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Maternal exposure to alkali, alkali earth, transition and other metals: Concentrations and predictors of exposure

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ABSTRACT

Most studies of metals exposure focus on the heavy metals. There are many other metals (the transition, alkali and alkaline earth metals in particular) in common use in electronics, defense industries, emitted via combustion and which are naturally present in the environment, that have received limited attention in terms of human exposure. We analysed samples of whole blood (172), urine (173) and drinking water (172) for antimony, beryllium, bismuth, cesium, gallium, rubidium, silver, strontium, thallium, thorium and vanadium using ICPMS. In general most metals concentrations were low and below the analytical limit of detection with some high concentrations observed. Few factors examined in regression models were shown to influence biological metals concentrations and explained little of the variation. Further study is required to establish the source of metals exposures at the high end of the ranges of concentrations measured and the potential for any adverse health impacts in children.

1. Introduction

The transition, alkali and alkaline earth metals occur commonly in nature and are often released from mining and refining processes or combustion of coal and oil (Moskalyk and Alfantazi in Zwolak, 2014). They are also commonly used in the electronics, semiconductor and defence industries with a number also used in medical and pharmaceutical applications. These metals include antimony (Sb), beryllium (Be), bismuth (Bi), cesium (Cs), gallium (Ga), rubidium (Rb), strontium (Sr), silver (Ag), thallium (Tl), thorium (Th) vanadium (V). Some of these metals (Bi, Ag and Sb) are replacements for heavy metals used in solder in the electronics industry (Asakura et al., 2009).

Antimony is usually present in the environment in very low concentrations (Sundar and Chakravarty, 2010). Most typically human exposure to antimony occurs through occupational exposure from emissions from mining, smelting, incinerators and power plants (Sundar and Chakravarty, 2010). However, there is increasing attention on emissions of antimony from the breakdown of brake linings in ambient air (Bukowiecki et al., 2009). Beryllium is used in a number of applications, most notably defence industries with its use in aircraft, instrumentation and electronic equipment (Middelton and Kowalski, 2010). Beryllium exposure has been well documented in the occupational literature but in the community setting concentrations have generally been low (CDC, 2013a). Bismuth has been used in pharmaceuticals and cosmetics and has been found in low concentrations in biological and environmental samples including blood, urine, food and water (Burguera et al., 2001; Dolara, 2014).

Metallic cesium is used in a variety of products and radioactive cesium is used to treat some cancers (Melnikov and Zanoni, 2010). Gallium is commonly used in the semiconductor and medical sectors (Chang et al., 2003). Silver is used both in its metallic form (jewellery, dental fillings, electronic equipment) and ionic form or when combined with other elements (silver nitrate, chloride, sulfide and oxide) (ATSDR, 1990a). Silver enters the environment

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through the breakdown of these products and can spread through soil and water.

Small amounts of strontium are ubiquitous in the environment and humans can be exposed to through air, food, water or consumption of soil or dust, however, food and drinking water are the largest contributors. Strontium is also commonly used in both pharmaceutical and electronics industries (ATSDR, 2004b).

Rubidium is a common alkali element and has been commonly found in soils and also foods (Usuda et al., 2014). It, like many of the alkali and transition metals, has also been used in the electronics industry (Usuda et al., 2014).

Thallium is considered very toxic (Staff et al., 2014). It is known to be associated with emissions from smelting operations (Garcia-Vargas et al., 2014). Thallium exposure for the general population usually comes from food, drinking water and soil (Staff et al., 2014; Tyrell et al, 2013). Thallium was used as a rodenticide in the past but this use has been banned in the US since 1972 (ATSDR, 1992). Thorium is a radioactive element found commonly in the environment (soil, water, plants and animals) at low levels and humans are exposed through water, air and food (ATSDR, 1990b). Thorium is also used in the manufacture of ceramics and in materials used for the nuclear and aerospace industries (ATSDR, 1990b).

Vanadium is a common element and is ubiquitous in the environment (Rehder, 2013). It is emitted from both natural and industrial processes and is a common component of steel (ATSDR, 2012). Human exposure is typically via food for the general population (Zwolak, 2014) and for those living close to industry using residual fuel oils may inhale larger quantities of vanadium, however, inhalation is not a main route of exposure (ATSDR, 2012).

