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Assessing arsenic exposure in households using bottled water or point-of-use treatment systems to mitigate well water contamination

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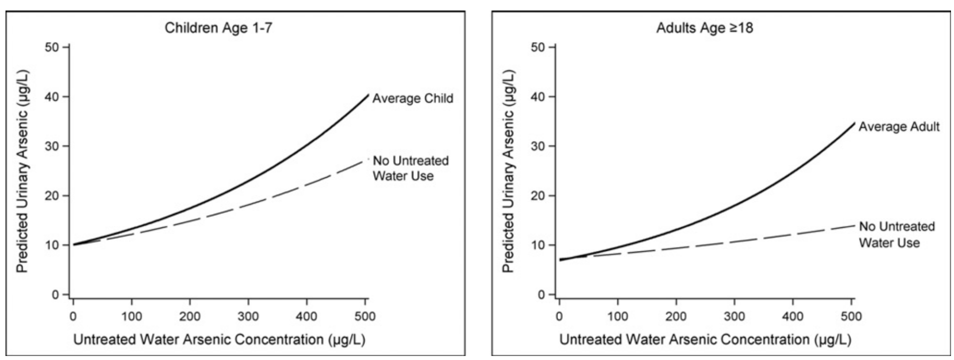
HIGHLIGHTS

- Common mitigation strategies to prevent well water arsenic exposure were assessed.
- These strategies were less able to prevent exposure when arsenic levels were >40 μg/L.
- Bathing was not a significant arsenic exposure source for children or adults.
- Untreated water use explained more arsenic exposure in adults than children.
- Complete compliance with a mitigation strategy is important in reducing exposure.

GRAPHICAL ABSTRACT



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ABSTRACT

There is little published literature on the efficacy of strategies to reduce exposure to residential well water arsenic. The objectives of our study were to: 1) determine if water arsenic remained a significant exposure source in households using bottled water or point-of-use treatment systems; and 2) evaluate the major sources and routes of any remaining arsenic exposure. We conducted a cross-sectional study of 167 households in Maine using one of these two strategies to prevent exposure to arsenic. Most households included one adult and at least one child. Untreated well water arsenic concentrations ranged from <10 μg/L to 640 μg/L. Urine samples, water samples, daily diet and bathing diaries, and household dietary and water use habit surveys were collected. Generalized estimating equations were used to model the relationship between urinary arsenic and untreated well water arsenic concentration, while accounting for documented consumption of untreated water and dietary sources. If mitigation strategies were fully effective, there should be no relationship between urinary arsenic and well water arsenic. To the contrary, we found that untreated arsenic water concentration remained a significant ($p \leq 0.001$) predictor of urinary arsenic levels. When untreated water arsenic concentrations were <40 μg/L, untreated water arsenic was no longer a significant predictor of urinary arsenic. Time spent bathing (alone or in

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combination with water arsenic concentration) was not associated with urinary arsenic. A predictive analysis of the average study participant suggested that when untreated water arsenic ranged from 100 to 500 μg/L, elimination of any untreated water use would result in an 8%–32% reduction in urinary arsenic for young children, and a 14%-59% reduction for adults. These results demonstrate the importance of complying with a point-of-use or bottled water exposure reduction strategy. However, there remained unexplained, water-related routes of exposure.

1. Introduction

Arsenic exposure is considered a worldwide public health problem (WHO, 2012). It is estimated that >200 million people worldwide could be exposed to elevated levels of naturally occurring arsenic in drinking water (Naujokas et al., 2013). Groundwater with elevated arsenic is prevalent in several regions of the United States, including the West, Midwest, parts of Texas and the Northeast (Ryker, 2001; Ayotte et al., 2003; Peters, 2008). In Maine, a state where over half the population relies on private wells for drinking water, 12% of wells have arsenic above the federal maximum contaminant level of 10 μg/L set for public water supplies (Loiselle et al., 2001). In more than 50 Maine towns, measured arsenic levels in private well water exceed 100 μg/L; the highest reported level is above 3000 μg/L (Maine Tracking Network, 2014).

Private well owners with elevated arsenic in their drinking water have several strategies available for reducing exposure. Strategies include switching to bottled water for beverage preparation and cooking, installing treatment systems that focus on a single area of water use, such as a kitchen sink (commonly referred to as point-of-use or POU), and treatment systems that treat all the water entering the home (commonly referred to as point-of-entry or POE). In a survey of central Maine residents with well water arsenic levels above 10 μg/L, more than 65% of respondents indicated they were using either bottled water or a POU treatment system to reduce exposure (Flanagan et al., 2015a). These two intervention strategies remained the most common even for households with water arsenic above 100 μg/L (Flanagan et al., 2015a).

