Chemosphere 202 (2018) 48–55

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Lead and cadmium excretion in feces and urine of children from polluted townships near a lead-zinc mine in Kabwe, Zambia

John Yabe [a], Shouta M.M. Nakayama [b], Yoshinori Ikenaka [b], Yared B. Yohannes [b], Nesta Bortey-Sam [b], Abel Nketani Kabalo [c], John Ntapisha [c], Hazuki Mizukawa [b], Takashi Umemura [b], Mayumi Ishizuka [b,*]

[a] The University of Zambia, School of Veterinary Medicine, P.O. Box 32379, Lusaka, Zambia
[b] Graduate School of Veterinary Medicine, Hokkaido University, Kita 18, Nishi 9, Kita-ku, Sapporo 060-0818, Japan
[c] Ministry of Health, District Health Office, P.O. Box 80735, Kabwe, Zambia

HIGHLIGHTS

- We measured lead and cadmium excretion levels in children near a Pb-Zn mine in Zambia.
- Fecal and urine Pb levels up to 2252 mg/kg and 2914 μg/L, respectively, were very high.
- Cd in fecal (up to 4.49 mg/kg) and urine (up to 18.1 μg/L) samples were elevated.
- Positive correlations were observed between fecal and urinary levels of Pb and Cd.
- Children living near the Pb-Zn mine are at serious risks of Pb and Cd poisoning.

ARTICLE INFO

Article history:
Available online 12 March 2018

Handling Editor: Martine Leermakers

Keywords:
Lead
Cadmium
Excretion
Children's health
Kabwe
Zambia

ABSTRACT

Lead (Pb) and cadmium (Cd) are toxic metals that exist ubiquitously in the environment. Children in polluted areas are particularly vulnerable to metal exposure, where clinical signs and symptoms could be nonspecific. Absorbed metals are excreted primarily in urine and reflect exposure from all sources. We analyzed Pb and Cd concentrations in blood, feces and urine of children from polluted townships near a lead-zinc mine in Kabwe, Zambia, to determine concurrent childhood exposure to the metals. Moreover, the study determined the Pb and Cd relationships among urine, feces and blood as well as accessed the potential of urine and fecal analysis for biomonitoring of Pb and Cd exposure in children. Fecal Pb (up to 2252 mg/kg, dry weight) and urine Pb (up to 2914 μg/L) were extremely high. Concentrations of Cd in blood (Cd-B) of up to 7.7 μg/L, fecal (up to 4.49 mg/kg, dry weight) and urine (up to 18.1 μg/L) samples were elevated. metal levels were higher in younger children (0–3 years old) than older children (4–7). Positive correlations were recorded for Pb and Cd among blood, urine and fecal samples whereas negative correlations were recorded with age. These findings indicate children are exposed to both metals at their current home environment. Moreover, urine and feces could be useful for biomonitoring of metals due to their strong relationships with blood levels. There is need to conduct a clinical evaluation of the affected children to fully appreciate the health impact of these metal exposure.

1. Introduction

Lead (Pb) and cadmium (Cd) are ubiquitous environmental toxicants as a result of contamination from a variety of sources including natural and anthropogenic causes. Children in polluted environments are particularly vulnerable to Pb exposure because of their inclination to ingest soil through pica and to assimilate a relatively greater amount of ingested Pb than adults (Calabrese et al., 1997, Manton et al., 2000; Caravanos et al., 2013). The detrimental effects of low blood lead levels (BLLs) are usually subclinical and may include neurodevelopmental impairment such as decreased IQ in children (Canfield et al., 2003). It has been observed that high BLLs in children can cause abdominal pain, encephalopathy, convulsions, coma and death (Needleman, 2004). Recently,

* Corresponding author.
E-mail address: ishizum@vetmed.hokudai.ac.jp (M. Ishizuka).

https://doi.org/10.1016/j.chemosphere.2018.03.079
0045-6535/

more than 400 children died of Pb poisoning due to artisanal mining activities in Nigeria, where long-term neurological impairment including blindness and deafness were also recorded (Pure Earth, 2014; Dooyema et al., 2012; Lo et al., 2012).

Similarly, Cd toxicity results in a wide range of biochemical and physiological dysfunctions in humans (Ercal et al., 2001). One of the most severe forms of chronic Cd toxicity is *itai itai* disease (a Japanese term meaning "ouch-ouch"), which is characterized by nephrotoxicity, osteoporosis and cardiovascular diseases (Kido et al., 1990; Uno et al., 2005). Cadmium has also been classified as a group I carcinogen as chronic inhalation exposure can produce lung cancer in humans (IARC, 1993). Although the toxic effects of Cd are mainly seen in adults (Kido et al., 1990; Umemura, 2000), exposure to children in even low amounts has associated with neurodevelopmental defects (Ciesielski et al., 2012). Moreover, exposure may have long-term consequences since Cd is a cumulative toxin and has a very long half time in the body.

Major sources of Pb and Cd pollution in many African countries include mining, industrial activities, municipal wastes and agricultural activities (Yabe et al., 2010). In Zambia, the closed Pb-Zn mine that operated from 1902 to 1994 in Kabwe town has contributed to extensive metal pollution in the surrounding residential areas, especially with Pb and Cd that was produced as by-product. Despite closure of the mine, dust emanating from the mine dumps has continued to serve as a source of metal pollution. In earlier studies, extensive Pb and Cd contamination of township soils in the vicinity of the mine were reported and pose a serious health risk to children in these townships (Water Management Consultants Ltd, 2006; Nakayama et al., 2011). Recently, clear evidence of Pb poisoning was reported in children from townships around the mine in Kabwe (Yabe et al., 2015). Using stable Pb isotope analysis, Nakata et al. (2016) revealed that soil was likely the main source of Pb exposure in Kabwe.

