Lead in drinking water: a response from the Atlantic PATH study

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Abstract: Exposure to lead through drinking water is an issue of increasing concern, particularly with recent high-profile cases of lead-contaminated water. The maximum acceptable concentration level for drinking water in Canada is 10 µg/L, whereas the current blood intervention level is 10 µg/dL. The health effects related to lead exposure are well established and there is evidence that blood lead levels as low as <5 µg/dL are associated with adverse health effects in both children and adults. We analyzed water and toenail samples for lead concentrations from the Atlantic Partnership for Tomorrow's Health (Atlantic PATH) project, a cohort of the general population in Nova Scotia. Approximately 46% of Nova Scotia residents use well water as their primary source of drinking water. Water from dug wells had higher lead concentrations compared to drilled wells, and the lowest lead levels were found in water from municipal supplies. Although the majority of the lead levels in the drinking water provided by Atlantic PATH participants were below the Canadian maximum acceptable concentration level, there were outliers, particularly among unregulated private well water sources. Given the health effects that are linked to low-level exposures, any exposure to lead in primary water sources remains a concern.

Key words: drinking water, lead, exposure

Introduction

Exposure to lead through drinking water is an issue of increasing concern, with significant attention in the mainstream media and related academic research. Most recently, a change in the water source from Lake Huron to the Flint River in Flint, Michigan resulted in the supply of more corrosive water, which occurred alongside a lack of adequate corrosion control measures (Bellinger, 2016). The failure to apply adequate corrosion control lasted for more than 18 months and allowed metals, including lead, to dissolve in the drinking water. Increases in both drinking water lead levels and human blood lead levels were reported. Of the residential water samples tested, more than 40% of the samples were > 5 µg/L (5 ppb), with the 90th percentile at 25 µg/L, and other samples ranging between 100 and 1,000 µg/L (Parks and Mantha, 2016; Edwards et al., 2015). The blood lead levels of children were examined after the change in water source, and there was an increase in the incidence of blood lead levels > 5 µg/dL from 2.4% to 4.9%, with a 6.6% increase in neighbourhoods that had the highest water lead levels. No other alternative source of increased lead exposure was identified during this time period (Hanna-Attisha et al., 2016).

The health effects related to lead exposure are well established and there is evidence that blood lead levels of as low as < 5 µg/dL are associated with adverse health effects in both children and adults (National Toxicology Program, 2012). Low-level effects of lead are associated with neurodevelopmental, neurodegenerative, cardiovascular, renal, reproductive, and developmental impacts. An increase of 1 µg/dL of lead levels in blood is associated with a deficit of approximately one IQ point (Health Canada, 2013a, 2013b). Fetuses and infants have an increased risk as they experience greater susceptibility to the toxic effects of lead exposure, which can result in a decrease in cognitive performance and an increase in attention-related behavioural issues (National Toxicology Program, 2012). Lead has also been classified as possibly carcinogenic to humans (2B carcinogen) (International Agency for Research on Cancer, 2016).

The United States Environmental Protection Agency (EPA) estimates that drinking water can contribute 20% or more of a person's total exposure to lead, and up to 40%–60% in infants with a formula diet. As lead is persistent in the body, is bioaccumulative and has health effects at very low levels, the EPA set the maximum contaminant level goal for lead in drinking water at zero (United States Environmental Protection Agency, 2016). Prior to 2012, the blood lead level of concern for

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children was 10 µg/dL. However, the Centers for Disease Control and Prevention no longer use the term “level of concern,” and now use a reference blood level of 5 µg/dL (Centers for Disease Control and Prevention, 2012, 2016).

