Association of Dental Caries and Blood Lead Levels

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Despite the dramatic decline in dental caries in the US population following the widespread practice of fluoridation of public water supplies, tooth decay remains a major public health problem. By age 17 years, 84% of US adolescents have experienced tooth decay in their permanent teeth—on average, involving 8 tooth surfaces. The annual treatment costs for dental caries in the United States are estimated to be at least $4.5 billion. If left untreated, tooth decay can result in substantial morbidity due to pain, dysfunction, and poor appearance. Although most children experience minimal levels of decay, about 25% of children account for 80% of all decayed surfaces observed in the population. Individuals who are impoverished experience a disproportionately high burden of dental caries. Unfortunately, factors responsible for this disparity in caries have remained elusive.

The role of trace elements in the development of tooth decay has been an area of study since the identification of fluoride’s protective effects. Lead, which accumulates in bones and teeth, is of particular interest because of its widespread distribution in the environment. Several ecologic and cross-sectional studies, conducted in the 1960s and 1970s, implicated lead as a risk factor for dental caries. These studies, however, were inconclusive. In recent years, lead has been identified as a risk factor for dental caries in 2 cross-sectional studies conducted in Spain. However, the most compelling basis for a causal relationship between lead exposure and dental caries showed prenatal and perinatal lead exposure to be linked to increased incidence of caries in a well-controlled animal study.

The purpose of the following analyses was to examine the association between blood lead level and dental caries status by using data collected in the Third National Health and Nutrition Examination Survey (NHANES III), a cross-sectional survey conducted from 1988 to 1994. We further assessed the role of lead as a confounder for factors that are important in understanding the distribution of dental caries in the United States.

Context Experiments show that dental caries rates are higher among lead-exposed animals, but this association has not been established in humans.

Objective To examine the relationship between blood lead levels and dental caries.

Design Cross-sectional survey conducted from 1988 to 1994 that included a dental examination and venipuncture blood lead assay.

Setting and Participants A total of 24,901 persons aged 2 years and older who participated in the Third National Health and Nutrition Examination Survey, which assessed the health and nutritional status of children and adults in the United States.

Main Outcome Measures For children aged 2 to 11 years, the sum of decayed and filled deciduous or primary surfaces; for persons aged 6 years and older, the sum of decayed and filled permanent surfaces; for those 12 years and older, the sum of decayed, missing, and filled surfaces.

Results The log of blood lead level was significantly associated with the number of affected surfaces for both deciduous and permanent teeth in all age groups, even after adjusting for sociodemographic characteristics, diet, and dental care. Among children aged 5 to 17 years, a 0.24-µmol/L (5-µg/dL) change in blood lead level was associated with an elevated risk of dental caries (odds ratio, 1.8; 95% confidence interval, 1.3-2.5). Differences in blood lead level explained some of the differences in caries prevalence in different income levels and regions of the United States. We estimated the population attributable risk of lead exposure to be 13.5% and 9.6% of dental caries occurring in 5- to 17-year-olds exposed to the high and moderate levels, respectively.

Conclusions Environmental lead exposure is associated with an increased prevalence of dental caries in the US population. Findings may help explain the distribution of caries by income and region of the United States.

JAMA. 1999;281:2294-2298

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universal household interviews and health examinations of approximately 40,000 persons aged 2 months and older who were interviewed over a 6-year period (1988-1994). The household interview collected demographic, socioeconomic, dietary, and health history information. The examination component consisted of physical and dental examinations and various laboratory tests from venipuncture and urine specimens.

The health examination included an oral health component performed by a licensed dentist on examinees aged 1 year and older. Results from the dental examination for coronal caries were used for this study. Details of the methods used in the oral health component of the survey that relate to coronal caries have been published previously. For children 2 to 11 years of age with at least 1 primary tooth, the sum of decayed and filled deciduous or primary surfaces (dfs) was analyzed. For persons 6 years and older with at least 1 permanent tooth, the sum of decayed and filled permanent surfaces (DFS) was analyzed. For persons 12 years and older, the sum of decayed, missing, and filled surfaces (DMFS) was also included in the analysis. Children aged 12 to 23 months only had a brief inspection for the presence of early childhood caries and were excluded from these analyses. For this study, persons were also categorized as being either caries free or caries active (non-caries free).

