

Arsenic Consumption in the United States

Abstract Exposure limits for arsenic in drinking water and minimal risk levels (MRLs) for total dietary exposure to arsenic have long been established in the U.S. Multiple studies conducted over the last five years have detected arsenic in foods and beverages including juice, rice, milk, broth (beef and chicken), and others. Understanding whether or not each of these foods or drinks is a concern to certain groups of individuals requires examining which types of and how much arsenic is ingested. In this article, recent studies are reviewed and placed in the context of consumption patterns. When single sources of food or drink are considered in isolation, heavy rice eaters can be exposed to the most arsenic among adults while infants consuming formula containing contaminated organic brown rice syrup are the most exposed group among children. Most food and drink do not contain sufficient arsenic to exceed MRLs. For individuals consuming more than one source of contaminated water or food, however, adverse health effects are more likely. In total, recent studies on arsenic contamination in food and beverages emphasize the need for individual consumers to understand and manage their total dietary exposure to arsenic.

Introduction

Arsenic is ubiquitous in air, water, and living things (Azcue, 1995) and is a component of more than 245 minerals (Mandal & Suzuki, 2002). The weathering of rocks converts the arsenic sulfides in these minerals to arsenic trioxide that then enters into the environment as dust and dissolves in rain, rivers, and groundwater (Mandal & Suzuki, 2002; U.S. Geological Survey, 2011). Although now prohibited, arsenic-based pesticides have a long history in agriculture and persist in previously treated soils. Humans can be exposed to arsenic in both inorganic and organic forms. Organic arsenic (e.g., monomethylarsonic acid [MMA] and dimethylarsinic acid [DMA]) exposure occurs mostly through fish and shellfish and is typically excreted and not absorbed by the body. Historically, organic arsenic is largely thought to be nontoxic and most arsenic-induced toxicity in people is thought to be a result of exposure to inorganic arsenic (Agency for Toxic Substances and Disease Registry [ATSDR], 2007). Recent studies of trivalent MMA and DMA, however, may put these historical assumptions about Denise Wilson Department of Electrical Engineering University of Washington

organic arsenic into question (see Roberge and co-authors, 2009, for discussion of this topic), but this review remains focused on inorganic species. Inorganic arsenic is typically found in two forms: trivalent As(III) or arsenite and pentavalent As(V) or arsenate (ATSDR, 2007). Recent studies show that many foods contain significant amounts of inorganic arsenic including milk and dairy products; beef, pork, and poultry; and certain fruits, grains, and vegetables that have high uptake rates from contaminated soils.

Safety Standards

Since arsenic is such a common contaminant in groundwater, exposure limits have been established for drinking water. The U.S. Environmental Protection Agency (U.S. EPA) has established a maximum contaminant level (MCL) for total arsenic of 10 parts per billion (ppb) (U.S. EPA, 2010). The MCL is a legal limit that dictates how much substance is allowed in public water systems under the Safe Drinking Water Act of 1974 (U.S. EPA, 2015). The MCL does not apply to private well water, bottled water, or other sources of water outside these public systems. California has recently enacted regulations for bottled water, however, which require testing for heavy metal contaminants, reporting the results to the state, and potentially notifying consumers via labeling requirements (Bottled, Vended, Hauled, and Processed Water, 2008).

No exposure limits are established for private well water. Individual well users are responsible for testing such water and limiting their exposure to arsenic. Around the world, exposure limits similar to that of U.S.

TABLE 1

Arsenic Contamination in Beverages (Recent Studies in the U.S.)

