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# Blood lead and cadmium levels and relevant factors among children from an e-waste recycling town in China

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ABSTRACT

*Background:* Primitive electronic waste (e-waste) recycling is ongoing in Guiyu, and thus toxic heavy metals may keep on threatening to the health of local children. Some related factors may contribute to the elevation of blood lead levels (BLLs) or blood cadmium levels (BCLs).
*Objective:* To investigate the children's BLLs and BCLs in Guiyu and Chendian as compare to discuss the effects of primitive e-waste recycling activities on children's health.
*Methods:* Two hundred and seventy-eight children less than 8 years who lived in Guiyu and Chendian were observed, and their BLLs and BCLs were determined by graphite atomizer absorption spectrophotometer. Questionnaire survey for risk factors was also performed and data were analyzed using spearman correlation analyses and logistic regression analyses.
*Results:* Children living in Guiyu had significantly higher BLLs and BCLs as compared with those living in Chendian ($p<0.01$). In Guiyu, 70.8% of children (109/154) had BLLs $>10\,\mu g/dL$, and 20.1% of children (31/154) had BCLs $>2\,\mu g/L$, compared with 38.7% of children (48/124) had BLLs $>10\,\mu g/dL$ and 7.3% of children (9/124) had BCLs $>2\,\mu g/L$ in Chendian ($p<0.01$, respectively). We also observed a significant increasing trend in BLLs with increasing age in Guiyu ($p<0.01$). Mean height of children in Guiyu was significantly lower than that in Chendian ($p<0.01$). The risk factors related to children's BLLs and BCLs mainly included father's engagement in the work related to e-waste, children's residence in Guiyu and the amount of time that children played outside near the road everyday.
*Conclusions:* There are close relationships between the BLLs, BCLs in children and the primitive e-waste recycling activities in Guiyu. Environmental pollution, especially lead pollution, has threatened the health of children living around e-waste recycling site.



## 1. Introduction

Electronic waste (e-waste) includes end-of-life electronic products such as computers, printers, photocopy machines, television sets, mobile phones, and toys that are composed of sophisticated blends of plastics, metals, and other materials. With today's technologically advancing societies and the demand for newer, more efficient, and effective technology, older and outdated electronic items become obsolete and are discarded in significant amounts. Thus, e-waste has become one of the fastest growing waste types around the world. While some e-waste is treated at its origin, some is illegally exported to other developing countries for recycling and disposal (Puckett et al., 2002). Guiyu, situated in Shantou, Guangdong province of south China, is a popular e-waste destination, and has nearly 20 years e-waste unregulated disposal history.

Nearly 60–80% of families in Guiyu are engaged in e-waste recycling operations. These primitive family-run recycling centers use methods such as sorting, firing, incineration, acidic and alkaline baths, manual assembly, open burning of wires and cables, and strong acid leaching. These operations are usually carried out with no or very little personal protection equipment or pollution control measures. In open burning of materials, fly ash particulates laden with heavy metals and other toxic materials are usually emitted, resulting in increased human exposure, contamination of food, soil, and surface water. Several studies have reported the soaring levels of toxic heavy metals and organic contaminants in workplace environment, surrounding soil and water sources of Guiyu (Brigden et al., 2005; Deng et al., 2007; Li et al., 2007; Leung et al., 2007; Luo et al., 2007; Puckett et al., 2002; Wang and Guo, 2006; Wong et al., 2007; Yu et al., 2006).

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Lead and cadmium were widely used in electronic devices, for example, lead was used as a major component of solders and lead oxide in the glass of cathode ray tubes (televisions and monitors), while in lead-acid batteries and in some PVC cables as stabilizers. Lead can build up in body through repeated exposures and have irreversible effects on the nervous system, particularly the developing nervous system in children (Brigden et al., 2005). Cadmium was used in electronics in some switches and solder joints, and as cadmium compounds in rechargeable batteries, UV stabilizers in older PVC cables and "phosphor" coatings in older cathode ray tubes. Same as lead, cadmium can accumulate in the body, causing damage to the kidneys and bone structure through long-term exposure (Akesson et al., 2005; Blumenthal et al., 1995; Järup et al., 2000). Cadmium and its compounds are known human carcinogens, primarily through inhalation of contaminated fumes and dusts (Shaham et al., 1996). Therefore, the body's lead or cadmium levels and their effects on children's health have become one of the important environmental health problems.