There is little published literature, especially regarding children, on the efficacy of household exposure reduction strategies for well water with elevated arsenic levels. Josyula et al. (2006) reported only a modest reduction (21%) in urinary arsenic levels following bottled water intervention in Arizona homes with arsenic levels averaging 20 μg/L. In a small pilot study, Spayd et al. (2015) reported more substantial reductions (>60%) in urinary arsenic levels in New Jersey well owners using either POU or POE treatment systems for water arsenic levels averaging around 40 μg/L. Effective exposure reduction depends on the ability of the treatment system to reduce water arsenic to levels where the contribution to exposure is minor relative to dietary sources (Gilbert-Diamond et al., 2011; Kurzius-Spencer et al., 2013). Once arsenic levels in the primary drinking water source are reduced to <10 μg/L, diet is likely to be the major source of exposure to arsenic (Kurzius-Spencer et al., 2013, 2014).

For bottled water and POU treatment strategies, effective arsenic exposure reduction will also depend on behavioral factors such as willingness to use only treated water or bottled water for beverage and food preparation, as well as for drinking. Occasional use of untreated water for beverage or food preparation after switching to bottled water or installing a POU treatment system could lead to significant exposure, especially if water arsenic levels are high. Exposure may also result from bathing-related contact with untreated water (Spayd et al., 2015).

We report results from a study of exposure to arsenic in households after implementing common mitigation exposure reduction strategies. We enrolled families residing in Maine that relied on private well water and used either bottled water or a POU treatment system to reduce their arsenic exposure from untreated well water. As there is a paucity of studies regarding arsenic exposure in young children, a focus of the study was to examine households with children younger than 6 years. The primary aim of this cross-sectional study was to determine whether arsenic in untreated well water was a significant exposure source in households employing either bottled water or POU exposure reduction strategies. A secondary aim was to evaluate sources and routes of remaining arsenic exposure, including lack of compliance with use of treated or bottled water, bathing habits, and diet.

2. Methods

2.1. Study design and population

Participant recruitment was aimed at constructing a convenience sample of families with young children (<6 years) and a wide range of private well water arsenic levels. Briefly, recruitment was done in one of two ways: by identifying households with elevated water arsenic levels (>10 μg/L) from state laboratory testing data or treatment company mailings to customers; or by identifying households with young children in areas likely to have elevated water arsenic levels through state birth records (see Supplemental Information for more detail). Participant recruitment and study sampling took place from 2001 to 2003.

All recruitment and study procedures were approved by the Institutional Review Boards of the Maine Center for Disease Control and Prevention (MECDC) and the U.S. Centers for Disease Control and Prevention (CDC). Families received study information along with recruitment letters, and those who chose to participate provided written informed consent. Participating households received reports summarizing their water and urine arsenic test results.

2.2. Survey and diary information

Each participating household completed a household survey, and each participating individual recorded a three-day diet and bathing diary. Home visits were conducted with each household the day after the three-day diet and bathing diary period ended. During the home visit, trained study personnel administered the household survey and reviewed and collected the three-day diet and bathing diaries. The household survey solicited information on the home's well type; information on the treatment system, if any; descriptions of other water sources; and the presence of other potential sources of arsenic exposure, such as pressure-treated wood or pesticides. The survey also queried individuals regarding their prior habitual use of untreated and treated water for drinking and beverage preparation, cooking, and brushing teeth, as well as recent seafood or seaweed consumption and adult smoking behavior. The diet and bathing diary was used to record the types and volumes of foods and beverages consumed, and the volumes and sources (e.g., bottled water, filtered water, untreated tap water) of any water used to prepare food. For bathing, participants recorded the number of daily bathing and/or showering events, including the duration of each event. A three day period for the diet and bathing diary was selected to avoid respondent fatigue (Thompson and Byers, 1994), and to capture any dietary arsenic exposure sources that would contribute to urinary arsenic levels based on the biological half-life for inorganic arsenic of 2 to 4 days (NRC, 1999; Zheng et al., 2002). One adult participant in each household was asked to keep proxy diaries for all child participants in the household. Study personnel reviewed diaries on the day of the home visit, and attempted to follow up on any missing or incomplete information.