Beverage	Arsenic Type	Contamination (ppb) ^a			% of U.S. EPA MCL ^a			
		Min	Mean	Мах	Min	Mean	Мах	
Cider (apple) ^b	Total arsenic	5.4	10	15	54	100	150	
	Inorganic arsenic	3.9	9.7	15	39	97	150	
Juice (apple) ^b	Total arsenic	11	18	30	110	180	300	
	Inorganic arsenic	6.9	15	25	69	150	250	
Juice (apple) ^c	Primarily inorganic	3.7	7.5	13	37	75	130	
Juice (apple blend) ^c	Primarily inorganic	3.5	9.2	20	35	92	200	
Juice (grape) ^{b*}	Total arsenic	7.0	22	48*	70	220	480	
	Inorganic arsenic	5.2	20	51*	52	200	510	
Milk⁵	Total arsenic	2.6	2.7	2.8	26	27	28	
	Inorganic arsenic	0.45	0.96	2.0	4.5	9.6	20	
Water (bottled) ^d	Total arsenic	0.08	0.62	1.9	0.8	6.2	19	
Wine ^e	Primarily inorganic	10	23	76	100	230	760	
^a ppb = parts per billion; U.S. EPA MCL = U.S. Environmental Protection Agency maximum contaminant limit.								

^appd = parts per billion; U.S. EPA MCL = U.S. Environmental Protection Agency maximum contaminar ^bRoberge et al., 2009.

°Wilson et al., 2012.

eWilson, 2015.

*Computed from mean values of multiple batches; variance within mean values may cause max inorganic arsenic to exceed max total arsenic.

EPA have been established for drinking water. The World Health Organization (WHO) provides a provisional guideline value for arsenic in drinking water of 10 µg/L or 10 ppb, identical to U.S. EPAs exposure limit (WHO, 2010). The European Union adheres to this standard, requiring all member countries to use 10 ppb or lower as a regulatory limit on drinking water (European Commission, 2012). Arsenic is not regulated in the U.S. in other beverages, but the Food and Drug Administration (FDA) has proposed an action level of 10 ppb for arsenic in apple juice (FDA, 2013).

To cover other dietary sources of arsenic, some agencies have identified total dietary intake thresholds for arsenic. In particular, the Agency for Toxic Substances and Disease Registry (ATSDR) in the U.S. has estimated minimal risk levels (MRLs) for total dietary intake of arsenic dependent on arsenic species. An MRL is the estimate of daily human exposure that is likely to cause no adverse noncarcinogenic health effects over a certain duration of exposure. For chronic exposures (365 days or more), the MRLs estimated by the ATSDR for various species of arsenic are 0.3 μ g As/kg body weight per day for inorganic arsenic, 0.01 mg As/kg body weight per day for MMA (organic) arsenic, and 0.02 mg/ kg body weight per day for DMA (organic) arsenic (ATSDR, 2007).

This review places recent studies of arsenic contamination of food and beverages into the context of U.S. EPA's MCL for drinking water (10 ppb) and the ATSDR total dietary intake MRL for inorganic arsenic ($0.3 \mu g$ As/kg body weight per day).

Health Impacts

Chronic exposure to arsenic is a global public health problem that continues to be a subject of research. A growing body of evidence supports the fact that even low exposures to arsenic can damage the body, making it vulnerable to a broad range of cancers and other pathological effects. Arsenic is well known to cause skin, lung, and bladder cancers as well as skin lesions, diabetes, cardiovascular disease, and other disorders in humans (Hughes, Beck, Chen, Lewis, & Thomas, 2011). A full review of adverse health effects resulting from arsenic exposure is outside the scope of this article but excellent recent reviews have been conducted for bladder cancer (Christoforidou et al., 2013), immune system damage (Dangleben, Skibola, & Smith, 2013), neurodevelopment in children (Rodriguez-Barranco et al., 2013), diabetes (Thayer, Heindel, Bucher, & Gallo, 2012), and hypertension (Abhyankar, Jones, Guallar, & Navas-Acien, 2012).