Considering the potential heavy metal contamination in the local living environment of Guiyu, we conducted a study to determine the blood lead levels (BLLs) of local children in 2004, and the result showed that 81.8% of children aged 1–6 years had high lead content in their blood (Huo et al., 2007). In order to evaluate the BLLs again and also blood cadmium levels (BCLs) together in children aged 1–7 years and some related risk factors for BLLs and BCLs, blood samples were collected and questionnaire surveys were performed from May to June in 2006.

## 2. Materials and methods

### 2.1. Subjects

Native children aged 1–7 years old in kindergartens were chosen in this study. One hundred and fifty-four children with a mean age of 5.1 years living in the three villages of Guiyu were selected as subjects. Simultaneously, we selected 124 children with a mean age of 4.6 years from neighboring town, Chendian, as a control for comparison because the local residents's work is mainly clothing manufacturing industry, not relate to e-wastes processing. The population, traffic density, cultural background, lifestyle, and socioeconomic status were very similar to each other in these two towns. After informed consents were obtained from their parents or guardians, venous blood samples were collected and physical indices were measured from children. Questionnaires were administered to parents. This study was approved by the Human Ethics Committee of Shantou University Medical College.

### 2.2. Blood sample collection and assay

All plastic tubes (Shenzhen Paka Plastic Packaging Co. Ltd., Guangdong, China) for blood collection were washed thoroughly, soaked with dilute nitric acid, and rinsed with deionized water before using. Blood samples were obtained from each volunteer at their kindergartens, collected by trained nurses and then stored at a −20 °C refrigerator with heparin as anticoagulant. Lead and cadmium in total blood was determined in Central Laboratory of Shantou University Medical College by graphite furnace atomic absorption spectrometry (GFAAS), which consisted of a Shimadzu AA-660 AAS and a GFA-4B graphite furnace atomizer and an ASC-60G autosampler (Shimadzu Corporation, Kyoto, Japan), with an injection volume set at 10 μl. The main parameters used for lead determination were a wavelength of 283.3 nm, a lamp current of 8 mA, a slit width of 1.00 nm, drying at 150 °C, ashing at 325 °C, and atomization at 1400 °C. The accuracy of the method was controlled by recoveries between 95% and 107% from the spiked blood samples. The parameters for cadmium analysis were a wavelength of 228.8 nm, a current of 8 mA, a slit width of 1.00 nm, drying at 150 °C, ashing at 350 °C, and atomization at 1500 °C. The recoveries of this method were 100–102%, which were also from spiked blood samples. We determined hemoglobin (Hgb) levels by hemoglobin cyanide (HiCN) method with Blood Cell Analyzer (LH-750, Beckman-Coulter, USA).

### 2.3. Evaluation of physical development indices

Children's physical growth and development, such as height, weight, head, and chest circumferences were measured before blood samples were collected. Weight and height were measured using a weighing and height scale (TZ120, Yuyao Balance Instrument Factory, Yuyao, China) with maximum weight of 120 kg (minimum scale: 50 g) and minimum height of 70 cm (minimum scale: 0.1 cm). Children were required to fast, urination, and take off shoes when were checked. Head and chest circumferences were measured using uniform flexible rulers (Shanghai Medical Instrument Co., Ltd., Shanghai, China; minimum scale: 0.1 cm). All the works were carried out by the same trained study members.

### 2.4. Questionnaire survey

Self-designed questionnaire was used to conduct a survey to parents or guardians. The questionnaire involved 25 items of factors that might influence children's BLLs or BCLs, including the house dwelling, their parent's education, jobs, social status and hobby, children's behavior habit (frequency of hand-to-mouth activity), dieting habit and nutritional condition, and so forth. Each question has four to six scaled answers. Parents's education was defined from illiteracy to undergraduate. The jobs that parents engaged were classified by their relation to e-waste recycling (e.g., other business, transporting e-waste, selecting e-waste, splitting e-waste, acid baths, and burning to recover metals).

