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Maternal exposure to metals—Concentrations and predictors of exposure ☆

A.C. Callan [a,*], A.L. Hinwood [a], M. Ramalingam [a], M. Boyce [a], J. Heyworth [b], P. McCafferty [c], J.Ø. Odland [d]

[a] Centre for Ecosystem Management, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027, Australia
[b] School Population Health, The University of Western Australia, 35 Stirling Highway Crawley, WA 6009, Australia
[c] ChemCentre, PO Box 1250, Bentley, WA 6983, Australia
[d] Department of Community Medicine, University of Tromsø, N-9037 Tromsø, Norway

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ABSTRACT

A variety of metals are important for biological function but have also been shown to impact health at elevated concentrations, whereas others have no known biological function. Pregnant women are a vulnerable population and measures to reduce exposure in this group are important. We undertook a study of maternal exposure to the metals, aluminium, arsenic, copper, cobalt, chromium, lithium, manganese, nickel, selenium, tin, uranium and zinc in 173 participants across Western Australia. Each participant provided a whole blood and urine sample, as well as drinking water, residential soil and dust samples and completed a questionnaire. In general the concentrations of metals in all samples were low with the notable exception of uranium (blood U mean 0.07 μg/L, range < 0.01–0.25 μg/L; urinary U mean 0.018 μg/g creatinine, range < 0.01–0.199 μg/g creatinine). Factors that influenced biological concentrations were consumption of fish which increased urinary arsenic concentrations, hobbies (including mechanics and welding) which increased blood manganese concentrations and iron/folic acid supplement use which was associated with decreased concentrations of aluminium and nickel in urine and manganese in blood. Environmental concentrations of aluminium, copper and lithium were found to influence biological concentrations, but this was not the case for other environmental metals concentrations. Further work is underway to explore the influence of diet on biological metals concentrations in more detail. The high concentrations of uranium require further investigation.

1. Introduction

Individuals may be exposed to metals via drinking water, inhalation of dust, direct contact with, or ingestion of, soil and dietary exposure, in the absence of occupational exposure or specific environmental contamination (Carpenter, 1994). A number of metals are of biological importance, such as copper, cobalt, chromium, manganese, selenium and zinc, with ingestion of appropriate amounts of these metals essential to maintain optimum health (da Silva and Williams, 2001). The biological functions of metals include acting as co-factors in enzyme reactions and playing roles in energy metabolism and other cellular activities (Bertini et al., 2001). For example as well as acting as an enzyme cofactor, manganese is important for bone formation (Zota et al., 2009) and chromium is believed to play a role in glucose homeostasis (Krejpcio, 2001). However, exposure to metals, including those required for biological functions, can cause health impacts if the exposure occurs at a sufficiently high concentration. Metals, such as aluminium, arsenic, nickel, tin and uranium have no known function in humans and exposure to these metals at elevated concentrations can result in health impacts including allergic reactions and skin lesions, gastrointestinal impacts, cardiovascular effects and impaired kidney function (Zamora et al., 1998; Barceloux, 1999; Abernathy et al., 2003). Lithium is used therapeutically in the treatment of bipolar disorders and has a narrow therapeutic range (Grandjean and Aubry, 2009). Treatment with lithium, as well as exposure to the metal via drinking water and other environmental sources, is associated with adverse health outcomes including effects on thyroid function (Grandjean and Aubry, 2009; Broberg et al., 2011).

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This project obtained Human Research Ethics Committee Approval from Edith Cowan University (#2020), WA Country Health Service (# 2008:16), St John of God Health Care (#389), Joondalup Health Campus (#1007) and King Edward Memorial Hospital for Women (#1815/EW 06.07.10).

* Corresponding author. Present address: School of Medical Sciences, Edith Cowan University, 270 Joondalup Drive, Joondalup 6027, Western Australia. Fax: +61 8 6304 5509.
E-mail address: a.callan@ecu.edu.au (A.C. Callan).

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Pregnant women are considered a vulnerable group in terms of exposure as many metals, including those with no known biological importance, are able to cross the placental barrier readily (Concha et al., 1998; Iyengar and Rapp 2001; Rudge et al., 2009). They may have health impacts on the developing foetus, as they have affinity for the same ligands and transporters used by essential metals (Golub and Domingo, 1996; Ballatori, 2002; Krewski et al., 2007; Vahter, 2009). Foetal development is seen as a specific window of vulnerability. The effects of prenatal exposure to lead and mercury have been well established (Bellinger et al., 1987; Grandjean et al., 1997), however more recently prenatal exposure to other metals have also been associated with a number of adverse health outcomes such as reduced birth weight and neurodevelopmental effects in the child including impaired cognitive abilities and disinhibited behaviour (Takser et al., 2003; Ericson et al., 2007; Vahter, 2009).

It is therefore important to assess the nature and degree of exposure in pregnant women as a surrogate of exposure to the unborn child. The paucity of data on prenatal metals exposure in Australia and the potential health impacts of prenatal metals exposure led to this study investigating metals exposure, and the factors influencing metals exposure, in non-smoking pregnant women using biological and environmental samples and questionnaire data. The focus of this paper is on the metals aluminium, arsenic, cobalt, copper, chromium, lithium, manganese, nickel, selenium, tin, uranium and zinc.

