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Urinary excretion of arsenic following rice consumption

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ABSTRACT

Patterns of arsenic excretion were followed in a cohort ($n = 6$) eating a defined rice diet, 300 g per day d.wt. where arsenic speciation was characterized in cooked rice, following a period of abstinence from rice, and other high arsenic containing foods. A control group who did not consume rice were also monitored. The rice consumed in the study contained inorganic arsenic and dimethylarsinic acid (DMA) at a ratio of 1:1, yet the urine speciation was dominated by DMA (90%). At steady state (rice consumption/urinary excretion) ~40% of rice derived arsenic was excreted via urine. By monitoring of each urine pass throughout the day it was observed that there was considerable variation (up to 13-fold) for an individual's total arsenic urine content, and that there was a time dependent variation in urinary total arsenic content. This calls into question the robustness of routinely used first pass/spot check urine sampling for arsenic analysis.

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1. Introduction

Rice is the dominant food source of inorganic arsenic exposure to the world's population (EFSA, 2009; Meharg et al., 2009; Meharg and Raab, 2010; Williams et al., 2005). Even for sub-populations where drinking and cooking water is enriched in inorganic arsenic, rice ingestion is a significant contributor to inorganic arsenic consumption (Kile et al., 2007; Mondal and Polya, 2008; Ohno et al., 2007). Elevated inorganic arsenic in rice has raised concern with respect to regulation and legislation, reinforcing the need for a standard to be set, as is the case for water (EFSA, 2009). Yet, an outstanding question remains regarding the bioavailability of inorganic arsenic (arsenite and arsenate) and organic arsenic species (DMA and monomethyl arsonic acid/MMA) from rice in the gut and transfer into the bloodstream. *In vitro* gut simulations suggest that inorganic arsenic availability in cooked rice is in the order of 60–100% (Ackerman et al., 2005; Laparra et al., 2005; Sun et al., 2012). While the only detailed *in vivo* investigation (using a swine model not human model), showed 90% inorganic arsenic gut bioavailability from rice through monitoring blood arsenic (Juhasz et al., 2006).

Arsenic is readily excreted *via* urine where it is present both as the original inorganic arsenic, and as the metabolites MMA and DMA (Mandal et al., 2001). Correlative approaches between rice consumption and urinary arsenic excretion identify that rice consumption leads to higher inorganic arsenic excretion (Cascio et al., 2011; Davis et al., 2012; Gilbert-Diamond et al., 2011). In a study in the USA looking at relationships between arsenic excreted in the urine and arsenic consumption is was observed that 93% of arsenic exposure was due to food intake, when the arsenic water concentration was below the national 10 μg/l standard (Kurzius-Spencer et al., 2013). A mass balance calculation from a rice eating trial in humans where urinary arsenic excretion was related to rice intake, indicated that ~60% of arsenic in rice was expelled from the body via urine (He and Zheng, 2010). While illustrative of the utility of the approach the trial had only two volunteers and no controls. Furthermore, rice consumption rate was not standardized and only composite urine samples were analyzed, so diurnal variation in arsenic excretion was not captured.

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Table 1
Total elements, arsenic speciation and spiked recoveries (of 5 μg/l for each elemental and species spike) in cooked rice and rice flour CRM (NIST 1568a), all $n = 3$, and percentage recovery of spike (of 5 μg/l for each elemental and species spike) for $n = 18$ urine samples. Numbers in parenthesis are standard errors of the mean. The speciation of arsenic in the rice CRM agrees with previous studies (Williams et al., 2005; Raab et al., 2009).

	Rice CRM (μg/kg)	Rice CRM percentage recovery (%)	Cooked rice (μg/kg)	Urine spiked percentage recovery (%)
DMA	183 (6)		99 (8)	119 (3)
MMA	11 (1)		3 (0)	–
Inorg. As	108 (4)		99 (2)	94 (1)
Tot. As	302 (8)	104 (3)	274 (9)	97 (1)
Tot. Cu	2891 (220)	120 (9)	4123 (330)	97 (1)
Tot. Zn	15,249 (705)	78 (4)	17,565 (1229)	85 (1)
Tot. Se	445 (13)	117 (4)	289 (10)	81 (1)
Tot. Cd	21 (1)	93 (6)	31 (1)	93 (1)
Tot. Pb	14 (14)	–	57 (1)	108 (1)

This current investigation reports urinary arsenic excretion in a controlled experiment to relate the dynamic pattern of arsenic species in urine, between days and within days, as well as calculating a mass balance. Cadmium, copper, zinc, selenium and lead urinary excretion were also monitored to determine if there was any interaction between arsenic and other trace elements. Nine volunteers, 6 consuming rice and 3 controls, were monitored daily through a transition of no rice consumption to a typical South East Asian rice consumption rate of 300 g per day (*circa.* the average for a UK Bangladeshi) (Cascio et al., 2011; Meharg and Zhao, 2012).