### 2.5. Statistical analyses

Independent-sample *t*-tests or covariance analyses were used to determine the differences between the comparison groups, and non-parametric analyses were used for data with skew distributions. *P*-values were calculated using Chi-square test for categorical data. Spearman rank correlation analysis was used to evaluate the relationships between BLLs and some physical indices. BLLs or BCLs were taken as dependent variables and the investigated 25 items with self-designed questionnaire as independent variables; the correlations between them were also performed with Spearman rank correlation analysis. The data of blood lead or cadmium concentration were divided into two groups: high-level group and low-level group taking 10 μg/dL as the boundary for BLLs and 2 μg/L as the boundary for BCLs, respectively. To explore some risk or protective factors for high BLLs and BCLs, logistic regression analyses were used for further discussion. All the analyses were conducted with SPSS statistical software version 13.0 (SPSS, Inc., Chicago, IL, USA). The level of significance was set at 0.05.

## 3. Results

### 3.1. BLLs in children

#### 3.1.1. Children's BLLs

According to the diagnostic criteria about children's BLLs that was defined by the US Centers for Disease Control (CDC, 1991), children had BLLs $\geqslant$10.0 μg/dL were considered as elevated BLLs. We collected blood samples for BLLs analyses among 154 children from Guiyu and 124 children from Chendian. The BLLs corresponded to the children's residence, controlling for age and sex. Table 1 shows that the BLLs in Guiyu children were significantly higher than those in Chendian children (covariates with age, $p<0.01$). Among Guiyu children, 70.8% of them (109/154) had BLLs greater than 10.0 μg/dL, compared with 38.7% of Chendian children (48/124) had elevated BLLs ($p<0.001$). The proportion of children with BLLs greater than 20 μg/dL was 10.4% in Guiyu, and 4.8% in Chendian, respectively, but BLLs greater than 45 μg/dL was not found in both groups. The BLLs and the rate of BLLs greater than 10.0 μg/dL in Guiyu were increased with age, older children tended to have higher BLLs than younger ones. We also found that the BLLs of children aged 5, 6, and 7 years in Guiyu were significantly higher than those in Chendian (all $p<0.01$), but no significant differences could be found between male and female in Guiyu and Chendian (both $p>0.05$).

#### 3.1.2. Effects of BLLs on children's physical indices and Hgb concentrations

The relationships between BLLs and height, weight, Hgb, head, and chest circumferences were evaluated by spearman correlation analyses, and no significant difference was found (all $p>0.05$). Even after stratified by age and sex, there was yet not significant difference.

**Table 1**
Children's BLLs ($\mu$g/dL) in Guiyu and Chendian

| | Guiyu | | | | Chendian | | | |
|---|---|---|---|---|---|---|---|---|
| | $n$ | Range | $\bar{x} \pm s$ | $\geqslant 10\,\mu$g/dL, $n$ (%) | $n$ | Range | $\bar{x} \pm s$ | $\geqslant 10\,\mu$g/dL, $n$ (%) |
| Total | 154 | 4.14–37.78 | 13.17±5.98[a] | 109 (70.8)[b] | 124 | 2.20–24.96 | 10.04±4.85 | 48 (38.7) |
| Age (years) | | | | | | | | |
| 1 | 14 | 4.85–16.01 | 9.89±3.83 | 5 (35.7) | 26 | 2.20–18.67 | 8.35±4.40 | 9 (34.6) |
| 4 | 28 | 4.14–19.83 | 11.41±3.88 | 16 (57.1) | 32 | 3.89–24.96 | 10.76±5.04 | 22 (46.9) |
| 5 | 39 | 4.74–23.31 | 12.73±4.64 | 27 (69.2) | 37 | 4.25–24.78 | 9.69±5.10 | 12 (32.4) |
| 6 | 57 | 5.02–37.78 | 14.87±7.23 | 45 (78.9) | 26 | 3.54–21.83 | 9.86±4.86 | 10 (38.5) |
| 7–8 | 16 | 7.70–27.78 | 16.72±5.94 | 14 (87.5) | 3 | 6.73–10.98 | 9.29±2.26 | 2 (66.7) |
| Sex | | | | | | | | |
| Male | 81 | 4.14–37.78 | 13.60±5.94 | 57 (70.4) | 71 | 2.20–24.78 | 9.91±4.78 | 31 (43.6) |
| Female | 73 | 4.85–33.33 | 12.99±6.17 | 50 (68.5) | 53 | 2.53–24.96 | 9.45±4.97 | 17 (32.1) |

[a] Compare with Chendian group using covariance analysis with age: $F = 31.53$, $p < 0.01$.
[b] Compare with Chendian group using Chi-square test: $\chi^2 = 26.37$, $p < 0.01$.

