BLOOD LEAD LEVELS AMONG RURAL THAI CHILDREN EXPOSED TO LEAD-ACID BATTERIES FROM SOLAR ENERGY CONVERSION SYSTEMS

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Abstract. We evaluate blood lead levels among Thai children to determine if exposure to lead-acid batteries is associated with elevated blood lead levels (EBLL). We screened 254 children aged 1-14 years old from 2 rural Thai villages for blood lead levels. We also screened 18 of 92 houses in these 2 villages for the presence of environmental lead. The overall prevalence of EBLL (≥10 g/dl) was 43.3% and the mean lead level among study subjects was 9.8 ± 5.1 g/dl. The blood lead levels significantly decreased with increasing age. Fifty point eight percent of children who lived in a house with vented lead-acid batteries had EBLL while 23.3% of children who lived in a house without vented lead-acid batteries had EBLL. Multiple logistic regression analysis revealed a significant positive association between the presence of vented lead-acid batteries and EBLL, after adjusting for other variables. Forty-two point nine percent of house floor dust samples collected near the batteries had elevated lead levels, 7.1% of house floor dust samples collected from other areas in the house had elevated lead levels and 0% of the house floor dust samples collected in houses without vented lead-acid batteries had elevated lead levels. In the sampled houses with vented lead-acid batteries, lead contamination was found in the drinking-water kept in household containers, but not in the tap water or other village sources of water. Improper care and placement of vented lead-acid batteries can result in lead contamination in the home environment causing EBLL in exposed children.

Keywords: elevated blood lead, children, lead exposure, lead-acid battery, Thailand

INTRODUCTION

Solar energy is usually thought of as being an environmentally friendly renewable energy source. Solar cell converts sunlight into electricity through a photovoltaic effect and then stores the energy in a battery. In 2004, the Thai Ministry of Energy began to supply solar energy devices to households in rural Thailand where no public electricity is available (Thai Solar Home System Project). These batteries use vented lead-acid ones to store the energy.

Lead is an important environmental pollutant of public health concern due to

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its toxic effects on many organs and systems (IARC, 2006; ATSDR, 2007; Bellinger, 2011; WHO, 2010a). Human exposure to lead is common. The major industrial use of lead is the production of lead batteries (ATSDR, 2007; WHO, 2010a). Children are more sensitive to lead toxicity than adults because of developing nervous systems, greater gastrointestinal absorption of lead, insufficient dietary intake of other minerals (*eg*, iron and calcium), and hand-to-mouth behavior (Mahaffey, 1995; Bellinger, 2004; ATSDR, 2007; WHO, 2010b). One of the most important effect of lead in young children is on the developing nervous system. A blood lead level ≥ 10 g/dl in children is considered elevated and is an indication of excessive exposure (CDC, 1991; American Academy of Pediatrics, 2005; ATSDR, 2007).

After detecting a higher rate elevated blood lead levels (EBLL) among refugee children from Myanmar arriving in the United States compared to children of Myanmar ancestry born in the US, the Centers for Disease Control and Prevention conducted a survey in 2009 to identify risk factors for EBLL among Myanmar children in refugee camps in Tak Province, northwestern Thailand (Mitchell *et al*, 2012). Significant lead exposures in these young children included exposure to car batteries and taking traditional medicines containing lead (Mitchell *et al*, 2012). Two other surveys of blood lead levels were conducted during 2010-2011 among Thai children aged 3-7 years old and pregnant women living along the Thailand-Myanmar border in two subdistricts of Umphang District, Tak Province, Thailand. The rate of EBLL was significantly greater in children (26.8%) than in pregnant women (8.2%) (Neesanan *et al*, 2011; Tak Provincial Health Office, 2012). Children who lived in rural areas had a much higher rates of EBLL (40.6%) than those in urban areas (6.3%). However, the environmental sources of lead exposure were not investigated. The present study was conducted in April 2012 to determine the risk factors for EBLL and the sourses of lead exposure among rural children.

