Surveillance of childhood blood lead levels in 11 cities of China

Tao Li, Yao-Hua Dai, Xiao-Hua Xie, Zang-Wen Tan, Shuai-Ming Zhang, Zong-Han Zhu
Beijing, China

Original article

Background: **Exposure to lead can be deleterious to children's health. Surveillance for blood lead levels (BLLs) is reported every year in the USA and some other countries. However, such reports are lacking in China which has the world's largest population of children. In this study, we provided the latest nationally representative data on BLLs among Chinese children living in cities, described the change in BLLs since 2004, and explored the risk factors for elevated BLLs (EBLLs) among children.**

Methods: **We studied 12 693 children aged 0-6 years in 2004 and 11 255 children aged 0-6 years in 2010. We evaluated the average BLLs and the prevalence of EBLLs, and a multivariate logistic regression model was used to estimate predictors of EBLLs.**

Results: **The geometric mean BLLs of children aged 0-6 years dropped by 16% (from 46.38±2.10 μg/L in 2004 to 38.95±1.83 μg/L in 2010), while the prevalence of EBLLs dropped by 87% (from 9.78% in 2004 to 1.32% in 2010). In a multivariate analysis, the following factors were associated with EBLLs: (1) children being cared for at home or at a boarding nursery (compared to children being cared for in a day nursery), (2) children having fathers with a lower education level, and (3) children often eating popcorn and chewing fingernails or sucking fingers were associated with EBLLs.**

Conclusions: **The results of this study demonstrated a substantial decline in BLLs from 2004 to 2010 among Chinese children 0-6 years living in cities. However, these levels were higher than levels in countries, such as the USA, Canada, Japan and Sweden. These data demonstrate that Chinese children's lead exposure remains a public health problem that requires additional effort and resources.**

World J Pediatr 2014;10(1):29-37

Key words: **child;**
gasoline;
lead;
surveillance

Introduction

For more than 100 years, exposure to lead has been known to be harmful to children's health. Many human activities such as burning fossil fuels, painting walls, using leaded petrol, drinking from leaded water pipes, smelting, and especially industry manufacturing processes, are associated with lead exposure.[1] Children, for whom are still developing, are especially vulnerable to the adverse effects of lead.[2] The USA Centers for Disease Control and Prevention (CDC) established the Childhood Lead Poisoning Prevention Program to eliminate childhood lead poisoning in the USA.[3] Nationally representative data about USA children's blood lead values have been available every year since 1997. However, although China has a large child population, national representative data on childhood lead levels in China have been lacking. All previous studies among Chinese children were conducted either in a special region such as a polluted area or had small sample sizes.

This study was approved by the Capital Institute of Pediatrics Ethics Committee and was conducted among children aged 0-6 years in 11 cities of China in 2004 and 2010. In this paper, we provided the data on blood lead levels (BLLs) in these two years, described the change in BLLs between 2004 and 2010, and explored recent risk factors for elevated BLLs (EBLLs, ≥100 μg/L).

Methods

Study population

Our study sample came from 11 cities all over China:

Author Affiliations: Department of Integrated Early Childhood Development Capital Institute of Pediatrics, Beijing, China (Li T, Dai YH, Xie XH, Tan ZW, Zhang SM); Chinese Pediatrician Association, Beijing, China (Zhu ZH)

Corresponding Author: Yao-Hua Dai, Department of Integrated Early Childhood Development, Capital Institute of Pediatrics, 2 Ya Bao Road, Chaoyang District, Beijing 100020, China (Tel: 8610 85636169; Fax: 8610 85622025; Email: yh.dai@263.net)

doi: 10.1007/s12519-014-0452-6

Guangzhou, Qingdao, Chengdu, Zhengzhou, Hohhot, Hefei, Wuhan, Beijing, Changsha, Shijiazhuang, and Yinchuan. The maternal and child care service hospital/center in each city was selected as the surveillance site. Our study was conducted during the same period (from May to August) in all sites in both 2004 and 2010. In each site, the first 1200 children aged less than 72 months and their parents were selected as participants when children went to see a doctor or received vaccinations or physical examinations. Children aged 72 months or older were excluded. Thus, in the 11 cities we recruited a total of 13 200 children every year.

Questionnaires

The study aims and methods were explained to the potential participants (parents and children). After the parents or guardians provided written informed consent for their child's participation, data were collected from the child's parents by trained doctors face-to-face in their home languages, using a questionnaire. The questionnaire variables were: child's sex and birth date, hygiene habits (washing hands), dietary habits (such as whether they eat some special foods or medicines including popcorn, preserved eggs, or milk, the use of Chinese herbal medicine and calcium/zinc/iron supplements), special habits (such as chewing on fingernails or fingers, biting or mouthing writing materials such as pencil, pen, eraser, pencil sharpener and biting or mouthing toys), parents' information (such as education levels, whether they use hair dye or whether they smoke), the residence location, the building floor on which they live, the kitchen fuel and the child care situation, (in this study termed nursery situation, including "at home", "day nursery" and "boarding nursery"). "Boarding nursery" means that the child stays in the nursery day and night and goes back to home one time every week or every two weeks.

Laboratory tests

A capillary sample was collected from each child enrolled by a trained blood sample collector. Before collecting the sample, each child's hands were washed thoroughly with soap and water, and the finger that would be punctured was cleaned with an alcohol swab. Schlenker et al[4] have shown that capillary sampling is an acceptable alternative to venipuncture that has been used to screen for lead poisoning among young children in many areas and countries including the USA. Forty μL of blood was obtained from each child and put into a centrifuge tube for mixing with diluents. The mixtures were stored at 4 degrees centigrade and shipped to the local maternal and children health center for laboratory analysis. All laboratories in our study subscribed to the National System of External Assessment of the Quality of Results which is conducted by the National Center of Clinical Laboratories. In 2004 and 2010, lead levels were measured with the same apparatus-BH2100 tungsten atomizer absorption spectrophotometer (produced by Beijing Bohui Innovation Technology Co., Ltd) in all the monitor sites for both surveys.