**Table 2**
Spearman correlation analysis between BLLs and some related factors ($n = 278$)

| Related factors | BLLs | |
|---|---|---|
| | $r_s$ | $p$ |
| Father's engagement in the type of work related to e-waste | 0.50 | 0.000 |
| The time that child play outside near the road everyday | 0.41 | 0.000 |
| The main function of the house | 0.23 | 0.004 |
| The distance that home was away from the street | −0.30 | 0.000 |
| Number of e-waste workshops around house within 50 m | 0.22 | 0.006 |
| Father returned home after work without replacing dresses | 0.26 | 0.001 |
| Mother's engagement in the type of work related to e-waste | 0.21 | 0.009 |
| Father's education level | −0.34 | 0.000 |
| Mother's education level | −0.26 | 0.001 |
| The average monthly household income | −0.28 | 0.000 |
| Cigarette consuming amount of family members everyday | 0.33 | 0.000 |
| Frequencies that child had the habit of sucking fingers | 0.19 | 0.018 |
| The number of preserved eggs that child had per month | 0.18 | 0.022 |
| The number of milk products that child had per month | −0.41 | 0.000 |
| The number of soybean products that child had per month | −0.20 | 0.010 |
| The number of praeparatum containing calcium, iron, zinc that child had per month | −0.19 | 0.015 |
| The number of time that child had a cold | 0.21 | 0.010 |
| Age | 0.33 | 0.000 |

#### 3.1.3. *Relationship between BLLs and related factors*

Through spearman rank analysis, 18 items were found correlate to children's BLLs (Table 2). Among these factors, "father's engagement in the type of work related to e-waste" had the highest relativity to the children's BLLs ($r = 0.502$, $p < 0.001$). Other risk factors contributed to high BLLs included house dwelling near or functioned as e-waste workshop, children's bad behavior, parent's bad behavior, and unhealthy lifestyle. The protected factors for BLLs were parent's education level, home incomes, nutrition, and so on.

After logistic regression analysis, six investigated factors were left and showed associations with BLLs (Table 3).

### 3.2. *BCLs in children*

#### 3.2.1. *Children's BCLs*

The BCLs of Guiyu children were significantly higher than those of Chendian children (Table 4, Mann–Whitney U test, $p < 0.01$), following the trend of BLLs results in these population. The threshold value of blood cadmium concentrations that the literatures reported as a risk of intoxication was 5 μg/L (Khassouania et al., 2000; Jin et al., 2002). Because all the children from Chendian had BCLs less than 5 μg/L, we regarded 2 μg/L as the cut-off point of BCLs. In Guiyu, 20.1% of children (31/154) had BCLs greater than 2 μg/L, compared with 7.3% of children (9/124) in Chendian had BCLs greater than 2 μg/L ($p < 0.01$). Female children had higher BCLs than male children in both groups, but significant differences could be only be found in Chendian children ($p < 0.01$).

#### 3.2.2. *Relationships between BCLs and related factors*

Spearman's rank correlation analysis was used to evaluate correlations between BCLs and the 25 investigated factors, and four variables were found correlate to BCLs (Table 5). After logistic regression analysis, six factors were left and showed associations with BCLs (Table 6).

## 4. Discussion

### 4.1. *BLLs in children*

The adverse health effects associated with elevated BLLs have been widely studied and documented. Children are particularly vulnerable to lead poisoning—more than adults because they absorb more lead from their environments (Grigg 2004; Guilarte et al., 2003; Jain and Hu 2006; Needleman 2004; Safi et al., 2006). BLLs ⩾ 10 μg/dL in children was defined by US CDC as elevated BLLs. Studies have increasingly shown that low blood lead concentrations, even less than 10 μg/dL, were inversely associated with children's IQ scores and academic skills (Jusko et al., 2008; Lanphear et al., 2000, 2005; Nevin 2000; Canfield et al., 2003; Schnaas et al., 2006). Therefore, no safety threshold for BLLs in young children has been identified (Chiodo et al., 2004; Koller et al., 2004).