Exposure levels as low as 50 µg/L in drinking water have been linked to statistically significant increases in bladder cancer around the world including regions of Michigan, Florida, and Idaho in the U.S. (Christoforidou et al., 2013). Even lower levels of 32 μ g/L in drinking water among subjects in New Hampshire in the U.S. have been linked to decreased aptosis (natural cell death that prevents uncontrolled proliferation of cells) and diminished expressions of both defense and inflammatory genes during chronic exposures (Andrew et al., 2008). Mean arsenic levels as low as 43 µg/L in drinking water caused significant changes in motor function among children (Parvez et al., 2011), and overall, a 50% increase in arsenic exposure in drinking water caused a significant decrease of -0.56 points in Full Scale IQ (Rodriguez-Barranco et al., 2013). In U.S. studies of drinking water with even lower arsenic levels (medians of 2 µg/L and 8.3 µg/L), hypertension was shown to increase with increasing arsenic exposure (Abhyankar et al., 2012). Thus, while the adverse nature of chronic arsenic exposure has been known and acknowledged for many decades, the evolving body of evidence in the scientific literature continues to expand the type of damage, the implications for long-term diseases including cancer, and the exposure limits at which these adverse effects begin.

Nevertheless, further investigation of humans who are chronically exposed to arsenic is essential to more fully understand connections between arsenic exposure levels and disease. Although this review evaluates recent studies of arsenic in food and water on the basis of existing exposure limits, any conclusions and recommendations made as a result of these exposure levels must be interpreted with caution. As in any such review, conclusions may need to be reevaluated based on emerging knowledge regarding the adverse health effects of environmental toxins.

^dSullivan & Leary, 2011.

Sources of Contamination

A range of recent studies published in the scientific literature confirms that arsenic is almost as ubiquitous in the food and beverage supply as it is in the environment (Tables 1, 2).

Beverages (Table 1): In response to California's regulations regarding heavy metal contamination in bottled water (Bottled, Vended, Hauled, and Processed Water, 2008), Sullivan and Leavey (2011) examined heavy metal content including arsenic in six sources of bottled spring waters. Results indicated that arsenic content in all waters tested was well below the U.S. EPA MCL of 10 ppb in drinking water. Likewise, milk samples tested by Roberge and co-authors (2009) indicated low levels of arsenic (below 3 ppb) in several different kinds of milk including whole, low fat, and fat free. In contrast, arsenic contamination in apple cider (Roberge et al., 2009), apple juice (Consumer Reports, 2012; Roberge et al., 2009; Wilson, Hooper, & Shi, 2012), apple blend juices (Wilson et al., 2012), and grape juices (Roberge et al., 2009) were substantially higher, ranging from 3.5 ppb to 51 ppb total arsenic, with a majority of species determined to be inorganic. Contamination in red wines was even greater than in apple, apple blend, and grape juices. A recent study of wines (Wilson, 2015) originating in California, New York, Oregon, and Washington demonstrated total arsenic concentrations ranging from 10 ppb to over 70 ppb. While arsenic levels in most juices and all wines exceeded the 10 ppb MCL, only 5.4% of tap water systems in the U.S. (and an estimated three million Americans served by these supplies) exceeded this limit (Natural Resources Defense Council, 2000).

Foods (Table 2): Recent studies have established baselines for and reinforced historic reports of arsenic contamination levels in several at-risk foods. While inorganic arsenic content in most beef and chicken broth (Roberge et al., 2009) and non-soy infant formula (Jackson et al., 2012a) remained below the 10 ppb MCL, arsenic levels in infant formula are of concern because infants and children have more immature detoxification capabilities than adults and do not process arsenic or other heavy metal contamination as well as adults. Children also drink and eat more per unit body weight, thereby increasing their total exposure (Rodriguez-Barranco et al., 2013).

TABLE 2

Arsenic Contamination in Foods (Recent Studies)

Food Item	Arsenic Type	Contamination (ppb) ^a			% of U.S. EPA MCL ^a			
		Min	Mean	Мах	Min	Mean	Max	
Food (liquid)								
Broth (beef) ^b	Total arsenic	7.5	11	19	75	110	190	
	Inorganic arsenic	1.3	4.5	13	13	45	130	
Broth (chicken) ^b	Total arsenic	6.2	7.9	11	62	79	110	
	Inorganic arsenic	0.27	1.1	1.8	2.7	11	18	
Infant formula 1°*	Inorganic arsenic	0.34	0.98	1.6	3.4	9.8	16	
Infant formula 2°*	Inorganic arsenic	8.00	NA	9.00	80.0	85.0	90.0	
Infant formula 3°*	Inorganic arsenic	15.0	NA	25.0	150	200	250	
Food (solid)								
Cereal bars ^c	Total arsenic	8.0	51	130	NA Total dietary intake minimal risk levels are more appropriate for solid food			
	Inorganic arsenic**	38	71	92				
Infant 1st stage food ^{c*}	Total arsenic***	0.32	3.6	20				
Infant 2nd/3rd stage food ^{c*}		1.7	12	22				
Rice (U.S.) ^d	Total arsenic	NA	181	753				
Seafood (amberjack) ^e		1,600	6,300	11,000				
Seafood (octopus) ^e	Total arsenic****	2,200	6,200	15,000				
Seafood (salmon) ^e		270	920	1,800				
Seafood (tuna) ^e		430	1,800	4,400				