The primary independent variable was environmental lead exposure. Blood specimens were collected during the examination component of the survey from examinees aged 1 year and older and lead levels were determined. Blood lead levels below the detection limit were assigned a value of 0.03 µmol/L (0.7 µg/dL). Lead levels were log transformed to normalize the distribution of blood lead levels.

Other potential independent associations with dental caries were analyzed. Demographic characteristics included age, sex, race, family poverty level, region of the country, educational level of head of household, and exposure to cigarette smoke in the home. Family poverty level was defined as the poverty income ratio (PIR), calculated as the total family income divided by the poverty threshold for the year of the interview. A PIR of 1 represents a family at 100% of the federal poverty level. As family income increases the PIR increases. Carbohydrate and calcium intakes from a 24-hour dietary recall interview were also included in the analysis. Use of oral health services was determined by time since the last visit to a dentist and how often the person visited a dentist or dental hygienist.

Bivariate analyses were conducted to determine associations with caries-free status. Analyses were stratified by age group (2-5 years, 6-11 years, and ≥12 years) to account for the different definitions of dental caries based on age. Variables found to be statistically significant based on χ² and t tests were included in logistic regression analyses to determine independent associations with caries-free status. In addition, variables were included if previous studies identified an important role in the epidemiology of dental caries. SUDAAN software (Research Triangle Institute, Research Triangle Park, NC) was used to account for the complex multistage sampling design of the survey. Sample weights were used to produce national estimates by adjusting for the oversampling of young children and older adults as well as for Mexican American and black individuals.

Previous epidemiological studies of caries in permanent teeth of children in the United States have focused on 5- to 17-year-olds. To put the findings into context, the potential public health impact of lead exposure on childhood caries in permanent teeth was examined for individuals aged 5 to 17 years. Population attributable risk (PAR) estimates were derived using Levin's formula:

\[ \text{PAR} = \frac{\text{Prevalence} \times (\text{Relative Risk} - 1)}{\text{Prevalence} \times (\text{Relative Risk} - 1) + 1} \]

where prevalence is the prevalence of the risk factor in the population and relative risk is that estimated using the observed odds ratio.

Assessment of environmental lead as a confounder of associations between other risk factors and permanent tooth decay in childhood was done by comparing risk estimates that were unadjusted for lead with estimates that were derived from analyses that included a lead variable. Poverty level, race, and geographic region were of interest because these factors have been shown to be associated with lead exposure and caries status.

## RESULTS

A total of 24,901 individuals had both an oral examination and a blood lead assay. Table 1 and Table 2 show the distributions by age group for dental caries and blood lead level, respectively.

There were statistically significant associations between log of blood lead level and caries status among all age groups in both unadjusted and adjusted analyses (Table 3). As defined by the sum of decayed and filled surfaces for deciduous (dfs) and permanent teeth (DFS) or the sum of decayed, missing, and filled permanent tooth surfaces (DMFS), the

<table>
<thead>
<tr>
<th>Age Group, y</th>
<th>No. of Subjects</th>
<th>dfs</th>
<th>% With dfs ≥ 1</th>
<th>Mean (SE)</th>
<th>DFS</th>
<th>% With DFS ≥ 1</th>
<th>Mean (SE)</th>
<th>DMFS</th>
<th>% With DMFS ≥ 1</th>
<th>Mean (SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-5</td>
<td>3547</td>
<td>2.15 (0.22)</td>
<td>23.9</td>
<td>. . .</td>
<td>. . .</td>
<td></td>
<td></td>
<td>. . .</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-11</td>
<td>2894</td>
<td>3.53 (0.16)</td>
<td>49.8</td>
<td>0.86 (0.07)</td>
<td>26.3</td>
<td>. . .</td>
<td></td>
<td>. . .</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥12</td>
<td>18,460</td>
<td>19.39 (0.45)</td>
<td>90.2</td>
<td>43.46 (0.68)</td>
<td>93.1</td>
<td></td>
<td></td>
<td>. . .</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*NHANES III indicates Third National Health and Nutrition Examination Survey; dfs, decayed and filled surfaces of deciduous teeth; DFS, decayed and filled surfaces of permanent teeth; DMFS, decayed, missing, and filled surfaces of permanent teeth; and ellipses, not applicable.
association of blood lead level and dental caries was statistically significant among all 3 age groups. Each of the linear regression models was adjusted for age, sex, race, educational level, PIR, cigarette smoke exposure, calcium intake, days since last dental visit, frequency of dental visits, and geographic region.

