Changes in Blood Lead Levels Associated with Use of Chloramines in Water Treatment Systems

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BACKGROUND: More municipal water treatment plants are using chloramines as a disinfectant in order to reduce carcinogenic by-products. In some instances, this has coincided with an increase in lead levels in drinking water in those systems. Lead in drinking water can be a significant health risk.

OBJECTIVES: We sought to test the potential effect of switching to chloramines for disinfection in water treatment systems on childhood blood lead levels using data from Wayne County, located in the central Coastal Plain of North Carolina.

METHODS: We constructed a unified geographic information system (GIS) that links blood lead screening data with age of housing, drinking water source, and census data for 7,270 records. The data were analyzed using both exploratory methods and more formal multivariate techniques.

RESULTS: The analysis indicates that the change to chloramine disinfection may lead to an increase in blood lead levels, the impact of which is progressively mitigated in newer housing.

CONCLUSIONS: Introducing chloramines to reduce carcinogenic by-products may increase exposure to lead in drinking water. Our research provides guidance on adjustments in the local childhood lead poisoning prevention program that should accompany changes in water treatment. As similar research is conducted in other areas, and the underlying environmental chemistry is clarified, water treatment strategies can be optimized across the multiple objectives that municipalities face in providing high quality drinking water to local residents.

lead levels were detected in water in early 2002, sampling protocols were altered in 2003. This made an informed assessment of human exposure to increased lead levels difficult to undertake, because test results can be heavily affected by changes in sampling methods (Edwards and Dudi 2004; Schock 1990).

Although some documentation of changes in water lead levels exists, only one published study, focused on Washington, DC, has evaluated blood lead levels (BLLs) associated with changes in water treatment options (Centers for Disease Control and Prevention (CDC) 2004). The report includes results from a longitudinal analysis of all childhood blood lead screening results from 1998 to 2003, showing an increase in the percent of BLLs > 5 μg/dL, which coincided with the change to chloramine disinfectant use. Additionally, BLLs were reported from a very limited nonrandom sample (n = 201) of residents in 52 households with high (> 300 ppb) lead in drinking water levels. Few conclusions can be drawn from this household data because 53% of those sampled were drinking filtered water (CDC 2004).

Using geographic information system (GIS)-based analysis, we sought to test the potential effect on childhood BLLs of switching to chloramines for disinfection in water treatment systems using data from Wayne County, located in the central Coastal Plain of North Carolina. In particular, we sought to answer three key questions:

- Are changes in BLLs detectable after switching from chlorines to chloramines for disinfection in water treatment systems?
- How do these changes differ according to the age of housing where the child resides?
- How can the answers to the first two questions help guide policy practice?

GISs have many applications in public and environmental health (Miranda et al. 2005; Vine et al. 1997) and have been well applied to research on lead exposure risk (Krieger et al. 2003; Miranda et al. 2002; Reissman et al. 2001; Roberts et al. 2003). GIS allows for the observation and analysis of complex spatio-temporal patterns that may be otherwise overlooked in traditional research and surveillance (Rushton 2003). Spatially based analysis is thus especially well suited to help determine whether changes in water treatment systems introduce systematic changes in childhood BLLs.

Wayne County provides an ideal setting for evaluating these questions for several reasons. First, the housing stock is distributed across a wide variety of age classes (Table 1), with approximately 15.6% built before 1926, 9.3% between 1926 and 1950, 35.5% between 1951 and 1975, and 39.6% after 1975. Second, Wayne County screens a relatively large proportion of 1- and 2-year-old children for lead, ranging from 75.5% in 2000 to 76.1% in 2003. As shown in Table 1, the children screened for lead are well-distributed across the housing age classes in the county. Third, Wayne County contains two main public water systems that together provide water for approximately three-fourths of the residential tax parcels within the county. Approximately 70% of residential tax parcels obtain drinking water through the Wayne Water Systems (WWS). These systems use chlorine for disinfection and sodium fluoride for fluoridation, and do not use an anticorrosive; these treatment options did not change over the course of the study period (1999–2003). Another 28% of residential tax parcels obtain drinking water through the Goldsboro Water System (GWS). This system uses fluorosilicic acid for fluoridation and zinc orthophosphate for anticorrosion. The GWS switched from using chlorine to using chloramines for disinfection in March 2000. This combination of sources of drinking water and treatment strategies allow us to compare outcomes within and across water systems. Figure 1 shows the geographic coverage for each of the water treatment systems across Wayne County.

