Long-Term Trends in Blood Lead Levels Among Children in Chicago: Relationship to Air Lead Levels

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ABSTRACT. *Objectives.* **To evaluate trends in blood lead levels among children in Chicago from 1968 through 1988, and to determine the impact of the changes in the Centers for Disease Control and Prevention (CDC) blood lead level of concern.**

Methods. **We reviewed a systematic sample of blood lead screening records of the Chicago Department of Health Laboratory for high-risk children aged 6 months to 5 years. Median blood lead levels for each quarter of the years 1974 through 1988 were determined and regressed against mean air lead levels recorded at air-monitoring stations in Chicago during the same period.**

Results. **Median blood lead levels declined from 30 µg/dL in 1968 to 12 µg/dL in 1988, and were strongly associated with declining average air lead levels ($r = .8$, $P < .001$) from 1974 through 1988. A regression model using log-transformed data predicted a decline of 0.56 µg/dL in the median blood lead level with each 0.1 µg/m^3 decline in the mean air lead level when the air lead level was near 1.0 µg/m^3; the predicted slope was steeper at lower air lead levels. Despite the nearly 20-fold reduction in air lead levels, the median blood lead level of 12 µg/dL in 1988 indicates substantial continuing lead exposure. The CDC blood lead level of concern was lowered twice from 1968 to 1988, but due to the decline in blood lead levels, fewer than 30% of the children were above the level of concern throughout most of the study.**

Conclusion. **Although substantial lead exposure persists in Chicago, reductions in airborne lead emissions seem to have contributed to a long-term decline in the median blood lead level of high-risk Chicago children.** ***Pediatrics*** **1994;93:195–200;** ***Centers for Disease Control and Prevention, blood lead level of concern, screening, air lead levels, seasonality, lead poisoning.***

ABBREVIATION. CDC, Centers for Disease Control and Prevention.

Exposure to lead is a threat to children's health in most industrialized societies throughout the world, and both leaded paint and leaded gasoline are important sources of childhood lead exposure.[1–4] The decline in average blood lead levels in the United States from 1976 through 1980 was shown to be highly correlated with the reduction in use of leaded gasoline.[5] Billick et al found that declining blood lead levels among children screened in Chicago and New York were correlated with declining air lead levels; however, both the overall decline and seasonal summer increases in blood lead levels were even more highly correlated with the amounts of leaded gasoline sold in each city.[6–8] Using data from the National Health and Nutritional Survey and the Chicago lead screening program up to 1980, Schwartz and Pitcher concluded that lead in gasoline may have accounted for more than half of the lead in blood of US citizens in the 1970s.[9] Since then, the use of lead in gasoline has been markedly reduced in this country,[10,11] and the US Environmental Protection Agency recently estimated that average blood lead levels declined from 15 to 20 µg/dL during the late 1970s to about 5 µg/dL in 1990.[12]

Although blood lead levels in the United States have been declining, children in this country continue to be exposed to deteriorated lead-based paint and lead-contaminated dust and soil. Recent evidence indicates that low-level lead exposure, previously thought to be harmless, has adverse effects on growth and neurobehavioral development.[11,13–15] The Centers for Disease Control and Prevention (CDC) lowered the blood lead level at which it recommends follow-up of individual children, from 40 µg/dL to 30 µg/dL in 1975, to 25 µg/dL in 1985, and to 15 µg/dL in 1991.

To determine whether the previously described downward trend in blood lead levels had continued, and to evaluate the impact of the lowered CDC blood lead level of concern on the proportion of children requiring follow-up, we reviewed data from the childhood lead screening program in Chicago, with 8 more years of data since the previous analysis. We used the same source for our data as the earlier studies of blood lead levels in Chicago,[6,9] but we obtained an original independent sample of the source for the entire 21-year period as described below.

METHODS

The City of Chicago Department of Health, Division of Laboratories, has continuously measured venous blood lead levels from children living in Chicago since the late 1960s. Approximately 50 000 venous samples have been tested each year by either atomic absorption spectrophotometry or anodic stripping voltametry. The vast majority of blood samples origi-

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Received for publication Jun 21, 1993; accepted Oct 8, 1993.

