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Assessment of dietary cadmium exposure: A cross-sectional study in rural areas of south China

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ABSTRACT

Individuals exposed to cadmium (Cd) polluted areas and/or Cd-polluted foods are at risk of renal dysfunction. To evaluate the pollution level and exposure assessment of Cd in rural areas of south China, 753 subjects, aged 45–75 years with foods cultivated from their own lands, were randomly selected. According to the dietary survey, the major foods included rice and vegetables. Our results showed that the median Cd concentrations of these foods were 0.33 and 0.08 mg/kg, respectively. The Cd concentrations of rice and vegetables samples were 65.31% and 23.75% higher than the Chinese Hygienic Standard. The median values of daily Cd intake were 0.11 and 0.03 mg/day in rice and vegetables. The average estimated lifetime exposure values were 303.57 mg in polluted-area and 44.70 mg in control-area, respectively. The total monthly Cd exposure was 70.98 μg/kg b.w. in the polluted area, in which rice was the most important food category, contributing to 77.49% of the total exposure. The results indicate the high risks of living nearby the mining district for a long time.

1. Introduction

Cadmium (Cd) is a toxic heavy metal found in contaminated food, drinking water and soils, and is associated with adverse health effects due to its long biological half-life (10–30 years) (Gunnar, Bruce, & Monica, 2014; Järup, 2003). Due to geochemical factors and insufficient industrialization, Cd contamination status in soil and environment has been increasingly severe (Faroon, Ashizawa, & Wright, 2012; Järup & Åkesson, 2009). Compared with other heavy metals, Cd in the soil and environment can be absorbed easily by plants (Cheng & Huang, 2007; Verma, George, Singh, & Singh, 2007), and then accumulated in human body through food chain. Cd accumulation in body causes sustained toxic effects and serious health injury, such as skeletal damage, neurotoxic effects and nephrotoxicity (Åkesson et al., 2006; Järup & Alfvén, 2004; Satarug, Garrett, Sens, & Sens, 2011).

Food crops grown on Cd-polluted soils or on soils naturally rich in Cd constitute the major source of non-workplace exposure. The metal residues data together with national nutritional survey, total diet study, food consumption survey, and household consumption survey were the most popular databases used in deriving the estimates of national Cd exposure (Soisungwan et al., 2003). The recent provisional tolerable monthly intake (PTMI) for Cd of 25 μg/kg b.w. established by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) (WHO, 2010), has been widely used as health-based guidance for Cd risk assessment in diet.

The environmental Cd exposure assessment was mostly conducted in the foreign countries. Japan, famous for its "Itai–itai"

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disease of 1950s, has conducted several population studies on Cd exposure (Nogawa, Kobayashi, Okubo, & Suwazono, 2004; Osawa et al., 2001). The dietary route was an almost exclusive route of Cd uptake, of which Cd in rice (11.7 μg/day) contributed about 40% of the total dietary intake (Watanabe et al., 2000). In extremely polluted areas of Australia, the Cd exposure level was reported at an estimated 93.50 μg/day (Satarug et al., 2003). A recent report of the European Food Safety Authority concluded that across Europe the average dietary intake of Cd in adults ranges between 1.90 and 3.00 μg/kg b.w. per week, and even 2.50–3.90 μg/kg b.w. per week in highly exposed adults (EFSA, 2009).

Rice and vegetables serve as the staple food in south China. A previous study reported that the dietary intake of Cd through contaminated rice consumption was calculated at 2.20 and 1.50 μg/kg b.w. per day for a 60-kg adult and 40-kg child, respectively, in northern Guangdong province (Yang, Lan, Wang, Zhuang, & Shu, 2006). Another study reported all Cd concentrations of fruits exceeding the tolerance limit of Cd in fruits (0.05 mg/kg) in Guangzhou, China (Li et al., 2006). However, few studies focused on the properties, distribution and chronic exposure assessment of Cd in the non-occupational exposure among residents in south China.

Cd distribution in south China is uneven, and due to historical reasons, certain areas were the major sources of pollution. In this article, a detailed dietary exposure assessment of Cd was performed in a specific environmental polluted area of south China. The objectives were (1) to determine the pollution characteristics and contamination levels in food samples; and (2) to provide a refined exposure assessment associated with dietary Cd.

