PERSONAL AND ENVIRONMENTAL RISK FACTORS SIGNIFICANTLY ASSOCIATED WITH ELEVATED BLOOD LEAD LEVELS IN RURAL THAI CHILDREN

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Abstract. A community-based study was conducted to determine personal risk factors and environmental sources of lead exposure for elevated blood lead levels (≥10 μg/dl, EBLLs) among rural children living at the Thailand-Myanmar border in Tak Province, northwestern Thailand. Six hundred ninety-five children aged 1-14 years old were screened for BLLs. Environmental specimens for lead measurements included samples of water from the streams, taps, and household containers, house floor dust, and foods. Possible lead release from the cooking ware was determined using the leaching method with acetic acid. The overall prevalence of EBLLs was 47.1 % and the geometric mean level of blood lead was 9.16 μg/dl. Personal risk factors significantly associated with EBLLs included being male, younger age, anemia, and low weight-for-age. Significant environmental risk factors were exposure to a lead-acid battery of solar energy system and use of a non-certified metal cooking pot. Some families whose children had high BLLs reported production of lead bullets from the used batteries at home. About one-third of the house dust samples taken near batteries contained lead content above the recommended value, compared with none of those taken from other areas and from the houses with no batteries. The metal pots were safe for cooking rice but might be unsafe for acidic food preparation. Both nutritional intervention and lead exposure prevention programs are essential to reduce EBLLs in this population.

Keywords: blood lead level, environmental lead exposure, lead, lead-acid battery, metal cooking pot, Thai children

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INTRODUCTION

Lead is a naturally occurring element found at low levels in the earth's crust. It can be dispersed throughout the environment primarily as the result of anthropogenic activities such as mining and smelting of ore, manufacture of lead-containing products, combustion of coal and oil, and waste incineration. The largest use of lead is for the production of batteries used in cars and other vehicles (ATSDR, 2007; WHO, 2010a). Lead is an important environmental pollutant of public health concern due to its wide range of organ toxicity (IARC, 2006; ATSDR, 2007; WHO, 2010b; Bellinger, 2011). Human exposure to lead is common and results from many industrial uses of lead, lead alloys, and lead compounds. Children are more vulnerable to lead toxic effects than adults because of many factors, including the developing nervous system, greater gastrointestinal absorption of lead, insufficient dietary intake (*eg*, iron and calcium), more contact with contaminated surfaces due to playing on the ground, and hand-to-mouth activities (Mahaffey, 1995; Bellinger, 2004; ATSDR, 2007; WHO, 2010a). The critical consequence of lead toxicity in young children is damage to the developing brain and nervous system (Bellinger, 2004; CDC, 2005; ATSDR, 2007; WHO, 2010b).

Blood lead measurement has been widely used for lead exposure screening in humans, particularly in children exposed to lead. The blood lead levels ≥10 μg/dl in children have long been used for case management and follow-up (CDC, 2002; American Academy of Pediatrics, 2005; Warniment *et al*, 2010). The US Advisory Committee on Childhood Lead Poisoning Prevention has recently recommended using the reference value based on the 97.5th percentile of the BLL distribution (5 μg/dl from the 2007-2010 NHANES) among children 1-5 years old (CDC, 2012). The areas where many children have high blood lead require communitywide prevention activities (CDC, 2005; ATSDR, 2007).

The US Centers for Disease Control and Prevention detected a high proportion of elevated blood lead levels (≥ 10 μg/dl, EBLLs) among refugee children arriving in the US and also among Myanmar children in the refugee camps near the Thailand-Myanmar border in Tak Province, northwestern Thailand (Mitchell *et al*, 2012). Risk factors for EBLLs in these young refugee children included anemia, exposure to car batteries, and taking traditional medicines.

A subsequent survey for blood lead levels among Thai children living at this border area similarly found a high rate of EBLLs (Neesanan *et al*, 2011). Exposure to a lead-acid battery was only the significant risk factor for EBLLs in a previous preliminary study with a small sample size (Swaddiwudhipong *et al*, 2013). The aim of this study was to determine personal risk factors and environmental sources of lead exposure significantly associated with EBLLs in a representative sample of children living at the Thailand-Myanmar border in Tak Province.

MATERIALS AND METHODS

Study subjects

A community-based survey was conducted in 2013 in Umphang District, located at the Thailand-Myanmar border in Tak Province, northwestern Thailand. The district had 6 sub-districts with 36 villages where most of the inhabitants were hilltribes. The study areas included 6 villages, one of which was randomly selected from each sub-district. All children aged 1-14 years old living in these 6 villages were the study subjects.