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nated from public lead screening programs and public health clinics, but some samples were submitted from public and private hospitals and offices of private health care providers. In general, the public screening programs were targeted toward children living in areas of the city where housing was believed to present a high risk of lead exposure. The proportion of samples from public screening programs has remained relatively consistent throughout the study. Samples were logged in, and results were recorded in the order in which they were received. The laboratory database was systematically sampled by taking every hundredth record from a two-digit, random number starting point. For records from 1988, the sampling proportion was increased from 1% to 2% to provide additional data for an evaluation of the sensitivity of the erythrocyte protoporphyrin test, the results of which have been published.[16]

After obtaining the sample, we excluded records of persons aged 6 years or older, those younger than 6 months, and those whose age could not be determined.

A search for multiple tests on the same person in the same year was performed by sorting by name, birth date, and age. For the 21-year period, we found 25 persons with multiple records in the same year, and no more than 5 such persons in any one year. For children with such multiple records, only the first record in any year was included in the sample. Fifty-five persons had multiple records in different years, and all these records were included. Of 9973 records that remained in the sample for analysis, 9604 (96%) of these had data on blood lead level recorded.

Until recently, laboratory instruments were not capable of accurately determining blood lead levels less than 10 μg/dL, so blood lead measurements at or below this level were recorded as 10 μg/dL during most of the years included in this study. Therefore, exact geometric mean levels could not be calculated, and we report median blood lead levels instead. Otherwise, blood lead levels were roughly log normally distributed, so any median level greater than 10 μg/dL should approximate the corresponding geometric mean.

Air lead levels for Cook County, which includes Chicago, were obtained from the Illinois Environmental Protection Agency. Data from at least 12 (mean 34, mode 40,41) separate sampling stations were available for each quarter of the years 1974 through 1988. For each quarter, air lead levels from all stations with data recorded were averaged to obtain that quarter's mean air lead level. Data were analyzed using Epi Info,[17] Quatro-Pro (Borland International, Inc, Scotts Valley, CA, 1991), and SAS (SAS Institute Inc, Cary, NC, 1992) computer software. Because significant first-order autocorrelation of residuals[18] was evident in ordinary least squares models relating blood lead to air lead levels, we report parameter estimates corrected for autocorrelation using Yule-Walker estimation through the SAS/ETS AUTOREG procedure.[19]

RESULTS

The number of records, mean ages of children in the sample, and median blood lead levels by year are shown in Table 1. The greater number of records in 1988 reflects the change in sampling from 1% to 2% for that year. The mean age of children across the entire sample was 2.5 years (±1.49 SD). The median blood lead level tended to be highest in 2-year-old children, except in aggregate results from 1975 through 1984 (Fig 1). Median blood lead levels by sex and race are shown in Table 2. Data on these variables were not recorded consistently during the entire study. For those years with sufficient data, the blood lead levels among males and females were similar; levels among blacks tended to be slightly higher than among Hispanics and whites.

Overall, the median blood lead level declined from 30 μg/dL in 1968 to 12 μg/dL in 1988 (Table 1). Fig 2 shows the median blood lead levels by quarter of each year overlayed with the corresponding average quarterly air lead levels for Cook County. The figure

TABLE 1. Median Blood Lead Level by Year

Year	No. of Records	Mean Age, y	Blood Lead Level, μg/dL
1968	314	2.9	30.0
1969	405	2.9	25.0
1970	402	2.8	25.5
1971	493	2.8	26.0
1972	566	2.9	28.0
1973	551	2.8	29.0
1974	523	2.5	25.0
1975	556	2.5	24.0
1976	546	2.4	24.0
1977	503	2.4	22.0
1978	465	2.2	20.0
1979	395	2.2	19.0
1980	399	2.4	18.0
1981	391	2.2	17.0
1982	377	2.1	16.0
1983	373	2.3	17.0
1984	368	2.3	18.0
1985	434	2.5	17.0
1986	435	2.5	14.0
1987	445	2.4	12.0
1988	663	2.7	12.0

