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Surveillance of childhood blood lead levels in Chengdu, China in 2010–2011

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INTRODUCTION Lead poisoning has been receiving great attention around the world. The Child Hygiene Cooperation Center of the World Health Organization in China has been conducting investigations to monitor blood lead levels (BLLs) from as early as 2004. However, only several lead poisoning studies have been conducted in China since August 2009. The aim of the present study was to investigate the BLLs in children aged < 7 years and to analyse the risk factors of high BLLs in Chengdu, China.

METHODS Questionnaires were distributed to children in Chengdu from 2010 to 2011. A total of 2,271 children were included in this study – 1,157 received BLL tests in 2010 and the remaining received the tests in 2011. BLL was measured using a tungsten atomiser absorption spectrophotometer.

RESULTS The mean BLL of the 2,271 children was 6.2 μg/dL and 2.03% of the children had BLLs ≥ 10 μg/dL. Mean BLL seemed to increase with age. Unhygienic habits (e.g. not washing hands frequently, biting of toys and pencils), history of pica, use of coal and residence in an industrial zone were found to be the main risk factors contributing to high BLL ($p < 0.05$). Children with high BLLs have a higher risk of manifesting anorexia and/or abdominal pain as compared to those with low BLLs ($p < 0.05$).

CONCLUSION The mean BLL of children in Chengdu (i.e. 6.2 μg/dL) was found to be higher than that of children in developed countries. Childhood lead poisoning remains a public health problem.

Keywords: blood lead level, children, China, lead poisoning, risk factor

INTRODUCTION

Lead, a highly toxic metal, is commonly found in the environment due to human activities, such as mining, manufacturing and burning of fossil fuels.[1] Lead is also widely used in a variety of products (e.g. lead car batteries, paints, water pipes, cosmetic products, hair dyes and building materials).[1,2] Therefore, the effect of lead exposure is an important health issue. This is especially the case when children are concerned, as they are more likely to play in dirt and insert objects into their mouths, resulting in a higher risk of lead exposure as compared to adults.[3] Many studies have revealed that elevated blood lead levels (BLLs), i.e. BLLs ≥ 10 μg/dL, can result in adverse health effects including encephalopathy, cardiovascular disease, immune system disease and anaemia.[4-10] Lead primarily affects the central nervous system, particularly the development of the brain.[1] Even low levels of lead exposure have been shown to be associated with impairment of children's cognitive function and abnormal infant behaviour.[11-13]

Since the last half of the 20th century, lead poisoning has been receiving serious attention in developed countries.[14] Thereafter, regulatory and environmental reforms have occurred, which resulted in significant mitigation of elevated BLLs among children in developed countries.[15] In recent years, lead exposure has received serious attention from Chinese scientists, and since 2004, the Child Hygiene Cooperation Center of the World Health Organization (WHO) in China has been carrying out investigations to monitor the BLLs of children from 14 Chinese cities.[16] One study conducted in China reported that lead poisoning has affected more than 4,000 children in several Chinese cities and that the BLLs of most of the affected children were > 25 μg/dL.[17] Such findings indicate that there is a need for large, population-based investigations to objectively assess BLLs and that practical guidelines for the prevention and treatment of childhood lead poisoning should be developed. Thus, the aim of the present study was to collect large amounts of data (i.e. BLLs and health points) on the children living in Chengdu, so as to examine the BLLs and analyse the risk factors and symptoms of lead poisoning.

METHODS

Children aged < 7 years were eligible for inclusion in the study. Only the results of the first set of BLL tests were used, and the child's name and identification number as well as time of investigation were documented. Children with known severe diseases, such as acute abdomen caused by acute appendicitis, were excluded. The number of children included in the study in 2010 and 2011 were 1,157 and 1,135, respectively. As 21 children participated in both enrolments, the second set of data (i.e. the data taken in 2011) of these children was excluded from the analysis. In other words, all analyses were done based on data from 2,271 children.

Children aged 3 to < 7 years were sampled from kindergartens during regular check-ups, while children aged < 3 years were

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sampled from community child health clinics during mandatory and periodic visits. Our study cohort included children from all 19 regions of Chengdu. The geographic distribution of the children is shown in Table I. As the analysis of BLLs was offered at no charge, most parents consented to their child's participation in the study. Fasting venous blood samples were collected from the children only after their parents had provided informed consent and answered the questionnaire that was administered. Blood sampling was done in the Department of Laboratory Medicine, West China Second University Hospital, Sichuan University, Chengdu, China. Information such as the child's inhabited environment, living habits and health status were gathered from the questionnaire. The child's health, as well as birth history, body weight, body height and BLL, was measured using a health questionnaire.