**Materials and Methods**

To analyze potential effects on BLLs associated with changes in water treatment processes, we first built a unified GIS consisting of tax parcel,
Chloramines and blood lead levels

We analyzed the data using both exploratory methods and more formal multivariate techniques. Because the distribution of blood lead screens is skewed toward the origin, we used the natural logarithm of the BLL as our dependent variable. In addition, because some residential parcels had more than one linked blood lead screen (e.g., different tenants/owners or multiple siblings from the same family), we used cluster analysis to ensure that we properly weighted the contribution of any one residence to the analysis. We classified each blood lead screen according to whether the drinking water source used chloramines in the disinfection process with a binary (0/1) variable (Table 2).

Previous research indicates that BLLs are typically related to the year the child’s residence was built and demographic variables such as household income and percent African-American race (Lanphear et al. 1998; Miranda et al. 2002; Pirkle et al. 1998; Roberts et al. 2003; Sargent et al. 1995); therefore, we included these variables in the analysis as well. Our general approach for specifying a parcel level model follows the methods established previously (Miranda et al. 2002).

Results

Exploratory graphical analysis reveals some interesting relationships. Figure 2 shows mean BLLs over time differentiated by drinking water source (WWS or GWS) and highlights the point in time when the GWS switched to chloramines for water disinfection. For both sources of drinking water, mean BLLs increased between the January 1999–February 2000 and the March 2000–December 2000 time periods.

A two sample t-test assuming equal variances revealed that the mean BLL was significantly higher ($p < 0.00001$) for children residing in residential tax parcels whose water source relied on chloramines for disinfection (mean BLL = 4.93 μg/dL) compared with those whose water source did not rely on chloramines (mean BLL = 4.19 μg/dL). This may, of course, result solely from artifacts such as the GWS serving more of the older housing stock or the GWS serving more homes in less well-maintained areas.

Exploratory graphical analysis was designed to look at differences in BLLs across age classes of homes. Figure 3 shows mean BLL by test year, differentiating between GWS and WWS. These figures are broken out by age of housing categories (pre-1926, 1926–1950, 1951–1975, after 1975). The mean BLLs are virtually indistinguishable across the different water treatment systems for housing built after 1950. This is consistent with empirical observations that older age classes of homes are more likely to contain lead pipes or lead-containing fixtures or solder (Safe Drinking Water Act Amendments of 1986; Troesken and Beeson 2003; U.S. EPA 1991).

Although the exploratory analysis provides insights regarding variables of interest, the question of whether the switch to chloramines by the GWS affected BLLs in children must be explored using multivariate analysis. We used log-linear cluster analysis of blood lead screens, with explanatory variables that included year built; census measures of income and percent African American; three dummy variables for seasons when the blood samples were taken (winter as reference) to control for any potential effect of seasonal variation in BLLs; a dummy variable indicating whether chloramines were being used by the water treatment system that served the home residence of the child at the time of the blood lead screen; and interactive terms that combined year built with the chloramine-use variable. The interactive terms were incorporated in two ways. First, we constructed an interactive variable (year built × chloramines)
that allows the effect of chloramines to be mitigated or exacerbated (we anticipated that it should be mitigated) with each incremental year added to year built; that is, we expected that the effect of chloramines on BLL would be less important and eventually unimportant as we moved into newer and newer housing stock. As shown in Table 3, this was borne out in the analysis. All coefficients on demographic and seasonal covariates were of the expected sign and consistent with previous studies.