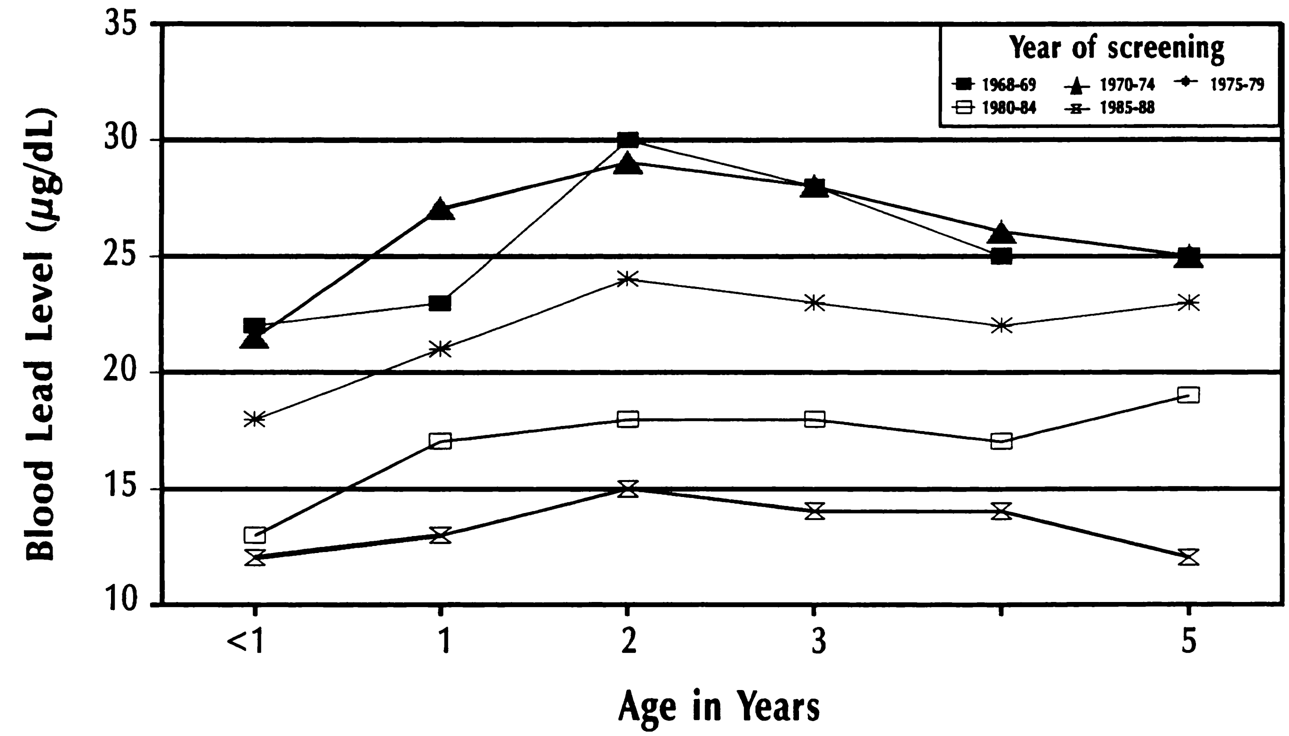

Fig 1. Median blood lead levels by children's age and year of screening.

TABLE 2. Median Blood Lead Levels

Years	Records with Data, %	By Sex, µg/dL, (n)	
		Female	Male
1968–1979	1	. . .	. . .
1980–1984	71	17 (648)	18 (710)
1985–1988	98	13 (943)	13 (1001)

Years	Records with Data, %	By Race, µg/dL (n)			
		Black	Hispanic	White	Other
1968–1970	20	. . .	. . .	. . .	. . .
1971–1985	71	24 (3719)	19 (723)	20 (423)	23 (90)
1986–1988	98	13 (1032)	11 (441)	12 (29)	10 (10)

demonstrates a somewhat erratic seasonal pattern of blood lead levels, which does not coincide exactly with changes in air lead levels. Blood lead levels consistently peaked in the summer quarter (July through September) of the years 1979 through 1983. From 1984 through 1986, however, levels peaked in the fall quarter (October through December).

