Continued Decline in Blood Lead Levels Among Adults in the United States

The National Health and Nutrition Examination Surveys

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Background: Declines in blood lead levels between 1976 and 1991 among US adults have been previously reported. More recent trends in blood lead levels and the association of lower blood lead levels with chronic disease have not been reported.

Methods: Data from 2 nationally representative cross-sectional surveys, the Third National Health and Nutrition Examination Survey conducted in 1988-1994 (n = 16,609) and the National Health and Nutrition Examination Survey conducted in 1999-2002 (n = 9961) were analyzed.

Results: The geometric mean blood lead level declined 41% from 2.76 µg/dL (0.13 µmol/L) in 1988-1994 to 1.64 µg/dL (0.08 µmol/L) in 1999-2002. The percentage of adults with blood lead levels of 10 µg/dL (0.48 µmol/L) or higher declined from 3.3% in 1988-1994 to 0.7% in 1999-2002 (P < .001). In 1999-2002, the multivariable-adjusted odds ratio of having a blood lead level of 10 µg/dL (0.48 µmol/L) or higher was 2.91 (95% confidence interval [CI], 1.74-4.84) and 3.26 (1.83-5.81) for non-Hispanic blacks and Mexican Americans, respectively, compared with non-Hispanic whites. After multivariable adjustment, persons in the highest quartile (≥ 2.47 µg/dL [≥ 0.12 µmol/L]) compared with those in the lowest quartile (< 1.06 µg/dL [< 0.05 µmol/L]) of blood lead levels were 2.72 (95% CI, 1.47-5.04) and 1.92 (95% CI, 1.02-3.61) times more likely to have chronic kidney disease and peripheral arterial disease, respectively. In addition, higher blood lead levels were associated with a higher multivariable-adjusted odds ratio of hypertension among non-Hispanic blacks and Mexican Americans.

Conclusions: Blood lead levels continue to decline among US adults, but racial and ethnic disparities persist. Higher blood lead levels remain associated with a higher burden of chronic kidney and peripheral arterial diseases among the overall population and with hypertension among non-Hispanic blacks and Mexican Americans.
1999-2002, respectively. In addition, we determined the association between demographic factors, socioeconomic characteristics, and elevated blood lead levels in 1999-2002. Finally, we also determined the association of the blood lead levels observed in NHANES 1999-2002 with hypertension, chronic kidney disease, and peripheral arterial disease.

METHODS

NHANES SURVEYS

NHANES III and NHANES 1999-2002 were nationally representative cross-sectional surveys of the civilian noninstitutionalized population of the United States. The procedures involved in these studies have been published in detail and are available online. In brief, each of these studies included a stratified multistage probability sample based on selection of counties, blocks, households, and persons within households. To provide stable subgroup estimates, Mexican Americans, non-Hispanic blacks, and adults 60 years or older were oversampled in NHANES III and NHANES 1999-2002.

Each participant’s NHANES information was obtained from an in-home interview followed by a medical evaluation and blood sample collection at a mobile examination center. Variables collected during the in-home interview that are of relevance to the present analysis are age, race/ethnicity, sex, cigarette smoking, alcohol consumption, a history of diabetes mellitus, pharmacologic treatment for hypertension, health insurance status, household income, having a high school education, and the year each participant’s current residence was constructed. Participants who reported having smoked at least 100 cigarettes during their lifetime were classified as current or former smokers depending on whether they answered the question “Do you smoke cigarettes now?” affirmatively or negatively, respectively. Alcohol consumption was defined as having an average of 1 or more drinks per week during the previous year. Diabetes mellitus status was based on self-report.

The NHANES 1999-2002 examination procedures included measurements of height, weight, blood pressure, and ankle-brachial index (ABI). Height was measured using a fixed stadiometer and weight by using a digital scale (Toledo Scale Corp, Toledo, Ohio) with participants wearing underwear, a disposable gown, and foam slippers. Body mass index was calculated as weight in kilograms divided by height in meters squared.

During a single examination visit, a physician took up to 3 blood pressure measurements using the standard protocol of the American Heart Association. Blood pressure was measured with the participant in a seated position following 5 minutes of quiet rest. Based on the average of all available blood pressure measurements, hypertension was defined as systolic or diastolic blood pressure of at least 140 mm Hg or 90 mm Hg, respectively, and/or self-reported current use of blood pressure—lowering medication.