A contrast test between tungsten atomizer absorption spectrophotometry and graphite furnace atomic absorption spectrophotometry had been conducted previously in the Institute of Environmental Health and Related Product Safety, China Center for Disease Control and Prevention, showing that the test results were not significantly different, and that there was a good correlation between the test values obtained using these two methods (r=0.99). Compared with the graphite furnace atomic absorption spectrophotometer, the tungsten atomizer absorption spectrophotometer has the advantages of simple sample preparation and operation, reasonable price, and time saving, and it is available for large scale epidemiological research. It has been recommended as one of the methods to test blood lead values in the National Guide to Clinical Laboratory Procedures (third edition) published by the Medical Administration Department of the Ministry of Public Health of China.[5] The blood lead testing system was calibrated with standard reference materials such as GBW09131-GBW09133 and GBW09139-GBW09140 obtained from the China Center for Disease Control and Prevention. An EBLL was defined a priori as a value of 100 μg/L or higher. For those children with two EBLLs measured from their capillary blood samples, venous blood was taken for a confirmatory measurement.

Statistical analysis

Data from this survey were manually put into Epidata 3.0 by specially trained staff and statistical analysis was performed using SAS (v. 9.1). By convention, we used geometric means and 95% confidence intervals to report the mean BLLs. This method was typically applied because of the skewed distribution of human blood lead values. After exponential transformation of the blood lead values, the distribution was normal. The percentage of EBLLs was calculated by child's age, sex, parents' education levels, child care situation, and 95% confidence intervals were calculated. After the initial BLLs data were log-transformed, the difference between the average BLLs in 2004 and 2010 was evaluated with Student's t test (alpha=0.05). The chi-square test was used to assess changes in percentage of EBLLs from 2004 to 2010. Finally, we determined the risk factors for EBLLs using data from 2010. Any variables that were found to be associated with EBLLs in the bivariate analysis at alpha=0.2 were put into a multivariate logistic regression model to determine the final risk factors. A stepwise method was used, and the criteria of entry and removal were 0.1 and 0.05, respectively. In our study, all of our hypothesis testing was at a 0.05 significance level in a two-tailed test.

Results

Sample

Of 13 200 children and caregivers recruited in 2004 and 2010, 96% completed the questionnaires and blood test in 2004 and 85% in 2010. Finally, there were 12 693 and 11 255 children aged 0-6 years enrolled in 2004 and 2010, respectively. The general characteristics of participants in these two national cross-sectional studies are shown in Table 1. There was no difference in sex composition, but there was a difference in age (P<0.001) between the samples of these two cross-sectional studies. The average age of the children was 3.6 years in 2004 and 3.4 years in 2010 (P<0.05). The information about the parents' education and the children's nursery enrollment is listed in Table 2. The educational levels of the fathers and the mothers in our study samples rose from 2004 to 2010. The 2010 sample included more children with child care at home (P<0.05), which might be due to the children's slightly younger age (Table 1).

Table 1. General characteristics of participants in 2004 and 2010

Variables	2004		2010	
	n	%	*n*	%
Overall	12 693		11 255	
Sex				
Boy	7027	55.4	6258	55.6
Girl	5666	44.6	4997	44.4
Age (y)				
0	801	6.3	850	7.6
1	987	7.8	1198	10.6
2	1148	9.0	1187	10.5
3	2568	20.2	2072	18.4
4	2805	22.1	2577	22.9
5	2608	20.5	2137	19.0
6	1777	14.0	1234	11.0

Table 2. Information on education of parents and children's nursery situation in 2004 and 2010

Variables	2004		2010	
	n	%	*n*	%
Overall	12 693		11 255	
Father's education				
College graduate or beyond	7394	58.3	6892	61.5
High school graduate	3764	29.6	3160	28.2
Junior high school or lower	1535	12.1	1151	10.3
Mother's education				
College graduate or beyond	6304	49.7	6148	54.9
High school graduate	4467	35.2	3699	33.0
Junior high school or lower	1922	15.1	1347	12.0
Nursery situation				
At home	3114	24.5	3429	30.5
Day nursery	8898	70.1	7330	65.1
Boarding nursery	681	5.4	496	4.4

Mean blood lead levels

The geometric mean BLLs in the total sample dropped by 16%, from 46.38±2.10 μg/L in 2004 to 38.95±1.83 μg/L in 2010. We found substantial declines in geometric mean BLLs across all demographic classifications: among boys and girls, for each age group, for each education level of parents, and for each nursery situation (P<0.05 for all children except those under one year of age).

The changes were complex among the 11 cities we sampled. For example, in two cities, Guangzhou and Hefei, we did not see any statistically significant differences in geometric mean BLLs between 2004 and 2010; in five cities, Qingdao, Hohhot, Wuhan, Beijing, Shijiazhuang, and Yinchuan, the geometric mean BLLs decreased from 2004 to 2010 (P<0.05); while in the three remaining cities, Chengdu, Zhengzhou, and Changsha, the geometric mean BLLs increased from 2004 to 2010 (P<0.05). This complex pattern of increases and decreases in mean BLLs across cities was not repeated for the prevalence of EBLLs where prevalence declined across all cities.