There are some studies reporting health effects associated with exposure to these metals in the occupational setting, with a wide range of health effects reported. Antimony has been associated with respiratory and cardiovascular effects due to occupational exposure; however, no causal links have been established (Sundar and Chakravarty, 2010). Beryllium has been associated with lung disease in workers as a result of inhalation of beryllium particles resulting in sensitization prior to developing chronic beryllium disease (Middelton and Kowalski, 2010). Gallium has been shown to interrupt iron metabolism and influence the immune system, with low blood concentrations (0.001–0.010 μg/L) shown to alter the progression of peripheral blood mononuclear cells in the cell cycle and stimulate the release of cytokines (Chang et al., 2003). At higher concentrations of in vitro gallium exposure apoptosis has been induced, suggesting immunotoxic effects (Chang et al., 2003). Exposure to high levels of silver and silver compounds (>0.1 mg/m^3 in air; > 50 mg/L in water; 0.1–20 μg/L in blood) could result in respiratory problems including breathing, lung or throat irritation, skin problems and stomach aches (ATSDR, 1990a; Drake and Hazelwood, 2005). Strontium has been associated with an increase in breast cancer; women with high urinary concentrations had an increased risk of cancer compared with those in the lowest concentration tertile (OR (95% CI): 2.24 (1.42–3.81) (Chen et al., 2012).

Padilla et al. (2010) used data from NHANES to investigate relationships between biological metals concentrations and obesity. Thallium concentrations were positively associated with BMI and waist circumference. The authors proposed that the potential mechanism by which thallium is linked to obesity is via induction of oxidative stress. Urinary thallium has also been found to be increased in a study of children with autism and those without (Mean ± SD 0.104 ± 0.083 μg/g creatinine and 0.058 ± 0.041 μg/g creatinine, respectively p value <0.05) (Adams et al., 2013). It is unclear whether this is due to other factors such as increased absorption and metabolism, differing exposure or other behavioural factors. Rubidium is generally considered to be non-toxic but there are a few papers that suggest increased concentrations associated with renal and hepatic impacts (Usuda et al., 2014).

Lung and breathing problems as well as cancer (lung and pancreas) have been reported in workers exposed to thorium (ATSDR, 1990b). Vanadium has been associated with irritation and inflammatory responses of the respiratory tract and immunotoxicity responses in occupational studies following inhalation (WHO, 2000). Vanadium has been linked to Parkinson's disease (Ngwa et al., 2013) but is also suggested to have positive therapeutic effects on a range of diseases (Rehder, 2013).

The transition, alkali and alkaline earth metals are being increasingly used in electronics and pharmaceutical applications. As outlined, these metals are also found ubiquitously in the environment with non occupational exposure possible from food, air, soil drinking water and dust exposures. Occupational literature indicates that some of the metals may be associated with health effects. However, there are few data on exposure to these metals in the general or vulnerable populations. We had the opportunity to examine these metals in a cohort of pregnant women to determine exposure concentrations. The aim of this study was to determine the concentrations of the metals in the blood, urine and drinking water of pregnant women residing in Western Australia. Demographic and lifestyle factors associated with the concentrations of these metals were also investigated.

2. Methods

A cross sectional study of persistent toxic substances exposure in non-smoking pregnant women aged greater than 18 years in Western Australia (WA) was undertaken. The study design, samples and recruitment methods are described in Callan et al. (2013). Pregnant women were recruited between 2008 and 2011 from across the state of Western Australia.

One hundred and seventy three women provided a first morning void urine, 172 provided a whole blood sample and a drinking water sample as well as completed a questionnaire about lifestyle and activities as well as residential characteristics and diet. All data were collected approximately two weeks prior to the birth of their baby. The population characteristics, demographic and lifestyle characteristics are shown in Supplementary data Table 1.

2.1. Chemical analysis of samples

Each sample was analysed for antimony, beryllium, bismuth, cesium, gallium, rubidium, silver, strontium, thallium, thorium and vanadium.

The blood, diluted urine and drinking water were analysed using an ICP-MS (Agilent 7500cs-Octopole Reaction Cell, Agilent Technologies, USA) at ChemCentre WA, full analytical procedures including QA/QC, are outlined in Callan et al. (2013).

2.2. Data handling and statistical analysis

Questionnaire data were stored in a Microsoft Access database. Descriptive statistics were generated using Stata software (version 12.1; StataCorp, College Station, TX). Biological and environmental metals concentrations below the Method Detection Limit (MDL) were assigned a value of half the respective MDL (Liu et al., 1997).

Urinary concentrations were adjusted for creatinine and adjusted values were used in the analysis. Creatinine was outside the normal range (<0.3 g/L) for 16 participants who had dilute urine samples, hence, concentrations were only analysed for 157 participants.

Due to the non-normal distribution of metals concentrations, data were transformed to natural logarithms prior to analysis. The