MATERIALS AND METHODS

Study area and subjects

The study area was two rural villages randomly selected from 14 villages in two previously surveyed subdistricts of Umphang District, Tak Province, Thailand. All the children aged 1-14 years old living in those two villages were included in the study. The study protocol was approved by the Mae Sot Hospital Ethics Committee. Informed consent was obtained from the children's parents prior to inclusion in the study.

One week prior to the survey, health education about lead toxicity through group lectures and discussions was conducted for village leaders, village health volunteers, and the members of those villages. Village health volunteers were asked to educate the other villagers who were unable to attend the discussions or group lectures. Parents of the subjects were interviewed regarding demographic characteristics, child behavior, cleaning practices and possible dietary and environmental sources of lead exposure. The body weight and height of each subject were measured to estimate nutritional status. Low weight for height was determined using the growth charts for Thai children (Department of Health, 2011). Venous blood was collected for measuring a blood lead level and complete blood count. Thorough cleansing of the puncture site before blood collection and use of lead-free collection equipment was performed to prevent lead contamination of samples.

Environmental survey

The study villages were located in rural areas with no mine or factory nearby. The majority of villagers were farmers. Their diet commonly consisted of cooked rice, locally grown vegetables (fresh or boiled), and homemade chili sauce mixed with salt. Many villagers used inexpensive non-certified metal pots for cooking. These pots could be purchased along the Thai-Myanmar border. Both study villages had their own piped public water from different water sources with no water treatment. The piped distribution system uses cement water storage containers, polyvinyl chloride (PVC) pipes and bronze or PVC taps.

There was no public electricity utility in either village, during the study so the government supplied each household with a solar energy conversion device which includes silicon solar cells, a charge controller, a vented lead-acid battery and connection accessories. The solar cells were outside but many villagers placed the batteries inside their houses. Periodic water replacement in the batteries was done at home. After the batteries lost their effectiveness, many villagers discarded the old battery and purchased a new one.

All the houses were made of bamboo or wood without paint. Most houses contained three areas: a common area, a sleeping area and a kitchen area. Environmental specimens were collected to measure lead levels from 18 houses randomly selected from the 92 houses in the study villagers. Only 18 houses were sampled due to financial constraints of the study. Of the 18 sampled houses, 14 had batteries and 4 did not. Three samples were obtained from each house, one each from the 3 areas commonly found in each house. One sample was always collected from the room containing the batteries. One tap water sample and one drinking-water container sample were collected from each house. Of the 18 sampled households, 11 reported using non-certified metal cooking pots and 7 used quality certified ones. To determine the possibility of lead release from the metal pot during rice cooking or from contaminated rice grains, we asked each household to cook rice twice, one with their own rice and our bottled water and the other with our rice and our bottled water (determined to low lead levels below the guideline values). Both samples of cooked rice were collected for lead analysis from each household.

In each village, we collected 2 samples of source water, 2 types of vegetables grown in the area, 1 sample from a nearly stream and 1 sample from the school playground to measure lead levels.

Laboratory analysis

The lead levels were determined using graphite furnace atomic absorption spectrometry (PerkinElmer, San Jose, CA); performed by the Department of Medical Sciences, Thai Ministry of Public Health, which has ISO/IEC 17025 accreditation. An EBLL was defined as a venous blood lead level ≥ 10 g/dl. Complete blood counts were performed using an auto-analyzer (Coulter HmX, Brea, CA). Anemia was determined using WHO hemoglobin threshold levels for each age group (WHO, 2008).