Elevated blood lead levels

The prevalence of EBLLs (≥100 μg/L) declined by 87% from 9.78% to 1.32% between 2004 and 2010. Obvious drops of the prevalence of EBLLs also were shown in each subgroup (P<0.05 for all) from 2004 to 2010. The trend that boys' BLLs were higher than girls' still existed in geometric mean (P<0.05) but not in percent of EBLLs. The prevalence of EBLLs was progressively higher among the older age children in the surveillance conducted in 2004 (Fig. 1). This had changed to approximately the opposite outcome in the 2010 study, although with less dramatic differences. Children under two years of age had a higher percent of EBLLs. The highest blood lead geometric means and highest percentage of EBLLs appeared among the children whose parents had less than a college graduate. The difference between those whose parents had high school graduate and junior high school or lower education was

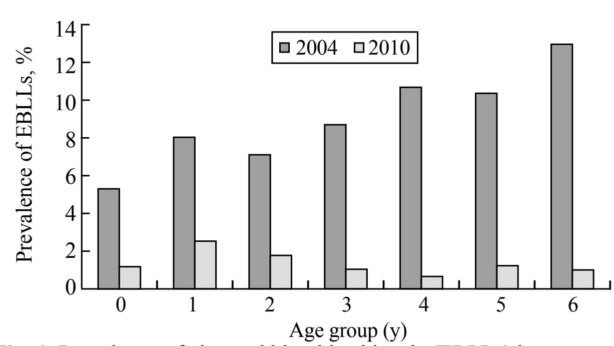

Fig. 1. Prevalence of elevated blood lead levels (EBLLs) by age group in 2004 and 2010.

not statistically significant. With regard to the child's nursery situation, the geometric means of BLLs rose from "at home", "day nursery" to "boarding nursery" (P<0.05), but the percent of EBLLs of children staying in a day nursery dropped from the highest level in 2004 to the lowest in 2010 (Table 3).

Risk factors

All variables shown in Table 4 were tested by bivariate analysis. For our analyses, age was divided into two groups: equal or less than 3 years, and older than 3 years. Variables such as age group, parents' education level, nursery situation (including at home, day nursery and boarding nursery), whether the community was near factories with lead, whether children washed hands before eating, whether children often ate popcorn, whether children often sucked fingers or chewed fingernails and whether children often mouthed or bit writing materials (especially pencils) or bit toys were significantly associated with EBLLs (P<0.05 for all) and these variables entered the multivariate analysis. When we set the criterion for inclusion into the multivariate analysis at P<0.20, factors including sex, cohabitants smoking, living on the building's ground floor and taking Chinese herbal medicine also entered the model.

In a multivariate model including the variables that were chosen through the bivariate analysis (Table 4), children who were cared for at home or a boarding nursery, parents with lower education level (due to the strong correlation between father and mother's education level, we only left factor "father's education level" in the multivariate analysis model), often eating popcorn and often chewing fingernails or sucking fingers, were more likely to have BLLs ≥100 μg/

Table 3. Geometric mean blood lead level and percentage of elevated blood lead levels among participants in 2004 and 2010

Variables	2004		2010	
	μg/L, mean (95% CI)	%, ≥100 μg/L (95% CI)	μg/L, mean (95% CI)	%, ≥100 μg/L (95% CI)
Overall	46.38 (45.78, 46.98)	9.78 (9.26, 10.29)	38.95 (38.52, 39.39)	1.32 (1.11, 1.54)
Sex				
Boy	48.04 (47.22, 48.87)	10.82 (10.09, 11.54)	40.03 (39.44, 40.63)	1.47 (1.17, 1.77)
Girl	44.40 (43.54, 45.27)	8.49 (7.76, 9.21)	37.64 (37.01, 38.28)	1.14 (0.85, 1.44)
Age (y)				
0	36.49 (34.67, 38.40)	5.37 (3.81, 6.93)	33.58 (32.11, 35.11)	1.29 (0.53, 2.05)
1	44.08 (42.22, 46.02)	8.11 (6.40, 9.81)	35.58 (34.18, 37.04)	2.59 (1.69, 3.49)
2	45.71 (43.96, 47.54)	7.14 (5.65, 8.63)	38.64 (37.24, 40.09)	1.85 (1.09, 2.62)
3	44.57 (43.24, 45.93)	8.76 (7.67, 9.86)	40.27 (39.26, 41.30)	1.16 (0.70, 1.62)
4	47.07 (45.81, 48.36)	10.70 (9.55, 11.84)	39.26 (38.42, 40.11)	0.74 (0.41, 1.07)
5	47.36 (45.98, 48.78)	10.43 (9.26, 11.60)	40.16 (39.18, 41.16)	1.31 (0.83, 1.79)
6	53.84 (52.15, 55.59)	13.45 (11.86, 15.04)	41.88 (40.58, 43.22)	1.13 (0.54, 1.73)
Father's education				
College graduate or beyond	45.20 (44.45, 45.97)	9.09 (8.43, 9.74)	38.51 (37.98, 39.06)	0.96 (0.73, 1.19)
High school graduate	47.89 (46.75, 49.06)	10.97 (9.97, 11.97)	40.57 (39.71, 41.44)	1.77 (1.31, 2.23)
Junior high school or lower	48.53 (46.83, 50.28)	10.16 (8.65, 11.67)	37.18 (35.77, 38.65)	2.35 (1.47, 3.22)
Mother's education				
College graduate or beyond	44.39 (43.58, 45.22)	8.63 (7.94, 9.32)	38.17 (37.60, 38.74)	0.96 (0.72, 1.20)
High school graduate	47.76 (46.74, 48.80)	10.72 (9.92, 11.63)	40.69 (39.91, 41.47)	1.62 (1.21, 2.03)
Junior high school or lower	50.01 (48.43, 51.65)	11.34 (9.92, 12.76)	37.84 (36.50, 39.23)	2.23 (1.44, 3.02)
Nursery situation				
At home	44.40 (43.32, 45.50)	8.12 (7.17, 9.08)	36.58 (35.76, 37.43)	2.16 (1.67, 2.64)
Day nursery	46.88 (46.15, 47.63)	10.50 (9.86, 11.13)	39.86 (39.34, 40.38)	0.86 (0.65, 1.07)
Boarding nursery	49.19 (46.81, 51.70)	7.93 (5.90, 9.96)	42.79 (40.79, 44.88)	2.42 (1.07, 3.77)
City				
Guangzhou	43.16 (41.39, 45.01)	9.06 (7.37, 10.74)	40.20 (38.62, 41.84)	3.19 (2.02, 4.35)
Qingdao	50.83 (48.82, 52.93)	10.19 (8.49, 11.88)	35.38 (34.15, 36.67)	0.60 (0.01, 1.18)
Chengdu	44.97 (43.17, 46.84)	10.01 (8.29, 11.73)	60.73 (59.63, 61.85)	1.52 (0.80, 2.24)
Zhengzhou	51.49 (49.77, 53.27)	7.43 (5.93, 8.93)	54.89 (53.67, 56.14)	2.69 (1.78, 3.59)
Hohhot	59.24 (57.61, 60.92)	14.25 (12.39, 16.12)	22.51 (21.40, 23.68)	1.10 (0.48, 1.72)
Wuhan	46.32 (44.29, 48.44)	8.94 (7.18, 10.70)	35.03 (34.27, 35.82)	0.24 (0.00, 0.57)
Beijing	60.66 (58.75, 62.62)	13.44 (11.23, 15.65)	39.10 (37.69, 40.57)	0.42 (0.05, 0.79)
Hefei	32.60 (31.30, 33.95)	2.78 (1.84, 3.71)	32.77 (31.67, 33.90)	0.90 (0.35, 1.46)
Changsha	35.99 (34.20, 37.87)	6.69 (5.26, 8.14)	44.67 (43.40, 45.98)	2.03 (1.13, 2.94)
Shijiazhuang	56.04 (54.13, 58.02)	9.74 (8.18, 11.40)	41.29 (40.16, 42.45)	0.67 (0.21, 1.13)
Yinchuan	38.63 (36.46, 40.93)	15.15 (13.08, 17.22)	31.73 (30.63, 32.88)	1.10 (0.45, 1.74)

