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Reverse Osmosis Filter Use and High Arsenic Levels in Private Well Water

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ABSTRACT. Inorganic arsenic causes cancer, and millions of people worldwide are exposed to arsenic-contaminated water. Regulatory standards for arsenic levels in drinking water generally do not apply to private domestic wells. Reverse osmosis (RO) units commonly are used by well owners to reduce arsenic concentrations, but may not always be effective. In a survey of 102 homes in Nevada, 19 used RO devices. Pre- and post-RO filtration arsenic concentrations averaged 443 μg/l and 87 μg/l, respectively. The average absolute and percent reductions in arsenic concentrations after filtration were 356 μg/l and 79%, respectively. Postfiltration concentrations were higher than 10 μg/l in 10 homes and higher than 100 μg/l in 4 homes. These findings provide evidence that RO filters do not guarantee safe drinking water and, despite regulatory standards, some people continue to be exposed to very high arsenic concentrations.

KEYWORDS: arsenic, reverse osmosis, water filters

Ingested inorganic arsenic (InAs) causes cancer of the skin, bladder, and lung, and has been linked to other health effects, including reproductive and developmental effects, cardiovascular disease, nonmalignant lung disease, and skin lesions.[1–3] Millions of people in the United States and worldwide are exposed to drinking water containing InAs,[4] and the health risks associated with these exposures may be quite high. For example, the National Research Council has estimated that the excess cancer risks associated with lifetime exposures to arsenic at the new US arsenic standard of 10 μg/l may be approximately 1 in 300.[3] There may be susceptible subpopulations for which the risk is even greater. The US drinking water standards for carcinogens other than arsenic have been set at levels associated with much lower estimated risks (ie, between approximately 1 in 10,000 and 1 in 1,000,000).[5]

The new US regulatory standard for drinking water InAs of 10 μg/l only applies to publicly supplied water,[6] not private domestic wells. According to the United States Geological Survey (USGS), 15% of the US population (approximately 45 million people) receives drinking water from private domestic wells.[7] To date, a comprehensive survey of private wells in the United States has not been done, so the actual number of people in this country exposed to high arsenic concentrations through private domestic wells is currently unknown. However, high arsenic concentrations have been documented in private wells in many states, including California, Nevada, Utah, Illinois, Michigan, Washington, Oregon, and New Hampshire.[8–15]

Owners of private domestic wells commonly use reverse osmosis (RO) water filtration units to reduce arsenic concentrations in well water used for drinking. However, it has been suggested that RO and other point-of-use filtration units may not always reduce arsenic concentrations to safe levels.[16] For example, a previous study of 351 homes in Churchill County, NV, (the same area where our study took

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place) reported that postfiltration arsenic levels were higher than 10 μg/l in approximately 50% of the 135 homes that used any treatment device on private well drinking water. Specific data on RO filters or pre- and postfiltration arsenic levels were not provided.[17] Several reports have evaluated the effectiveness of point-of-use RO filtration units in laboratory settings or in formal field testing programs and have reported that these filters can reduce arsenic concentrations by up to 80% to 99%.[18–22] However, because of poor maintenance, improper setup and use, differences between filter types from different manufacturers, and differences in water chemistry, the effectiveness of RO filters being used in real-life situations may differ from that reported in laboratory settings or formal testing programs.

In a recent study of 102 homes in an arsenic-exposed region in western Nevada, we identified 19 homes in which residents were using RO units to filter domestic well water used as their primary drinking water source.[23] In this report, we present the arsenic concentrations in the drinking water of each of these homes before and after RO filtration. Our first goal in this report was to evaluate the effectiveness of RO units that were in actual use. Unlike most previous investigations, this study involves a field investigation of private domestic wells rather than public water supplies and involves RO filters that were purchased by the user and not part of a formal testing or maintenance program. The use and effectiveness of these filters is a public health concern because many residents in arsenic-exposed areas in the United States and other countries use private well water for drinking and may be relying on point-of-use RO filtration devices to provide them with safe drinking water. Our second goal was to document the fact that despite the new US arsenic regulatory standard, and despite the use of water filters, very high arsenic exposures still are occurring in the United States.