The maximum acceptable concentration (MAC) for lead in drinking water in Canada is 10 µg/L (10 ppb), while the current blood intervention level remains at 10 µg/dL (Health Canada, 1992, 2013a). Although lead is detected in the blood levels of all Canadians, it has decreased in the general population from a mean of 4.8 µg/dL in 1979 (Health Canada, 2013a). The most recent Canadian Health Measures Survey measured lead as part of its human biomonitoring efforts. It found that the geometric mean of the whole blood concentration among participants aged 6–79 years was 1.1 µg/dL (95% CI: 1.0–1.2). The median at the 10th percentile was 0.49 µg/dL (95% CI: 0.46–0.52), 1.0 µg/dL (95% CI: 0.96–1.1) at the 50th percentile, 2.4 µg/dL (95% CI: 2.3–2.5) at the 90th percentile, and 3.2 µg/dL (95% CI: 2.9–3.4) at the 95th percentile (Health Canada, 2015). Health Canada (2013a) recognizes the health effects can occur as a result of low-level exposure to lead, and has concluded that “additional measures to further reduce exposures of Canadians to lead, with a particular focus on vulnerable populations, are warranted.” The federal risk management strategy includes a review of the drinking water guidelines, including exposure to lead and sampling and monitoring strategies (Health Canada, 2013a).

The Atlantic Partnership for Tomorrow's Health (Atlantic PATH) study sought to contribute to discussions about the recent concerns related to drinking water lead exposure. The objectives of this paper are to (i) analyze drinking water and toenail samples from the Atlantic PATH study participants for lead concentrations, (ii) evaluate the potential for toenail clipping samples to be used as a noninvasive approach for measuring lead exposure in humans, and (iii) determine whether the various drinking water sources (municipal, drilled wells, dug wells) are mediators of differing levels of lead exposure.

Methods

Atlantic PATH is a longitudinal cohort study that is part of the Canadian Partnership for Tomorrow Project, and includes over 30,000 adult participants aged 35–69 years from Nova Scotia, New Brunswick, Prince Edward Island, and Newfoundland and Labrador (Borugian et al., 2010; Yu et al., 2014a). The data collected from participants at baseline recruitment included socio-demographic, health and lifestyle information; physical measures; and blood, urine, saliva, and toenail samples. Well water samples in Nova Scotia were also collected as part of a sub-study focused on arsenic and heavy metal exposures (Yu et al., 2014b). It should be noted that Atlantic PATH's protocol for testing water instructed participants to run the tap for 10 minutes to flush the system. However, this technique may artificially lower lead levels compared to water that has not been flushed (Ngueta et al., 2016). Ethical approval was received by the relevant research ethics boards and all participants provided written informed consent.

For this paper, water samples ($n = 2,750$) and toenail samples ($n = 2,345$) were selected based on the participants'

residing in Nova Scotia; exclusion criteria included samples from an unknown water source. Toenail and water samples were analyzed for lead and other elements using ICP-MS, described previously (Yu et al., 2014b). We utilized the Fisher's exact statistical test to examine the differences in the prevalence of high water lead among water samples with different characteristics. The relationship between lead concentrations in water and toenails were analyzed by using linear regression with adjustment for age, sex, ethnicity, education, smoking, and alcohol use. Differences in lead concentrations of toenail clipping samples across water source were detected with general linear models. Statistical significance was defined as $P < 0.05$. All P values were two-sided. Data management and analyses were performed with SAS statistical package version 9.4 (SAS Institute, Cary, North Carolina).

Results

Approximately 46% of the population of Nova Scotia uses well water as their primary source of water (Nova Scotia Department of Environment and Labour, 2006). The majority of the water samples collected from Atlantic PATH participants were obtained from the primary drinking water source of the household. The sources of the water samples collected from Atlantic PATH participants included 26% municipal water ($n = 709$), 53% drilled wells ($n = 1,454$), 18% dug wells ($n = 503$), and 3% other/unknown water sources ($n = 84$). The geometric mean for lead concentrations in all drinking water samples was 0.35 µg/L (95% CI, 0.32, 0.37), see Table 1.