CI: confidence interval.

Table 4. Bivariate analysis for risk factors for elevated blood lead levels among children aged 0-6 years in 2010

Variables	Blood lead level ≥100 µg/L			
	%	OR	95% CI	*P*
Overall	1.32			
Sex				0.13
Boy	1.47	1.29	(0.93, 1.80)	
Girl	1.14	1.00	Reference	
Age group (y)				<0.01
0-3	1.66	1.63	(1.17, 2.26)	
4-6	1.03	1.00	Reference	
Father's education level				<0.01
College graduate or beyond	0.96	1.00	Reference	
High school graduate	1.77	1.87	(1.30, 2.67)	
Junior high school or lower	2.35	2.49	(1.58, 3.91)	
Mother's education level				<0.01
College graduate or beyond	0.96	1.00	Reference	
High school graduate	1.62	1.70	(1.19, 2.44)	
Junior high school or lower	2.23	2.35	(1.51, 3.66)	
Nursery situation				<0.01
At home	2.16	2.54	(1.81, 3.57)	
Day nursery	0.86	1.00	Reference	
Boarding nursery	2.42	2.86	(1.53, 5.34)	
Father's occupation contacted with lead				0.43
Yes	1.52	1.18	(0.78, 1.78)	
No	1.29	1.00	Reference	
Mother's occupation contacted with lead				0.55
Yes	1.62	1.23	(0.63, 2.43)	
No	1.32	1.00	Reference	
Father uses hair dye				0.32
6 times or more every year	1.61	1.23	(0.82, 1.87)	
Less than 12 times every year	1.31	1.00	Reference	
Mother uses hair dye				0.47
6 times or more every year	1.54	1.18	(0.76, 1.81)	
Less than 12 times every year	1.31	1.00	Reference	
Cohabitants smoking				0.17
Yes	1.46	1.27	(0.91, 1.77)	
No	1.15	1.00	Reference	
Living floor				0.10
Bungalow/ground floor	1.74	1.40	(0.94, 2.09)	
Second floor or above	1.25	1.00	Reference	
Whether to live near arterial roads				0.66
Yes	1.44	1.10	(0.71, 1.70)	
No	1.31	1.00	Reference	
Main kitchen fuel				0.76
Coal and its products	1.49	1.14	(0.50, 2.59)	
Other fuel	1.31	1.00	Reference	
Whether factories with lead exist nearby community				0.03
Yes	2.05	1.56	(1.04, 2.34)	
No	1.32	1.00	Reference	
Whether children wash hands before eating				<0.01
Sometimes or never	1.75	1.63	(1.18, 2.26)	
Always	1.08	1.00	Reference	
Whether children take Chinese herbal medicine				0.10
More than 1 time every week	1.94	1.53	(0.93, 2.51)	
Less than 2 times every month	1.28	1.00	Reference	
Whether children eat animal milk or its products				0.38
Every day or sometimes	1.29	0.83	(0.56, 1.25)	
Do not eat or almost never eat	1.54	1.00	Reference	
Whether children often eat popcorn				<0.01
Yes	2.33	2.01	(1.37, 2.94)	
No	1.18	1.00	Reference	
Whether children eat preserved egg				0.98
Every day or sometimes	1.34	1.01	(0.57, 1.79)	
Almost not nor never eat	1.33	1.00	Reference	
Whether children take calcium/zinc/iron supplement				0.42
Every day or sometimes	1.24	0.88	(0.63, 1.21)	
Almost not nor never eat	1.42	1.00	Reference	
Whether children often chew fingernails or suck fingers				<0.01
Yes	1.85	1.82	(1.32, 2.52)	
No	1.03	1.00	Reference	
Whether children often bite writing materials				0.02
Yes	2.16	1.75	(1.12, 2.74)	
No	1.24	1.00	Reference	
Whether children often bite toys				0.01
Yes	1.99	1.68	(1.16, 2.44)	
No	1.19	1.00	Reference	

CI: confidence interval; OR: odds ratio.