For individuals with at least 1 arm and weighing 180 kg (400 lb) or less, systolic blood pressure for the ABI was measured via blood pressure cuffs on the right brachial artery and both posterior tibial arteries. For individuals aged 40 to 59 years, 2 measurements were taken and averaged at each site, whereas for individuals aged 60 years or older, 1 measurement was taken at each site. For individuals with conditions that precluded measurement of the right arm, the left brachial artery systolic blood pressure was taken. For each ankle, the ABI was calculated as the ratio of the average ankle systolic blood pressure to arm systolic blood pressure. The smaller of the 2 measurements was considered the ABI for this study. Peripheral arterial disease was defined as an ABI of less than 0.9.

Serum creatinine levels were measured by the Jaffe modified kinetic method using a Hitachi 917 analyzer (Boehringer Mannheim Corp, Indianapolis, Ind). We added 0.13 mg/dL (11 µmol/L) to each NHANES 1999-2000 participant’s measured serum creatinine concentration and 0.02 mg/dL (2 µmol/L) to each NHANES 2001-2002 participant’s concentration to align the concentrations with the assays employed in the development of the Modification of Diet in Renal Disease study equation. Kidney function was assessed by estimating the glomerular filtration rate with the simplified prediction equation from the Modification of Diet in Renal Disease study. Specifically, estimated glomerular filtration rate was calculated as follows:

\[ 186.3 \times (\text{Serum Creatinine in Milligrams per Deciliter})^{-1.154} \times \text{Age}^{-0.203} \times (0.742 \text{ if Female}) \times (1.21 \text{ if African American}) \]

Individuals with an estimated glomerular filtration rate lower than 60 mL/min per 1.73 m² were considered to have chronic kidney disease.

MEASUREMENT OF BLOOD LEAD LEVELS

All blood samples were venous specimens. They were shipped on dry ice to the NHANES laboratory at the National Centers for Environmental Health at the Centers for Disease Control and Prevention in Atlanta, Ga. Identical methods for measuring blood lead levels were used for NHANES III and NHANES 1999-2002 and are described in detail online. Specifically, blood lead levels were measured using whole blood and graphite furnace atomic absorption spectrophotometry as described by Sassa et al. An elevated blood lead level was defined a priori as 10 µg/dL (0.48 µmol/L) or higher. Because there was a low number of NHANES 1999-2002 participants with blood lead levels of at least 10 µg/dL (0.48 µmol/L) (n=113), persons with blood lead levels of at least 5 µg/dL (0.24 µmol/L) (n=655) were categorized as having elevated blood lead levels in secondary analyses.

The protocols for NHANES III and NHANES 1999-2002 were approved by the National Center for Health Statistics of the Centers for Disease Control and Prevention institutional review board.

STATISTICAL ANALYSIS

Because of the skewed distribution, blood lead levels were log-transformed, and the age-standardized geometric mean and 95% confidence interval were calculated by age grouping (18-39, 40-59, 60-74, and ≥75 years), sex, and race/ethnicity (non-Hispanic white, non-Hispanic black, or Mexican American) for NHANES III and NHANES 1999-2002. Age standardization was made to the year 2000 US population. Next, we calculated the age-standardized prevalence of elevated blood lead levels for 1988-1994 and for 1999-2002 (≥5 µg/dL [≥0.24 µmol/L] and ≥10 µg/dL [≥0.48 µmol/L], respectively), overall and by age grouping, sex, and race/ethnicity. We compared differences in the prevalence estimates across the 2 surveys using the Wald χ² test, taking into account the complex survey design used in NHANES III and NHANES 1999-2002. We calculated these test statistics as the difference in prevalence estimates divided by the standard error of the difference, calculated as the square root of the sum of each estimate’s variance.

Then, we determined the association of age grouping, race/ethnicity, and sex with elevated blood lead levels (≥5 µg/dL [≥0.24 µmol/L] and ≥10 µg/dL [≥0.48 µmol/L]) using multivariable logistic regression models and data from NHANES 1999-2002. The initial multivariable models included age group, race/ethnicity, and sex, and a subsequent model provided additional adjustment for current and former cigarette smoking,
alcohol consumption, having a high school education, and having health insurance. Next, the age-standardized geometric mean blood lead level and the prevalence of a blood lead level of 5 µg/dL (0.24 µmol/L) or higher was calculated by household income (> $20,000 vs < $20,000 per year), health insurance status, living in housing built before or after 1978 (the year the US government banned lead-based paint from housing), having a high school education, and smoking status (current, former, or never). The association between each of these variables and a blood lead level of 5 µg/dL (0.24 µmol/L) or higher was also calculated using logistic regression after adjusting for age, race/ethnicity, and sex.