2. Materials and methods

2.1. Study designs

Nine adult male volunteers avoided foods that may be elevated in arsenic (rice, rice products, mushrooms, chicken and seafood) for 1 week. After this time period, 6 (randomly selected) volunteers switched to a diet where 300 g dry weight of cooked rice was consumed in 3 sittings throughout the day. Rice was cooked by boiling in distilled deionized water. The rice, American short grain, for the entire trial was

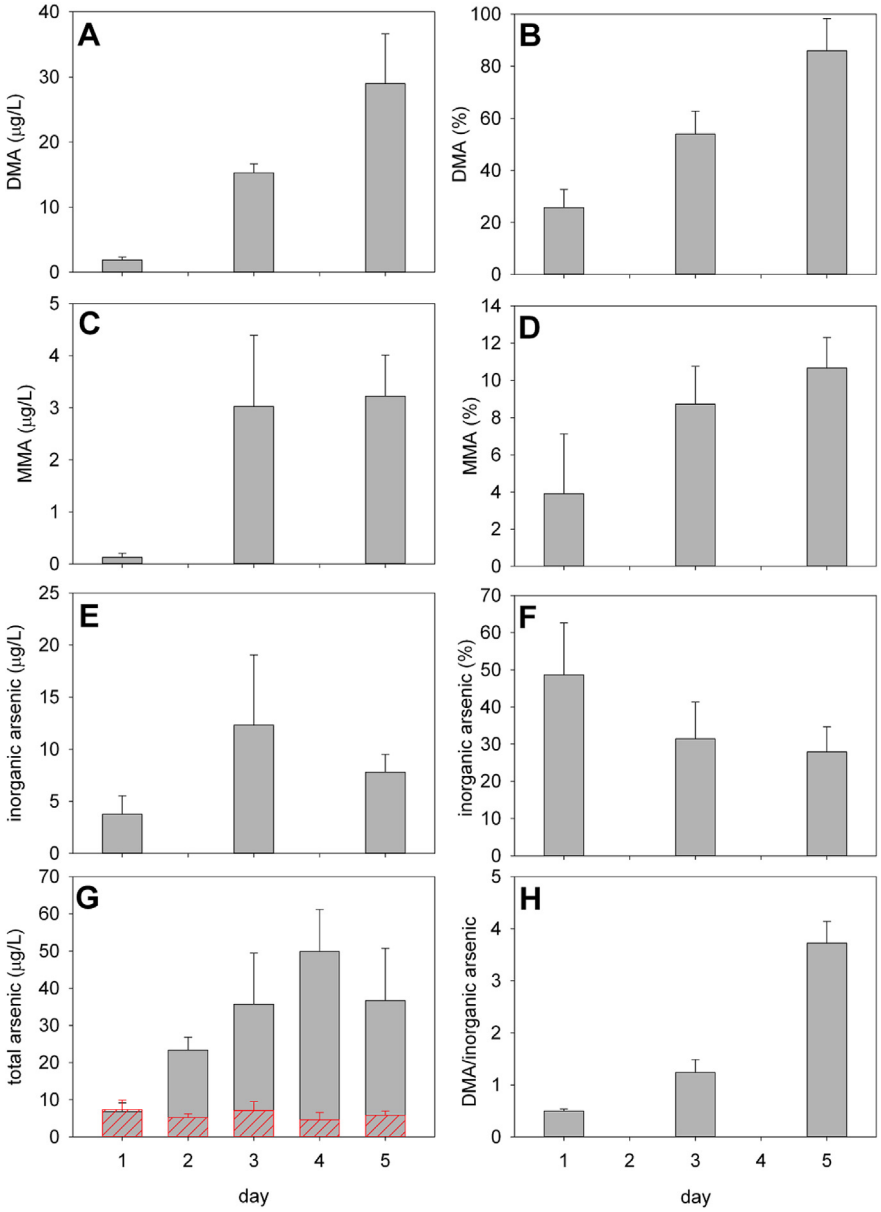

Fig. 1. Arsenic speciation in first daily urine pass on 3 days from 6 individuals eating 300 g d.wt. of rice per day (grey filled bars) *versus* individuals not eating rice (red hashed bars). Error bars show the standard error of the mean. A = DMA concentration for days 1, 3 and 5. B = % DMA#, C = MMA concentration, D = % MMA#, E = Inorg. arsenic, F = % Inorg. arsenic#, G = total arsenic concentrations for all days, H = [DMA]/[inorg. arsenic]. # *calculated from the species sum.* (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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