Table 5. Multivariate logistic model of elevated blood lead levels (≥100 µg/L) among children aged 0-6 years in 2010

Factors	Adjusted odds ratios†	95% Wald confidence limits
Nursery situation (day nursery)		
At home	2.14	(1.50, 3.05)
Boarding nursery	2.71	(1.44, 5.11)
Father's education level (college graduate or beyond)		
High school graduate	1.76	(1.22, 2.53)
Junior high school or lower	2.11	(1.32, 3.38)
Whether often eat popcorn*	2.13	(1.43, 3.15)
Whether often chew fingernails or suck fingers*	1.54	(1.09, 2.15)

*: referent category: no; †: adjusted for nursery situation, father's education level, whether often eat popcorn and whether often chew the fingernails or suck fingers.

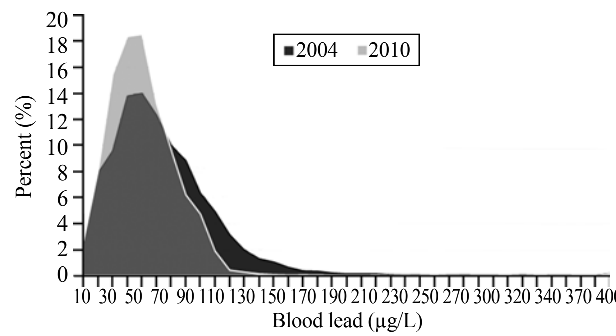

Fig. 2. The distribution of blood lead levels in 2004 and 2010.

L (Table 5). Other factors such as main kitchen fuel, whether the child's hands were washed before eating, whether the child ate animal milk or its products (protective factors), whether the child ate preserved eggs, often sucked the fingers or chewed the fingernails and often bit writing materials (especially pencils) or toys did not reach statistical significance at alpha=0.05 and were excluded from the model.

Discussion

Blood lead levels (BLLs)

A continuous scale comparison between the 2004 and 2010 blood lead distributions revealed an increase in 2010 of the proportion of values from 0 to 70 µg/L and a decrease in the proportion of values over 70 µg/L (Fig. 2). Over all, we found that the geometric mean BLL among children aged 0-6 years in the 11 cities of China dropped by 16% from 2004 to 2010. To put these values into perspective, the mean BLLs in children in these cities in China was now lower than the mean in South Africa (64 µg/L for children aged 5-11 years).[6] But it was more than two times that among USA children aged 1-5 years (11.7 µg/L in 2009-2010) and higher than that of children in Sweden (21 µg/L for children aged 7-11 years), Germany (19.1µg/L for children aged 3-5 years and

Table 6. Comparison of blood lead levels of children among different countries

Countries (city or area)	Number of samples	Year of survey	Age period (y)	Mean of blood lead (μg/L)	Prevalence of EBLLs (%)
Canada[12] (nationally)	910	2007, 2009	6, 11	9.0*	<1
Germany[9]	692	2003, 2006	3-8	19.1 (1.6)* for 3-5 y 17.3 (1.6)* for 6-8 y	0.0
Japan[11] (Tokyo, Shizuoka, and Osaka)	182	2005, 2010	1-6	12.2 (15.0)* for 1-3 y 10.6 (15.3)* for 4-6 y	Negligible
Korea[10] (Seoul, Seongnam, Ulsan, Incheon, and Yeoncheon)	667	2008	8-11	19±6.7†	-
India[13] (Chennai)	756	2005, 2006	3-7	114 (53)*	54.5
South Africa[6] (Three suburbs of the Cape Peninsula)	429	2002	5-11	64†	10
China, current study (11 cities across China)	11 255	2010	0-6	38.95 (1.83)*	1.32
China, current study (11 cities across China)	12 693	2004	0-6	46.38 (2.10)*	9.78

*: geometric mean (SE); †: arithmetic mean±SE. "-": not provided; EBLLs: elevated blood lead levels.

17.3 μg/L for children aged 6-8 years), South Korea (19 μg/L for children aged 8-11 years, arithmetic mean), and Japan (12.2 μg/L for children aged 1-3 years).[7-11]

The prevalence of EBLL dropped by 87% from 9.78% in 2004 to 1.32% in 2010, much less than in the study conducted in South Africa (10% for children aged 5-11 years).[6] But, it still was almost two times of that among American children <72 months in 2010 (0.61%).[3] The latest survey conducted in Canada among Canadian children aged 6 to 11 years revealed that the geometric mean blood lead was 9 μg/L and fewer than 1% had EBLLs.[12] More comparisons of BLLs among other countries and China are listed in Table 6.