Health education about lead toxicity and the benefit of the screening program was given to the inhabitants before the survey. All target children were identified by village health volunteers and local health workers. Their parents or relatives were interviewed about demographic characteristics, children's behaviors, food and drinking water, cookware, house cleaning practices, and possible environmental sources of lead exposure at home. Body weight of each participant was measured to determine nutritional status.

Low weight-for-age was determined using the growth charts for Thai children (Department of Health, 2011). Venous whole blood was collected for measurements of a blood lead level and complete blood count. Thorough cleansing of the puncture site before blood collection and use of lead-free sample collection equipment and containers were performed to prevent external lead contamination of samples.

Ethical considerations

The Tak Provincial Health Office Ethics Committee approved this study protocol (Tak 2/2556, 2013 May10), and informed consent was obtained from the children's parents before the examination.

Environmental survey

There were no mines nor factories in the study villages. Nearly all villagers were farmers, and none worked in the lead manufacturing industries. Their usual diet consisted of cooked rice, locally grown vegetables, pork (occasionally), and homemade chili sauce mixed with salt. Many villagers used inexpensive non-certified metal pots for cooking. These pots could be purchased at the Thailand-Myanmar border. All the study villages had their own public piped water systems from different sources of water, with no water treatment processes. The piped distribution systems contained cement water storage containers, polyvinyl chloride (PVC) pipes, and bronze or PVC taps. In each study village, five samples of water from the sources and taps were obtained for lead measurements.

Because of no public electricity in the study villages, in 2004-2005, the government supplied each household with a complete set of solar energy conversion devices, including silicon solar cells, a charge controller, a vented lead-acid battery, and their connection accessories. However, this energy system could not continuously be supported to all households due to limited resources. The villagers commonly placed the solar cells outside but kept the batteries inside their houses. Periodic water replacement was commonly done at home. After the batteries had been discarded, many villagers purchased a new lead-acid one, but some could not buy it and stopped using this energy system.

All houses were made of bamboo or wood without painting. Each house normally contained three areas including common, sleeping, and kitchen areas. Environmental specimens for lead measurements were collected from 30 houses, 5 of which were randomly selected from each study village. One wipe sample of floor dust and one water sample from a drinking-water container were collected from each sampled house. In the house with a battery, an additional floor dust sample for lead measurement was collected near the battery.

To determine the possibility of lead release from the metal pot during cooking, we randomly selected 18 non-certified metal cooking pots from the families whose children had EBLLs. Samples of cooked rice from these 18 pots were obtained for lead analysis. Lead was experimentally extracted from these 18 pots by leaching with acetic acid according to the American Society for Testing and Materials and the lead concentrations in leaching solutions were compared to the US Federal Drug Agency action level of 1mg/l for large hollowware (FDA, 2000).

Laboratory analysis

The lead levels in blood were determined by a graphite furnace atomic absorption spectrometry (AAS) (Varian Model AA280Z®, Palo Alto, CA), by the laboratory of Mae Sot General Hospital. Quality assurance and control were conducted with simultaneous analysis of samples of the reference whole blood Lyphocheck® (Bio-Rad; Gladesville, NSW, Australia). The hospital has received the national laboratory accreditation. The lead concentrations in environmental samples were determined using an AAS by the Department of Medical Sciences, Thailand Ministry of Public Health. This national laboratory has received ISO/IEC 17025 accreditation. The laboratory complied with mandatory quality control measures.

In this study, an EBLL was defined as a venous blood lead value ≥10 μg/dl for comparison with other previous studies. A complete blood count was measured by using an auto-analyzer (Coulter®HmX Hematology Analyzer, Bechman Coulter, Brea, CA). Anemia was determined using the WHO hemoglobin threshold for each age group (WHO, 2008).

Statistical analysis

The Epi Info™ (version 7, CDC, Atlanta, GA) was used to analyze the study data. The prevalence of EBLLs was presented in percentages of the study children. The geometric means and geometric standard deviations were used to summarize blood lead levels, and the median and range for lead concentrations in environmental samples. The chi-square test was used for comparison of proportions. The analysis of variance, the Mann-Whiteney *U* test, or the Kruskal-Wallis test was used for comparison between means. Multiple logistic regression analysis was used to determine risk factors for EBLLs, after adjusting for other co-variables. Adjusted odds ratios and their 95% confidence intervals were calculated to indicate the strength of association.