Venous blood specimens were collected in Vacutainer tubes (Becton Dickinson, Franklin Lakes, NJ, USA) containing heparin lithium, and BLL was analysed twice using a well-controlled BH2100 tungsten atomiser absorption spectrophotometer (Beijing Bohui Innovation Technology Co Ltd, Beijing, China) within an hour after sampling. The mean BLL of the two measurements was recorded. Seronorm™ Trace Elements Whole Blood (SERO, Billingstad, Norway) was used at the beginning and end of each day to ensure that the equipment was properly calibrated.

Data obtained from the questionnaires was inputted into an EpiData database (The EpiData Association, Odense, Denmark). In accordance with WHO guidelines, the present study defined elevated BLL as a BLL value ≥ 10 μg/dL.[18,19] Statistical analyses were conducted using the Statistical Package for the Social Sciences version 18.0 (SPSS Inc, Chicago, IL, USA). Variance analysis was used to examine the differences in BLLs between groups. Differences among the age, gender, nationality and housing environment of the children were evaluated in a pairwise method using *t*-tests. Logistic regression analysis was used to analyse the risk factors of high BLL. Chi-square test was used to assess the correlation between BLL and clinical symptoms. A p-value < 0.05 was considered to be statistically significant.

Table I. Geographic distribution of the children in the study (n = 2,271).

Region	No. of children				Total
	2010		2011		
	Urban	Suburban	Urban	Suburban	
Jinjiang	65	38	57	21	181
Qingyang	49	23	58	13	143
Jinniu	62	35	52	27	176
Wuhou	83	44	96	49	272
Chenghua	38	20	54	16	128
Longquan	32	21	37	15	105
Qingbaijiang	20	17	25	14	76
Xindu	25	15	28	19	87
Wenjiang	58	33	53	28	172
Jintang	25	11	27	16	79
Shuangliu	42	26	37	18	123
Pixian	49	20	41	22	132
Dayi	26	19	24	17	86
Pujiang	37	14	25	20	96
Xinjin	28	15	26	11	80
Dujiangyan	43	27	38	18	126
Penzhou	18	8	23	11	60
Qionglai	25	11	27	15	78
Chongzhou	21	14	23	13	71
Total	746	411	751	363	2,271

Table II. Characteristics of the children in the study (n = 2,271).

Variable	No. of children		
	2010	2011	Total
Age* (yr)	4.59 ± 1.87	4.51 ± 1.86	4.55 ± 1.86
Gender			
Male	684	672	1,356
Female	473	442	915
Ethnicity			
Han	1,114	1,073	2,187
Tibetan	43	41	84
Housing environment			
Urban	746	751	1,497
Suburban	411	363	774
BLL† (μg/dL)	6.5 ± 3.4 (1.9–56.5)	6.0 ± 3.5 (1.0–64.2)	6.2 ± 3.5 (1.0–64.2)
BLL (μg/dL)			
BLL < 10	1,139	1,086	2,225
10 ≤ BLL < 20	12	22	34
20 ≤ BLL < 40	2	3	5
BLL ≥ 40	4	3	7

*Data presented as mean ± standard deviation. †Data presented as mean ± standard deviation (range). BLL: blood lead level

RESULTS

The mean age of the 2,271 children was 4.55 years (Table II). Among them, 1,356 were male and 915 were female, and 2,187 were of Han ethnicity and 84 were of Tibetan ethnicity. Most (n = 1,497) of the children lived in urban areas; 774 children lived in suburban areas. The mean BLL of the children was 6.2 (range 1.0–64.2) μg/dL and most (n = 2,225) of the children had BLLs < 10 μg/dL.

The mean BLLs of the children according to their age are presented in Table III. 2.03% of the children had BLLs ≥ 10 μg/dL. The percentages of children with BLLs ≥ 10 μg/dL in 2010 and 2011 were 1.56% and 2.51%, respectively. We found that BLLs tended to increase with age (Fig. 1). There was no significant difference between the BLLs of the boys and those of the girls, according to the 2010 dataset (Table IV). However, evaluation of the 2011 dataset showed that the boys had significantly higher BLLs than the girls ($p < 0.05$). We found no significance difference between the BLLs of Han children and those of Tibetan children. While children who lived in urban areas had higher BLLs than those who lived in suburban areas, this difference was also not significant.

Logistic regression analysis was performed to find factors that were significantly associated with high BLL (i.e. ≥ 10 μg/dL). Confounders that were entered into the logistic regression analysis

Table III. Mean blood lead levels (BLLs) and percentage of children (n = 2,271) with BLLs ≥ 10 μg/dL, according to age.