Although the changes in blood levels by quarter do not coincide exactly with changes in air lead levels, the overall decline in blood lead levels is associated with a corresponding decline in air lead levels, and average air lead levels by quarter are highly correlated with median blood lead levels by quarter, as shown in Fig 3 ($r = .8, P < .0005$). A regression model using log-transformed median blood lead and air lead levels appeared to fit the observed data better than a linear model (Fig 3), and it also accounted for the observed change in blood lead to air lead slope as air lead levels increased. At an air lead level of 0.25 µg/m^3, this model predicts a blood lead decrease of 1.62 µg/dL for every 0.1 µg/m^3 decrease in air lead; but at an air lead of 1.0 µg/m^3 it predicts a blood lead decrease of only 0.56 µg/dL for every 0.1 µg/m^3 decrease in air lead. The addition of dummy terms for season did not meaningfully change the slope or reduce the significance of the association between air lead and blood lead, and none of the coefficients for season reached statistical significance at the $P = 0.05$ level. When a sequentially ordered variable for each quarter was added, the association between air lead and blood lead was no longer statistically significant, and a statistically significant effect of season was observed in the following model:ln(blood lead) = 3.238 + 0.002 × ln(air lead) – 0.013 × time – 0.007 × spring + 0.081 × summer + 0.053 × fall (winter is the referent season).

Only the coefficients for time ($P = 0.0001$) and summer ($P = 0.02$) were statistically significant.

The proportion of blood lead levels greater than or equal to each concurrent CDC blood lead level at which follow-up of individual children was recommended is shown in Fig 4. The proportion of children above the concurrent CDC level for follow-up has been less than 30% in each year of the study except 1975. Fig 4 would suggest that the proportion of children at or above the current follow-up level, 15 µg/

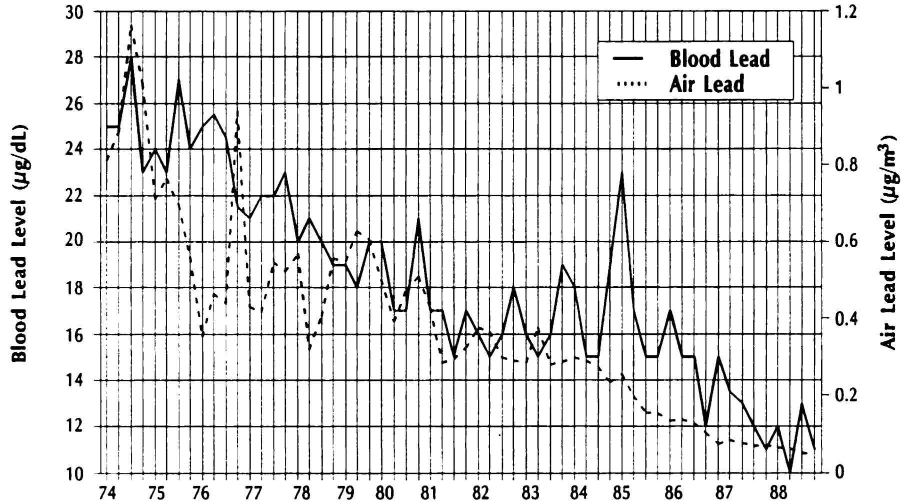

Fig 2. Mean air lead levels and median blood lead levels by quarter, 1974 through 1988.

dL, which was established in 1991, might have been close to 30% in that year. Although the proportions of children with blood lead levels above 30 μg/dL and 40 μg/dL have notably decreased, the most dramatic declines occurred among children at the lower end of the blood lead distribution. There was a 60% decline (30 μg/dL to 12 μg/dL) in the median blood lead level from 1968 through 1988, compared with a 42% decline (55 μg/dL to 31 μg/dL) in the 95th percentile blood lead level during the same period.

DISCUSSION

Trend in Blood Lead Levels

The previously described downward trend in blood lead levels among high-risk children in Chicago continued through the 1980s, with a corresponding decrease in average air lead levels. Decreased use of lead in gasoline resulted in lower air lead levels,[10] and previous studies have indicated that the decline in average blood lead levels during the 1970s in Chicago, New York, and the United States as a whole, was primarily due to the decreased use of leaded gasoline.[5,6,9] Although we did not measure the consumption of leaded gasoline directly, the high correlation between declining air lead levels and blood lead levels reported here further support the conclusion that decreased use of leaded gasoline has resulted in a substantial decline in blood lead levels among high-risk children in Chicago.