RESULTS

Blood lead levels

Of 778 children living in the six study villages, 695 (89.3%) participated in the screening program. The remaining subjects (10.7%) were absent and could not be contacted at the time of the survey. The overall prevalence of EBLLs was 47.1 %, and the geometric mean level of blood lead was 9.16 μg/dl. Only 50 children (7.2%) had blood lead levels <5 μg/dl. Twenty-one children (3.0 %) contained blood lead values ≥20 μg/dl, but none had symptomatic lead poisoning. Table 1 presents blood lead levels in the study children, by gender, age, presence of anemia, and low weight-for-age. The blood lead levels were significantly higher in boys than girls. The levels of blood lead significantly decreased with age. The blood lead levels were significantly higher in children with anemia compared with those with normal hemoglobin values. Children with low weight-for-age had significantly higher blood lead than those with normal or excess weight.

Of the 695 study children, 84 (12.1%) had never had a battery for a solar system in their houses (never users), 299 (43.0%) stopped using the solar energy system due to damaged batteries or devices (former users), and the remaining subjects (312, 44.9%) were current users. The proportion of EBLLs significantly increased from

Table 1
Blood lead levels in the study children, by gender, age, presence of anemia, and low weight-for-age.

Characteristics	No. examined	Blood lead levels ≥ 10 µg/dl *n* (%)	*p*-value[a]	Mean ± SD[b]	*p*-value[c]
Total	695	327 (47.1)		9.16 ± 1.73	
Gender					
Male	330	177 (53.6)	< 0.01	9.68 ± 1.72	< 0.01
Female	365	150 (41.1)		8.71 ± 1.73	
Age (years)					
< 5	204	118 (57.8)		10.40 ± 1.69	
5-9	270	131 (48.5)	< 0.01	9.29 ± 1.67	< 0.01
10-14	221	78 (35.3)		7.99 ± 1.78	
Anemia					
No	527	228 (43.3)	< 0.01	8.84 ± 1.71	< 0.01
Yes	168	99 (58.9)		10.24 ± 1.77	
Low weight for age					
No	391	159 (40.7)	< 0.01	8.45 ± 1.76	< 0.01
Yes	304	168 (55.3)		10.16 ± 1.65	

[a]Differences between proportions; [b]geometric mean ± geometric standard deviation; [c]differences between means.

Table 2
Blood lead levels in the study children, by environmental source of lead exposure.

Exposures	No. examined	Blood lead levels ≥ 10 µg/dl *n* (%)	*p*-value[a]	Mean ± SD[b]	*p*-value[c]
Total	695	327 (47.1)		9.16 ± 1.73	
Use of a battery of solar energy system					
Never	84	27 (32.1)		7.94 ± 1.56	
Former	299	130 (43.5)	<0.01	9.18 ± 1.68	<0.01
Current	312	170 (54.5)		9.50 ± 1.81	
Use of a non-certified metal pot for cooking[d]					
No	209	80 (38.3)	<0.01	7.87 ± 1.92	<0.01
Yes	486	247 (50.8)		9.78 ± 1.62	
Use of a traditional/herbal remedy					
No/rarely	681	319 (46.8)	0.44	9.13 ± 1.73	0.37
Occasionally/sometimes	14	8 (57.1)		10.72 ± 1.48	
Mouthing a cosmetic product/toy					
No/rarely	641	299 (46.6)	0.46	9.11 ± 1.74	0.52
Occasionally/sometimes	54	28 (51.9)		9.79 ± 1.54	

[a]Differences between proportions; [b]geometric mean ± geometric standard deviation; [c]differences between means; [d]an inexpensive metal pot with no quality certification.

Table 3
Multiple logistic regression analysis of the determinants of elevated blood lead levels (≥10 μg/dl) in the study children.

Variables in a model	Prevalence of elevated blood lead levels		
	Odds ratio	95 % CI	*p*-value
Gender (male/female)	1.573	1.147-2.158	0.005
Age (<5/10-14 years)	2.680	1.745-4.115	<0.001
Age (5-9/10-14 years)	1.708	1.156-2.523	0.007
Anemia (yes/no)	1.495	1.024-2.184	0.037
Low weight for age (yes/no)	1.638	1.187-2.261	0.003
Use of a household battery of solar system (current/never)	2.537	1.464-4.397	<0.001
Use of a household battery of solar system (former/never)	1.250	0.720-2.171	0.428
Use of a non-certified metal cooking pot (yes/no)	1.579	1.103-2.259	0.013
Use of a traditional/herbal remedy (sometimes, occasionally/rarely, no)	1.166	0.373-3.648	0.792

32.1% in never users to 54.5% in current users (Table 2). The geometric mean level of blood lead correspondingly increased from 7.94 in never users to 9.50 mg/dl in current users. Children with exposure to food cooked in a non-certified metal pot had significantly higher blood lead levels than those with no exposure had. The study revealed no significant associations between blood lead levels and exposures to traditional/herbal remedies, cosmetic products, toys, food cans, candies, and tobacco smoking among family members.

