Cyanide	. . .	. . .	3.617	0.914-14.309
Trifluralin	. . .	. . .	0.886	0.216-3.633
Naphthalene	. . .	. . .	0.877	0.251-3.071
Ethylbenzene	. . .	. . .	2.319	0.550-9.784

**IRR indicates incidence rate ratio; CI, confidence interval; and ellipses, not applicable. The natural log of the population is entered into the model as an offset term.*
†Air pollutant estimates are adjusted for the following sociologic confounding factors: number of African Americans, number of persons living below the determined poverty level, census-defined urbanization, southern state, number of persons aged ≥18 years who did not graduate from high school, number of persons aged 16-29 years, and county area.

cating that most counties faced relatively low levels of air pollution in 1990 and were well within the benchmark concentrations suggested in the toxicological literature.[20] **Table 2** presents the negative binomial regression estimates. Incidence rate ratios are based on the range (eg, a change between the maximum and minimum value) of each pollutant. All sociologic covariates and air lead levels were entered into the unadjusted and adjusted air pollutant models. In the unadjusted model, the difference between the highest and lowest levels of air lead is associated with an incidence rate ratio of 14.09 (95% confidence interval [CI], 3.68-53.99) The difference between the highest and lowest levels of air lead in the adjusted model are much more conservative, with an incidence rate ratio of 4.12 (95% CI, 1.02-16.61). This means that even while adjusting for sociologic covariates and 9 other air pollutants, the incidence of homicide was estimated to be nearly 4 times higher in a county that had an air lead level equivalent to 0.17 μg/m³, the maximum air lead concentration observed among all counties, than in a county with an air lead level equivalent to 0 μg/m³. The other 9 air pollution indicators have CIs for rate ratios that encompassed both negative and positive values, which indicate that the relationship between estimated air lead concentrations and homicides is not likely to be the result of a relationship between homicide and air pollution in general.

COMMENT

The major finding of this study is that there is an association between air lead concentrations and homicide rates in the contiguous United States in 1990. At this time, however, it is not possible to say that the observed relationship is causal. Nevertheless, the finding of an association between lead exposure and homicide is consistent with the few individual-level studies examining the role of lead exposure in delinquency and aggression. Moreover, the results of this study contribute to the emerging and controversial issue concerning the role of lead exposure in predisposing some individuals to committing crime and displaying violent behaviors.

The following weaknesses limit the generalizability of these findings and suggest directions for future research. First, we studied ecologic aggregates rather than individuals. The implications of our findings indicate that persons who commit homicide tend to be exposed to higher levels of lead in the environment than other persons. However, without further conformation of these results at the individual level of analysis, we cannot be certain that this is the case.

Second, our analysis is based on estimated air lead concentrations rather than actual measures of air lead. While these estimates are generally deemed valid, there is a possibility that some systematic bias in the estimation procedure, of which we are unaware, artificially produced the observed relationship between air lead concentrations and homicide rates.

Third, our analysis fails to consider sources of lead in the environment other than air lead concentrations. Data for water and soil concentrations of lead were not available for the entire United States during the period under investigation. Because recent research indicates that soil and water are important pathways to lead exposure,[21,22] such an omission might be substantial if air lead, soil lead, and water lead concentrations are determined to be unrelated. Currently, however, we are not aware of any empirical evidence that would indicate such a possibility. In short, it is unlikely that counties with high air lead concentrations also have low soil lead and water lead concentrations.

Fourth, the homicide data used in this study represent the homicide victim's rather than homicide offender's county of residence. To the extent that offenders and victims may not have resided in the same county, measurement error may be present in our analysis and is likely to weaken the observed relationship between lead and homicide.

For much of the 20th century, lead's deleterious effects on health were widely accepted. Often, however, these affects were only associated with extreme cases of lead exposure that occurred through occupational exposure or lead paint ingestion by children. In recent years, research has pointed toward the neurotoxicity and behavioral effects of lead at subclinical levels and through a variety of environmental mediums. The results of our ecological study indicate that these additional environmental pathways may be more ubiquitous than imagined, affecting patterns of serious forms of violence such as homicide. If the association uncovered in this analysis is truly reflective of a causal relationship, these findings may have important policy implications that link the need for continued efforts toward lead abatement, human health and behavior, and crime control.

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