Although these comparisons were not performed in the same age groups or in the same period, they nonetheless demonstrated significant disparities. In addition, studies documented that even BLLs less than 100 μg/L are linked with substantial neuro-behavioral deficits such as intelligence quotient reduction, drop of ability in math and reading and some behavior problems.[14] There is no evidence of a safe level of lead below which children are not affected.[15]

In this study, especially in the data from 2010, we found some groups of children with higher geometric mean BLLs but lower percent of EBLLs. This can be been used to diagnose an EBLL because of the high level of lead (≥100 μg/L). In future studies, we should consider a standard based on a lower BLL.

Risk factor analysis

The variables that were part of the 2010 risk factor analysis showed both expected and unexpected results.

In the bivariate analysis, younger children (<3 years old) were 1.63 times (P<0.05) more likely to have EBLLs compared with those older than 3 years, which was opposite to the trend of geometric means and was also opposite to the trend shown in 2004. In that study, children at older ages were more likely to have EBLLs. It was due to the fact that the reference value (100 μg/L) was too much higher for recent BLLs among children in China, and a new reference like 50 μg/L set by USA CDC was needed. Our 2010 results were compared to those of Lanphear:[16] Younger age (<3 years old) was associated with EBLLs in the bivariate analysis but not in the multivariate analysis. It might be due to the overlap with other factors when in the bivariate analysis.

Children's hand-to-mouth behavior and pica (e.g., sucking fingers, chewing fingernails, and mouthing writing materials and toys) were significantly associated, as expected, with EBLLs in the bivariate analysis. However, the behavior of often biting toys was not identified as a risk factor in the multivariate analysis. This lack of predictive relationship might be due to the promotion of the quality of toys made in China nowadays under the severe export pressures and supervision of the government of China.

The child's nursery situation was tested as a predictor. When we set "day nursery" as the referent category, the adjusted odds ratios (ORs) were 2.14 (95% confidence interval: 1.50-3.05) and 2.71 (95% confidence interval: 1.44-5.11) for children cared for at home and at a boarding nursery, respectively. We do not know the reasons behind this finding. In the future it would be useful to conduct an examination of day nurseries in the study cities to learn if there are some hygiene practices and/or environmental provisions that explain why these day nursery sites should present less risk for lead exposure than other child care environments.

Father's lower education level was found to be a risk factor both in the bivariate and multivariate analyses. Compared with those fathers who had a college graduate or beyond, fathers with a high school graduate education were 1.76 times (95% confidence interval: 1.22-2.53) more likely to have a child with an EBLL. When the father had an education level at junior high school or lower, it was higher (adjusted OR=2.11, 95% confidence interval: 1.32-3.38).

Children's eating of popcorn was another factor that was associated with EBLLs (adjusted OR=2.13, 95% confidence interval: 1.43-3.15) in our study. It was also demonstrated to be a risk factor in studies by Zhang, Bao and Li.[17-19] However, it was not statistically significant in the multivariate analysis of another study conducted in China.[20] In the current study and in Zhang's research,[17] the product specifically referred to was popcorn produced in a traditional method rather than by more modern processes. In the traditional method, the pot of popcorn is produced by hand in a private workshop, and the sealing layer between the pot and the lid contains a large amount of lead. Information on the cooking method was not specifically requested in Shen's study,[20] which may be the main reason for the difference between the findings. There have been studies documenting that the lead value in popcorn produced by the traditional method is 43 times the lead concentration in the raw materials, and a child became lead poisoned after eating a large amount intake of popcorn produced by the traditional method.[21,22]

Parents with lead exposure at the workplace can bring home lead dust on their skin, hair, shoes, and clothing.[23] In our study, children whose fathers' occupation involved contact with lead were 1.18 times more likely to have EBLLs than others in the bivariate analysis, but this was not found to be statistically significant. It was 1.32 times for the mother's occupation. The fact that parental occupational lead exposure was not observed to be a risk factor for children's elevated blood levels might be due to increased trends toward the promotion of healthier work environments and the improvement of workers' health habits along with the development of the economy and the improvement of the Chinese standard of living.

Cohabitants' smoking was not associated with EBLLs in the bivariate or multivariate analyses. This differed from previous studies showing that exposure to second hand tobacco smoke contributed to increased BLLs.[24] In 1977, the World Health Organization reported that tobacco contains some lead at concentrations between 2.5 and 12.2 μg/cigarette. Willers et al[25] documented that there is a significant association between higher lead levels in children and parental smoking in the home and that maternal smoking was more likely than paternal smoking to be associated with higher blood lead levels in their children. Perhaps we did not find this association in our study because much of the smoking in our study took place outdoors rather than indoors and therefore may not have had a discernable effect on the children's BLLs.

Lead in soil or house dust has been shown to be the dominant source of bioavailable lead to provide continuous lead exposure to young children and leaded petrol had been established as the dominant source for many years until lead was phased out of petrol.[26] Soil lead concentrations can reflect the historic deposition of lead from petrol.[27] Even in the USA where sharp reductions in environmental lead sources (i.e. leaded petrol and household paint) have occurred, higher bioavailable soil lead still exists along arterial roads and freeways compared with areas near local residential streets.[28] In China, unleaded petrol was first used in Beijing, Shanghai and Guangzhou in 1997 and its use was expanded across China in 2000. Chen et al[29] reported that there was about 6.7% petrol lead (from past use) embedded in Shenzhen residential dust and about 15.6% in Guangzhou dust. In Liu's study, leaded petrol emissions contributed 12% in the topsoil from 14 parks in Shanghai.[30] In our study, children living near arterial roads were not more likely to have EBLLs than those not living near arterial roads (P=0.66). Further research is needed to monitor the soil lead concentrations along the arterial roads. Future analyses need to take into account the date the arterial road was built. It was possible that many of the roads in our study were built in recent years and less lead was deposited.