Among all water samples, 2.2% ($n = 59$) had lead levels in excess of the MAC (> 10 µg/L), and these were predominantly from well water sources (Table 1). Water from dug wells had higher lead concentrations compared to drilled wells, and the lowest lead levels were found in water from municipal supplies.

Unlike for blood and drinking water, there is no guideline reference value for lead in toenails. However, while they have not yet been validated, toenails have the potential to be used as a biomarker for chronic lead exposure. The mean concentration for lead in the Atlantic PATH toenail samples ($n = 2,345$) was 0.35 µg/g (95% CI, 0.32, 0.39), and the geometric mean was 0.15 µg/g (95% CI, 0.14, 0.16) (Table 2). In general, compared with males and participants in the younger age group, females and those in the older age group had significantly lower lead concentrations in toenails, respectively (all $P < 0.001$). The geometric mean for females ($n = 1,671$) was 0.14 µg/g (95% CI, 0.13, 0.15), with 0.16 µg/g (95% CI, 0.14, 0.17) among females aged 35–49 years and 0.13 µg/g (95% CI, 0.12, 0.14) among females aged 50–69 years. Male participants ($n = 674$) had higher levels of lead in toenails with a geometric mean of 0.19 µg/g (95% CI, 0.17, 0.21), with 0.23 µg/g (95% CI, 0.19, 0.27) among males aged 35–49 years, and 0.18 µg/g (95% CI, 0.16, 0.20) among males aged 50–69 years. The differences between these groups may be due to variations in cumulative lead exposures from different sources, such as drinking water, diet, smoking, and occupational exposures (Richter et al., 2013) that were not controlled for in the unadjusted analysis.

Table 1. Differences in prevalent high water Pb (≥ 10 $\mu\text{g/L}$) by characteristics

Characteristics	No.	%	P^a
Main home water			0.22
Yes	54/2,612	2.1	
No	5/138	3.6	
Well water			0.001
Yes	54/2,040	2.7	
No	5/710	0.7	
Water source			<0.001
Municipal treated water	5/709	0.7	
Drilled well	26/1,454	1.8	
Dug well	22/503	4.4	
Other/unknown	6/84	7.1	

^a P values were derived using the Fisher's exact test.

For every 1% increase of lead in water, there was a 0.1% increase of lead in toenails ($P < 0.001$). In the multivariable model controlling for important nondrinking water lead exposures, including smoking, diet, and occupational exposures, the geometric mean for lead in toenails with exposure to municipal treated water was 0.11 $\mu\text{g/g}$ (95% CI, 0.08, 0.15), see Table 3. Lead levels in toenail samples from those with a drilled well water source were slightly higher (geometric mean of 0.13 $\mu\text{g/g}$, 95% CI, 0.10, 0.18). The highest levels of lead

exposure were evident in the participants sourcing water from a dug well, geometric mean of 0.20 $\mu\text{g/g}$ (95% CI, 0.14, 0.28).

Discussion

While most studies on lead in drinking water concentrate on specific populations or occupational groups, the Atlantic PATH project focused on a cohort of Nova Scotians who were recruited from the general population. This study included both water and toenail samples, which provides a unique perspective on lead exposure among the general population, many of whom source drinking water from a private well. The use of toenails as an indicator of environmental exposure to lead may be of particular interest to those working in community monitoring and public health. Toenail clippings are a highly stable source for measuring the body burden of a range of elements, including lead, and they are easily collected, maintained, and transported. The collection of toenails involves a noninvasive process compared to blood samples, which may result in a higher rate of participation from the public.