METHODS

We identified the homes used in this report as part of a larger study[23] in which we evaluated the effectiveness of arsenic field test kits. The earlier study involved assessing arsenic levels in the drinking water sources in 102 homes. We had identified these 102 homes from records of private and public wells in western Nevada for which arsenic concentrations had been measured and archived by the Nevada State Health Division.[15] For the earlier study, we divided all wells with archived records into high (> 200 μg/l), medium (50–200 μg/l), and low (< 50 μg/l) arsenic concentration categories and randomly selected an approximately equal number of wells from each category. We did this so that we would be studying a group of wells with a broad range of arsenic concentrations. We then contacted the resident(s) at the address listed for each selected record by mail or phone regarding the study. The Committee for Protection of Human Subjects at the University of California, Berkeley, approved this study, and we obtained informed consent from the residents of each water source prior to sample collection. We completed the research in accordance with the Declaration of Helsinki.

At each of the 102 homes, we collected information on the primary drinking water source and the use of water filtration units. The present study includes data on all homes in which residents reported using a point-of-use reverse osmosis filtration unit on their primary drinking water supply. At each of these homes, we collected 2 water samples, 1 before and 1 after RO filtration. Because of the difficulty of removing RO units, we usually collected the prefiltration sample from a water faucet outside the home. We collected the second sample from the subject's primary source of drinking water (in most homes, this was the faucet in the kitchen), after water from that source had run through the home's RO filtration unit under normal use conditions. The water from all sources ran for several minutes before we collected each sample. We collected all samples without preservatives into unused sterile 50-ml polypropylene bottles, which we transported overnight on ice to the University of Washington for laboratory analysis.

For the laboratory analysis, each sample was divided into 1-ml portions in amber crimp-top vials and spiked with 0.01 ml concentrated hydrochloric acid and 0.01 ml 30% aqueous hydrogen peroxide. We prepared standards similarly using National Institute of Standards and Technology (NIST)-traceable stock solutions. We diluted samples to concentrations of < 200 μg/l as required. The lower limit of quantitation was 10 μg/l. We performed instrumental analysis by automated flow injection using borohydride reduction and continuous arsine detection by atomic fluorescence spectroscopy. The InAs concentrations included the trivalent and pentavalent forms combined. We ran all samples and standards in duplicate. The average relative percent difference across duplicate samples was 5.4%, and the average coefficient of variation was 3.6%. Quality control procedures also consisted of the use of 1 blank and 1 calibrant per 8 samples, and 3 analyses of standard reference materials. The average InAs level in the 34 blank samples was 0.93 ± 2 μg/l. The average InAs level in 42 aqueous calibration check samples spiked with 50 parts per billion (ppb) InAs was 53.0 ± 8.5 μg/l (average recovery = 105.9%). The average InAs level measured in 6 NIST Ultra-Chek 100 ppb samples was 94.9 ± 11.2 μg/L (average recovery = 94.9%). Recalibration occurred daily, after the processing of approximately every 40 to 60 samples.

We present the water arsenic concentrations before and after filtration for each home. We calculated absolute reduction in arsenic concentration with filtration use by subtracting the after-filtration measurement from the before-filtration measurement. We calculated percent reduction by dividing the absolute reduction by the before-filtration measurement and multiplying by 100%. For arsenic concentrations below the lower limit of the quantitation level, we used a value of approximately 50% of this level.

RESULTS

In our larger study of arsenic concentrations at 102 residences, we identified 19 homes in which residents were using RO units to filter private well water. Table 1 and Figure 1 show the arsenic concentrations before and after filtration. All prefiltration arsenic levels were higher than the new US Environmental Protection Agency's (USEPA) standard of 10 μg/l. The average arsenic concentration before filtration was 443 μg/l (range = 36–2,363 μg/l), and the average arsenic concentration after filtration was 87 μg/l (range = <10–641 μg/l). The average absolute reduction in arsenic concentration was 356 μg/l (range = −2–2,358 μg/l). The average percent reduction with filtration was 79% (range = −1– > 99%). If the 1 well with a very high prefiltration arsenic concentration of 2,363 μg/l is excluded as a possible outlier, the average absolute and percent reductions with RO filtration were 245 μg/l and 78%, respectively. In 9 of 19 homes (47%), arsenic levels were reduced to a level below the USEPA standard of 10 μg/l. In the remaining 10 homes (53%), arsenic concentrations after RO filtration remained above 10 μg/l. The average pre- and postfiltration arsenic concentrations in these 10 homes were 480 μg/l (range = 124–887 μg/l) and 161 μg/l (range = 11–641 μg/l). In 4 homes, postfiltration arsenic concentrations were over 100 μg/l, 10 times the USEPA regulatory standard for the level of arsenic in public water.