Age (yr)	Mean BLL ± SD (μg/dL)			% of children with BLLs ≥ 10 μg/dL		
	2010	2011	Total	2010	2011	Total
0	5.1 ± 1.6	4.8 ± 1.8	4.9 ± 1.7	1.00	2.00	1.50
1	5.8 ± 2.5	6.3 ± 7.6	6.1 ± 5.8	1.00	4.00	2.50
2	6.3 ± 4.8	5.7 ± 2.6	6.0 ± 3.8	1.00	3.00	2.00
3	6.6 ± 5.1	5.8 ± 1.9	6.2 ± 3.8	3.11	2.21	2.66
4	6.6 ± 2.2	6.1 ± 2.3	6.4 ± 2.3	1.97	2.05	2.01
5	6.7 ± 1.5	6.6 ± 4.6	6.6 ± 3.4	0.00	2.48	1.22
6–7	7.0 ± 3.6	6.1 ± 2.2	6.6 ± 3.1	1.80	2.62	2.18
Total	6.5 ± 3.4	6.0 ± 3.5	6.2 ± 3.5	1.56	2.51	2.03

SD: standard deviation

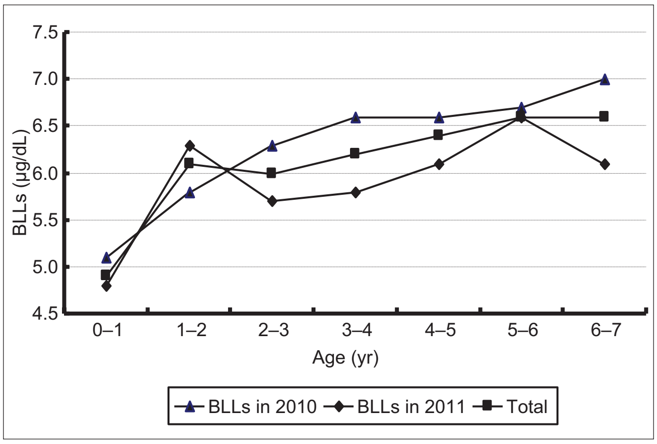

Fig. 1 Graph shows the trend of blood lead levels (BLLs) by age.

Table IV. Mean blood lead levels (BLLs) of the children (n = 2,271) according to gender, ethnicity and housing environment.

Variable	2010		2011		Total	
	Mean BLL ± SD (μg/dL)	p-value	Mean BLL ± SD (μg/dL)	p-value	Mean BLL ± SD (μg/dL)	p-value
Gender		0.838		0.017		0.071
Male	6.5 ± 3.2		6.2 ± 3.7		6.3 ± 3.4	
Female	6.4 ± 3.7		5.7 ± 3.3		6.1 ± 3.5	
Ethnicity		0.512		0.989		0.641
Han	6.5 ± 3.5		6.0 ± 3.6		6.2 ± 3.5	
Tibetan	6.1 ± 1.6		5.9 ± 2.7		6.1 ± 2.2	
Housing environment		0.252		0.926		0.427
Urban	6.1 ± 3.3		6.4 ± 2.8		6.3 ± 3.1	
Suburban	5.9 ± 3.7		6.5 ± 3.9		6.2 ± 3.8	

SD: standard deviation

Table V. Risk factors found to be significantly associated with high blood lead level in logistic regression analysis.

Risk factor	p-value	Adjusted OR
Pica history	0.040	3.607
Infrequent hand-washing	0.046	5.650
Habit of sucking fingers	0.041	2.569
Habit of biting toys	0.028	2.573
Habit of biting pencils	0.011	3.327
Use of coal	0.031	1.413
Frequent consumption of Chinese medical herbs	0.047	2.060
Frequent consumption of puffed foods	0.039	1.910
Use of breast milk substitutes	0.046	1.490
Residence in industrial zone	0.021	3.148

OR: odds ratio

included gender (male), ethnicity (Han), living in scattered housing, residing in a single-storey house, residing in a house beside the streets, use of lead fuel and pica history. Factors that were found to be significantly associated with high BLL (i.e. $p < 0.05$) and their adjusted odds ratios are listed in Table V. Risk factors that were found to be significantly associated with high BLL in children aged < 7 are: (a) pica history; (b) infrequent hand-washing; (c) the habit of sucking fingers, biting toys or biting pencils; (d) the use of coal; (e) frequent consumption of Chinese medical herbs and puffed foods; (f) the use of breast milk substitutes; and (g) residence in an industrial zone.

Table VI. Clinical correlates of blood lead levels (BLLs) of children (n = 2,271) aged 0–7 years.

Clinical correlate	No. of children		χ^2	p-value
	BLL ≥ 10 μg/dL (n = 46)	BLL < 10 μg/dL (n = 2,225)		
Anorexia	18	233	37.652	< 0.001
Abdominal pain	9	215	4.971	0.040
Constipation	7	461	0.834	0.361
Difficulty in learning	5	198	0.215	0.643

The correlation between elevated BLL and clinical symptoms such as anorexia, abdominal pain (i.e. lead-induced colic, and not acute appendicitis, cholecystitis or other causes of acute abdomen), constipation and difficulty in learning were assessed. The results of this analysis are shown in Table VI. Anorexia and abdominal pain were found to be significantly related to elevated BLL ($p < 0.05$).