Next, the NHANES 1999-2002 population was divided into quartiles by blood lead level. The prevalences of hypertension, chronic kidney disease, and peripheral arterial disease were separately calculated by blood lead quartile with trends across quartiles assessed using the χ² test for trend. Because the effect of environmental lead exposure on blood pressure has been noted to differ by race/ethnicity, the prevalence and adjusted odds ratios of hypertension were calculated for non-Hispanic whites, non-Hispanic blacks, and Mexican Americans, separately. The race/ethnicity–stratified odds ratios of hypertension were determined after adjustment for age, sex, body mass index, diabetes mellitus, current and former cigarette smoking, health insurance status, and having a high school education. The adjusted odds ratios of chronic kidney disease and peripheral arterial disease were determined after adjustment for these potential confounders and for race/ethnicity.

We applied sample weights that account for the unequal probabilities of selection, oversampling, and nonresponse for all analyses using SUDAAN statistical software (version 8.0; Research Triangle Institute, Research Triangle Park, NC). We estimated standard errors using the Taylor series linearization method.

### RESULTS

Between 1988-1994 and 1999-2002, the age-standardized geometric mean blood lead level declined by 41% from 2.76 µg/dL (1.33 µmol/L) to 1.64 µg/dL (0.08 µmol/L) (Table 1). Substantial declines in blood lead levels occurred in each age group, among men and women, and among non-Hispanic whites, non-Hispanic blacks, and Mexican Americans. The age-standardized prevalence of blood lead levels of 5 µg/dL (0.24 µmol/L) or higher declined from 20.5% to 5.0% between 1988-1994 and 1999-2002 (Figure, A; P < .001). Large declines in the prevalence of blood lead levels of 5 µg/dL (0.24 µmol/L) or higher were also present within each age group, among men and women, and among non-Hispanic whites, non-Hispanic blacks, and Mexican Americans (P < .001 for all). In addition, the age-standardized prevalence of blood lead levels of 10 µg/dL (0.48 µmol/L) or higher decreased from 3.3% in 1988-1994 to 0.7% in 1999-2002 (Figure, B; P < .001). The age-standardized prevalence of blood lead levels of 10 µg/dL (0.48 µmol/L) or higher decreased to less than 1.0% of the population for each age group, women, and non-Hispanic whites in 1999-2002 (P < .001 for all). In addition, the age-standardized prevalence of blood lead levels of 10 µg/dL (0.48 µmol/L) or higher declined from 5.7% to 1.2% among men, from 7.3% to 1.8% among non-Hispanic blacks, and from 4.5% to 1.7% among Mexican Americans between 1988-1994 and 1999-2002 (P < .001 for all).

### Table 1. Age-Adjusted Geometric Mean Blood Lead Levels Among NHANES III (1988-1994) and NHANES 1999-2002 Participants

<table>
<thead>
<tr>
<th>Blood Lead Level, µg/dL, Mean (95% CI)</th>
<th>NHANES III (1988-1994)</th>
<th>NHANES 1999-2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>2.76 (2.61-2.92)</td>
<td>1.64 (1.59-1.68)</td>
</tr>
<tr>
<td>Age group, y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18-39</td>
<td>2.21 (2.07-2.36)</td>
<td>1.28 (1.23-1.33)</td>
</tr>
<tr>
<td>40-59</td>
<td>2.97 (2.79-3.15)</td>
<td>1.81 (1.75-1.87)</td>
</tr>
<tr>
<td>60-74</td>
<td>3.61 (3.42-3.80)</td>
<td>2.17 (2.09-2.25)</td>
</tr>
<tr>
<td>≥ 75</td>
<td>3.75 (3.57-3.94)</td>
<td>2.32 (2.20-2.44)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>3.61 (3.40-3.83)</td>
<td>2.08 (2.02-2.14)</td>
</tr>
<tr>
<td>Women</td>
<td>2.13 (2.02-2.25)</td>
<td>1.31 (1.27-1.35)</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Hispanic white</td>
<td>2.65 (2.49-2.82)</td>
<td>1.58 (1.54-1.62)</td>
</tr>
<tr>
<td>Non-Hispanic black</td>
<td>3.29 (3.12-3.46)</td>
<td>1.65 (1.76-1.94)</td>
</tr>
<tr>
<td>Mexican American</td>
<td>2.96 (2.78-3.14)</td>
<td>1.86 (1.74-1.98)</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval, NHANES, National Health and Nutrition Examination Survey. SI conversion factor: To convert lead to micromoles per liter, multiply by 0.0483.

