Blood Lead Levels Among Children Aged <6 Years — Flint, Michigan, 2013–2016

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During April 25, 2014–October 15, 2015, approximately 99,000 residents of Flint, Michigan, were affected by changes in drinking water quality after their water source was switched from the Detroit Water Authority (DWA), sourced from Lake Huron, to the Flint Water System (FWS), sourced from the Flint River.* Because corrosion control was not used at the FWS water treatment plant, the levels of lead in Flint tap water increased over time. Adverse health effects are associated with lead exposure (*1*). On January 2, 2015, a water advisory was issued because of detection of high levels of trihalomethanes, byproducts of disinfectants.[†,§] Studies conducted by local and national investigators detected an increase in the prevalence of blood lead levels (BLLs) ≥5 μg/dL (the CDC reference level) among children aged <5 years living in Flint (*2*) and an increase in water lead levels after the water source switch (*3*). On October 16, 2015, the Flint water source was switched back to DWA, and residents were instructed to use filtered tap water for cooking and drinking. During that time, pregnant and breastfeeding women and children aged <6 years were advised to consume bottled water.[¶] To assess the impact on BLLs of consuming contaminated drinking water, CDC examined the distribution of BLLs ≥5 μg/dL among children aged <6 years before, during, and after the switch in water source. This analysis enabled determination of whether the odds of having BLLs ≥5 μg/dL before the switch differed from the odds during the switch to FWS (before and after the January 2, 2015, water advisory was issued), and after the switch back to DWA. Overall, among 9,422 blood lead tests in children aged <6 years, 284 (3.0%) BLLs were ≥5 μg/dL during April 25, 2013–March 16, 2016. The adjusted probability of having BLLs ≥5 μg/dL was 46% higher during the period after the switch from DWA to FWS (and before the January 2, 2015, water advisory) than during the period before the water switch to FWS. Although unrelated to lead in the water, the water advisory likely reduced tap water consumption and increased consumption of bottled water. Characterizing exposure to lead contaminated drinking water among children aged <6 years living in Flint can help guide appropriate interventions.

Blood lead testing in Michigan is targeted to children living at or below the poverty level as well as to children enrolled in Medicaid. The Centers for Medicare & Medicaid Services requires all children on Medicaid to receive blood lead screening at ages 12 and 24 months, or at ages 36 and 72 months if previous screening has not been conducted. Confirmed BLLs ≥5 μg/dL are defined as having one venous blood lead test result ≥5 μg/dL or two capillary blood lead test results ≥5 μg/dL drawn within 12 weeks of each other.

Analyses of BLLs obtained during four periods were conducted. These included the period 1) before the switch from DWA to FWS (April 25, 2013–April 24, 2014); 2) after the switch from DWA to FWS, but before the water advisory was issued (April 25, 2014–January 2, 2015); 3) after the switch to FWS, and after issuance of the water advisory (January 3, 2015–October 15, 2015); and 4) after the switch back to DWA from FWS (October 16, 2015–March 16, 2016).

Michigan blood lead surveillance data were reviewed, cleaned and de-duplicated, and each tested child was assigned a unique identifier based on name, sex, date of birth and physical address. Based on the date of the blood test, results were assigned to one of the four periods. If a child had multiple BLL tests during a single period, the single highest result was used, with venous blood tests preferred over capillary tests. If a BLL of ≥5 μg/dL was reported during a given period, no subsequent blood lead tests from that child were included in the analysis. Analyses were limited to tests on children living in residences in the FWS service area; children living in areas serviced by an alternative water system were not included. Ninety-six percent of all test result addresses were geocoded. To enumerate all children aged <6 years, records of children living in the area served by FWS were accessed by reviewing data from the Michigan Care Improvement Registry[**,††] and the Michigan Community Health Automated Medicaid Processing System (CHAMPS).[§§] Children aged <6 years living in areas serviced

* https://www.michigan.gov/documents/snyder/FWATF_FINAL_REPORT_21March2016_517805_7.pdf.

† http://www.mlive.com/news/flint/index.ssf/2015/01/flint_water_has_high_disinfect.html.

§ https://www.cityofflint.com/wp-content/uploads/City-of-Flint-Violation-Notice-MCL-TTHM-12_16_14.pdf.

¶ https://www.epa.gov/sites/production/files/2016-03/documents/flint_oh_fsv4.pdf

** https://www.mcir.org/.

†† http://www.michigan.gov/mdhhs.

§§ http://www.michigan.gov/mdhhs/0,5885,7-339-71551_2945_5100-145006--,00.html.

by the FWS were identified in each data set using identifiers assigned by the Michigan Data Warehouse.