Table 1.—Arsenic Concentrations in Private Well Water From 19 Homes in Nevada Before and After Filtration With Reverse Osmosis

	Arsenic concentration (μg/l)			
Well No.	Before filtration	After filtration	Absolute reduction	% Reduction
5050A	2,363	< 10	2,358	> 99
5025A	887	641	246	28
5036B	727	17	710	98
5019A	670	12	658	98
5034A	609	528	81	13
5035B	579	11	568	98
5049A	394	30	364	92
5043B	359	< 10	354	99
5063A	334	143	191	57
5069B	306	24	282	92
5078B	252	< 10	247	98
5000C	226	< 10	221	98
5054B	170	172	–2	–1
5074B	129	< 10	124	96
5073B	124	31	93	75
5002A	115	< 10	110	96
5038B	73	< 10	68	93
5082B	64	< 10	59	92
5072C	36	< 10	31	86
Average	443	87	356	79

COMMENT

We found that more than half of the RO units evaluated did not reduce arsenic levels to below the US public water arsenic standard, and in several homes, arsenic concentrations were not reduced to levels below 100 μg/l. We used a convenience sample and did not choose wells in a completely random fashion. Thus, the proportions and effectiveness reported here may not be directly generalizable to all homes using RO units on private well water with high arsenic concentrations. Nevertheless, the number of high postfiltration arsenic levels we identified suggests that, in wells with high arsenic concentrations, point-of-use RO units may not always effectively reduce arsenic concentrations to safe levels.

Most previous studies on the effectiveness of arsenic removal by point-of-use RO devices either have involved testing RO devices in the laboratory or have been part of formal treatment and testing programs.[18–22] Researchers[19,20,22] conducting laboratory tests have reported that point-of-use RO devices reduce arsenic levels by approximately 70% to 99%, depending on device manufacturer, prefiltration arsenic concentration, amount of water filtered, water pH, and other factors.

In San Ysidro, a town in New Mexico with a population of approximately 200, Thomson et al[21] evaluated point-of-use RO devices in a relatively large field-sampling program.

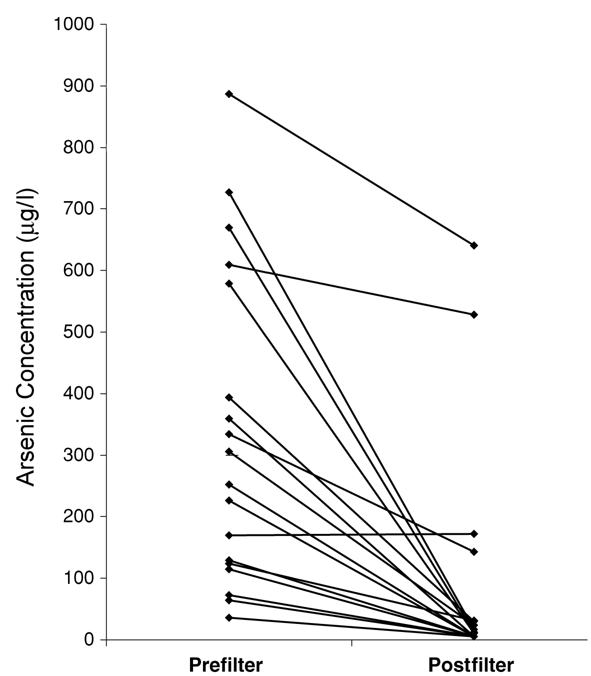

Fig. 1. Arsenic concentrations from private well water from 18 homes in Nevada before and after reverse osmosis filtration. (For display purposes, we did not include the home with the very high prefiltration arsenic concentration [pre- and postfiltration arsenic concentrations of 2363 and <10 μg/l] in the figure.)