In a multivariable model including age, race/ethnicity, and sex, persons in the older age groups, men, and non-Hispanic blacks and Mexican Americans were more likely to have blood lead levels of 5 µg/dL (0.24 µmol/L) or higher (Table 2, P < .001 for all). Also, men, non-Hispanic blacks, and Mexican Americans were more likely than women and non-Hispanic whites, respectively, to have blood lead levels of 10 µg/dL (0.48 µmol/L) or higher (P < .001 for all). Each of these associations remained significant after further adjustment for current and former cigarette smoking, alcohol consumption, having a high school education, and having health insurance. Also, after multivariable adjustment, the odds ratios of having blood lead levels of 10 µg/dL (0.48 µmol/L) or greater were higher for persons in the older age groups, but this trend was not significant (P= .16).

Age-standardized geometric mean blood lead levels and the prevalence of blood lead levels of at least 5 µg/dL (0.24 µmol/L) were higher among persons with an income of less than $20,000 per year, no health insurance, living in a house built prior to 1978, and not having a high school education, and among former and current smokers (Table 3, P < .001 for all).

The prevalence of chronic kidney disease and peripheral arterial disease were each progressively higher at the higher quartile of blood lead level (Table 4, P < .001). After adjustment for age, race/ethnicity, sex, diabetes mellitus, body mass index, current and former cigarette smoking, alcohol consumption, having a high school education, and having health insurance, the multivariable-adjusted odds ratios of chronic kidney disease and peripheral arterial disease were progressively higher at higher lead quartiles (each P value for trend, < .001). In these multivariable-adjusted models, persons in the highest quartile of blood lead level (≥ 2.47 µg/dL [≥ 0.12 µmol/L]) were 2.72 (1.47-5.04) times more likely to have...
chronic kidney disease, and 1.92 (1.02-3.61) times more likely to have peripheral arterial disease compared with their counterparts in the lowest quartile of blood lead level (H.06 µg/dL [0.05 µmol/L]).

Hypertension was also progressively more common at higher quartiles of blood lead level among each race/ethnicity subgroup (Table 5; each P<.001). After multivariable adjustment, no association was present between higher lead levels and hypertension among non-Hispanic whites (P value for trend,.61). In contrast, the multivariable-adjusted odds ratios of hypertension were higher with each increasing quartile of blood lead for non-Hispanic blacks (P value for trend,.06) and Mexican Americans (P value for trend,.04).

**COMMENT**

The data presented in this study, derived from 2 national surveys, document the continued decline in environmental lead exposure in the US population. Substantial declines in blood lead levels occurred between 1988-1994 and 1999-2002 in the overall US adult population in every age group; for non-Hispanic whites, non-Hispanic blacks, and Mexican Americans; and among men and women. The geometric mean blood lead level and prevalence of blood lead levels of 10 µg/dL (0.48 µmol/L) or higher declined by 41% and 79%, respectively, between 1988-1994 and 1999-2002. In 1999-2002, the geometric mean blood lead level of adults in the United States was 1.64 µg/dL (0.08 µmol/L), and 0.7% of adults had a blood lead level of 10 µg/dL (0.48 µmol/L) or higher. However, non-Hispanic blacks and Mexican Americans remain disproportionately affected by exposure to environmental lead and are 3 times more likely to have blood lead levels of 10 µg/dL (0.48 µmol/L) or higher compared with non-Hispanic whites.

The continued decline in blood lead levels among all demographic groups investigated provides evidence of the benefits from public health initiatives aimed at removing lead from population-wide sources. However, lead exposure remains an environmental health problem among low socioeconomic populations in the United...
A continued diligent effort to eliminate lead pollution in the United States, especially targeting vulnerable communities, is crucial. Given the association between low-level lead exposure and chronic disease, further efforts to reduce environmental lead exposure are warranted. Available strategies for the reduction of lead exposure include use of safe removal practices for lead-based paint and clean-up of lead-contaminated dust and soil.