Among children 5 to 17 years of age, comparisons of caries-free children vs those with some caries (DMFS ≥1) showed that a 0.24-µmol/L (5-µg/dL) change in blood lead level was associated with an elevated risk for caries (odds ratio, 1.8; 95% confidence interval, 1.3-2.5). We used the age-specific tertiles shown in Table 2 to define high, moderate, and low exposure to lead in children aged 5 to 17 years. The population attributable risk of lead exposure is estimated to be 13.5% of dental caries among individuals exposed to the highest age-specific tertile of lead level and 9.6% of caries among individuals exposed to the middle age-specific tertile of lead level, compared with the lowest tertile (Table 4).

Lead exposure was further assessed as a confounder by examining changes in point estimates that occurred when regression model coefficients were compared with and without adjustment for the log of blood lead level. Results were obtained for the 5- to 17-year-old age group for both logistic regression and linear regression models, using caries status (present or absent) and number of DMFS as the dependent variables, respectively. Adjustment for blood lead level attenuated the association of caries status most strongly with PIR (TABLE 5). Comparing the Northeast with the West, regional differences in caries status are reduced after adjustment for lead as evidenced by the change in the parameter estimate when comparing models with and without lead exposure. In the logistic regression models, the difference between the unadjusted and adjusted parameter estimate for the association between residence in the West region of the United States and dental caries status equates to a 17% difference in the relative risk estimate attributable to lead exposure (unadjusted odds ratio, 0.75 vs adjusted odds ratio, 0.91).

**COMMENT**

Trace elements in the environment have long been implicated in the development of dental caries. The discovery of the protective role of fluoride in dental caries during the 1930s and 1940s was followed by the widespread practice of adjusting public water supplies to an optimal level of 0.8 to 1.2 ppm of fluoride. Since then, dental caries levels in children in the US population have dramatically declined. This decline has largely been attributed to the increased levels of fluoride in drinking water and dentifrices.

The association between poverty status and dental caries in the NHANES III data has been the topic of a recent study. Vargas et al showed that family income level was particularly linked with the proportion of children having decayed teeth. As income level increased, children were less likely to have any decayed teeth. About 20% of 6- to 14-year-old children from families with incomes at 0% to 100% of the federal poverty level had at least 1 decayed tooth. Only 3% of children from families with incomes that were 301% of the federal poverty level or higher had 1 or more decayed teeth.

The results of the present analyses suggest that environmental lead exposure may explain, at least in part, the disproportionately high rate of dental caries among disadvantaged children and adolescents. Without the lead exposure variable in the statistical model, the PIR shows that the odds of having a decayed, filled, or missing permanent tooth decrease as income level increases, a finding consistent with that of Vargas et al. Statistical adjustment for lead exposure reduced the strength of the association between income level and caries status. This suggests that the association between poverty and dental caries is partially explained by lead exposure.

These data are also consistent with the hypothesis that the decline in en-
vironmental lead exposure\textsuperscript{18,19} may also have contributed to the decline in the prevalence of dental caries. Previous epidemiological studies have not reported associations between lead exposure and dental caries that are as strong as those observed in this analysis. On a population basis, the widespread exposure to a strong protective factor such as fluoride allows for the emergence of other risk factors.\textsuperscript{20,21} We speculate that when fluoride exposure was variable in the population, the impact of other risk factors was overshadowed by the caries patterns explained by fluoride exposure. Now that exposure to fluoride is relatively uniform, the role of lead in dental caries has become more striking.