Lead is considered to be one of the major heavy metal contaminants during the process of e-waste recycling (Wong et al., 2007). In Guiyu, the soaring levels of lead had been found in samples of dust, soil, river sediment, surface water, and groundwater because of primitive e-waste recycling during the last 10 years (Puckett et al., 2002; Brigden et al., 2005; Wang and Guo 2006; Yu et al., 2006). In our previous study conducted in Guiyu in 2004, the mean BLL of children was 15.30 μg/dL, and 81.8% of children had BLLs > 10.0 μg/dL, which were significantly higher than that of Chendian group (Huo et al., 2007). In this study, we found that the mean BLLs of Guiyu children was 13.17 μg/dL and 70.8% of them had BLLs > 10.0 μg/dL. Though the subjects in these two studies were different, all of them came from the same

**Table 3**
Logistic regression analysis between BLLs and investigated factors ($n = 278$)

| Investigated factors | High or low BLLs[a] | | | | |
|---|---|---|---|---|---|
| | $B$ | Wald | $p$ | OR | 95% CI |
| Father's engagement in the type of work related to e-waste | 1.53 | 9.11 | 0.003 | 4.61 | 1.71–12.45 |
| The time that child play outside near the road everyday | 0.55 | 5.39 | 0.020 | 1.73 | 1.09–2.76 |
| Frequencies that child had the habit of sucking fingers | 1.05 | 6.34 | 0.012 | 2.85 | 1.26–6.42 |
| Number of soybean products that child had per month | −1.29 | 6.78 | 0.009 | 0.28 | 0.11–0.73 |
| The average monthly household income | −0.64 | 5.66 | 0.017 | 0.53 | 0.31–0.89 |
| Age | 0.54 | 4.56 | 0.033 | 1.72 | 1.05–2.83 |

[a] High or low BLLs, taking 10 μg /dL as boundary; CI: confidence interval.

**Table 4**
Children's BCLs ($\mu$g/L) in Guiyu and Chendian

| | Guiyu | | | | Chendian | | | |
|---|---|---|---|---|---|---|---|---|
| | $n$ | Range | $\bar{x} \pm s$ | ⩾2 μg/L, $n$ (%) | $n$ | Range | $\bar{x} \pm s$ | ⩾2 μg/L, $n$ (%) |
| Total | 154 | 0.00–9.72 | 1.58±1.20 | 31 (20.1) | 124 | 0.00–3.49 | 0.97±0.70 | 9 (7.3) |
| Age (years) | | | | | | | | |
| 1 | 14 | 0.09–3.39 | 1.37±0.83 | 1 (7.1) | 26 | 0.00–2.67 | 0.96±0.80 | 3 (11.5) |
| 4 | 28 | 0.04–3.84 | 1.41±0.84 | 6 (21.4) | 32 | 0.00–3.20 | 1.03±0.78 | 3 (9.4) |
| 5 | 39 | 0.00–2.77 | 1.28±0.68 | 6 (15.4) | 37 | 0.00–3.49 | 0.95±0.72 | 3 (8.1) |
| 6 | 57 | 0.00–9.72 | 1.78±1.68 | 13 (22.8) | 26 | 0.00–1.80 | 0.85±0.53 | 0 (0) |
| 7–8 | 16 | 0.00–2.68 | 1.46±0.78 | 5 (31.3) | 3 | 0.85–1.03 | 0.94±0.09 | 0 (0) |
| Sex | | | | | | | | |
| Male | 81 | 0.00–3.39 | 1.36±0.72 | 16 (19.8) | 71 | 0.00–2.35 | 0.87±0.55 | 2 (2.8) |
| Female | 73 | 0.00–9.72 | 1.66±1.56 | 15 (20.5) | 53 | 0.00–3.49 | 1.06±0.86 | 7 (13.2) |