Statistical analysis

Variables were expressed in percentages. The mean and standard deviation were used to summarize normally distributed data, and the median and range for non-normally distributed values. The chi-square test or the Fisher's exact test was

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

Characteristics	No. Surveyed	Blood lead levels (g/dl) < 10 No. (%)	≥ 10 No. (%)	*p*-value[a]	Mean ± SD	*p*-value[b]
Total	254	144 (56.7)	110 (43.3)		9.8 ± 5.1	
Age (years)						
< 5	70	31 (44.3)	39 (55.7)		11.2 ± 5.7	
5-9	96	56 (58.3)	40 (41.7)	0.033	9.5 ± 4.6	0.018
10-14	88	57 (64.8)	31 (35.2)		8.9 ± 4.9	
Gender						
Male	118	64 (54.2)	54 (45.8)	0.462	10.2 ± 5.2	0.155
Female	136	80 (58.8)	56 (41.2)		9.3 ± 5.0	
Low weight for height						
No	206	121 (58.7)	85 (41.3)	0.401	9.4 ± 5.1	0.129
Yes	48	25 (52.1)	23 (47.9)		10.7 ± 5.3	
Anemia						
No	185	108 (58.4)	77 (41.6)	0.274	9.4 ± 4.7	0.160
Yes	69	35 (50.7)	34 (49.3)		10.4 ± 5.8	

[a]Differences between proportions; [b]Differences between means

used for comparison of proportions. The analysis of variance or the Mann-Whitney *U* test was used to compare means. Multiple logistic regression analysis was used to determine risk factors for EBLL, after adjusting for other co-variables. The adjusted odds ratios and their 95% confidence intervals were used to determine strength of association.

RESULTS

Blood lead levels

A total of 254 of 281 children (90.4%) aged 1-14 years old living in the study villages were included in the survey. The remainder (9.6%) were either absent or could not be contacted at the time of the survey. Forty-six point five percent of the participants were male. The overall prevalence of EBLL was 43.3% and the mean lead level was 9.8 ± 5.1 g/dl (Table 1). Nine children (3.5%) had blood lead levels ≥ 20 g/dl but none were symptomatic. The blood lead levels decreased significantly with increasing age. Children aged <5 years had the highest percentage of EBLL and the greatest mean blood lead level. The mean blood lead level was higher among boys than girls but the difference between genders was not statistically significant. Children with a low weight for height had a higher mean blood lead level than those with a normal or elevated weight for height, but the difference was not statistically significant. Similar findings were found for children with anemia.

Of the 254 study children, 73 (28.7%) had no batteries in their houses after having been discarded or they build a new house without using solar energy or for

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

Exposures	No. surveyed	Blood lead levels (g/dl) < 10 No. (%)	Blood lead levels (g/dl) ≥ 10 No. (%)	*p*-value[a]	Mean ± SD	*p*-value[b]
Total	254	144 (56.7)	110 (43.3)		9.8 ± 5.1	
Battery inside the house						
No	73	56 (76.7)	17 (23.3)	<0.001	8.4 ± 4.5	0.010
Yes	181	89 (49.2)	92 (50.8)		10.3 ± 5.4	
Use of a non-certified metal pot for cooking[c]						
No	114	73 (64.0)	41 (36.0)	0.019	8.9 ± 5.0	0.024
Yes	140	69 (49.3)	71 (50.7)		10.5 ± 5.4	
Use of a traditional/herbal remedy						
No/rarely	247	144 (58.3)	103 (41.7)	0.459	9.7 ± 5.6	0.731
Occasionally/sometimes	7	3 (42.9)	4 (57.1)		10.5 ± 2.2	
Mouthing a cosmetic product/toy						
No/rarely	238	134 (56.3)	104 (43.7)	0.997	9.7 ± 4.9	0.571
Occasionally/sometimes	16	9 (56.3)	7 (43.8)		10.5 ± 7.3	

[a]Differences between proportions; [b]Differences between means; [c]An inexpensive metal pot with no quality certification.

other reasons. Fifty point eight percent of children who lived in a house with batteries had EBLL compared to 23.3% of children who lived in a house without batteries (Table 2). The mean blood lead level was significantly higher among children exposed to batteries than those who were not. Children exposed to food cooked in a non-certified metal pot had significantly higher blood lead levels than those whose food was cooked in a certified metal pot. The study revealed no significant associations between blood lead levels and exposure to traditional/herbal remedies, cosmetic products, toys, candies, food cans or tobacco smoking by family members.