Pollution levels in households that burn coal generally exceed air quality guidelines.[31] In addition, a study in Shanghai showed that coal consumption fly ash was a dominant source of lead exposure to children. The primary source of atmospheric lead in China, especially in South China, is the vast combustion of lead-containing coal, not gasoline.[32] In Germany, heating with coal or other fossil fuels is significantly associated with increased lead levels in house dust.[33] In our study, however, using coal or its products as the main kitchen fuel was not associated with EBLLs (P=0.76). The lack of association in the current study might be due to the promotion of improved housing conditions, such as setting up independent kitchens. Detailed information will need to be collected in any new survey.

Maternal frequent use of hair dyes had been shown to be a risk factor for EBLLs in a previous study from China.[34] In our study, however, parental frequent use of hair dyes (12 times every year or more) was not shown to be a risk factor. This might be due to the low percent of hair dye use in our study sample (1.23% for fathers and 0.66% for mothers).

The USA CDC has announced to change its guidelines for children's exposure to lead, reducing by half the previous BLL at which intervention is recommended.[35] The new BLL reference value is 50 μg/L and is based on the 97.5th percentile of the population BLL in children ages 1-5 years in the USA. Under this new value, the percent of children whose BLLs were equal or more than 50 μg/L in our study would have changed from 54.31% in 2004 and 36.43%

in 2010, which was far higher than that of the USA (it was 6.66% in 2010).

Our study had several limitations. The blood lead concentrations were measured with a BH2100 Tungsten atomizer absorption spectrophotometer in all monitoring sites, rather than a graphite furnace absorption spectrophotometer (the more accepted method). We chose to use the BH2100 Tungsten atomizer absorption spectrophotometer because of its timesaving and low cost features. We used a blood lead concentration to document the lead exposure of children. Although bone lead may be the most valuable measurement of internal dose, it would not have been accepted among the Chinese population for this large public health study which needed to maintain minimum intrusiveness.[36] A capillary sample rather than a venous blood sample was collected from each child enrolled to ensure a high participation rate in such a large sample. Our study sites (cities) were not selected randomly, which means that the results may not be representative of all cities in China. In addition, all of our samples were collected from children in cities and no children were from rural areas. These data are not, therefore, representative of all children in China.

In conclusion, we found that BLLs declined between 2004 and 2010 among Chinese children living in the 11 cities. This may have resulted from the promotion of healthier city environments with close attention paid by the central government to the banning of production and sale of leaded gasoline in 2000. Other policies may be also effective, such as the rules prohibiting the building of lead smelting mills in cities or suburbs issued in 2007 by the National Development and Reform Commission.[37] When compared to some developed countries such as the USA, Canada, Japan and Sweden, however, our children's BLLs were far higher. In our study, some risk predictors still existed, such as certain nursery situations, father's education level, and children's hygiene habits and dietary habits. Further efforts to prevent lead exposure and eliminate EBLLs among Chinese children are crucial.

Acknowledgements

We thank Beijing Bohui Innovation Technology Co., Ltd for funding this study. We are also grateful to the Ministry of Health of China and the staff members of these 11 surveillance sites.

Funding: This study was supported by Beijing Bohui Innovation Technology Co., Ltd.

Ethical approval: This study was approved by the ethics committee of the Capital Institute of Pediatrics.

Competing interest: No competing interests are involved in the study.

Contributors: Li T wrote the first draft of this paper. All authors contributed to the intellectual content and approved the final version. Dai YH is the guarantor.

References

1 Tong S, von Schirnding YE, Prapamontol T. Environmental lead exposure: a public health problem of global dimensions. Bull World Health Organ 2000;78:1068-1077.
2 Hernberg S. Lead poisoning in a historical perspective. Am J Ind Med 2000;38:244-254.
3 CDC's National Surveillance Data (1997-2011). http://www.cdc.gov/nceh/lead/data/national.htm (accessed December 20, 2012).
4 Schlenker TL, Fritz CJ, Mark D, Layde M, Linke G, Murphy A, et al. Screening for Pediatric Lead Poisoning. Comparability of simultaneously drawn capillary and venous blood samples. JAMA 1994;271:1346-1348.
5 National Guide to Clinical Laboratory Procedures (Third Edition): Medical Administration Department of Ministry of Public Health, P.R. China, 2006.
6 Mathee A, Röllin H, von Schirnding Y, Levin J, Naik I. Reductions in blood lead levels among school children following the introduction of unleaded petrol in South Africa. Environ Res 2006;100:319-322.
7 Na YS, Jung KA, Kim SM, Hong YS, Ryu MH, Jang SJ, et al. The histone deacetylase inhibitor PXD101 increases the efficacy of irinotecan in in vitro and in vivo colon cancer models. Cancer Chemother Pharmacol 2011;68:389-398.
8 Strömberg U, Lundh T, Schütz A, Skerfving S. Yearly measurements of blood lead in Swedish children since 1978: an update focusing on the petrol lead free period 1995-2001. Occup Environ Med 2003;60:370-372.
9 Kolossa-Gehring M, Becker K, Conrad A, Lüdecke A, Riedel S, Seiwert M, et al. German Environmental Survey for Children (GerES IV)--first results. Int J Hyg Environ Health 2007;210:535-540.
10 Cho SC, Kim BN, Hong YC, Shin MS, Yoo HJ, Kim JW, et al. Effect of environmental exposure to lead and tobacco smoke on inattentive and hyperactive symptoms and neurocognitive performance in children. J Child Psychol Psychiatry 2010;51:1050-1057.
11 Yoshinaga J, Takagi M, Yamasaki K, Tamiya S, Watanabe C, Kaji M. Blood lead levels of contemporary Japanese children. Environ Health Prev Med 2012;17:27-33.
12 Wong SL, Lye EJ. Lead, mercury and cadmium levels in Canadians. Health Rep 2008;19:31-36.
13 Roy A, Bellinger D, Hu H, Schwartz J, Ettinger AS, Wright RO, et al. Lead exposure and behavior among young children in Chennai, India. Environ Health Perspect 2009;117:1607-1611.
14 Lanphear BP, Dietrich K, Auinger P, Cox C. Cognitive deficits associated with blood lead concentrations <10 microg/dL in US children and adolescents. Public Health Reports 2000;115:521-529.
15 Barbosa F Jr, Tanus-Santos JE, Gerlach RF, Parsons PJ. A critical review of biomarkers used for monitoring human exposure to lead: advantages, limitations, and future needs. Environ Health Perspect 2005;113:1669-1674.
16 Lanphear BP, Hornung R, Ho M, Howard CR, Eberly S, Knauf K. Environmental lead exposure during early childhood. J Pediatr 2002;140:40-47.

