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Identifying the Blood Lead Reference Value Based on the Advisory Committee on Childhood Lead Poisoning Prevention Guidelines and Factors Associated with Elevated Blood Lead Levels among Preschool Children in Thailand, 2019

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Abstract

The blood lead reference value (BLRV) is used for guiding lead prevention and control measures. It is usually defined as the 97.5th percentile of the population-based blood lead level in each country. This study aims to determine the BLRV and factors associated with elevated (≥5 µg/dL) blood lead levels among children aged 1–5 years in Thailand. A cross-sectional study was conducted using secondary data extracted from a national survey, implemented in 171 hospitals during October 2018–September 2019. Demographic characteristics and potential risk factors including lead-related industries were collected. Multilevel logistic regression was used. Of 3,184 children included in the survey, the BLRV was 6.9 µg/dL. Three significant risk factors were identified: living near a lead factory (adjusted odds ratio (AOR) 2.09, 95% CI 1.27–3.42), exposure to the manufacture of fishing tackle (AOR 4.39, 95% CI 1.54–12.50), and exposure to the manufacture of shot and ammunition (AOR 6.30, 95% CI 1.81–21.93). Despite a calculated BLRV of 6.9 µg/dL, we propose a BLRV of 5 µg/dL in Thailand based on guidelines from the United Kingdom. Surveillance of blood lead levels should be established among children at high risk of lead exposure.

Keywords: blood lead reference value, elevated blood lead level, preschool children, Thailand

Introduction

Lead is an important chemical with its properties suitable for use in many materials and industries, including pipes, weights, storage batteries, shot and ammunition, fishing tackle, cable covers, and protection from radiation.[1,2] Children and adults can be exposed to lead in various routes such as ingestion, inhalation, and skin absorption.[3,4] As a toxic metal, lead has harmful properties. Children are especially at risk, causing anemia, damage of the nervous system and limited growth and development.[1,4–6]

In the United States, repeated surveys of children aged 1–5 years have been conducted since 1976 as the part of National Health and Nutrition Examination Survey.[7,8] Part of the survey includes measurements of blood lead levels (BLL). Established in 1989, the Advisory Committee on Childhood Lead Poisoning Prevention (ACCLPP) have provided recommendations for prevention and control measures regarding childhood lead poisoning including the determination of the blood lead reference value (BLRV).[9] To identify children with a high blood lead level, ACCLPP use the 97.5th percentile of the population-based blood lead level surveyed among children aged 1–5 years.[8] Based on the National Health and Nutrition Examination Survey data during 2007–2010, the BLRV in the United States has been set to be 5 micrograms per deciliter (µg/dL) since 2012. However, the value was decreased to 3.5 µg/dL in 2021 based on the 2015–2018 surveys.[10] Since no level is considered to be safe, prevention and control measures should aim to prevent any exposure to lead. The BLRV would be the action level, guiding appropriate interventions to protect children from lead toxicity. However, determination of the BLRV varies depending on the baseline BLL of specific populations in each country.

Based on the Health Data Center in Thailand, it is reported that the incidence of lead poisoning among children aged 0–5 years in 2018 was 0.23 per 100,000 population.[11] However, this value may be an underestimate since all of the reported cases had severe symptoms and required treatment in hospital. Asymptomatic cases with a high BLL, or even those with mild symptoms, will be undiagnosed unless their blood is tested. In Thailand, a national survey on BLL among children, which assessed factors potentially causing lead exposure, was undertaken for the first time under the project “Smart Children Stay Safe and Stay Away from Lead” implemented in the 2019 fiscal year (October 2018–September 2019).[12] At that time, Thailand still used a BLRV of 10 µg/dL based on the U.S. Centers for Disease Control and Prevention recommended level in 1991.[10] This study aims to determine the BLRV among children aged 1–5 years, examine factors associated with an elevated blood lead level, and provide recommendations for lead prevention and control measures among children in Thailand.

Methods

A cross-sectional study was conducted using secondary data extracted from the “Smart Children Stay Safe and Stay Away from Lead” project.[12] The project was implemented to Well Child clinics in 171 hospitals in 48 provinces, covering all 12 health regions of Thailand and Bangkok, the capital city, in the 2019 fiscal year. The method of the survey is as follows. Quota sampling was used to recruit participants. Sampling was proportionate to the total number of children aged 1–5 years in each of the 13 areas. At least two provinces were included from each health region, except Bangkok, which included only one. A total of 48 provinces, selected by the health regions, asked governmental hospitals that had Well Child Clinics about their willingness to participate in the project. The study population included children aged 1–5 years who visited a Well Child Clinic in the selected hospitals. Written informed consent was obtained from the children’s parents or legal guardians before collecting blood samples and other information using a structured questionnaire. Variables collected included demographic characteristics (age, gender, school attendance) and three potential risk factors that reflect a child’s exposure to lead, namely (1) parent’s or guardian’s occupations (if related to lead), (2) if any work is related to lead at the home, and (3) residential location (within 30 meters of a factory or enterprise that manufactures lead). We also collected nine types of industries related to the abovementioned risk factors that may have caused exposure to the children, namely (1) jewelry manufacturing, (2) demolition and construction of buildings, (3) ship manufacturing, (4) paint manufacturing, (5) machinery and/or motor vehicle manufacturing, (6) battery storage, (7) shot and ammunition, (8) electronic waste, and (9) fishing tackle.