Because fluoride exposure is strongly linked to dental caries risk, one must consider whether lead exposure is simply a marker for residence in an area that is not served by fluoridated drinking water. An association between patterns of lead exposure and fluoridation exposure would result in a mixing of effects and a spurious association between lead and dental caries. However, since fluoridation occurs at the community level, this seems unlikely. In the United States, efforts to prevent tooth decay focus on community drinking water systems. At present, 70% of all cities with populations of more than 100,000 receive fluoridated water.\textsuperscript{3} It seems likely that elevated lead exposure is independent of fluoridation status since public water supplies serve the same water to individuals with a range of lead exposure. Nevertheless, the NHANES III data do not provide information on fluoride exposure so further study is needed to resolve this issue.

Small geographic differences in prevalence surveys of dental caries in representative samples of US schoolchildren have been reported.\textsuperscript{1,2} While the magnitude of these regional differences has declined over time, lead exposure may explain some of the observed differences. The West region has generally had lower rates of mean DMFS in children aged 5 to 17 years and the Northeast region has had high rates of DMFS. Data collected in 1971-1974 and 1979-1980 showed differences of 8.1 vs 6.3 and 5.6 vs 4.4 DMFS, respectively, for Northeast and West regions.

Lead exposure may be a confounder for these observed regional differences. Specifically, our results suggest that some of the advantage children in the western United States experience relative to children in the Northeast may be partially explained by lead exposure. Other regional differences did not appear to be confounded by lead exposure. NHANES III was not designed to account for seasonal variation in lead exposure and this may introduce measurement error in the assessment of regional patterns associated with blood lead levels.\textsuperscript{14}

We cannot demonstrate conclusively that environmental lead exposure is causally linked to dental caries on the basis of observational data alone. Because of the complexity of factors that are linked both to dental caries and lead exposure, residual confounding is likely to be problematic. However, we have attempted to adjust for the potential confounding effect of socioeconomic status in our models, and the plausibility of these observations is strengthened by recent experimental data.

Watson et al\textsuperscript{10} found that exposure to lead, prenatally and perinatally, resulted in a high rate of dental caries in laboratory rats. In the study, female rats were exposed to 34 ppm of lead in drinking water as young adults, during pregnancy, and during lactation. Maternal blood lead levels averaged 2.32 µmol/L (48 µg/dL). After weaning, experimental and control rat pups

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**Table 4.** Odds Ratios and Population Attributable Risk Estimates for Association Between Dental Caries and Blood Lead Level in US Children Aged 5 to 17 Years\textsuperscript{*}

<table>
<thead>
<tr>
<th>Blood Lead Level</th>
<th>% of Subjects</th>
<th>Odds Ratio (95% Confidence Interval)</th>
<th>Population Attributable Risk, %</th>
<th>Estimated No. of Children Affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>29.7</td>
<td>1.36 (1.01-1.83)</td>
<td>9.6</td>
<td>1274800</td>
</tr>
<tr>
<td>High</td>
<td>23.5</td>
<td>1.66 (1.12-2.48)</td>
<td>13.5</td>
<td>1418500</td>
</tr>
</tbody>
</table>

\textsuperscript{*Comparison of the highest and middle tertiles of blood lead level distribution with the lowest tertile (referent group). Models were adjusted as described in the second footnote to Table 3.}

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**Table 5.** Assessment of Confounding Due to Lead Exposure by Comparing Unadjusted and Adjusted Models for Blood Lead Level\textsuperscript{*}