These results indicate that the change to chloramine disinfection led to an increase in BLLs, the impact of which is progressively mitigated in newer housing. This makes sense in that increases in dissolved lead in water can only happen when a lead source is present, a condition that is much more likely in older housing. The year of construction at which the newness of the housing exerts a stronger influence on BLLs than use of chloramines is 1951, as calculated from the model shown in Table 3. Data on the age of housing contain inaccuracies, especially for the oldest housing stock. Because of these inaccuracies, the model presented in Table 3 (which uses a continuous age-of-housing variable) is vulnerable to bias in estimating the year built coefficient.

To avoid this bias, we also estimated a model using categorical age-of-housing variables. Given the differences across age classes demonstrated in Figure 3 and the crossing point calculated from the model presented in Table 3, we also chose to construct an interactive term that split housing age categories into 25-year increments. Thus we included (year built before 1926 × chloramines), (year built 1926–1950 × chloramines), (year built 1951–1975 × chloramines), and (year built after 1975 × chloramines) as explanatory variables, with the newest housing group serving as the referent group. These results are shown in Table 4.

Again, all coefficients on demographic and seasonal covariates were of the expected sign and of very similar size to the same coefficients in Table 3. These results also demonstrate a dose–response effect vis-à-vis age of housing; that is, the increase in BLLs for children screened at locations or times where chloramines were used is greatest in houses built before 1926, followed by houses built in 1926–1950, followed by houses built in 1951–1975.

**Discussion**

When municipal water treatment systems introduce the use of chloramines for the purpose of reducing carcinogenic by-products, they may inadvertently increase exposure to lead in the water supply. Tables 3 and 4 indicate that use of chloramines in Wayne County, North Carolina, is a significant predictor of BLLs, and the extent of the effect decreases in newer housing stock. Definitive conclusions regarding the use of chloramines are difficult because of the particular combinations of disinfection agents, anticorrosives, coagulants, and fluoride additives used in water treatment systems. We are currently pursuing the data to undertake a more comprehensive analysis.

Although we were not able to perform a more expansive analysis at this time, the results presented in this article provide policy guidance to municipalities. In prioritizing children to screen for elevated BLLs when chloramines are not being used, local health departments should target children living in housing built before 1950. Similarly, when chloramines are being used, local health departments should target children living in housing built before 1975. This suggests that, assuming the results from Wayne County can be generalized to other areas, local health departments need to expand their scope of targeted screening in the years following the introduction of chloramines as a water-disinfection agent. Local health department officials may also wish to provide more intensive outreach and education to residents of older housing, including techniques such as flushing water pipes before consumption.

In addition, after changes in water treatment, surveillance on lead in water can focus on housing built before 1975, in spite of the fact that lead solder was not banned until 1986. Additional analyses indicate that after introducing chloramines, again assuming the Wayne County case can be generalized, local health departments can focus both blood lead screen and water-testing efforts on that part of the housing stock built before 1965 (Miranda ML, Kim D, Hull AP, Paul CJ, Overstreet Galeano MA, unpublished data). Because routine monitoring failed to detect increases in water lead levels both in North Carolina and in Washington, DC, we wish to emphasize the recommendations of water chemistry experts Edwards and Dudi (2004) and Schock (1990): (a) water lead levels should be closely monitored after changing to use of chloramines; and (b) a sampling program designed to fully document the variability of water lead levels should be implemented. Appropriate and timely collection of water lead level data would enable meaningful assessment of human exposure and also provide water treatment systems with insights regarding which exposure control strategies are most appropriate.