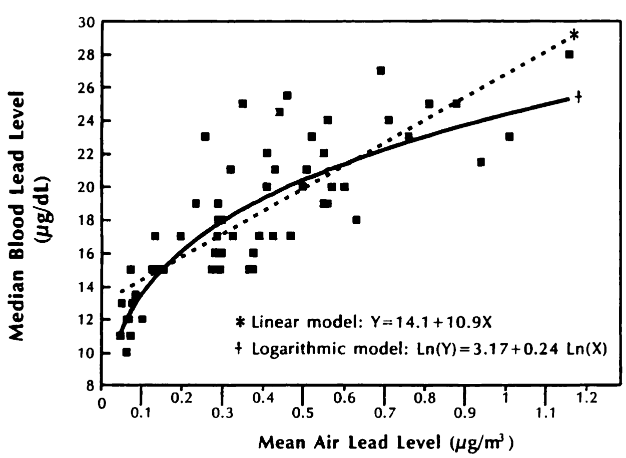

Fig 3. Quarterly mean blood lead levels by mean air lead levels.

Other reductions in childhood lead exposure that may have resulted from educating parents about the hazards of lead paint, the replacement of older homes that contain lead-based paint, and the control of non-atmospheric lead in foods, may also have contributed to declining blood lead levels. Public health interventions to reduce exposure from deteriorated lead paint in individual households have largely been limited to homes of children with blood lead levels above 25 μg/dL, and it is unlikely that the limited number of household interventions completed would account for the observed decline in the median blood lead level of high-risk children in Chicago.

Relationship of Gas Lead, Air Lead, and Blood Lead

Combustion of leaded gasoline probably has its greatest effects on blood lead levels by contaminating dust, soil, and food, which children then ingest, and to a much lesser degree by contaminating the air they inhale.[8,10,20,21] Air lead levels measured at fixed monitoring stations can only approximate the amounts of lead that children inhale, and do not measure the exposure from lead deposited and then ingested on dust, soil, and food. This might explain the lack of a significant relationship between air lead levels and blood lead levels when a variable for time is added to our regression model. As the use of lead in gasoline decreased, children's lead exposure from ingested lead may have declined more steadily over time than did the more variable air lead levels, which could be influenced by changes in measurement techniques, as well as atmospheric changes. A sequential variable for time would then correlate better than air lead levels with the declining blood lead levels that resulted primarily from the comparatively steady decrease in exposure from lead ingestion.

Data on sales of lead in gasoline, when available, may be a more complete measure of children's lead exposure from combustion of lead in gasoline than air lead levels. When Schwartz and Pitcher added a linear time variable and seasonal dummy variables to their regression model relating gasoline lead sales to

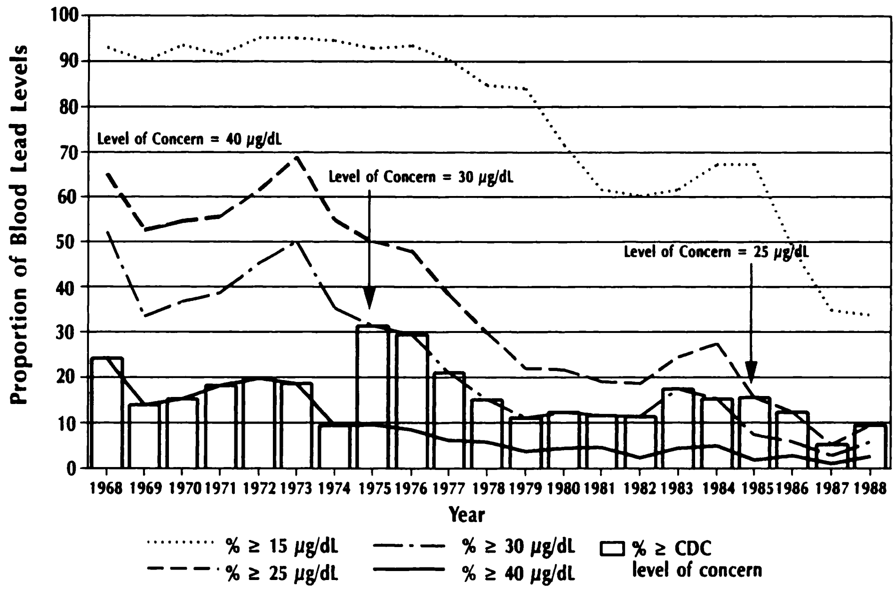

Fig 4. Proportion of blood lead levels at or above Centers for Disease Control and Prevention (CDC) levels of concern.

blood lead, the coefficient for gasoline lead sales remained significant.[9]

We estimate that, when airborne lead levels are near 1.0 μg/m^3, a reduction in airborne lead emissions that resulted in a decrease in air lead of 0.1 μg/m^3 would also result in a decrease of about 0.6 μg/dL in the median blood lead level of children, by reducing overall exposure from the various pathways described above. The results of two previous studies provide similar estimates.[7,22] At lower air lead levels, our model predicts that the same change in air lead levels would produce greater changes in blood lead levels.