^appb = parts per billion; U.S. EPA MCL = U.S. Environmental Protection Agency maximum contaminant limit. ^bRoberge et al., 2009.

°Jackson et al., 2012a, 2012b.

^dDuxbury & Zavala, 2005.

^eMorgano et al., 2014.

*Estimated based on powder formula reconstituted with arsenic-free water: infant formula 1 = no organic brown rice syrup (OBRS); infant formula 2 = dairy with OBRS; infant formula 3 = soy with OBRS. 1st stage food = single vegetable and fruit purees; 2nd/3rd stage food = multiple foods, containing a combination of meat, grain, vegetable, or fruit. **Speciated in only 12 of 29 total samples.

***72%-91% of arsenic in these samples was inorganic.

**** Approximately 10% of total arsenic was inorganic in these samples.

Rice has long been a concern with regard to arsenic contamination, although this concern is greater in countries outside of the U.S. where rice is a primary staple in the diet. Even so, total arsenic content in rice grown in the U.S. has been found to be as high as 753 ppb, with a majority being inorganic in nature. Due to concern over a connection between added sugar in infant formula and childhood obesity (Moskin, 2008), some infant formulas use organic brown rice syrup (OBRS) as a "healthier" alternative to added sugar. Derived from rice, OBRS is used as a healthy alternative sweetener to high-fructose corn syrup and has been implicated in the arsenic contamination of not only infant formula but cereal bars and other foods (Jackson et al., 2012b). In contrast to rice and rice products, arsenic in seafood is primarily organic (less toxic) in nature, with only about 10% of arsenic detected in most fish appearing as inorganic species (Duxbury & Zavala, 2005).

Summary: Comparing arsenic levels in food and beverages to the safety standards (U.S. EPA MCL) for drinking water is only one approach to understanding its impact on the U.S. consumer. An alternative approach is to consider total dietary arsenic as a function of both arsenic contamination and consump-

TABLE 3

Total Inorganic Arsenic Dietary Intake Estimated by Beverage and Consumption Pattern

Beverage (Inorganic Arsenic)	Individual	Estima	ated Arsen (µg)	ic/Day	% of ATSDR MRL ^a			
		Min	Typical	Мах	Min	Typical	Мах	
Juice*	Child (girl)	1.6	2.3	2.5	16	24	26	
(20 ppb ^a)	Child (boy)	2.0	2.4	2.6	21	26	27	
	Adolescent (girl)	1.9	2.1	2.2	10	11	12	
	Adolescent (boy)	2.0	2.2	2.7	9.3	11	13	
	Adult (woman)	1.4	2.3	2.5	6.3	10	11	
	Adult (man)	1.6	2.3	3.5	6.2	8.6	13	
Milk* (0.96 ppb)	Child (girl)	0.16	0.24	0.25	0.05	0.08	0.08	
	Child (boy)	0.60	0.79	0.81	0.20	0.27	0.27	
	Adolescent (girl)	0.07	0.11	0.12	0.36	0.59	0.62	
	Adolescent (boy)	0.11	0.17	0.23	0.52	0.80	1.1	
	Adult (woman)	0.08	0.16	0.18	0.36	0.61	0.75	
	Adult (man)	0.10	0.16	0.20	0.36	0.61	0.75	
Water, bottled** (0.62 ppb)	Child	0.10	0.14	0.27	1.0	1.5	2.8	
	Adult (female)	0.27	0.38	0.47	1.2	1.7	2.1	
	Adult (male)				1.0	1.4	1.8	
Wine** (23 ppb)	Adult (female)	0	0.28	2.7	0	1.2	12	
	Adult (male)				0	1.0	10	

^aATSDR MRL = Agency for Toxic Substances and Disease Registry minimal risk level; ppb = parts per billion.

