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Potential Exposure to Arsenic from Infant Rice Cereal

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Abstract

Background—Rice is known to be high in arsenic, including in infant rice cereal. Although arsenic in drinking water is currently regulated, there are currently no US regulations regarding arsenic concentrations in food.

Objective—We used published values to estimate arsenic exposure via rice cereal relative to breast milk or formula for 6- to 12-month-old infants in the general US population.

Results—We found that arsenic exposure from 3 servings of rice cereal exceeded that of formula made with water containing arsenic at 10 mg/L, the US Environmental Protection Agency maximum contaminant level.

Conclusions—Our findings suggest that rice cereal can markedly increase arsenic exposure among US infants relative to breast milk and formula.

Keywords

arsenic; environmental exposure; infant formula; rice cereal

Introduction

Arsenic is a known carcinogen and suspected immunotoxicant.¹ We previously reported that infant formula can be an important source of arsenic exposure, especially when reconstituted with arsenic-contaminated water.² However, solid foods are also a potential source of arsenic, especially those containing rice.³⁻⁵ Infant rice cereal, often the first solid food an infant receives, has been reported to contain elevated concentrations of arsenic.⁶⁻⁸ This is potentially of concern because early life is a period of both heightened vulnerability to arsenic⁹ and high dietary intake relative to adults.¹⁰

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Although arsenic in drinking water is currently regulated at concentrations $>10 \mu\text{g/L}$, the maximum contaminant level (MCL) set by the US Environmental Protection Agency (EPA),¹¹ there are currently no US regulations regarding arsenic concentrations in food.¹² We therefore developed exposure models using published data to compare infant arsenic exposure from rice cereal versus formula prepared with water at and below the MCL.

Methods

Rice Cereal

We estimated the per-serving exposure to arsenic by multiplying the mean serving size¹³ by the concentration of total or inorganic arsenic in rice cereal reported by the US Food and Drug Administration⁸ and then dividing by the body weight recommended by the US EPA.³ We estimated exposure using both central tendency and upper bound inputs. For central tendency inputs, we used the median concentration of arsenic in rice cereal (total arsenic: $0.20 \mu\text{g/g}$; inorganic arsenic: $0.12 \mu\text{g/g}$)⁸ and mean body weight (3-6 months: 7.4 kg ; 6-12 months: 9.2 kg).¹⁰ Upper bound inputs included the maximum concentration of arsenic in rice cereal (total arsenic: $0.37 \mu\text{g/g}$; inorganic arsenic $0.25 \mu\text{g/g}$)⁸ and fifth percentile body weight (3-6 months: 5.7 kg ; 6-12 months: 7.1 kg).¹⁰ Both models used the mean serving size (3-6 months: 11.6 g ; 6-12 months: 17 g or ~ 4 tablespoons) because no upper bound was available.¹³ The water used to reconstitute the cereal was assumed to be free of arsenic.

Although water contains primarily inorganic forms of arsenic (As^{III} and As^{V}), rice typically contains organic forms, including dimethylarsinic acid (DMA), a metabolite of inorganic arsenic.⁸ The toxicity of the organic forms is less understood; however, the trivalent forms of DMA appear to be toxic.¹¹ Therefore, we calculated exposures for both total and inorganic arsenic and relied on total arsenic for our comparisons.

Infant Formula

We estimated central tendency and upper bound arsenic exposure ($\mu\text{g/kg/d}$) for infants fed exclusively with formula prepared using tap water containing arsenic at 3 target concentrations: 1, 5, and $10 \mu\text{g/L}$. The total concentration of arsenic in formula included the target concentration of arsenic in tap water plus the concentration of arsenic in formula powder. The total concentration of arsenic in formula was then multiplied by the age-specific body weight-adjusted ingestion rate.¹⁰ For central tendency inputs we used the target concentration of arsenic in tap water (1, 5, or $10 \mu\text{g/L}$), the median concentration of arsenic in formula powder ($1.1 \mu\text{g/L}$),⁴ and the mean body weight adjusted ingestion rate (L/kg/d ; birth–1 month: 0.15; 1-3 months: 0.14; 3-6 months: 0.11; 6-12 months: 0.08).¹⁰ Upper bound inputs used the target concentration of arsenic in tap water (1, 5, or $10 \mu\text{g/L}$), the maximum concentration of arsenic in formula powder ($1.8 \mu\text{g/L}$),⁴ and the upper percentile body weight-adjusted ingestion rate, defined by the US EPA as the mean plus 2 standard deviations (L/kg/d ; birth–1 month: 0.22; 1-3 months: 0.19; 3-6 months: 0.15; 6-12 months: 7.1).¹⁰