17 Zhang B, Chen Z, Hu XJ, Yao SF, Qin LZ, Lin YY, et al. Study on blood lead level and related factors in children. Matern Child Health Chin 2010;25:1636-1638. [In Chinese]
18 Bao H, Meng J, Qu R, Zhao LY. Investigation on the leveI of blood lead and its influence factors for 0-6 children in Anshan area. Strait J Prev Med 2005;11:16-18. [In Chinese]
19 Li HQ, Zeng XQ, Wang ZH. Blood lead level and related factors in children from 2 kindergartens in Chongqing. Acta Acad Med Mil Tert 2003;25:2043-2045. [In Chinese]
20 Shen XM, Yan CH, Wu SH, Shi R. Parental education to reduce blood lead levels in children with mild and moderate lead poisoning: a randomized controlled study. Zhonghua Er Ke Za Zhi 2004;42:892-897. [In Chinese]
21 Xie HB, Li SQ. An analysis to popcorn lead level in market. Chin J Public Health 2005;21:918. [In Chinese]
22 Wei HJ, Jin YP, Ma WX. Lead poisoning of a child associated with higher intake of popcorn. Heilongjiang Med J 2011;24:813-814. [In Chinese]
23 Chiaradia M, Gulson BL, MacDonald K. Contamination of houses by workers occupationally exposed in a lead-zinc-copper mine and impact on blood lead concentrations in the families. Occup Environ Med 1997;54:117-124.
24 Kaji M, Gotoh M, Takagi Y, Masuda H. Blood lead levels in Japanese children: Effects of passive smoking. Environ Health Prev Med 1997;2:79-81.
25 Willers S, Schütz A, Attewell R, Skerfving S. Relation between lead and cadmium in blood and the involuntary smoking of children. Scand J Work Environ Health 1988;14:385-389.
26 Mielke HW, Gonzales CR, Powell E, Jartun M, Mielke PW Jr. Nonlinear association between soil lead and blood lead of children in metropolitan New Orleans, Louisiana: 2000-2005. Sci Total Environ 2007;388:43-53.
27 Mielke HW, Gonzales C, Powell E, Mielke PW Jr. Urban soil-lead (Pb) footprint: retrospective comparison of public and private properties in New Orleans. Environ Geochem Health 2008;30:231-242.
28 Wu J, Edwards R, He XE, Liu Z, Kleinman M. Spatial analysis of bioavailable soil lead concentrations in Los Angeles, California. Environ Res 2010;110:309-317.
29 Chen J, Tong Y, Xu J, Liu X, Li Y, Tan M, et al. Environmental lead pollution threatens the children living in the Pearl River Delta region, China. Environ Sci Pollut Res Int 2012;19:3268-3275.
30 Liu J, Ai Y, McCauley L, Pinto-Martin J, Yan C, Shen X, et al. Blood lead levels and associated sociodemographic factors among preschool children in the South Eastern region of China. Paediatr Perinat Epidemiol 2012;26:61-69.
31 Moriske HJ, Drews M, Ebert G, Menk G, Scheller C, Schöndube M, et al. Indoor air pollution by different heating systems: coal burning, open fireplace and central heating. Toxicol Lett 1996;88:349-354.
32 Liang F, Zhang G, Tan M, Yan C, Li X, Li Y, et al. Lead in children's blood is mainly caused by coal-fired ash after phasing out of leaded gasoline in Shanghai. Environ Sci Technol 2010;44:4760-4765.
33 Meyer I, Heinrich J, Lippold U. Factors affecting lead and cadmium levels in house dust in industrial areas of eastern Germany. Sci Total Environ 1999;234:25-36.
34 Ji GZ, Deng FM, Wu XY, Li QX, Song JH, Li WH, et al. An epidemiologic survey on blood lead levels in preschool children living in towns of Hunan Province. Zhongguo Dang Dai Er Ke Za Zhi 2010;12:645-649. [in Chinese]
35 CDC Response to Advisory Committee on Childhood Lead Poisoning Prevention Recommendations in "Low Level Lead Exposure Harms Children: A Renewed Call for Primary Prevention.", 2012. http://www.cdc.gov/nceh/lead/ACCLPP/CDC_Response_Lead_Exposure_Recs.pdf (accessed December 21, 2012).
36 Hu H, Aro A, Rotnitzky A. Bone lead measured by X-ray fluorescence: epidemiologic methods. Environ Health Perspect 1995;103 Suppl 1:105-110.
37 Access condition of lead and zinc industry, 2007. http://www.ndrc.gov.cn/zcfb/zcfbtz/2007tongzhi/t20071113_172130.htm. (accessed December 21, 2012).

Received December 21, 2012
Accepted after revision September 9, 2013