<table>
<thead>
<tr>
<th>Variable</th>
<th>Logistic Regression Models, Caries vs Caries Free</th>
<th>Linear Regression Models, DMFS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unadjusted for Lead</td>
<td>Adjusted for Lead</td>
</tr>
<tr>
<td>Poverty income ratio</td>
<td>-0.11 0.04 .01 -.06 0.05 .22</td>
<td>-0.09 0.09 .30 -.06 0.10 .58</td>
</tr>
<tr>
<td>Race</td>
<td>-0.26 0.18 .16 -.31 0.19 .10</td>
<td>-0.04 0.29 .89 -.03 0.30 .91</td>
</tr>
<tr>
<td>Other vs white</td>
<td>-0.68 0.25 .01 0.59 0.26 .03</td>
<td>1.12 0.80 .17 0.84 0.82 .31</td>
</tr>
<tr>
<td>Region</td>
<td>-0.04 0.39 .91 0.005 0.38 .99</td>
<td>-0.44 0.83 .60 -.41 0.83 .63</td>
</tr>
<tr>
<td>Midwest vs Northeast</td>
<td>-0.01 0.37 .96 0.05 0.36 .88</td>
<td>-.074 0.87 .40 -.65 0.89 .47</td>
</tr>
<tr>
<td>South vs Northeast</td>
<td>-0.28 0.39 .47 -.09 0.37 .81</td>
<td>-.060 0.86 .49 -.42 0.87 .63</td>
</tr>
</tbody>
</table>

\textsuperscript{*Logistic regression models compare individuals with some dental caries (decayed, missing, and filled permanent tooth surfaces [DMFS] ≥1) with individuals who are caries free in the permanent dentition (DMFS = 0). Linear regression models use the sum of DMFS as the dependent variable. All models are limited to children aged 5 to 17 years. Models were also adjusted as described in the second footnote to Table 3. Data source: Third National Health and Nutrition Examination Survey. ©1999 American Medical Association. All rights reserved.
were fed a high-sugar diet known to accelerate caries development. After 5 weeks, pups born to the lead-exposed rats had significantly more dental caries lesions than controls.

Three different mechanisms can be hypothesized concerning lead exposure and dental caries: salivary gland function, enamel formation, and interference with fluoride in saliva. Watson et al showed differences in salivary gland function, which suggested that exposure to lead during salivary gland development may have adversely affected the ability of the gland to produce adequate amounts of saliva. Saliva has several protective properties that operate against caries: it acts as a buffering agent when acids are produced, it physically removes debris from tooth surfaces, and it has immunologic and bacteriostatic properties. Lead also incorporates into tooth structure before the eruption into the mouth and this may result in defective enamel that is more susceptible to caries. Also, lead may interfere with the bioavailability of fluoride by binding to fluoride ions in saliva and plaque, thereby reducing the preventive capacity of fluoride to remineralize enamel after an acid challenge.

The cross-sectional nature of the NHANES III data imposes limitations on the ability to test mechanism-specific hypotheses. For example, if lead exposure at the time of enamel formation were the most relevant mechanism for a lead-caries causal association, one would need to assume that current blood lead level is a good estimate of lead exposure during early childhood when teeth are formed. In cross-sectional data, such as NHANES III, the most relaxed assumptions would be required for a recent temporal effect if lead exposure status were subject to change over time.

The present analysis supports the hypothesis that environmental lead exposure is a risk factor for dental caries. Nonetheless, a mechanistic role to explain differences in caries prevalence has not been clearly established for lead. In support of a causal role for lead in dental caries, there are compelling experimental data from well-controlled animal studies that support the biologic plausibility of the hypothesis and we have observed a dose-response trend. Still, to satisfy the criteria for causality, further prospective investigations will be needed to demonstrate that lead exposure precedes the development of caries in humans after adequate control of potential confounders and that these findings are consistent across different populations and with different study designs.

In conclusion, these data suggest that blood lead levels are associated with dental caries in the US population. These data further indicate that approximately 2.7 million excess cases of dental caries in older children and adolescents may be attributable to environmental lead exposure itself or a factor that is directly linked to environmental lead exposure. If a causal association between environmental lead exposure and dental caries is substantiated, it would have important implications concerning the need to broaden the focus of health interventions for dental caries beyond modifying dietary habits, improving personal oral hygiene behaviors, and increasing fluoride exposure in high-risk groups.

Funding/Support: This research was supported by a grant from the National Institute of Environmental Health Sciences (ROI-ES-08338) and an Institutional National Research Service Award from the Bureau of Health Professions, Health Resources and Services Administration, Public Health Service (1T-32 PE-10027).

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