Age was defined as age at the time of the test. Children were excluded once they reached age 6 years. The two race categories examined were black or African American and white, the most frequently recorded races. If a child's race was missing in the database, race was recorded as other/unknown. To improve child race and sex ascertainment, the child blood lead surveillance data were merged with Michigan's CHAMPS Medicaid system, which reports race and sex more comprehensively than child blood lead surveillance data.

Prevalences were calculated to examine the proportion of BLLs ≥5 μg/dL in children aged <6 years by age group, sex, race, and season. To examine whether there was a change in the proportion of BLLs ≥5 μg/dL among children aged <6 years before, during, and after the switch to FWS, logistic regression was used to calculate odds ratios (ORs) and 95% confidence intervals (CIs). The analysis was configured to account for the possibility that some children might have had multiple BLL tests over the four periods. Multivariable regression analyses were conducted for the combined analysis period to adjust for possible confounding variables by age group, sex, race, and season.

During the assessment period, an estimated 9,622 children aged <6 years lived in residences within the area served by FWS. Among these children, 7,306 received 9,672 blood lead tests before, during, and after the water source switch period. Among these tests, 250 (2.6%) were results from a child who had a previously detected BLL ≥5 μg/dL at some point during the study period; these subsequent tests were excluded from the analysis, leaving 9,422 tests for analysis. Among these, 53% represented the highest venous blood lead test level, 46% represented the highest capillary blood lead test level in the absence of venous blood lead test, and 1% represented the highest blood lead test level among tests of unknown type.

During the period before the water source switch, among 2,408 blood lead tests, 3.1% of BLLs were ≥5 μg/dL; during the early switch period, this percentage increased to 5.0% (Table 1). The probability of having a BLL ≥5 μg/dL was significantly higher during the early switch period than the period before the switch (OR = 1.65; CI = 1.20–2.26) (Table 2).

After controlling for covariates, the probability of having BLLs ≥5 μg/dL remained significantly higher during the early period after the water source switch compared with the period before the switch (adjusted odds ratio = 1.46; CI = 1.06–2.01) (Table 3). Additionally, the probability of having BLLs ≥5 μg/dL was significantly higher for children aged 1–2 years compared with children aged <1 year and significantly higher during summer and fall months compared with winter months (Table 3).

Summary

What is already known about this topic?

In 2014, the city of Flint, Michigan, switched its water source from the Detroit Water Authority (DWA) to the Flint Water System (FWS). Drinking water can become contaminated with lead when there is corrosion in leaded plumbing. Because corrosion control was not used at the FWS water treatment plant, the levels of lead in Flint tap water increased over time.

What is added by this report?

During April 25, 2013–March 16, 2016, among 9,422 blood lead tests received by 7,306 children aged <6 years living in the area served by FWS, 3.0% of blood lead level (BLL) test results were elevated (≥5 μg/dL). The proportion of elevated BLLs was significantly higher (5.0%) during the early period of the switch from DWA to FWS compared with the previous period when residents consumed water from DWA (3.1%). After the switch back to DWA, the percentage of elevated BLLs returned to levels comparable to those found before the water source switch.

What are the implications for public health practice?

Flint residents have been recently advised by the U.S. Environmental Protection Agency that when using an approved and properly installed and maintained water filter, it is safe for persons to drink filtered tap water, including pregnant women, nursing and bottle-fed children, and children aged <6 years. Regular household tap water can be used for bathing and showering; however, young children should be prevented from drinking bath water. All children aged <6 years living in Flint should have their blood tested for lead level, if they have not had a blood lead test since October 2015. Case management should be provided to all children with elevated BLLs.

Discussion

In the United States, children with elevated BLLs typically have been exposed to lead through residential lead paint hazards often found in older homes or lead-contaminated house dust or soil (*1*). However, children and adults also can be exposed to lead through drinking water (*4*). Lead most commonly enters drinking water as a result of corrosion of leaded plumbing materials and is rarely found at the distribution point or wellhead (*5*). There are three main factors that might influence the level of lead leeching into drinking water. These include 1) whether the plumbing included lead pipes, 2) the pH of finished water, and 3) the presence or absence of mineral scale in the plumbing (*5*). Mineral scale on the inner surface of older plumbing prevents lead from leaching into drinking water; however, when mineral scale is removed or has not developed, lead might leach into drinking water from lead solder, even in "lead-free" plumbing (*5*).