Multiple logistic regression analysis was used to determine risk factors for prevalence of EBLL. Independent variables included in the analysis were age, gender, presence of anemia, low weight for height, exposure to a household battery and use of a non-certified metal cooking pot. Age and exposure to a household battery were two factors significantly associated with EBLL (Table 3). Compared to children aged 10-14 years, those aged < 5 years had a 2.9-fold (95% CI: 1.3-6.9) risk of EBLL. There was a 3.0-fold (95% CI: 1.4-6.3) higher risk of EBLL among those exposed to household batteries.

Lead levels in environmental samples

Environmental samples for lead measurements were collected from 18 randomly selected houses, of which 14 had batteries and 4 did not. In the houses with batteries, lead levels in floor dust samples collected near batteries were higher than those taken from other areas and higher than those taken from the houses with no batteries (Table 4). Six of

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

Variables in the model	Prevalence of elevated blood lead levels		
	Odds ratio	95 % CI	*p*-value
Age, ratio of < 5 years to 10-14 years	2.9	1.3-6.9	0.012
Age, ratio of 5-9 years to 10-14 years	1.5	0.7-2.8	0.269
Male to female ratio	1.4	0.8-2.6	0.256
Low weight for height, ratio of yes to no	1.1	0.5-2.6	0.787
Anemia, ratio of yes to no	1.3	0.6-2.5	0.474
Exposure to a household battery, ratio of yes to no	3.0	1.4-6.3	0.003
Use of a non-certified metal cooking pot ratio of yes to no	1.5	0.8-2.7	0.160

the 14 house dust samples (42.9%) taken near batteries contained lead levels above the US Environmental Protection Agency (EPA) recommended levels versus 7.1% in those samples taken from other areas in houses with batteries and 0% from houses without batteries.

Most study children drank unboiled pipe water kept in plastic or earthen containers with no lids. Household water containers were rarely cleaned. In the 14 sampled houses with batteries, 71.4% of drinking-water samples had a lead content above WHO guideline values, but none of the samples taken from the tap or village water sources had elevated lead levels. All the vegetable and cooked rice samples (using either non-certified or certified metal pots) had safe lead levels. Lead levels in soil samples ranged from 4.6 to 160.0 mg/kg; all below the US EPA recommended level of 400 mg/kg.

Nearly all villagers ate meals with their fingers and rarely washed their hands before eating. They rarely cleaned their houses. During the survey, food and beverage cans, traditional/herbal remedies, cosmetic products, and children's toys were seldom found in the studied houses. Few villagers had motorcycles or cars. Almost none of the villagers knew about battery care or its health hazards before the survey. They rarely cleaned the batteries or the surrounding areas even after opening them for adjustments. When the batteries had problems, many villagers tried to correct the problem themselves at home by opening the batteries and cleaning the inside using hot water.

DISCUSSION

Young children are more vulnerable to lead exposure than older children and adults due to their innate curiosity, hand-to-mouth behavior, and higher lead absorption in the gastrointestinal tract (Bellinger, 2004; ATSDR, 2007; Levin *et al*, 2008; WHO, 2010b). Children are also more likely to have nutritional deficiencies that lead to increased absorption of lead (Mahaffey, 1995). Young children, particularly those ages < 5 years, are at higher risk of the adverse effects of lead (WHO, 2010a). The highest prevalence of EBLL in this study was in children aged < 5 years.

The following findings suggest ex-

Table 4
Lead content in environmental specimens in studied villages and sampled houses (N=18).