**Conclusions**

Several caveats must be mentioned that temper the possible conclusions from this study. First, although the results are directly relevant to Wayne County, the extent to which they can be extrapolated to other areas in North Carolina, the Southeastern United States, or the United States more generally is yet to be determined. We are currently pursuing the data required to replicate the current study in other locations. Second, blood lead surveillance data are decidedly nonrandom in that

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**Table 3.** Clustered multivariate regression results using a simple interaction term.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>SE</th>
<th>P &gt;</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year built (continuous)</td>
<td>−1.55 × 10⁻³</td>
<td>3.74 × 10⁻⁴</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Household median income</td>
<td>−4.38 × 10⁻⁴</td>
<td>1.02 × 10⁻⁶</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Percent African American</td>
<td>1.60 × 10⁻³</td>
<td>3.14 × 10⁻⁴</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Use of chloramines</td>
<td>4.059</td>
<td>1.32</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Use of chloramines × year built</td>
<td>−2.38 × 10⁻³</td>
<td>6.74 × 10⁻⁴</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Screened in spring</td>
<td>−0.020</td>
<td>0.025</td>
<td>0.427</td>
<td></td>
</tr>
<tr>
<td>Screened in summer</td>
<td>0.078</td>
<td>0.025</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Screened in fall</td>
<td>0.083</td>
<td>0.025</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>4.395</td>
<td>0.730</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

The referent group for the season variables is winter (December, January, and February).

**Table 4.** Clustered multivariate regression results using categorical age of housing interaction term.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>SE</th>
<th>P &gt;</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year built before 1926</td>
<td>0.169</td>
<td>0.356</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Year built 1926–1950</td>
<td>0.120</td>
<td>0.049</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>Year built 1951–1975</td>
<td>0.005</td>
<td>0.025</td>
<td>0.841</td>
<td></td>
</tr>
<tr>
<td>Household median income</td>
<td>−4.93 × 10⁻⁶</td>
<td>1.09 × 10⁻⁶</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Percent African American</td>
<td>1.66 × 10⁻³</td>
<td>3.18 × 10⁻⁴</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Use of chloramines</td>
<td>−0.087</td>
<td>0.038</td>
<td>0.021</td>
<td></td>
</tr>
<tr>
<td>Use of chloramines × year built before 1926</td>
<td>0.167</td>
<td>0.062</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>Use of chloramines × year built 1926–1950</td>
<td>0.161</td>
<td>0.071</td>
<td>0.024</td>
<td></td>
</tr>
<tr>
<td>Use of chloramines × year built 1951–1975</td>
<td>0.108</td>
<td>0.048</td>
<td>0.023</td>
<td></td>
</tr>
<tr>
<td>Screened in spring</td>
<td>−0.022</td>
<td>0.025</td>
<td>0.376</td>
<td></td>
</tr>
<tr>
<td>Screened in summer</td>
<td>0.078</td>
<td>0.025</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>Screened in fall</td>
<td>0.081</td>
<td>0.025</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>1.327</td>
<td>0.0466</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

The referent group for the interaction term is use of chloramines × year built after 1975.
programs typically target children living in the highest risk housing, based, in many cases, on age of housing. However, because Wayne County screens such a high proportion of young children, this concern is somewhat mitigated. In spite of targeted screening efforts, the distribution of age of housing where sampled children resided differs by < 2 percentage points from the distribution for the whole county. Third, some environmental chemists hypothesize that the dissolution of lead from pipes into water after switching to chloramines is a transient process, because a new coating may eventually develop on the inside of pipes, effectively creating a new barrier between the water and the lead source. This temporal dimension is unexplored in the current analyses. Fourth, we did not analyze lead in direct water and thus can only indirectly suggest that the increase in BLLs after the switch to chloramines was caused by an increase in lead in drinking water. We are currently working with the State of North Carolina to identify houses to sample for lead in water based on a geographic sampling design; we will analyze these data when they become available.

In the present study we directly analyzed the effects of changes in water treatment options on BLLs. This study provides important policy guidance to communities that may be balancing trihalomethane exceedances against possible increases in lead in drinking water. As similar research is conducted in other areas, and the underlying environmental chemistry is clarified, water treatment strategies can be optimized across the multiple objectives that municipalities face in providing high-quality drinking water to local residents.

**References**


**Chloramines and blood lead levels**