Despite being one of the most pervasive and persistent heavy metals in the environment, lead has no known necessary function in humans. Instead, high levels of lead exposure have been repeatedly documented to cause significant neurological defects and several chronic diseases. Many people believe that lead-abatement interventions have all but eliminated the major health consequences of lead poisoning. However, several studies have demonstrated that even low-level lead exposure results in increased risk for hypertension, chronic kidney disease, and peripheral arterial disease. For example, in the population-based Cadmibel study, Staessen et al showed that each 10-fold increase in blood lead level was associated with a 13-mL/min (0.22-mL/s) and 30-mL/min (0.50-mL/s) lower estimated creatinine clearance rate among men and women, respectively. In the present study, higher blood lead levels conferred an increased risk for:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Blood Lead ≥5 µg/dL</th>
<th>Blood Lead ≥10 µg/dL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age group, y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18-39</td>
<td>1.00 (Reference)</td>
<td>1.00 (Reference)</td>
</tr>
<tr>
<td>40-59</td>
<td>2.33 (1.71-3.17)</td>
<td>2.61 (1.90-3.59)</td>
</tr>
<tr>
<td>60-74</td>
<td>3.45 (2.43-4.89)</td>
<td>4.67 (3.18-6.85)</td>
</tr>
<tr>
<td>≥75</td>
<td>5.11 (3.30-7.91)‡</td>
<td>8.54 (5.24-13.92)‡</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td>1.00 (Reference)</td>
<td>1.00 (Reference)</td>
</tr>
<tr>
<td>Men</td>
<td>4.02 (2.96-5.46)‡</td>
<td>3.28 (2.30-4.67)‡</td>
</tr>
<tr>
<td>Race/ethnicity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Hispanic white</td>
<td>1.00 (Reference)</td>
<td>1.00 (Reference)</td>
</tr>
<tr>
<td>Non-Hispanic black</td>
<td>2.07 (1.60-2.69)‡</td>
<td>1.96 (1.51-2.54)‡</td>
</tr>
<tr>
<td>Mexican American</td>
<td>2.55 (1.93-3.36)‡</td>
<td>2.24 (1.67-2.90)‡</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval; NHANES, National Health and Nutrition Examination Survey.
SI conversion factor: To convert lead to micromoles per liter, multiply by 0.0483.
*Adjusted for age, race/ethnicity, and sex.
†Adjusted for age, race/ethnicity, sex, current and former cigarette smoking, alcohol consumption, having a high school education, and having health insurance.
‡P < .001 (P-value for trend, <.001 across age groups).
In this study, we found that higher blood lead levels were associated with higher rates of hypertension among non-Hispanic blacks and Mexican Americans. However, the association between low-level lead exposure and hypertension has become increasingly controversial. Most previous studies reported lead exposure to be significantly and positively associated with an elevated blood pressure and an increased risk of hypertension. However, other studies have disputed the presence of a relation between low-level lead exposure and hypertension. The adverse effect of lead on blood pressure has been reported to be stronger among non-Hispanic blacks and Mexican Americans than for non-Hispanic whites, which is consistent with previous findings. Documentation that environmental lead exposure may be a contributing factor in the occurrence of hypertension among minority populations is important because it may provide further understanding into the disparities in hypertension in the United States. Hypertension is more common, more severe, and usually appears earlier in life in non-Hispanic blacks. Understanding the role of low-level environmental lead exposure in the pathogenesis of hypertension should remain an important public health priority.

A limitation of our study is that blood lead concentration is not an optimal biomarker. Data indicate that bone lead is the most valuable measurement of internal exposure to bone lead and can accurately assess persons who are exposed to chronic low-level environmental lead pollutants over a long period of time. However, bone lead measurements are impractical for large-scale population studies. Given that mean blood lead levels reported in the present study fell dramatically between 1988-1994 and 1999-2002, it is possible that the association between higher blood lead levels and chronic kidney disease and peripheral arterial disease may have decreased risk of chronic kidney disease and peripheral arterial disease.

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peripheral arterial disease may be the result of much higher blood lead levels at some previous time. Unfortunately, data were not available in the present study to determine previous sources or levels of lead exposure. Finally, it has been proposed that kidney dysfunction may result in the decreased excretion of lead, and this may explain the higher lead levels among patients with chronic kidney disease. Given the cross-sectional design of the present study, data were not available to examine this hypothesis. However, results from most previous studies suggest that higher blood lead levels are the cause, rather than the result, of lower renal function.

In conclusion, the virtual disappearance of overt lead poisoning may have caused complacency toward the hazards of low-level chronic lead exposure. Despite major overall reductions in the United States, blood lead levels remain associated with hypertension among non-Hispanic blacks and Mexican Americans, who continue to have higher blood lead concentrations compared with non-Hispanic whites. In addition, blood lead levels are significantly associated with chronic kidney disease and peripheral arterial disease in the overall population. Given the strong associations between higher blood lead levels and several chronic diseases observed in the present study, continued efforts to reduce environmental lead exposure are warranted.

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REFERENCES