Multiple logistic regression analysis was used to determine risk factors for prevalence of EBLLs (Table 3). Independent variables in the analysis included gender, age, presence of anemia, low weight-for-age, exposure to a household battery, use of a non-certified metal cooking pot, and a traditional/herbal remedy. The analysis revealed significant relationships between EBLLs and being male, younger age, anemia, low weight-for-age, exposure to a household battery, and use of a non-certified metal cooking pot.

Lead levels in environmental samples

Most study children drank unboiled piped water kept in a plastic or earthen water container. None of the water samples taken from the village water sources, taps, and household water containers had lead content above the WHO guideline value (Table 4).

Samples of house floor dust were collected for lead measurements from 30 randomly selected houses, of which 15 had batteries and 15 did not. In the houses with batteries, lead concentrations of the dust samples collected near batteries were significantly higher than those taken from other areas and also higher than those taken from the houses with no batteries. In addition, 5 of the 15 dust samples (33.3%) taken near batteries contained lead content above the level recommended by the US EPA (2001), compared with none of those taken from other areas and from the

Table 4
Lead levels in the environmental samples in the 6 study villages.

Environmental samples	No. examined	Median (range) of lead levels	Above the guideline levels *n* (%)
Drinking water (mg/l)			
Village water sources	30	ND (ND-0.007)	0 (0.0)[a]
Village taps	30	ND (ND-0.007)	0 (0.0)[a]
Household water containers	30	ND (ND-0.006)	0 (0.0)[a]
House floor dust (μg/100 cm²)[b]			
15 houses with batteries – battery areas	15	2.83 (0.05-7.46)	5 (33.3)[c]
– other areas	15	1.10 (0.06-3.62)	0 (0.0)[c]
15 houses with no batteries	15	0.94 (0.25-2.33)	0 (0.0)[c]
Non-certified metal cooking pot			
Cooked rice from 18 pots (mg/kg)	18	ND	0 (0.0)[d]
Leaching solution by acetic acid from 18 pots (mg/l)	18	0.18 (ND-0.85)	0 (0.0)[e]

[a]>0.01 mg/l, recommended by the WHO (2011); [b]p=0.012, comparison of lead content of the house dust samples among the 3 groups; [c]>4.3 μg/100 cm^2 (40 μg/ft^2), recommended by the US EPA (2001); [d]>1 mg/kg, recommended by the Thailand Ministry of Public Health (2013); [e]>1 mg/l, recommended by the US FDA (2000); ND = not detectable.

houses with no batteries.

We randomly selected 18 non-certified metal cooking pots from the families whose children had EBLLs for testing the possibility of lead release from the pots during cooking. All samples of cooked rice from these 18 pots were safe for consumption. All the lead concentrations in leaching solutions from these 18 pots were lower than the US FDA action value of 1 mg/l for large hollowware (FDA, 2000). However, wide ranges of lead concentrations in these leaching solutions were detected, and one (0.85 mg/l) was close to the guideline value.

Lead concentrations in soil, locally grown crops, and vegetables in the areas were found to be lower than the guideline values recommended by the US EPA (2001) and the Codex Alimentarius Commission (2010). Details of this survey were reported elsewhere (Office of Disease Prevention and Control 9, 2013).

Most villagers took meals with their fingers and rarely washed their hands before eating foods. They rarely cleaned their houses. During the survey, food and beverage cans, traditional/herbal remedies, cosmetic products, and child's toys were seldom found in the houses. Few villagers had motorcycles or cars. Nearly all villagers had not known about battery care and its health hazards before the survey. They rarely cleaned the batteries and surrounding parts, even after opening them for adjustments. When the batteries were in trouble, many villagers tried to repair them at home, such as using hot water to clean inside the batteries.

In the survey, there were 14 families with 21 children having high blood lead (≥20 μg/dl). The families of five of them reported production of lead bullets by melting lead from the used battery in a cooking pot and molding on a chopping block in their kitchens. Other families in the study villages denied such lead bullet production.

