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Case report

What's in your water? A well-known risk for arsenic toxicity

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Abstract

Arsenic cannot be tasted, seen or smelled and can vary in concentration between water wells even in condensed areas. American domestic well water is not regulated to meet the same drinking water standards as other types of water supplies and often contains arsenic. If arsenic is not detected in a well water sample, it is unlikely to be found later. Conversely, if it is detected in a new well, it is recommended to retest six months later as levels may fluctuate in the first months following well construction. It is up to the well owner to test their water and remove arsenic through commercially available water filters. If it is not detected and removed via filtration, a variety of serious, yet common, medical conditions may arise from chronic arsenic exposure, some of which are life-threatening. These include diabetes mellitus, hypertension, skin cancer, renal, bladder and lung cancers, polyneuropathy and cardiac QTc prolongation. Testing is best done through urine speciation if an initial total urine arsenic concentration is elevated. Consider a complete blood count, renal and liver function tests, an electrocardiogram as well as a urinalysis assessing for evidence of hematuria when examining patients with histories concerning for chronic arsenic exposure.

Key words: family medicine, rural health, community health, arsenic, well water

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Case Presentation

A 67-year-old woman presented to the family medicine clinic requesting a urine test for arsenic. She stated that she had spent multiple hours on the telephone with her insurer clarifying the cost and coverage of this test and had the test identification number written down for reference. She was willing to pay out of pocket if required, she stated. She reported that her and her husband had lost four dogs to cancer in the previous four years and were worried that the arsenic level in their well water was the reason. She stated that independent testing had confirmed that their levels were high, although the results were not with her. I agreed that this was a reasonable test and ordered a urine arsenic speciation test at her request. However, knowing very little about the compound's effect on mammalian physiology and even less about its prevalence in rural well water, I was unsure of the specific testing that should be ordered nor what physical examination to perform. The following is a summarized guide of what to do in a similar presentation. Arsenic toxicity from ingested water and food is a worldwide phenomenon capable of causing significant morbidity.

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Background

Arsenic exists naturally in the environment in various forms; some are toxic, some benign. The toxic forms include inorganic species, and their partially detoxified metabolites called monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA)[1]. The inorganic forms are dangerous to humans, and unfortunately symptoms of their toxicity are generally insidious and nonspecific in both severity and time course[2]. Exposure to higher-than-average levels of arsenic occurs mainly in workplaces, near or in hazardous waste sites, and areas with high levels naturally occurring in soil, rocks, and water. Globally, it is estimated that over 226 million people in 56 countries are exposed to unsafe concentrations of arsenic found in their drinking water and food[3]. The highest levels are found in the groundwater of

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Argentina, Bangladesh, Chile, China, India, Mexico, and the United States[4].

While specific Occupational Safety and Health Administration (OSHA) standards exist for general industry, maritime, and construction workplace exposure to arsenic and there are maximum levels of arsenic allowed in community water systems set by the United States Environmental Protection Agency, most states' health departments only require initial arsenic testing for newly drilled wells and then recommend homeowners test existing private wells periodically. As a result, once a private well is put into service, the user is responsible for properly maintaining their well, testing it regularly and treating the water when necessary. As such, there are no all-encompassing well water stewardship guidelines as they pertain to dissolved particles such as arsenic.

In Minnesota, twenty-one percent of residents (1.2 million people) get their drinking water from a private well[5]. More locally in rural Minnesota where this patient resides, inorganic arsenic has been detected in 40% of new wells drilled in the state since 2008[6]. Of these, 10% are above the safe threshold established nationally as 10 mcg/L by the United States' Environmental Protection Agency[3]. Arsenic is most frequently found due to previous geological glacial coverage throughout the United States, resulting in significant amounts of arsenic in ground sediment country-wide[7]. As water flows through underlying bedrock, arsenic leaches into groundwater sources[4, 7]. The concentration of arsenic in surface and groundwater is about 1 part in a billion parts of water (1 ppb), although it may exceed 1,000 ppb in contaminated areas or where soil arsenic levels are elevated[8]. The highest levels tend to be in the states of Alaska, California and Wyoming[9]. American domestic well water is not controlled to meet the same drinking water standards as other types of water supplies[6, 9]. As a result, it is up to the well owner to test their water and remove arsenic through commercially available water filters. Arsenic cannot be tasted, seen or smelled and can vary in concentration between wells even in a compact area, a fact which led to its use as in intentional poison in the past[8]. Heating or boiling well water will not remove arsenic, nor will using chlorine disinfection[10]. However, reverse osmosis, ultra-filtration, distillation and anion exchange will[6]. Conversely, connection to a community public water supply is another option, as these must comply with Environmental Protection Agency standards in the United States, and hence are regularly tested for arsenic[11]. If arsenic is not detected in a well water sample, it is unlikely to be found later[6]. Conversely, if it is detected in a new well, it is recommended to retest six months later as levels may fluctuate in the first few months following well construction[6].