2. Materials and methods

2.1. Study design

The Australian Maternal Exposure to Toxic Substances (AMETS) study was a cross sectional study of metals exposure in non smoking pregnant women aged greater than18 years in Western Australia. Participants provided a sample of blood and urine as well as samples of residential soil, dust and drinking water and completed a questionnaire. Ethics approval was obtained for this study from Edith Cowan University Human Research Ethics Committee, WA Country Health Service, St John of God Health Care (Subiaco and Bunbury), Joondalup Health Campus and King Edward Memorial Hospital. All participants provided written informed consent.

2.2. Study population

Non smoking participants were recruited from across the State in and around the towns of Esperance, Albany, Bunbury, Busselton, Margaret River/Dunsborough, Bridgetown/Nannup, Collie, Geraldton, Port Hedland, Kalgoorlie and Perth between 2008 and 2011.

2.3. Recruitment

Recruitment was undertaken by approaching GPs and community health centres and attending antenatal classes to advertise the study and interest potential participants. In addition, advertisements through local community groups, organisations and newspapers were placed requesting volunteers to contact researchers. Information was also provided at shopping centres, farmers' markets, local events and inclusion in local media. Of 363 women who initially enrolled in the study, 173 (48%) completed all the required protocols including the provision of biological and environmental samples The final number of participants represents less than 1% of the target population over the time period of the study.

2.4. Data collection

Each participant was asked to provide a sample of blood, first morning void urine, drinking water, residential soil and dust samples. Sample packs with instructions were sent out to all participants.

All samples were collected approximately 2 weeks prior to birth. If a baby arrived early, participants were asked to provide samples up to a week after birth if they felt they were in a position to do so. Only two participants provided blood and urine samples post-partum. All samples were collected between 2008 and 2011.

2.4.1. Questionnaire

Participants completed a questionnaire that focused on demographic and lifestyle information and included questions relating to activities that may increase metals exposure, including a food frequency component. Information was sought on maternal age, maternal and paternal occupations, socioeconomic variables, housing variables, details relating to medical conditions and history, smoking habits and diet. Participants were also asked to report any hobbies that they participated in, or that other family members undertook at their home.

2.4.2. Blood sample

Participants presented at Pathwest (Health Department WA) blood collection centres. Whole blood samples were collected using the established vacutainer technique into 6 mL NH Trace Elements Sodium Heparin vacuettes. Blood samples were then sent directly to the Perth collection centre within 24 h and were frozen at $-20\ ^{\circ}C$.

2.4.3. Urine sample

Pre-labelled 60 mL polyethylene urine containers were provided to each participant to collect a first morning void mid-stream urine sample on the day of blood collection. Urine samples were directly frozen at $-20\ ^{\circ}C$.

2.4.4. Drinking water sample

Each participant provided a 500 mL drinking water sample from the most common source at their home. Each 500 mL container was acid washed in 2% nitric acid by research staff prior to collection of drinking water samples. Drinking water samples were directly frozen at $-20\ ^{\circ}C$.

2.4.5. Soil and dust samples

Each participant was provided with labelled plastic bags to collect a residential soil sample and a dust sample. Participants were asked to sample a minimum of four bare areas of soil on their property and combine into the soil sample bag provided. Dust samples were collected by participants by emptying the contents of their vacuum cleaners into the plastic bag provided.

2.5. Sample preparation

2.5.1. Blood

Frozen blood samples were thawed to room temperature and 1.0 g was weighed and prepared for microwave digestion using high purity concentrated nitric acid (HNO_3) and hydrochloric acid were inserted into the teflon reaction vessel. The digestion vessels were then filled 10 mL of 1:1 HNO_3, capped and digested using European Standard 1380:2002 method in a (1000 W) 'Milestone Ethos Touch Control Microwave' (supplied by Milestone, Italy). The clear blood digestate was quantitatively transferred into a 2% HNO_3 rinsed disposable centrifuge tube and diluted with milli-Q ($>18\ M\Omega\ cm$) for measurement.

2.5.2. Urine

The preparation of urine for analysis of metals analysis was undertaken using APHA method 3114B and method 3120B (APHA, 1998). The urine samples were thawed to room temperature, homogenised (vigorous shaking) and diluted with 1% HNO_3 and 0.5% HCl. Creatinine was measured using a discrete analyser (Labmedics/Thermo Fisher Aquakem 250).

2.5.3. Drinking water

Acidified (1% HNO_3) drinking water samples were brought to room temperature and analysed directly by inductively coupled plasma mass spectrometry (ICP-MS).

2.5.4. Soil

Soil samples, delivered in individual plastic bags, were mixed thoroughly by hand. They were then air dried in the laboratory for two days. At room temperature, the dried samples were shaken separately in a closed sifting pan before being passed through a sieve size of 1.0 mm meshes. Large and unwanted substances were removed either by hand or captured via sieving. The sieved soil was then split into subsamples using an open chute riffle splitter. Each soil sample was mixed several times in the splitter device before an adequate homogenous sample was extracted for metal analysis. Approximately 1 g of soil accurately weighed to 4 decimal places was placed into a clean beaker for digestion. To minimise cross contamination between samples, the sieves were cleaned with a brush and fresh paper tissue, after each step of sample sieving and when necessary rinsed with acetone. The splitter device was cleaned in between each sample using a high pressure air hose.

2.5.5. Dust

Preparation of the dust samples was similar to soils except that a smaller size of 0.6 mm mesh sieve was used for the removal of large non-dust material and to