Seasonality

Although season did not seem to confound the relationship between air lead and blood lead levels, an independent effect of season was observed once the decrease in blood lead levels over time was accounted for in our model, indicating that blood lead levels tended to be higher in the summer than in the winter. This is consistent with results from several other studies.[8,23–25] In US cities through the 1980s, although air lead levels typically were higher in winter,[10] both gasoline usage and the concentration of lead in leaded gasoline were higher in the warmer months.[10,22] Schwartz and Pitcher found that coefficients for time and season lost significance when they added data on sales of lead in gasoline to their model.[9] Other explanations for the seasonal pattern of blood lead levels have been proposed, including increased exposure of children to outdoor lead sources while playing outside,[24] the influence of rain on lead dust dispersion,[24] increases in lead paint dust exposure from exposed window wells,[26] and changes in the rate of lead absorption due to the metabolic influences of sunlight and vitamin D.[27] Further studies of the interacting determinants of blood levels may better explain the observed changes in seasonal patterns, such as the shift in the peak of median blood lead levels from the summer quarter to the fall quarter during the 1980s in Chicago.

Influence of Age and Sampling

For most years, blood lead levels tended to be highest among 2-year-old children. Although this finding derives from cross-sectional screening data rather than a longitudinal study of a single cohort, it is consistent with results from several other studies.[7,15,24] The lack of a consistent decline in the median blood lead levels of children older than 2 years in the years 1975 through 1984 might be due to some change in screening strategy during those years, such as an increased emphasis on screening only those older children at highest risk of lead exposure. Nevertheless, during the whole study, the laboratory methods and overall screening strategy have remained relatively consistent, and we believe that the results reported here are reasonably representative of high-risk Chicago children.

Geometric mean blood lead levels for urban black and white children in National Health and Nutritional Survey II were 20.8 μg/dL and 15.6 μg/dL, respectively,[28] compared with median blood lead levels of 22.0 μg/dL and 18.5 μg/dL from our data for the same years (1976 through 1980). These results seem consistent given that the Chicago screening program concentrated on children at high risk of lead exposure.

Implications for Prevention Programs

The lowering of the blood lead levels at which CDC recommends follow-up of individual children might have substantially increased the case management burden of lead poisoning prevention programs if blood lead levels had not declined. Fig 4 indicates that the proportion of high-risk children requiring follow-up in Chicago has generally remained less than 30%.

Despite relatively low air lead levels in 1988, the median blood lead level among children screened in Chicago was still high enough to cause concern about adverse effects. Furthermore, the 95th percentile blood lead level has decreased proportionately less than the median level. This suggests that significant reservoirs of high lead exposure remain in Chicago.

Lead poisoning prevention efforts in the United States should now be aimed at reducing these remaining sources of high lead exposure, primarily deteriorated lead paint and lead-contaminated soil and dust.[11]

Although predictions of the impact of reducing air lead levels are not likely to be perfectly precise, the estimates of the expected decrease in blood lead from this study could be usefully applied, in conjunction with other estimates, to estimate the decrease in children's blood lead levels that could be expected with reductions in airborne lead emissions. Even small changes in blood lead may substantially change overall IQ distributions in large populations,[11] and the results of this study add to a large body of evidence indicating that blood lead levels decline substantially with reductions in airborne lead emissions.

The benefit to children's health from reducing lead in gasoline has not yet been extended to many parts of the world where leaded gasoline is still used extensively.[2,3,29] The control of airborne lead emissions should, therefore, be an international health priority in countries and regions where leaded gasoline and other emissions continue to contribute substantially to children's lead exposure.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of Terry Sweitzer of the Illinois Environmental Protection Agency and William Sanders of the US Environmental Protection Agency for assistance in obtaining data on air lead levels; Drs. Sue Binder and David Olson of the CDC for providing advice and critical review during the course of this study; and Mary Boyd, also of CDC, for help in compiling the dataset of laboratory records.

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