DISCUSSION

The mean BLL of the 2,271 children (aged < 7 years) in the present study was 6.2 μg/dL, and the prevalence of elevated

BLL was found to be 2.03% for both years (2010 and 2011). We also observed that BLLs rose with increasing age. Several risk factors were identified to be associated with elevated BLL, including the use of coal, pica history, residence in an industrial zone, unhygienic habits (e.g. sucking fingers, not frequently washing hands, biting toys and biting pencils), the use of breast milk substitutes, and frequent consumption of Chinese medical herbs and puffed foods. The present study also showed that anorexia and abdominal pain were significantly associated with elevated BLL.

In the present study, the mean BLL of the children in 2010 and 2011 were 6.5 μg/dL and 6.0 μg/dL, respectively. In a previous study,[20] the mean BLL of children in Chengdu in 2007, 2008 and 2009 were found to be 6.6 μg/dL, 5.7 μg/dL and 6.4 μg/dL, respectively. In other words, the BLLs of children in 2010–2011 are similar to those in 2007–2009. One study reported that there was no difference in the BLLs of children before and after the lead poisoning event in Longchang, which is situated not far from the city of Chengdu.[17] As studies have shown that even 'low' BLLs (i.e. > 5 μg/dL) may influence children's neurobehavioral performance,[1,21,22] effective measures should be taken to reduce the BLLs of children.

In 1997, the United States Centers for Disease Control and Prevention divided the prevalence of elevated BLL into three categories: (a) higher than 12%: high epidemic area; (b) 6%–12%: moderate epidemic area; and (c) lower than 5.9%: low epidemic area.[20] Based on this categorisation and the sharp decrease in the prevalence of elevated BLL (from 9.2%[19] to 2.03% since 2007) in Chengdu, Chengdu is now a low epidemic area. This sharp decrease in the presence of elevated BLL is likely due to the elimination of leaded gasoline, which has been implemented in China since July 1, 2000.

Although Chengdu currently belongs to the 'low epidemic area' category, the BLLs of the children in Chengdu are still relatively high; the mean BLL of the children in the present study was > 6 μg/dL. Therefore, even though no lead poisoning event has been reported in Chengdu (unlike in Longchang, which has BLLs > 25 μg/dL[17]), BLL detection should still be carried out routinely to prevent high BLLs from causing unwanted damages.

The present study's finding that BLLs increase with age, from 0 to < 7 years, is consistent with that of many studies.[23,24] The evaluation of our 2011 dataset showed that BLLs were significantly higher in boys than in girls. This finding is consistent with that of Zhang et al's study, which involved 14 Chinese cities in 2004–2006.[16] However, the 2007–2010 data from the present study and a previous study[20] yielded different results; the data obtained during that period showed no significant difference in the BLLs of boys and girls. This may be due to population mobility or sampling error. There may also be regional differences in the BLLs of boys and girls. In the present study, we also found that the mean BLL of Tibetan children was slightly lower than that of the Han children in Chengdu, although this difference did not reach a significant level.

In the present study, we found that children with unhygienic habits (e.g. sucking fingers, not frequently washing hands, biting toys and biting pencils) were more likely to have elevated BLLs. This finding, although not observed in our previous study,[20] is consistent with many other studies.[3,25-27] Frequent consumption of Chinese medical herbs and puffed foods as well as the use of breast milk substitutes were found to be risk factors for elevated BLL in both our previous study[20] and the present study.

Elevated BLL is a known multi-target toxicant, with effects on the haematopoietic, nervous, immune and gastrointestinal systems.[4-10] Abdominal pain is frequently reported when BLL is > 40 μg/dL. In the present study, anorexia and abdominal pain were found to be significantly associated with elevated BLL. While lead toxicity is an uncommon cause of acute abdominal pain, several cases of acute abdominal pain have been reported to be caused by lead toxicity.[28,29] The diagnosis of lead toxicity is often delayed, as the abdominal pain is often mistaken to be caused by acute appendicitis, acute cholecystitis or other more common causes of acute abdomen. The monitoring of BLLs in children suffering from anorexia and/or abdominal pain may be useful in identifying children with elevated BLL.

The present study was not without limitations. First, we only evaluated and identified a small number of risk factors associated with elevated BLL. Second, the sample size was relatively small. To obtain more comprehensive and accurate findings, future studies should evaluate a greater number of risk factors and use a larger sample size.

In conclusion, the BLLs of children in Chengdu were found to be higher than those of children from other areas in China and developed countries. As lead poisoning in children is a public health problem in China, unhygienic habits in children and environmental pollution should be considered and addressed. In order to prevent lead poisoning, there needs to be greater collaboration among the government, the society and families.

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