**Table 5**
Spearman correlation coefficients between BCLs and some investigated factors ($n = 278$)

| Investigated factors | BCLs | |
|---|---|---|
| | $r_s$ | $p$ |
| The time that child play outside near the road everyday | 0.23 | 0.003 |
| Father's engagement in the type of work related to e-waste | 0.23 | 0.004 |
| Number of e-waste workshops around house within 50 m | 0.19 | 0.020 |
| The distance that home was away from the street | −0.18 | 0.027 |

kindergartens with same living background. Therefore, this study showed that children in Guiyu had somewhat decline in BLLs. The reason is possible that more measures taken by the local government to control the scale and pollution of primitive e-waste recycling, and the importing e-wastes behavior prohibited by the country, and health education about the dangers and means of preventing lead poisoning was provided through booklet, lectures, and poster by us to local parents and children. However, most children had been still threatened by lead poisoning. Compared with the control group, both mean BLLs and high blood lead rate in Guiyu group were significantly higher, which was similar with the results of the study conducted in 2004. It indicated that there was a close relationship between the BLLs of children and the primitive e-waste recycling.

From a study conducted in 15 cities in China recently, the mean BLLs of children was 5.95 μg/dL, and only 10.45% of subjects had BLLs greater than 10 μg/dL, and boy's mean BLLs (5.95 μg/dL) was higher than girls's (5.50 μg/dL) (Zhang et al., 2005). The mean BLLs of children living in industrial and urban areas were also significantly higher than that of children living in suburbs and rural areas (Wang and Guo, 2006). In Guiyu, although the mean BLLs of children had been declined, it was still very higher than the nationwide level, and there were not significantly difference between boys and girls. Additionally, although Guiyu is a rural area, the children's BLLs were also higher than the nearby urban area, Shantou City (7.9 μg/dL; Luo et al., 2003). We also observed high BLLs not only in Guiyu children, but also in Chendian children (8.3 μg/dL), which were higher than the results from a study conducted in some other cities of China (Zhang et al., 2005). It seemed that lead contamination might have spread from Guiyu to nearby areas by dust, river, and air and contributed to the elevation of Chendian children's BLLs.

Though there were no relationships between physical indices, Hgb and BLLs, the mean height of Guiyu children (104.35±6.93 cm) was significantly lower than that of Chendian children (105.81±7.59 cm). It has been known that lead is associated with physical development of children by blocking the absorption of calcium, iron and other elements, and inhibiting the synthesis and utilization of hormone (Huseman et al., 1992; Camoratto et al., 1993; Hmomond and Succop, 1995; Kim et al., 1995). Many studies also showed that high BLLs had negative correlation with children's stature (Schwartz et al., 1986; Kim et al., 1995; Qi et al., 2002; Huang et al., 2005). Therefore, we suggested that the environmental lead contamination in Guiyu might have done harm to local children's stature. Further studies should be conducted to determine the relationship between them while controlling some confounding factors based on larger sample size.

In this study, 25 related factors were evaluated through Spearman correlation analysis and it showed that the living environment and life-style factors were associated with BLLs (Table 2). Parents's behaviors, educational levels, incomes, and habits also could influence the BLLs of children. In Guiyu, the concentration of lead in dusts collected from the workshops were

**Table 6**
Logistic regression analysis between BCLs and investigated factors ($n=278$)

| Investigated factors | High or low BLLs[a] | | | | |
|---|---|---|---|---|---|
| | *B* | Wald | *p* | OR | 95% CI |
| Sex | 1.11 | 5.41 | 0.020 | 3.03 | 1.19–7.69 |
| The time that child play outside near the road everyday | 0.49 | 4.98 | 0.026 | 1.63 | 1.06–2.51 |
| The number of soybean products that child had per month | −1.62 | 11.16 | 0.001 | 0.20 | 0.08–0.51 |
| The number of canned food that child had per month | 0.97 | 5.07 | 0.024 | 2.63 | 1.13–6.11 |
| Mother's education level | −0.94 | 7.07 | 0.008 | 0.39 | 0.20–0.78 |
| The average monthly household income | −0.54 | 5.11 | 0.024 | 0.58 | 0.36–0.93 |

[a] High or low BCLs, taking 2 μg/L as boundary.