2. Materials and methods

2.1. Participants and samples

In the geochemical map of Cd distribution in China, Cd level in soil was high in northern Guangdong, which had been mined and smelted in history. It had been reported that Cd level may be at a high level in these areas (Wang et al., 2012; Yang et al., 2011). According to the results of food safety surveillance study on Cd in rice and survey on Cd concentrations in soil in Guangdong Province, the areas with mean Cd concentrations >0.15 mg/kg in rice and >0.5 mg/kg in soil were chosen as the Cd-polluted area, and those with Cd concentrations <0.10 mg/kg in rice and <0.19 mg/kg in soil were chosen as the control-area. The lifestyle and habits of the residents living in the control-area were similar with those in the polluted-area, although they were 200 km apart for the geographic locations.

All of the 753 subjects (513 from Cd-polluted areas and 240 from control-areas, aged 45–75 years, gender parity) included in this study were randomly recruited. All foods they consumed were cultivated from their own lands. Each participant in the present study was required to answer a health questionnaire (including questions on diet, present and previous places of residence, occupation, health condition, *etc.*), 24-h dietary recall survey in continuous three days (including the food types, food consumption, *etc.*) and food frequency questionnaires in a year. All the questionnaires used in this survey were from the normalized texts that were widely used in Europe recently (Kirkpatrick et al., 2014; Toobert et al., 2011). All the information was obtained by our investigators going door to door for each participant, and then double input into computer with the EpiData software by two professionals. Data from the questionnaires were further used to calculate the average daily food consumption of each participant. All participants in this study provided written informed consent.

Food samples (470 raw rice samples and 417 raw vegetable samples) were collected from the local households of the study participants according to dietary survey, and Cd concentrations were tested to assess human exposure to Cd through diet. All the samples were collected and stored in sealed polythene bags and quickly sent to the laboratory and frozen at −4 °C until analysis.

2.2. Chemical analysis

HNO_3 (65%, with the purity of ppb level) and H_2O_2 (guaranteed reagent) were both purchased from Merck company (German), and deionized water was obtained from a Milli-Q water purification system (Millipore, USA). Cd standard solution (1000 mg/L, GSB04-1713-2004), Cd reference material for rice flour (GBW08510), and spinach powder (GBW10015) were all supported by National Research Center for Certified Reference Material (China).

The concentrations of Cd in all the collected food samples were determined by inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7700x, Agilent Technologies, USA) after closed-vessel microwave digestion procedures. Briefly, 0.50 g rice sample or 1.00 g raw vegetable was accurately weight into a polyethylene bottle, filled with 6 mL HNO_3 and 2 mL H_2O_2 solution overnight, digested at 150 °C for 4 h and then restored at room temperature. Evaporated to nearly 1.00 mL, and diluted to 50.00 mL with water, and then analyzed by ICP-MS.

Strict quality control procedures were conducted as follows: a solution blank and two reference material samples were run in each batch to check for contamination, peak identification, and accurate quantification; a standard solution and a reference material sample were inserted after every 20 samples during the instrumental analysis; and a paralleled sample was assayed after every 10 samples in order to evaluate the reproducibility of the method.

2.3. Food consumption and exposure assessment

Food categories were clustered into 8 species (rice, flour products, vegetables, meat, fish, eggs, beans and water). Food consumption of each resident was calculated according to their 24-h dietary recall in continuous three days survey results.

The dietary Cd exposure for each individual was adjusted monthly according to their body weight, I_i (μg/kg b.w./month), and used as a chronic exposure assessment model. It was calculated as follows (Sand & Becker, 2012):

$$I_i = 30 \times \frac{\sum_{i=1}^{g} copt_{ij} \times conc_j}{bw_i} \tag{1}$$

where g is the number of food categories; $copt_{ij}$ is the i'th individuals (average) consumption of food category j (g/day); $conc_j$ is the mean Cd contamination level of food category j (mg/kg); and $b.w._i$ is the reported body weight for the i'th individual (kg b.w.). The value of $\sum_{i=1}^{g} copt_{ij} \times conc_j$ was defined as daily Cd intake for different food categories. Monthly Cd exposure level for individuals was compared with the PTMI (25 μg/kg b.w./month) established by the JECFA (WHO, 2010) to estimate the exposure assessment.

The estimated lifetime exposure (LE) was used in the carcinogenic risk assessment, and was calculated as follows:

$$LE_i = \frac{conc_i \times copt_i \times f \times 365 \times age_i \times abt}{cont} \tag{2}$$

where *conc* represents the Cd level of rice (mg/kg); *copt* is a measure of rice consumption (kg/day); f is the age coefficient, the f values of individuals aged 20–60 years and ≥60 years are 1.00 and 0.82, respectively; *age* is the age of the individuals (year); *abt* denotes the gastrointestinal absorption coefficient through food con-