Consuming water with elevated levels of arsenic will usually cause an individual to be asymptomatic. However, multiple serious medical conditions have been known to arise with prolonged exposure. These include an insidious onset of diabetes, cancers of the bladder, liver, lungs and skin and cardiovascular and respiratory disease[9, 12]. Skin conditions include non-specific skin lesion formation and discoloration followed by a risk of skin cancer[4, 13, 14]. Skin does not absorb arsenic, so arsenic-containing water is safe for washing dishes and clothes, showering and bathing, but is considered a toxin when used for watering food crops[4, 6].

Chronic arsenic exposure can present as the 'great masquerader', as its symptomatology can easily give the illusion of other commonly seen medical conditions such as the following:

- Symmetrical sensorimotor polyneuropathy[8, 14, 15]: Seen in the stocking and glove distribution with decreased pain, decreased sensation to touch and temperature and symmetrical weakness alongside decreased deep tendon reflexes. EMG studies typically show distal motor and sensory neuropathy. This can mimic vitamin B_{12} deficiency and diabetic neuropathy.
- Hypertension and prolongation of the QTc interval[16, 17]: Hypertension is certainly common, and usually attributed to lifestyle factors and sodium intake.
- Diabetes mellitus type 2[14, 18]: Some studies have found a dose-response correlation between arsenic exposure in drinking water and the risk of developing diabetes mellitus type 2. This again is often considered due to lifestyle choices rather than environmental causes.
- Chronic respiratory[14, 19]: Cough, dyspnea and hemoptysis present in a dose-response relationship with prolonged arsenic ingestion. Toxicity can be mistaken for chronic restrictive and obstructive diseases.
- Hematologic abnormalities[2, 20]: Most commonly this includes anemia, leukopenia, thrombocytopenia and elevated liver function tests. The peripheral blood smear may contain basophilic stippling, although this is not specific for arsenic poisoning.
- Skin cancer[21]: Commonly attributed to sun or chemical exposure, although arsenic in drinking water is well-established as a cause of cutaneous cancers.

How to Investigate

Patient History: Inquire about the source of drinking water, condition of household pets, diet (emphasising frequency of seafood ingestion as *organic* arsenic is found particularly in fish and shellfish and is the less harmful variant compared to *inorganic* arsenic, but both are found in urinary samples for 48 hours), hobbies (which may include close contact with pesticides and herbicides in agriculture), home heating sources (such as wood-burning stoves and fireplaces), medications (especially homeopathic or naturopathic products), occupational exposure (arsenic used in alloys in lead-acid batteries for cars, semiconductors, and light-emitting

diodes) and residential history such as proximity to former smelters or industry[20]. In this case, the family and deceased dogs had all been drinking water from a private well. Other species, including domesticated animals and pets, have been shown to be useful indicators for biomonitoring toxic metals in the environment[22]. In this case, four dogs had been lost to cancer. Since pets closely share the same environment as their owners, they are exposed, at least in part, to the same pollutants[23]. This is analogous to the historical use of canaries in coal mines to detect carbon monoxide since they have faster respiration rates than humans causing them to become sick before the miners.

Physical examination: Obtain a blood pressure measurement, examine the skin closely for rashes and small corn-like elevations, Mee's lines of the nails and evidence of peripheral neuropathy of the hands and feet[19].