hundreds of times higher than typical levels recorded for indoor dusts in other parts of world (Brigden et al., 2005), and soaring levels of lead also were found in water courses of Guiyu (Wang and Guo, 2006; Wong et al., 2007). Under this situation, children could intake lead contaminants from air, water, and food with more outdoor activities, especially the older children. Among the related factors, "father's engagement in the type of work related to e-waste" was the most important one (OR = 4.61). Father who engaged in e-wastes recycling work (especially "acid baths" and "burning to recover metal residues" works) might take the lead-contaminated dusts to home and add the chances of lead exposure to children. On the other hand, social and economic status, some dietary factors such as intake of milk, soybean products, and supplements of calcium, iron, zinc may be protective factors for BLLs. Therefore, one can implement nutritional interventions to reduce lead absorption. Children should receive an adequate amount of calcium in their diets, because calcium has been found to decrease the intestinal absorption of lead. It is possible that iron and vitamin C prevent or decrease lead absorption, but as the nature of the relationship between these substances and lead is still not clear, most physicians will not supplement lead-poisoned children with iron unless a child is iron-deficient (Campbell and Osterhoudt, 2000).

### 4.2. BCLs in children

Exposure to low levels of cadmium was associated with renal damage and once thought to be mostly an occupational hazard (Bressler et al., 2004), but attention has now focused on the general population. Cadmium is a cumulative toxic metal that has been well documented in children, and accumulates in the human body when they are young as early as infant (Friedmana et al., 2006). The level of cadmium excreted in the urine is considered to reflect body burden or long-term exposure, before developing renal damage, whereas BCLs was an indicator of more recent exposure (Lauwerys et al., 1994; Järup et al., 1998). Although the threshold value of BCLs beyond 5 μg/L was reported as a risk of intoxication (Bernard and Lauwerys, 1984; Khassouania et al., 2000), recent studies have suggested that estimates of levels of cadmium in the body that produce renal damage in the kidney were too high and that tolerated cadmium limit should be defined lower (Satarug et al., 2000; Järup et al., 2000).

In this study, the mean BCLs of children in Guiyu was 1.58 μg/L, which was significantly higher than that in Chendian (0.97 μg/L) ($p<0.01$). The result was much similar with the BLLs. It revealed that the environmental cadmium contamination was more severe in Guiyu than that in Chendian. As cadmium compounds were widely used in electronic products, such as solder joints, rechargeable batteries, and "phosphor" coatings in older cathode ray tubes, primitive e-waste recycling could release this heavy metal to the environment. Studies had showed that high level of cadmium had been found in Guiyu local dusts, water, and sediments in rivers (Brigden et al., 2005), which may be the primary reason that associated with the higher BCLs in Guiyu. However, this was the first study to reveal the children's BCLs in an e-waste recycling area. Although most participants had blood cadmium concentrations less than 5 μg/L and lower than Dongguang city of Guangdong province (2.24 μg/L, Hua et al., 2005), however, compared with results from recent studies conducted in some other cities in China, such as Xian City (0.46 μg/L, Watanabe et al., 2000) and Urumqi City (0.64 μg/L, Zhao et al., 2006), children in Guiyu had higher BCLs.

Generally, it was thought that smoking or passive smoking was the major source of non-occupational exposure to cadmium for humans (Satarug et al., 2000). However, no significant correlation could be found between children's BCLs and passive smoking in this study by spearman correlation analysis. But the factors related to e-waste showed significant correlation with BCLs (Table 5). Father's engagement in the type of work related to e-waste and the amount of time that children played outside near the road everyday were major factors contributed to children's BCLs. In Guiyu, most e-waste disposal places were located in the family workshops and many tons of e-waste material and process residues were dumped in workshops, yards, roadsides, open fields, irrigation canals, riverbanks, ponds, and rivers. If the house dwelling, father's occupation, and children's behavior habit were close to e-waste, there were more chances for children to expose to cadmium, and thus increased the children's BCLs. On the other hand, social and economic status, mother's education level, some dietary factors such as soybean products may also be protective factors for BCLs.

In conclusion, the higher BLLs and BCLs, especially the elevated BLLs in Guiyu children are found in this study. The higher lead and cadmium levels may be due to environmental contamination, which is related to the primitive e-waste recycling activities in local region. Although the BLLs of children had somewhat decreased compared with the former investigation conducted in 2004, it was still a serious threat to children's health around the e-waste recycling area. It is necessary to pay more attention to the health effects of primitive e-waste recycling. Policies that help reduce environmental lead and cadmium exposure should be made, and health education and reasonable nutrition should be provided to local families.

## Competing interests

The authors declare that they have no competing interests.

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