DISCUSSION

The present study indicated that both personal and environmental factors played important roles in EBLLs in these rural children. After adjusting for other co-variables, personal risk factors significantly associated with EBLLs included younger age, being male, presence of anemia, and low weight-for-age. A reverse correlation of blood lead level with age in children has been widely documented (Bellinger, 2004; Schnaas *et al*, 2004; ATSDR, 2007; Levin *et al*, 2008; WHO, 2010b; CDC, 2013). Young children are more vulnerable to lead exposure than older children and adults due to their innate curiosity, age-appropriate hand-to-mouth behavior and higher lead absorption in the gastrointestinal tract (Bellinger, 2004; ATSDR, 2007; Levin *et al*, 2008; WHO, 2010b).

Because young children are at greater risk of lead exposure and neurotoxicity, they should be the primary targets for exposure prevention programs. The findings of gender difference in blood lead levels in our children were consistent with those previously reported from Thailand and other developing countries (Wang *et al*, 1992; Ruangkanchanasetr and Suepiantham, 2002; Neesanan *et al*, 2011; Iriani *et al*, 2012; Naicker *et al*, 2012) and might be due to behavioral differences between boys and girls.

Several studies have shown an association between low iron levels and EBLLs in children (Wright *et al*, 1999, 2003; Bradman *et al*, 2001; Mitchell *et al*, 2012).This study similarly showed a significant relationship between EBLLs and anemia. However, anemia can also be the toxic effect of lead on the hematological system. Both increased blood lead and anemia,which can cause adverse health effects, should be corrected. Lead absorption and susceptibility to toxicity have been found to increase in the status of nutritional deficiencies (such as for iron and calcium) and during a fasting period (Rabinowitz *et al*, 1980; Flanagan *et al*, 1982; Mahaffey, 1995; Ros and Mwanri, 2003; Liu *et al*, 2011).

Our study indicated that the prevalence of EBLLs significantly increased in children with low weight-for-age, who might have some nutritional deficiencies and periods of fasting. Nutritional interventions should be one essential component of lead poisoning prevention programs for children in areas where nutritional deficiencies and lead exposure remain prevalent.

In developed countries, eliminations or regulations of the use of lead in gasoline, paints, solder, plumbing, pesticides, and ammunition have resulted in marked reductions in environmental contamination and blood lead levels (ATSDR, 2007; WHO, 2010a; CDC, 2013; Etchevers *et al*, 2014). However, significant sources of lead exposure remain common in many developing countries. In Thailand, environmental risk factors of EBLLs reported previously included presence of peeling paint in or outside the house, eating paint chips, their household members' occupations related to printing or lead smelting, exposure to lead-containing soil, and drinking contaminated water (Ruangkanchanasetr and Suepiantham, 2002; Chomchai *et al*, 2005; Pusapukdepob *et al*, 2007; Neesanan *et al*, 2011).

The present study found a significant association between EBLLs and exposure to a lead-acid battery of solar energy systems. Improper care of batteries within households might contribute to lead contamination in home environments, as demonstrated by higher lead concentrations in the floor dust samples collected near the battery, compared to those taken from other areas and from the houses without batteries. Production of round lead bullets from the used batteries at home was an additional hazardous practice in these areas. Poor sanitary practices, including rarely cleaning the houses, taking meals with fingers, and seldom washing hands before eating foods might increase lead exposure in these children. Safety use and proper care of lead batteries, including placing them with covers outside the houses are important because children spend most of their time indoors.

Lead-glazed ceramic cookware used in food preparation has been one important source of lead exposure in Mexico and some local communities in the US (Rojas-López *et al*, 1994; Rothenberg *et al*, 2000; Schnaas *et al*, 2004; ATSDR, 2007; Lynch *et al*, 2008; Villalobos *et al*, 2009). Use of a metal cooking utensil was identified as an independent factor associated with EBLLs in children in Pakistan (Rahbar *et al*, 2002). The present study also suggested a significant association between EBLLs and use of a non-certified metal cooking pot. The suspected pots appeared to be safe for cooking rice in this study. However, a wide range of lead concentrations in leaching solutions by acetic acid from these pots suggested that the pots might be unsafe for cooking acidic foods.The use of a quality certified cookware should be encouraged, particularly for acidic food preparation.

This study indicated that excessive exposure of humans to lead could occur even in the remote areas and result from human activities. Both nutritional intervention and lead exposure prevention programs are essential to reduce EBLLs in this population.

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