Laboratory investigations

1. Urine arsenic testing. This is the mainstay of testing for chronic arsenic exposure as a measure of current or very recent exposure. A single urine sample (along with a urine creatinine to correct for its concentration) is preferred. It is important to note that unless specified, urine arsenic testing provides a "total" urine arsenic concentration which includes the nontoxic organic forms. As a result, if the total urine arsenic concentration is elevated, no conclusion can be drawn until fractionation or 'speciation' testing confirms the presence of inorganic and/or methylated arsenic forms. When ordering urine arsenic testing, it is therefore recommended to simultaneously obtain 'speciation' especially on any elevated result. Consuming seafood within three days of testing may increase total urine arsenic concentrations (e.g., up to 300 mcg/24-hour urine). Few clinicians are aware of this and often misinterpret elevated arsenic results[24]. However, the laboratory will report out the individual levels of inorganic arsenic, the methylated metabolites (e.g., MMA and DMA), the organic arsenic and total arsenic concentration when speciation testing is performed. In this case, the laboratory assay specifically measured and summed the arsenite (As+3) and arsenate (As+5) as the inorganic arsenic, the MMA and DMA as the methylated arsenic, and arsenocholine and arsenobetaine as the organic fraction (Table 1). The National Health and Nutrition Examination Survey (NHANES) measures a random sample of American participants routinely for arsenic levels. Results from 2015–2016 indicate that the average urine total arsenic level to be 4.4 mcg/L[12]. Some studies suggest that minor health risks may be associated with total urinary levels above 50 mcg/L[17, 20].

2. Hair and fingernail arsenic testing. Inorganic arsenic is bound into hair and fingernail fibers and can be used to indicate past exposures. However, there is a lack of standardization for analysis, and commercial laboratory hair analyses can be highly inaccurate due to contamination from hair dye products and as such are not routinely recommended in the medical setting[1, 25]. However, long after urine levels have returned to baseline, the arsenic content of hair and nails may remain as the only clues of a history of arsenic exposure[8].

Table 1 Random urine arsenic speciation results

Component	Result	Reference range
Inorganic arsenic (mcg/L)	<3	–
Organic arsenic (mcg/L)	<3	–
Methylated arsenic (mcg/L)	10	–
Toxic arsenic concentration (mcg/L)	10	<35
Total arsenic concentration (mcg/L)	12	–

The sum of the inorganic, organic, methylated species of arsenic may not match the total arsenic concentration reported due to the presence of unidentified organic species of arsenic and/or rounding.

3. Whole blood arsenic testing. Not recommended for the initial analysis of arsenic exposure, as it is rapidly cleared from the blood and absorbed into non-vascular tissues. Elevated whole blood arsenic concentrations above 12 ng/mL indicate considerable exposure but will only be detected immediately after ingestion and as such, are not used for screening[1].

4. Consider a complete blood count, renal and liver function tests, an electrocardiogram for persistent QTc prolongation as well as a urinalysis assessing for evidence of hematuria which may be used to screen for renal and bladder cancers. If there are signs or symptoms of peripheral neuropathy, electromyogram (EMG) testing is also recommended.

Treatment

Medical management guidelines for arsenic and inorganic arsenic compounds do exist from the Center for Disease Control[26]. Ultimately the care provided depends on the clinical status of the patient, although for acute arsenic intoxication, gut decontamination and hemodynamic stabilization are key factors in the initial management[27]. Patients with suspected acute arsenic poisoning generally require rapid stabilization with fluid and electrolyte replacement in an intensive care setting. Chelating agents (e.g., 2-3-dimercapto-1-propanesulfonate (DMPS) or meso 2,3-dimer-captosuccinic acid (DMSA)) administered within hours of arsenic absorption may successfully prevent the full effects of arsenic toxicity[28]. For both acute and chronic over exposure to arsenic, the identification and removal of the toxic source and supportive measures are important. After intervention, follow-up urine arsenic testing may be necessary to confirm reduction in exposure and follow-up clinical testing may be necessary to verify resolution of clinical and laboratory test abnormalities.

Conclusion of the Case

This patient's clinical examination was positive for hypertension, but no other concerning features were present on history aside from her well-water exposure and the deaths of family dogs. Her levels are listed in Table 1 (all within normal limits) as obtained by urinary arsenic speciation results. While some methylated arsenic (e.g., DMA) was detected, the total amount of toxic arsenic (inorganic plus methylated arsenic) was less than the reference range. Previous studies using samples from the Multi-Ethnic Study of Atherosclerosis (2000–2002) and the 2003–2006 National Health and Nutrition Examination Survey also demonstrated median concentrations and interquartile ranges in parenthesis of DMA of 6.7 µg/L (3.4–13.6) and 3.5 µg/L (2.0–5.9), respectively[29]. The undetectable concentrations of the non-toxic organic arsenic species (e.g., arsenobetaine) are also consistent with minimal exposure to seafood in this case. In the end, she was relieved about her results and recommendation was provided to filter her well water for removal of arsenic.

The patient has given verbal and written consent to publish the article.

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