Clinical presentations of metal poisoning vary widely depending upon the age at exposure, the amount of exposure and the duration of exposure. Since chronic Pb poisoning in children is asymptomatic and may result in a delay in the appropriate diagnosis, measurement of concentrations in biological samples plays a pivotal role in the diagnosis and management of patients (Lowry, 2010). Currently, Pb concentration in whole blood (Pb-B) is the main biomarker used to monitor exposure and has been widely used in epidemiological studies (CDC, 2012). However, independent of the mode of exposure, absorbed metals such as Pb and Cd are excreted primarily in urine and the biliary-fecal route (Gwiazda et al., 2005; Swaran and Vidhu, 2010). Therefore, Pb and Cd biomonitoring using fecal and urine samples could be useful as they are easy to collect and are non-invasive. Moreover, whereas blood Cd (Cd-B) is the most common marker of recent exposure, urinary Cd (Cd-U) may reflect the kidney burden and is associated with renal health effects (Akerstrom et al., 2013). Evaluating relationships of Pb and Cd among blood, urine and fecal compartments may be useful for understanding exposure patterns. Therefore, the current study measured Pb and Cd concentrations in blood, feces and urine of children with known BLLs (Yabe et al., 2015), from contaminated townships in the vicinity of a Pb-Zn mine in Kabwe, Zambia to determine concurrent childhood exposure. Moreover, the study analysed Pb and Cd relationships in matched feces, urine and blood as well as accessed the potential of urine and fecal analysis for biomonitoring of Pb and Cd exposure in children.

2. Materials and methods

2.1. Sampling sites

Kabwe town, the fourth largest town and the provincial capital of Zambia's Central Province, is located at about 28°26′E and 14°27′S. Kabwe has a long history of open-pit Pb-Zn mining. The mine operated almost continuously from 1902 to 1994 without addressing the potential risks of metal pollution. Cadmium was obtained as a by-product of processing zinc-containing ores. As shown in the survey by Water Management Consultants Ltd (2006), soils in townships in the vicinity of the closed mine and homes downwind from the mine dumps were highly polluted with Pb exceeding acceptable levels for residential areas (Fig. 1). In the current study, fecal and urine samples were collected from children at health centers located in Chowa, Kasanda and Makukulu townships, in May–June of 2012. Matched samples were collected from the same children and townships where extremely high levels of Pb-B were reported by Yabe et al. (2015). More details about the study site and township description, which are in the vicinity of the mine can be obtained from the previous study (Yabe et al., 2015).

2.2. Sample collection

The study was approved by the University of Zambia Research Ethics Committee (UNZAREC) and the Ministry of Health, Zambia. Before sampling commenced, an awareness campaign about the research activities was conducted by community health workers in each township to encourage parents/guardians to take their children under the age of 7 to the selected health centres for sample collection. After informed and written consent was obtained from the children's parents or guardians, paired fecal and urine (morning spot-urine) samples were collected in clean metal-free specimen containers at Chowa, Kasanda and Makululu clinics. Blood samples were collected as described earlier by Yabe et al. (2015). For each child, data on the age, sex, residential area, medical history and past or current metal chelation therapy were recorded. Sample collection and questionnaire administration were done by laboratory technicians and nurses, respectively. In addition to selecting children under the age of 7 years, other inclusion criteria included children that were residing in communities in the vicinity of the Pb-Zn mine. The children must have been born or resided in the selected communities for at least 1 year. Only the children whose parents responded to the awareness campaign and signed the informed consent were selected. Efforts were made to collect urine samples in 50 ml urine containers in the morning of sample collection at the health centres. To avoid sample contamination, all sample collection supplies were kept in plastic ziploc storage bags

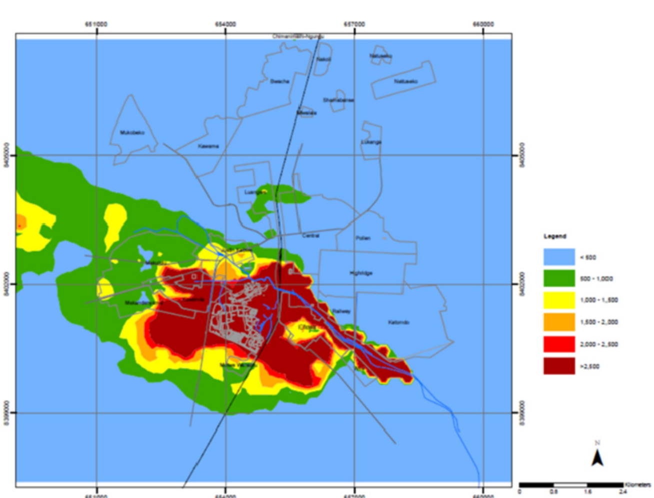

Fig. 1. Map of Kabwe showing distribution of Pb (mg/kg) in township soils around the Pb-Zn mining complex (Water Management Consultants Ltd, 2006).