*Maximum mean inorganic arsenic content in ppb, based on data in Table 1.

**Maximum mean total arsenic (where most species are inorganic), based on Table 1.

tion patterns for high-risk foods and beverages. This approach is considered next.

Consumption Patterns

Consumption patterns can vary widely among children and adults, ethnicity, culture, and preferences of U.S. consumers. To understand arsenic exposure and potential health risk in terms of total dietary intake, Tables 3 and 4 use the ATSDR MRL of 0.3 µg inorganic As/kg body weight per day as a point of comparison for multiple foods and beverages consumed by individuals of various ages. The data in Tables 3 and 4 are estimated based on the following:

1. Average weight for children and adults is estimated based on Centers for Disease Control and Prevention (CDC) anthropometric data (n.d.) for the U.S.: eightyear-old boy (31.3 kg) or girl (31.9 kg); 15-year-old boy (70.1 kg) or girl (63.3 kg); and average male (88.9 kg) or female (75.5 kg) adult.

- **2.** Consumption patterns are based on available data in market research and scientific literature and are broken down into three levels: minimum, typical or mid-range, and maximum.
- 3. Inorganic arsenic consumption per day in μ g (As/day) is calculated as the amount of food or beverage ingested for a particular consumption pattern (e.g., min, typical, max) multiplied by the mean inorganic arsenic contamination level for a particular food or beverage, based on recent studies from the peer-reviewed literature. In cases where multiple studies considered the same food or beverage, the maximum mean contamination level among all studies is used.
- **4. Percentage of ATSDR MRL** is computed as arsenic exposure (in μg As/kg of body weight per day) due to a particular food or beverage divided by the ATSDR MRL for inorganic arsenic of 0.3 μg inorganic As/ kg body weight per day. Arsenic exposure

is calculated as the inorganic arsenic consumption per day divided by average body weight for a particular type of individual.

Juice consumption: juice consumption patterns were estimated using data based on the National Health and Nutrition Examination Survey (NHANES) as analyzed by Storey and co-authors (2006). Six categories of consumption patterns from the Storey study were used as follows: (a) girls and boys between 6 and 11 years of age; (b) emerging adolescents and adolescents between 12 and 19 years of age; and (c) men and women (adults) between 20 and 39 years old. Fruit juice consumption was broken down by three ethnicity groups: white, African-American, and Mexican-American. In most cases, fruit juice consumption by African-American children and adults is highest (max) and consumption by whites the lowest (min). Boys and girls between 6 and 11 years old consume between 78.6 and 128.4 g (0.08-0.13 L) of fruit juice a day; adolescents between 96.2 and 136.1 g (0.10-0.14 L); and adults between 71.8 and 174.5 g (0.07–0.17 L) of juice per day. These numbers are consistent with the 42.8 L of juice consumed per year on average by individuals in the U.S. (Euromonitor, 2002).

Milk consumption: milk consumption patterns are estimated using similar data based on the NHANES survey as analyzed by Storey and co-authors (2006). Boys and girls between 6 and 11 years old consume between 165 and 298 g (0.16–0.29 L) of milk a day; adolescents between 72 and 241 g (0.07–0.23 L) of milk per day; and adults between 83 and 208 g (0.08–0.20 L) of milk per day.

Bottled water consumption: bottled water consumption patterns were estimated using data from the NHANES survey as analyzed by Drewnowski and co-authors (2013a, 2013b). Bottled water consumption is very similar among children, so only a single category of children's exposure (an eight-year-old child) was estimated. Bottled water consumption ranged from 160 to 231 mL per day for children and from 413 and 758 mL per day for adults (Drewnowski et al., 2013a, 2013b).