In 1986, because of high arsenic concentrations (> 50 μg/l) in the local public water supplies, 73 RO units were provided to homes and businesses in San Ysidro. This program also included routine device maintenance, although maintenance may not have been performed or effective in all cases. Testing in 1987 showed an average prefiltration arsenic concentration of 68 μg/l and postfiltration concentrations between <0.5 μg/l (the detection limit) and 20 μg/l.[19] Subsequent analyses several years later, however, showed that RO performance diminished over time with approximately 30%–40% of devices not meeting the new USEPA standard of 10 μg/l.[21]

Our study is different from the San Ysidro study in that it involved individual privately owned domestic wells, more recent data (our sample collection took place in the summer of 2005), a wider range of arsenic concentrations, and different types of RO systems that the consumers purchased and were not part of a long-term formal testing or maintenance program. We also found that a large fraction of point-of-use RO units did not provide water with arsenic concentrations below 10 μg/l. This fraction was somewhat greater in our study than was in the San Ysidro program, which could be related to the overall higher arsenic concentrations in our study, or differences in maintenance, water chemistry, or RO manufacturer. Our study was designed to evaluate filter effectiveness not the exact reasons why performance was diminished. Thus, such information as filter life span or maintenance schedules was not collected. RO system manufacturers note that the carbon and sediment filters need to be replaced every year, and the membrane every 2 to 3 years. Other researchers[19,20,22,24] have noted that the effectiveness and life span of the RO system may be affected by water feed pressure, total gallons of water used, water hardness, pH, temperature, and other aspects of the water chemistry. Another factor to consider in the effectiveness of an RO system is the arsenic concentration; that is, very high levels of arsenic may be too high to bring down to levels that are safe for drinking.[16] Further research on exactly how these factors affect filter performance in real-life situations may help in developing public health interventions aimed at reducing high arsenic exposures in people who rely on these devices to provide safe drinking water.

The results of this study serve as a reminder that the new USEPA regulatory standard for arsenic applies only to public water supplies and that many people in the United States still may be exposed to high arsenic concentrations through the use of private well water. As discussed, the number of people exposed to high arsenic concentrations through private well water is unknown. One possible way to estimate this number is to use information on arsenic levels from public water supplies. Prior to the implementation of the new regulatory standard, the USEPA estimated that approximately 5% of all public water supplies in the United States had arsenic levels above 10 μg/l.[25] The USGS has estimated that approximately 45 million people in the United States obtain their drinking water from private domestic wells. Given this, if the proportion of private wells with arsenic concentrations above 10 μg/l is similar to the proportion of public water supplies with levels above 10 μg/l, then the number of people consuming water from private wells with arsenic concentrations above 10 μg/l could be more than 2 million people (representing 5% of 45 million). This number could be an underestimate because it is based on data from public water supplies, which are federally regulated and thus more likely to be tested for arsenic than are private wells. With more stringent regulations for testing and public use, it seems probable that public water sources with high arsenic concentrations are more likely to be identified—and thus, treated or avoided—than are private wells with similarly high arsenic concentrations. If true, the proportion of private wells with high arsenic concentrations would likely be higher than that seen for public water sources and therefore could be higher than the estimates provided here. Because of a lack of research on private wells, the true proportion of private wells with high arsenic levels is unknown. Despite this uncertainty, the estimate presented above is still valuable because it highlights the large number of people that may be exposed through this route and the need for further research to characterize more accurately this potentially large exposure group.

Although the size of this study was small and the sample of homes was not randomly selected, our findings serve as an important reminder that RO filters will not always ensure safe drinking water and that high arsenic exposures continue to occur in the United States. These findings suggest that public health officials and health care workers in areas with known arsenic exposures should make efforts to inform and remind people who use RO filters with private well water of the importance of proper filter maintenance, limited filter life span, the possible need for follow-up postfiltration arsenic testing, and the possible need for alternative treatment devices or an alternative water source. Although there may be a need for further research to evaluate which factors may have the greatest impact on filter effectiveness, these measures could help avoid inadvertent arsenic exposures, and therefore could help reduce arsenic-associated health risks.

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