Lead in drinking water has been linked to elevated blood lead concentrations (*6*). Among children aged 0–1 year who

TABLE 1. Number and percentage of elevated (≥5 µg/dL) blood lead level test results in children aged <6 years,* by assessment period, age group,† sex, race, and season — Flint, Michigan, April 2013–March 2016§

BLL testing	Before switch from DWA to FWS 04/25/2013–04/24/2014	After (early) switch to FWS (before water advisory) 04/25/2014–01/02/2015	After (late) switch to FWS (during water advisory) 01/03/2015–10/15/2015	After switch from FWS back to DWA 10/16/2015–03/16/2016
No. of BLL tests overall	**2,408**	**1,694**	**1,990**	**3,330**
BLL levels	**No. (%)**	**No. (%)**	**No. (%)**	**No. (%)**
≥5 µg/dL overall	**74 (3.1)**	**84 (5.0)**	**78 (3.9)**	**48 (1.4)**
5–9	59 (2.5)	71 (4.2)	68 (3.4)	37 (1.1)
10–14	9 (0.4)	10 (0.6)	6 (0.3)	4 (0.1)
15–19	2 (0.1)	2 (0.1)	0 (0)	4 (0.1)
20–39	4 (0.2)	1 (0.1)	4 (0.2)	2 (0.1)
≥40	0 (—)	0 (—)	0 (—)	1 (<0.1)

Characteristic	No. of tests	No. (%) with BLLs ≥5 µg/dL	No. of tests	No. (%) with BLLs ≥5 µg/dL	No. of tests	No. (%) with BLLs ≥5 µg/dL	No. of tests	No. (%) with BLLs ≥5 µg/dL
Age group (yrs)								
<1	127	1 (0.8)	145	5 (3.4)	152	3 (2.0)	367	3 (0.8)
1–2	1,563	58 (3.7)	1,040	59 (5.7)	1,245	57 (4.6)	1,331	26 (2.0)
3–5	718	15 (2.1)	509	20 (3.9)	593	18 (3.0)	1,632	19 (1.2)
Sex								
Male	1,226	44 (3.6)	868	42 (4.8)	1,036	39 (3.8)	1,714	28 (1.6)
Female	1,168	30 (2.6)	819	42 (5.1)	943	39 (4.1)	1,604	19 (1.2)
Unknown	14	0 (—)	7	0 (—)	11	0 (—)	12	1 (8.3)
Race								
Black or African American	1,337	38 (2.8)	1,020	56 (5.5)	1,159	47 (4.1)	2,003	29 (1.4)
White	571	25 (4.4)	435	24 (5.5)	574	23 (4.0)	894	16 (1.8)
Other/unknown	500	11 (2.2)	239	4 (1.7)	257	8 (3.1)	433	3 (0.7)
Season								
Winter (December–February)	530	7 (1.3)	120	3 (2.5)	327	6 (1.8)	2584	35 (1.4)
Spring (March–May)	606	18 (3.0)	237	7 (3.0)	551	15 (2.7)	321	7 (2.2)
Summer (June–August)	588	19 (3.2)	653	39 (6.0)	544	25 (4.6)	0	0 (—)
Fall (September–November)	684	30 (4.4)	684	35 (5.1)	568	32 (5.6)	425	6 (1.4)

Abbreviations: BLL = blood lead level; DWA = Detroit Water Authority; FWS = Flint Water System.
* All children were Flint residents, defined as living in a residence in the FWS service area.
† At time of test.
§ Some children with BLLs <5 µg/dL were counted in multiple periods.

consume, on average, 1,200 mL of drinking water per day, a lead concentration in water of 20 parts per billion might be sufficient to raise the blood lead level of a child from 0 to 5 µg/dL in the absence of other lead sources (*7*).

Very young children consume more water per unit of body mass than do older children and adults, and they are more likely to engage in hand-to-mouth behaviors that put them at higher risk for exposure to lead in house dust and soil. Additionally, BLLs in children tend to rise in warm weather months, a phenomenon that might be related to differential seasonal distribution of lead dust in houses as well as higher exposure to street dust associated with increased outdoor activity (*8*). However, even after controlling for age and season, the period after the water source was switched from DWA to FWS, and before the water advisory was issued, remained independently associated with an increased probability of BLLs ≥5 µg/dL among children aged <6 years living in the area served by FWS.

The findings in this report are subject to at least five limitations. First, spurious associations might have resulted from failure to control for all confounders because substantial information for certain covariates (e.g., race) was either not collected or missing. Second, although this analysis demonstrates increased prevalence of BLLs ≥5 µg/dL coincident with the switch to FWS, its observational nature limits attribution exclusively to the switch in drinking water source. Third, exposure to other known sources of lead that might have contributed to a child's probability of being exposed was not ascertained. Fourth, infants who are primarily fed formula mixed with tap water are likely to have been more exposed to contaminated water; however, few children aged <1 year were tested. Thus, the impact of the high water lead levels for this age group might have been underestimated. Finally, the decline in the proportion of BLLs ≥5 µg/dL after the switch back to DWA might have resulted, in part, to increased and continuing bottled water consumption rather than the switch back to DWA, reflecting a change in behavior, rather than an effect of the change in municipal drinking water source.

