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THE JOURNAL OF PEDIATRICS • www.jpeds.com

ORIGINAL ARTICLES

Blood Lead Levels of Children in Flint, Michigan: 2006-2016

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Objective We evaluated the increases in blood lead levels (BLLs) observed in young children in Flint, Michigan, during their exposure to corrosive Flint River water during the years 2014 and 2015 and compared their BLLs to those of Flint children measured during the years 2006-2013 and 2016.

Study design This was a retrospective study design using BLLs extracted from databases from 2006 to 2016. We analyzed a population sample of 15 817 BLLs from children aged ≤5 years with potential exposure to contaminated Flint River water. Percentages of BLLs ≥5.0 μg/dL and geometric mean (GM) BLLs were analyzed over time.

Results A significant decline in the percentages of BLLs ≥5.0 μg/dL from 11.8% in 2006 to 3.2% in 2016 was observed ($P < .001$). GM ± SE BLLs decreased from 2.33 ± 0.04 μg/dL in 2006 to 1.15 ± 0.02 μg/dL in 2016 ($P < .001$). GM BLLs increased twice: from 1.75 ± 0.03 μg/dL to 1.87 ± 0.03 μg/dL (2010-2011) and from 1.19 ± 0.02 μg/dL to 1.30 ± 0.02 μg/dL (2014-2015). Overall, from 2006 to 2016, there was a 72.9% decrease in the percentage of children with BLLs ≥5.0 μg/dL and a 50.6% decrease in GM BLLs.

Conclusion These findings suggest that the 11 year trend of annual decreases in BLLs in children in Flint, Michigan, reversed to a degree consistent with random variation from 2010 to 2011, and again during the exposure to Flint River water in 2014-2015. Historically, public health efforts to reduce BLLs of young children in Flint have been effective over the 11-year period studied. *(J Pediatr 2018;■■:■■-■■).*

See editorial, p •••

The exposure of young children to lead has been and continues to be widespread in the US.[1-4] Lead is a potent neurotoxin, and elevated blood lead levels (BLLs) are associated with decreased IQ scores, academic failure, and aggressive behaviors in children.[5-9] Mean lifetime BLLs as low as 1.0-10.0 μg/dL are inversely associated with childhood IQ scores; greater blood lead concentrations can cause other toxic effects, including anemia, encephalopathy, and kidney damage.[2,5,6]

Flint is a "rust-belt" community with a high percentage of Medicaid recipients matching the socioeconomic profile of a city with children at greater risk for lead exposure from multiple sources. The well-publicized water source switch of April 25, 2014, to October 15, 2015, resulted in a much greater percentage of households having tap water that exceeded the maximum lead water concentration of 15 parts per billion allowable by the 1991 Lead and Copper Rule.[10,11] Previous studies of children from Flint, Michigan, observed an increase in the percentage of BLLs greater than the current Centers for Disease Control and Prevention (CDC) reference value of 5.0 μg/dL during 2014-2015.[10,11] Given that there is no safe established BLL, we set out to analyze annual BLL changes in children in Flint, Michigan, over the last decade, including the months of exposure to Flint River water, and place their BLLs in historical context. Previously published studies have only contained percentages of BLLs of children in Flint, Michigan, greater than or equal to the threshold concentrations of 5.0 μg/dL and/or 10.0 μg/dL. This study reports mean BLLs of children from Flint, Michigan, before 2013 and the percentages of BLLs ≥5.0 μg/dL in children from Flint, Michigan, before 2013 and thus, provides a complete assessment of their lead exposure. In addition, this study includes blood lead concentrations of children from Flint, Michigan, for a prolonged time period that includes years before, during, and after their exposure to Flint River drinking water.

Methods

We conducted a retrospective study of BLLs from a population sample of children aged ≤5 years residing in Flint, Michigan, over an 11-year period from 2006

BBL	Blood lead level
CDC	Centers for Disease Control and Prevention
DWA	Detroit Water Authority
GM	Geometric mean
HMC	Hurley Medical Center

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The authors declare no conflicts of interest.

https://doi.org10.1016/j.jpeds.2017.12.063

to 2016. Hurley Medical Center (HMC) contains the regional children's hospital and is the major single source that analyzes pediatric BLLs in Flint. In the medical center databases, 2006 is the earliest year available for analysis and allows for a decade-long examination of BLLs. The first full year following cessation of exposure to the Flint River water is 2016. All blood samples were collected at the medical center or sent to the institution from participating medical practices. Primary care doctors affiliated with this institution provide primary care clinical services for the majority of Medicaid-enrolled children in the region. BLLs associated with home addresses were obtained through the Epic EMR (Epic Systems Corporation, Verona, Wisconsin) for 2012-2016. Other databases were used to access BLLs at the medical center before 2012.