Specimens		No. surveyed	Lead content Median (range)	No. (%) exceeding the guideline levels
House floor dust (g/100 cm^2)				
Houses with batteries:	Battery areas	14	3.3 (0.1-9.2)	6 (42.9)[a]
	Other areas	28	1.4 (0.2-7.2)	2 (7.1)[a]
Houses without batteries:	Any area	12	1.1 (0.1-3.0)	0 (0.0)[a]
Drinking water (mg/l)				
Village water sources		4	ND (ND-0.006)	0 (0.0)[b]
Houses with batteries:	From tap	14	ND (ND-0.005)	0 (0.0)[b]
	From containers	14	0.014 (ND-0.122)	10 (71.4)[b]
Houses without batteries:	From tap	4	ND (ND-0.005)	0 (0.0)[b]
	From containers	4	ND (ND-0.009)	0 (0.0)[b]
Food (mg/kg)				
Vegetables grown in the village		4	ND	0 (0.0)[c]
Houses with batteries:	Cooked rice[d]	28	ND	0 (0.0)[c]
Houses with no batteries:	Cooked rice[d]	8	ND	0 (0.0)[c]

[a]>4.3 g/100 cm^2 (40 g/ft^2), recommended by the US Environmental Protection Agency (2001).
[b]>0.01 mg/l, recommended by the World Health Organization (WHO, 2011).
[c]>0.1-1 mg/kg for various foods, recommended by the Codex Alimentarius Commission, Joint FAO/WHO (2010).
[d]Using either non-certified or quality certified metal pots.
ND, not detectable.

posure to a household lead-acid battery might increase risk for EBLL in study children: 1) blood lead levels were significantly higher in children who lived in the houses with batteries than those who did not. Multiple logistic regression analysis showed a positive association between household battery exposure and EBLL, after adjusting for other co-variables. 2) lead levels in the floor dust taken near batteries were higher than those collected from other areas and higher than those taken from houses without batteries. A significant proportion of dust samples collected near batteries contained lead above the guideline values. 3) in the houses with batteries, lead contamination was demonstrated in drinking water kept in household containers, but not in tap water or village water sources.

Poor sanitary practices including improper battery care, rarely cleaning houses or water containers and seldom covering the water containers, which could increase the likelihood of lead contamination from the batteries. Eating with fingers and seldom washing hands before eating food, frequently observed in these children, may also have increased their exposure to lead.

Contaminated dust and soil are common sources of lead exposure for children in countries that no longer use leaded petrol (American Academy of Pediatrics, 2005; ATSDR, 2007; Levin *et al*, 2008; WHO, 2010a). The weathering, peeling or chipping of lead-based paints, mainly found in older houses, plays a role in children's exposure. Lead-containing dust may be brought into the home on the clothes of those who work in industries where such dust is generated. Previous studies in Thai children also reported similar risk factors for EBLLs including the presence of peeling paint in or outside the house, eating paint chips, household members with an occupation related to printing or lead smelting and exposure to lead-containing soil (Ruangkanchanasetr and Suepiantham, 2002; Chomchai *et al*, 2005; Pusapukdepob *et al*, 2007). The present study found improper care of vented lead-acid batteries in households contributes to lead contamination at home and EBLL in exposed children. Increased blood lead levels in children linked to batteries has mostly been reported near places involved with battery manufacturing, recycling or repair through contaminated environments or the clothe of workers in those places and the children who are members of their houses (Matte *et al*, 1989; Tabaku *et al*, 1998; Suplido and Ong, 2000; de Freitas *et al*, 2007; Haefliger *et al*, 2009; Khan *et al*, 2010; Gottesfeld and Pokhrel, 2011; Tuakuila *et al*, 2012). The present study found an increased risk of EBLL in children exposed to lead-acid batteries at home.

Over the past few years, significant emphasis has been put on the search for new energy systems based on renewable sources which require less energy consumption and are more environmentally friendly. Solar cells are one of the most promising systems due to their energy conversion efficiency. However, the safe storage, use and care of lead batteries in households is essential.

In the present study we were unable to measure lead levels in the air as a possible source of lead exposure for the study children.

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