TABLE 2. Odds ratios (ORs)* comparing elevated blood lead levels (BLLs) (≥5 µg/dL) during three water source switch periods with BLLs before the first switch, among children aged <6 years,† by age group,§ sex, race, and season — Flint, Michigan, April 2013–March 2016

Characteristic	Before switch from DWA to FWS 04/25/2013–04/24/2014	After (early) switch to FWS (before water advisory) 04/25/2014–01/02/2015 OR (95% CI)	After (late) switch to FWS (during water advisory) 01/03/2015–10/15/2015 OR (95% CI)	After switch from FWS back to DWA 10/16/2015–03/16/2016 OR (95% CI)
Overall	**Referent**	**1.65 (1.20–2.26)¶**	**1.29 (0.93–1.78)**	**0.46 (0.32–0.67)¶**
Age group (years)				
<1	Referent	4.50 (0.52–39.0)	2.54 (0.26–24.7)	1.04 (0.11–10.1)
1–2	Referent	1.56 (1.08–2.26)¶	1.24 (0.86–1.81)	0.52 (0.32–0.83)¶
3–5	Referent	1.92 (0.98–3.78)	1.47 (0.74–2.94)	0.55 (0.28–1.10)
Sex				
Male	Referent	1.37 (0.89–2.10)	1.05 (0.68–1.63)	0.45 (0.28–0.72)¶
Female	Referent	2.05 (1.28–3.31)¶	1.64 (1.01–2.66)¶	0.46 (0.26–0.81)¶
Race				
Black or African American	Referent	1.99 (1.31–3.02)¶	1.45 (0.94–2.23)	0.50 (0.31–0.82)¶
White	Referent	1.28 (0.72–2.26)	0.91 (0.51–1.62)	0.40 (0.21–0.75)¶
Other/Unknown	Referent	0.76 (0.24–2.40)	1.43 (0.57–3.59)	0.31 (0.09–1.12)
Season				
Winter (December–February)	Referent	1.92 (0.49–7.51)	1.40 (0.47–4.19)	1.03 (0.45–2.32)
Spring (March–May)	Referent	1.00 (0.41–2.41)	0.91 (0.46–1.83)	0.73 (0.30–1.76)
Summer (June–August)	Referent	1.90 (1.09–3.33)¶	1.44 (0.79–2.65)	—
Fall (September–November)	Referent	1.18 (0.71–1.94)	1.30 (0.78–2.17)	0.31 (0.13–0.76)¶

Abbreviations: CI = confidence interval; DWA = Detroit Water Authority; FWS = Flint Water System.
* Adjusted for correlation among children with blood lead measurements in more than one period.
† All children were Flint residents, defined as living in a residence in the FWS service area.
§ At time of test.
¶ Statistically significant OR.

TABLE 3. Multivariable adjusted odds ratios (AORs)* comparing odds of elevated blood lead levels (≥5 µg/dL) among children aged <6 years,† by selected covariates§ — Flint, Michigan, April 2013–March 2016

Covariate	AOR (95% CI)
Period	
Before switch from DWA to FWS	Referent
After (early) switch to FWS (before water advisory)	1.46 (1.06–2.01)¶
After (late) switch to FWS (after water advisory)	1.28 (0.92–1.76)
After switch from FWS back to DWA	0.75 (0.51–1.12)
Age group (yrs)**	
<1	Referent
1–2	2.25 (1.25–4.06)¶
3–5	1.36 (0.73–2.53)
Season	
Winter (December–February)	Referent
Spring (March–May)	1.41 (0.91–2.16)
Summer (June–August)	2.14 (1.44–3.18)¶
Fall (September–November)	2.25 (1.57–3.22)¶

Abbreviations: CI = confidence interval; DWA = Detroit Water Authority; FWS = Flint Water System.
* Adjusted for correlation among children with blood lead measurements in more than one period.
† All children were Flint residents, defined as living in a residence in the FWS service area.
§ The most parsimonious model is shown; sex and race were no longer statistically significant in the full model.
¶ Statistically significant AOR.
** At time of test.

There might be multiple sources of early childhood lead exposure (*9*) in areas with houses built before lead paint use in the United States was banned in 1978 (*10*). However, this analysis suggests increased lead exposure related to consuming contaminated water in Flint. Flint residents have been recently advised by the U.S. Environmental Protection Agency that when using an approved and properly installed and maintained water filter, it is safe for persons to drink filtered tap water, including pregnant women, nursing and bottle-fed children, and children aged <6 years.¶¶ Regular household tap water can be used for bathing and showering; however, young children should be prevented from drinking bath water. Efforts to provide case management to all children residing in Flint with BLLs ≥5 µg/dL began in 2016. All children aged <6 years living in Flint should have their blood tested for lead, if they have not had a blood lead test since October 2015.

¶¶ https://www.epa.gov/flint/filter-study.

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