We verified that all samples in the database had a subject with a matching home address within Flint boundaries for all years tested. If a subject had more than 1 BLL obtained during any 1 year studied, only the single greatest value was retained for analysis to avoid having >1 BLL per child for that year and to match previously used methodology using HMC data.[10] All data were reviewed, cleaned, and manually de-duplicated, and each tested child was assigned a unique identifier based on individual demographics including sex, date of birth, and home address. All BLLs were analyzed in Warde Medical Laboratory, Ann Arbor, Michigan, by using atomic absorption spectrophotometry; electrothermal atomizer methodology (Zeeman Atomic Absorption Spectrophotometer, Model AA280Z; Agilent Technologies, Santa Clara, California), which was coupled with the graphite tube atomizer (Model GTA120). The detection limit of the method used was 0.5 μg/dL. Therefore, we conservatively assigned a value of 0.4 μg/dL to the BLL of any child with an undetectable BLL. The study was approved by the institutional review board of the medical center (HMC) where the data were obtained.

Outcome Measures

Changes in the percentage of BLLs ≥5.0 μg/dL and in geometric mean (GM) BLLs in children were analyzed. We opted to use GM BLLs to evaluate BLLs instead of arithmetic means because the CDC uses GM data to analyze population exposure to environmental toxins in blood.[12] GMs are used specifically to provide a better estimate of central tendency for data that are distributed with a long tail at the upper end of the distribution.[13] The CDC used national estimates of GMs based on data from the National Health and Nutrition Examination Survey to determine the current CDC reference value of 5.0 μg/dL for BLLs.[14]

We evaluated BLLs in children aged ≤5 years from January 1, 2006, through December 31, 2016. Geocoded addresses were used to determine trends over time in BLLs inside the boundaries of Flint, Michigan. The switch to Flint River water exposure occurred on April 25, 2014, and the switch back to the Detroit Water Authority (DWA) occurred on October 15, 2015. Our results include data obtained over a full year (2016) after the switch back to the DWA and controlled for seasonal variability of BLLs.[15]

Statistical Analyses

We first computed estimates of BLL percentages greater than the CDC reference level of 5.0 μg/dL based on the data for each of the years between 2006 and 2016. Differences in the percentages between years were assessed by performing pairwise comparisons. This analysis accounted for the possibility that some children might have had multiple BLL tests over the 11 years studied. The SEs of the differences in the percentages arising from these pairwise comparisons allowed for the possibility that blood samples of a given child may have been measured multiple times, introducing non-zero covariances among observations in the data. Essentially, a child with the same medical record number was treated as a cluster of related observations when estimating the SEs of the differences in the percentages.

The percentages of elevated BLLs from different years were compared formally by computing an estimate of their difference, along with a delta method[16] estimate of the SE of the difference (once again allowing for clustering of repeated measures on the same child across any 2 years); forming a test statistic defined by the estimated difference divided by its standard error; and forming a 95% CI for the difference. The null hypothesis that the difference in percentages for any 2 given years was zero was tested formally by comparing the test statistic with a standard normal distribution to compute a 2-tailed *P* value. Comparisons of the aforementioned percentages and the GM BLLs between 2006 and all succeeding years through 2016 were performed to globally understand the magnitude of the BLL changes over this time frame. Percentages of elevated BLLs and GM BLLs in 2012, 2013, 2014, and 2015 were compared with those in the succeeding year. Percentages and GM BLLs in 2013 (last prewater switch year) also were compared with those in 2015 (first postwater switch year).

A modified Bonferroni[17-19] adjustment, which is known to be less conservative than a full Bonferroni adjustment, was applied to all *P* values from these comparative analyses to account for the multiple year or period comparisons performed. The Bonferroni adjustment is an adjustment made to *P* values when multiple pairwise comparison tests are being performed simultaneously on a single data set and reduces the chances of making a Type I error when performing the multiple comparisons. We sought to perform a large number of pairwise comparisons of the percentages of BLLs ≥5.0 μg/dL and GM BLLs of interest (14 comparisons for each statistic). Applying a standard Bonferroni adjustment for these multiple pairwise comparisons would require a given comparison to produce a *P* value of .05/14 = 0.003571 for a difference to be deemed significant, using the standard .05 level of significance. This approach was deemed to be extremely conservative and would have limited our statistical power to detect differences that may have been important in magnitude. All analyses were performed with commands in the Stata software (Version 14.2; StataCorp LLC, College Station, Texas).

FLA 5.5.0 DTD ■ YMPD9696_proof ■ March 15, 2018