Wine consumption: in 2012, the Wine Market Council reported that approximately 44% (100 million) of the 228 million adults in the U.S. consumed wine. Of these wine drinkers, 43% (43 million or 19% of all adults) were considered marginal drinkers, consuming 7% of the total volume of 295 million cases of wine. The remaining 57% of wine drinkers (57 million or 25% of all adults) were considered core drinkers, consuming 93% of the total volume of wine consumed in the U.S. Core wine drinkers consume wine anywhere from daily to once a week while marginal drinkers consume wine less often than weekly (Wine Market Council, 2012). Thus, the core (max) wine drinker consumes about 11.5 gallons (43.3 L) of wine per year (max) while the marginal drinker (typical) consumes about 1.13 gallons (4.3 L) of wine per year.

Cereal bar consumption: cereal bars weigh between 28 g and 100 g and are consumed by an unknown percentage of the 30% of Americans who are heavy consumers of morning goods (*Wall Street Journal*, 2014). Total inorganic arsenic consumption from a typical cereal bar as estimated in Table 4 is based on a mean inorganic arsenic level of 71 µg/g (ppb) as identified by Jackson and co-authors (2012b), an average consumption of one cereal bar per day, and on three different sizes: small (28g), medium (55 g), and large (100 g).

Infant formula consumption: data from the Infant Feeding Practices Study II indicate that a large number of infants consume formula during the first 12 months of life. Fifty-two percent of infants receive formula while still in the hospital. By two months, 61% of infants are receiving formula in their daily diets. This number stays relatively stable until one year of age, when formula consumption drops off to 36.4% of infants (Grummer-Strawn, Scanlon, & Fein, 2014). Data for infant formula in Table 4 are based on a maximum formula consumption of 2.5 ounces per pound of body weight per day; typical formula consumption is estimated at half this amount: and minimum formula consumption is estimated at zero corresponding to babies less than six months of age who are 100% breastfed.

Rice consumption: approximately 18.2% of adults surveyed in the NHANES survey consume some white or brown rice during a randomly chosen day of observation data. The average rice consumed was 61.2 g (dry weight) or just over one cup of cooked rice. Many Americans consume no rice at all on any given day while some consume up to 126.5 g in a single day (Batres-Marquez, Jensen, & Upton, 2009).

Seafood consumption: the average American consumes approximately 2.7 pounds of tuna per year and 2.0 pounds of salmon per

TABLE 4

Total Inorganic Arsenic Dietary Intake Estimated by Food and Consumption Patterns

Food (Inorganic Arsenic)*	Individual	Estima	ated Arsen (µg)	ic/Day	% of ATSDR MRL ^a			
		Min	Mid	Max	Min	Mid	Max	
Cereal bars	Adult (female)	2.0	3.9	7.1	8.8	17	31	
(71 ppb ^a)	Adult (male)				7.5	15	27	
Formula 1**	Infants (6 kg)	0	0.46	0.92	0	26	51	
(0.98 ppb)	Infants (9 kg)	0	0.69	1.4	0	26	51	
Formula 2** (8.5 ppb)	Infants (6 kg)	0	4.0	8.0	0	221	442	
	Infants (9 kg)	0	6.0	12	0	221	442	
Formula 3** (20 ppb)	Infants (6 kg)	0	9.4	19	0	520	1040	
	Infants (9 kg)	0	14	28	0	520	1040	
Rice (180 ppb)	Adult (female)	0	11	23	0	49	101	
	Adult (male)				0	41	85	
Salmon (92 ppb)***	Adult (female)	0	0.23	0.52	0	1.0	2.3	
	Adult (male)				0	0.9	2.0	
Tuna (180 ppb)***	Adult (female)	0	0.6	1.4	0	2.7	6.1	
	Adult (male)				0	2.3	5.2	

^aATSDR MRL = Agency for Toxic Substances and Disease Registry minimal risk level; ppb = parts per billion. *Maximum mean inorganic arsenic content in ppb, based on data in Table 2.