There was significant variation in toenail lead levels by drinking water source, with the highest toenail lead in participants using dug wells, after adjustment for other factors that may affect lead exposure. Dug wells also had the highest levels of lead in drinking water. Although the majority of the lead levels in the drinking water provided by Atlantic PATH participants were below the Canadian MAC, there were outliers, particularly among unregulated private well water sources. Unlike private well water sources, municipal water suppliers are required to implement corrosion control plans to limit leaching of contaminants, such as lead from pipes into the water. Water from dug wells tends to rely upon surficial groundwater, which has lower pH and higher corrosivity levels compared to

Table 2. Lead in toenail samples

	All	Males	Females
Pb in toenail samples ($\mu\text{g/g}$)	n = 2,345	n = 674	n = 1,671
Mean (95% CI)	0.35 (0.32, 0.39)	0.46 (0.38, 0.55)	0.31 (0.27, 0.35)
GM (95% CI)	0.15 (0.14, 0.16)	0.19 (0.17, 0.21)	0.14 (0.13, 0.15)
Median (IQR)	0.14 (0.07, 0.29)	0.17 (0.09, 0.38)	0.13 (0.07, 0.27)
35–49 years	n = 639	n = 155	n = 484
Mean (95% CI)	0.38 (0.31, 0.44)	0.51 (0.33, 0.68)	0.34 (0.27, 0.40)
GM (95% CI)	0.17 (0.16, 0.19)	0.23 (0.19, 0.27)	0.16 (0.14, 0.17)
Median (IQR)	0.16 (0.08, 0.28)	0.21 (0.12, 0.48)	0.15 (0.08, 0.32)
50–69 years	n = 1,706	n = 519	n = 1,187
Mean (95% CI)	0.35 (0.30, 0.39)	0.45 (0.35, 0.55)	0.30 (0.26, 0.34)
GM (95% CI)	0.144 (0.136, 0.153)	0.18 (0.16, 0.20)	0.13 (0.12, 0.14)
Median (IQR)	0.14 (0.07, 0.28)	0.16 (0.08, 0.35)	0.12 (0.06, 0.26)

Note: CI, confidence interval; GM, geometric mean; IQR, inter-quartile range.

Table 3. Lead concentration in toenail clipping samples by water source among participants with both water and toenail clipping samples (n = 1,393)

	Lead in toenail clippings (µg/g), GM (95% CI)	
Water sources	Simple model ^a	Multivariable model ^b
Municipal treated water	0.13 (0.11, 0.14)	0.11 (0.08, 0.15)
Drilled well	0.15 (0.14, 0.16)	0.13 (0.10, 0.18)
Dug well	0.23 (0.20, 0.26)	0.20 (0.14, 0.28)
Other/unknown	0.14 (0.10, 0.19)	0.12 (0.08, 0.19)
Overall <i>P</i> value	<0.001	<0.001

Note: GM, geometric mean; CI, confidence interval.

^aAdjusted for age and sex.

^bAdjusted for age, sex, ethnicity, education, smoking, and alcohol use.

bedrock aquifers that drilled wells draw upon. In this study, we were unable to determine if the lead exposure is occurring as a result of untreated water itself or lead leaching from the pipes as a result of corrosive water.

Given the health effects that are linked to low-level exposures, any exposure to lead in water sources remains concerning. While much of the focus of lead exposure is related to children, there is also evidence linking the cumulative exposure of lead in older adults to cognitive decline (Weuve et al., 2009). Given the aging population in Nova Scotia, this adds to the concerns about lead exposure via drinking water. Furthermore, unlike municipal water sources, private wells are essentially unregulated and therefore testing and treatment is the responsibility of the homeowner. Under such an approach to environmental public health, the onus is placed on private citizens to test their well water to ensure water safety. There is an opportunity for community-based public health efforts to develop knowledge translation campaigns for well water users that provide clear and informative outreach and education efforts. For instance, people with dug wells could be targeted by specific efforts describing the possibility of being exposed to higher levels of lead as a result of their water supply, as well as detailed information about potential remediation strategies. In Canada, residents who rely on well water for their primary drinking source are encouraged to regularly test their water for lead and other contaminants, and to consider the appropriate treatment options to reduce their exposure levels if necessary, such as filtration and reverse osmosis (Nova Scotia Environment, 2008).

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