Results

Estimated exposure as a result of rice cereal was elevated (Table 1, Fig. 1). Two servings of rice cereal per day resulted in higher total arsenic exposure for 6- to 12-month-old infants than formula made with water containing 5 µg/L. The estimated 1.11 µg/kg/d from 3 servings of rice cereal per day exceeded exposure from formula mixed with water at the MCL and was 6.5 times higher than exposure for a 60-kg adult ingesting 1 L/d of water at the MCL (0.17 µg/kg/d).⁶

Discussion

Our results indicate that infant rice cereal can be an important source of arsenic exposure for US infants during weaning, consistent with reports from Europe.^{6,7} Infants consuming both formula mixed with arsenic-containing water and rice cereal can have especially high exposures. Although we used the MCL as a point of comparison, it is based on chronic, adult-onset disease¹¹ and was not explicitly designed to protect infants.⁹ According to the American Academy of Pediatrics, rice cereal provides no advantage over other grains as a first solid food,¹⁴ and both the the American Academy of Pediatrics and US

Food and Drug Administration suggest that infants would benefit from an array of grain cere-als.^{14,15} Future research should investigate how effective a no- or low-rice cereal intervention could be at reducing infant exposure to arsenic.

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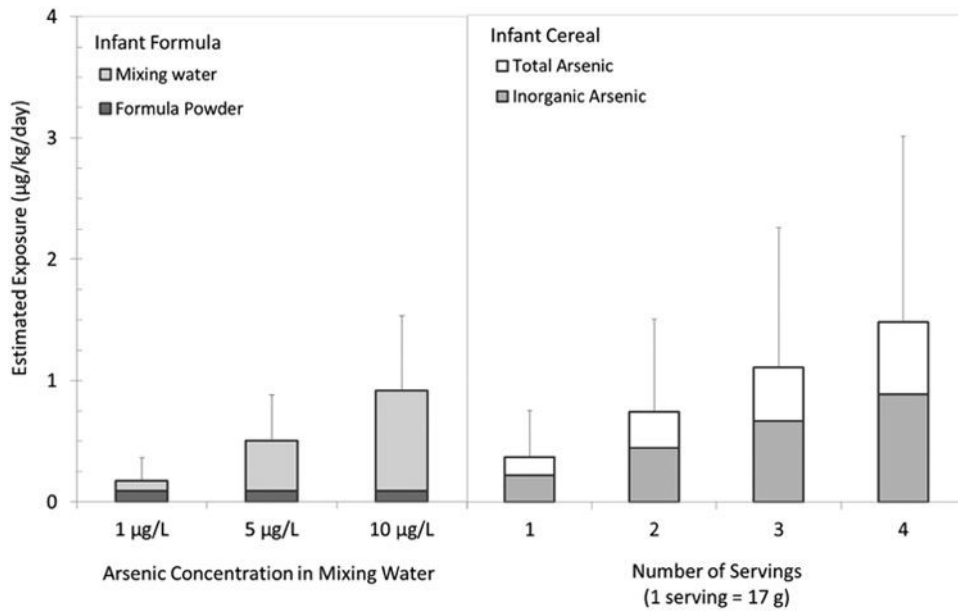


Figure 1. Estimated daily exposure to arsenic via formula (left) or rice cereal (right) for 6- to 12-month-old infants. Columns represent central tendency estimates and error bars represent upper bound estimates.

Table 1
Central Tendency (Upper Bound) Estimated Daily Exposure ($\mu\text{g}/\text{kg}/\text{d}$) for Infants During the First Year of Life as A Result of Formula Mixed with Tap Water Containing Arsenic at 1, 5, or 10 $\mu\text{g}/\text{l}$ Versus 1-4 Servings of Infant Rice Cereal

	Infant Age (mo)			
	Birth to <1	1 to <3	3 to <6	6 to <12
Infant formula, tap water arsenic				
1 $\mu\text{g}/\text{L}$	0.32 (0.62)	0.29 (0.53)	0.23 (0.42)	0.17 (0.36)
5 $\mu\text{g}/\text{L}$	0.92 (1.5)	0.85 (1.29)	0.67 (1.02)	0.51 (0.88)
10 $\mu\text{g}/\text{L}$	1.67 (2.6)	1.55 (2.24)	1.22 (1.77)	0.92 (1.53)
Servings of infant rice cereal				
1 serving/d	NE	NE	0.32 (0.76)	0.37 (0.89)
2 servings/d	NE	NE	0.63 (1.52)	0.74 (1.77)
3 servings/d	NE	NE	0.95 (2.28)	1.11 (2.66)
4 servings/d	NE	NE	1.27 (3.04)	1.48 (3.55)

NE, not estimated because rice cereal is not recommended at this age.