**Refer to Table 2 for content of these foods.

***Based on assumption that approximately 10% of arsenic in seafood is inorganic.

year, second only to shrimp at 4 pounds per year and relative to a total of 15.8 pounds of seafood overall (Seafood Health Facts, 2010). Of the seafood tested recently by Morgano and co-authors (2014), tuna and salmon are consumed far more than amberjack and octopus in the U.S. and are therefore used as benchmark estimates of arsenic exposure through seafood consumption. Americans consume about 3.5 ounces of seafood a week compared to the recommended dietary intake of approximately twice that amount (USA Today, 2011). Thus, seafood consumption is estimated at a minimum of 0 pounds per year, a typical level corresponding to what Americans do eat (2.7 pounds of tuna and 2.0 pounds of salmon per year), and a maximum level corresponding to what American should eat (slightly over twice that amount). All total intake estimates assume that only 10% of the arsenic ingested is inorganic, which is typical for most seafood (Duxbury & Zavala, 2005).

Chicken and beef broth were not included in Table 4 because consumption rates in the U.S. are low. A heavy soup consumer in the U.S. has approximately four cans of soup per month, or approximately 1.4 ounces on average per day (Business Insider, 2011). Even if all soup contained heavily contaminated broth (12.5 ppb from Table 1), a heavy soup consumer would consume only 0.52 µg of inorganic arsenic per day, or 2.3% of the ATSDR MRL for a typical American female weighing 75.5 kg and 1.9% of the ATSDR MRL for a typical American male weighing 88.9 kg. By similar reasoning, arsenic content in 1st, 2nd, and 3rd stage foods for infants was not included in Table 4. Arsenic levels in these foods are much lower than in infant formulas, and consumption of these foods is significantly lower than infant formula.

Discussion

The issue of arsenic contamination in the food and beverage supply has been presented in two different ways. In comparing arsenic levels in beverages to the U.S. EPA drinking water safety standard or MCL (Table 1), several beverages raise some concern as to their health risk. Grape juice and wine, in particular, demonstrate mean arsenic levels over twice the U.S. EPA MCL and maximum levels at 5 and over 7.5 times the MCL, respectively. While fewer brands are contaminated at levels above the MCL in apple ciders and juice, many brands of apple juice still contain arsenic contamination over the MCL. On the other end of the spectrum, milk and bottled water are relatively safe, with inorganic arsenic levels averaging below 1 ppb. With regard to liquid food, only infant formula sweetened with OBRS demonstrates arsenic contamination above the U.S. EPA MCL (Table 2). While the usefulness of comparing inorganic arsenic contamination in solid food to the U.S. EPA MCL may be limited, arsenic levels in cereal bars, rice, and seafood are nevertheless well above the 10 ppb exposure limit (Table 2).

The human body does not differentiate inorganic arsenic consumed from different foods and beverages, which makes total dietary intake a more useful measure of the total risk of adverse health effects from chronic arsenic poisoning. When put into the context of total dietary intake by body weight (Tables 3 and 4), it is evident that heavy consumers of contaminated rice and OBRS-containing foods (e.g., some cereal bars and infant formulas) are at most risk of adverse health effects when a single source of arsenic contamination is considered. Even moderate consumers of multiple contaminated foods or heavy consumers of mildly contaminated foods can be at risk for adverse health effects from total dietary arsenic intake. Consumption of apple and grape juice, wine, and certain seafood in combination can pose just as much risk as highly contaminated rice products.

Conclusion

The ubiquitous presence of arsenic in the environment and subsequent frequency of contamination in both foods and beverages underscores the need for individuals to un-

derstand their total arsenic exposure based on consideration of the whole diet. While this review has highlighted a diverse range of food and beverages that are contaminated with inorganic arsenic, a much wider range of food and beverages remains to be tested. Because full disclosure of arsenic contamination in the food, water, and beverage supply is at best a distant possibility, it has become more and more important for individuals even in developed countries like the U.S. to be tested periodically for arsenic exposure. Since urine and hair tests are readily available to assess exposure, such individual testing may be far more feasible than widespread testing of all potential dietary sources of arsenic.

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continued on page 14

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