Figure 1. Map showing the 48 provinces of Thailand that were included in the national survey project, 2018-2019

Venous blood (2 mL) was collected and tested by Graphite Furnace Atomic Absorption Spectroscopy technique at the Reference Laboratory and Toxicology Center, Division of Occupational and Environmental Diseases.[13] A blood lead level (BLL) greater than or equal to 5 µg/dL was considered as elevated.

Data was analyzed using Microsoft Excel and Stata version 14. For the descriptive study, categorical variables were expressed as frequency and percentage. Comparisons between children with non-elevated and elevated BLL by each categorical variable were performed using a Chi-square test. The prevalence of BLL in the study population was adjusted for sampling weights. Summary statistics included mean and standard deviation, median with interquartile range (IQR), and range. The 97.5th percentile of the blood lead level was calculated in order to determine the BLRV. For the analytical study, a multilevel logistic regression model with independent variance–covariance structure of the random effects was fit to the data in which children were nested within hospitals and hospitals nested within provinces. Predictor variables included gender, age group (<3 versus 3–5 years), school attendance, lead exposure, and the nine aforementioned risk industries. Predictors with a *p*-value <0.2 were selected for the multivariable analysis. Adjusted odds ratio (AOR) with 95% confidence interval (CI) were presented with a significance level of 0.05.

Results

The participants in the study included 3,184 children aged 1–5 years from 48 provinces of Thailand (Figure 1). The population-based blood lead levels ranged from 0–42.8 µg/dL and the median was 1.1 µg/dL (IQR 0.4–2.2). Children aged 3–5 years had a higher BLL than those aged <3 years. The BLRV overall was 6.9 µg/dL (Table 1).

Table 1. Comparison of blood lead levels among children aged <3 years and 3–5 years, Thailand

Age group (years)	No. of children	Blood lead level (µg/dL)				
		Median	Range	IQR	Mean±SD	P97.5
1–5	3,184	1.1	0–42.8	0.4–2.2	1.7±2.3	6.9
<3	1,728	0.9	0–28.6	0.2–1.9	1.5±2.1	6.4
3–5	1,456	1.4	0–42.8	0.7–2.4	2.0±2.5	7.6

IQR: interquartile range, SD: standard deviation, P97.5: 97.5th percentile

Of 3,184 children, 52.0% were male and 56.8% were attending school. There were 606 (19.0%) children whose parent's or guardian's occupations were related to lead, 351 (11.0%) lived in a home where lead was used for manufacturing, and 420 (13.2%) lived near a factory or enterprise that manufactured lead. Manufacture of machinery and motor vehicles (10.6%) was the most common enterprise in which children were exposed to lead, followed by demolition and construction of buildings (6.0%), and paint manufacturing (5.6%) (Table 2). The proportion of children with an elevated BLL was higher in children aged 3-5 years and those who were attending school. Children whose parent's or guardian's occupations were related to lead or those who lived in a house where lead was used for manufacturing or whose house was located near a factory or enterprise which manufactured lead were significantly more likely to have an elevated blood lead level. If the enterprise involved making fishing tackle or ammunition then the likelihood of having an elevated blood lead level was significantly higher (Table 2).

Results of the univariate and multivariate analysis are shown in Table 3. Older age, attending school, having a parent or guardian whose occupation involved lead, living in a house where lead was used for manufacturing, living in a house near a lead factory or enterprise, exposure to manufacturing of fishing tackle, and exposure to manufacturing of shot and ammunition were significant risk factor on univariate analysis. On multivariate analysis, only three significant risk factors remained: living in a house located near a lead factory or enterprise (AOR 2.09, 95% CI 1.27–3.42), exposure to manufacturing of fishing tackle (AOR 4.39, 95% CI 1.54–12.5), and exposure to manufacturing of shot and ammunition (AOR 6.30, 95% CI 1.81–21.93).

Table 2. Comparison of epidemiological characteristics and lead-related risk factors among children with and without elevated blood lead levels (n=3,184)

Characteristic	Blood lead level n (%)			*p*-value*
	Total†	≥5 µg/dL	<5 µg/dL	
Gender				
Male	1,654 (52.0)	82 (5.0)	1,572 (95.0)	
Female	1,530 (48.0)	73 (4.8)	1,457 (95.2)	0.807
Age group (years)				
<3	1,728 (54.3)	66 (3.8)	1,662 (96.2)	
3–5	1,456 (45.7)	89 (6.1)	1,367 (93.9)	0.003
Attending school				
Yes	1,808 (56.8)	109 (6.0)	1,699 (94.0)	
No	1,376 (43.2)	46 (3.3)	1,330 (96.7)	<0.001
Risk factors of children's exposure to lead				
Parent's or guardian's occupations related to lead				
Yes	606 (19.0)	43 (7.1)	563 (92.9)	
No	2,578 (81.0)	112 (4.3)	2,466 (95.7)	0.005
Work related to lead at home				
Yes	351 (11.0)	32 (9.1)	319 (90.9)	
No	2,833 (89.0)	123 (4.3)	2,710 (95.7)	<0.001
Home located near lead factories or enterprises				
Yes	420 (13.2)	43 (10.2)	377 (89.8)	
No	2,764 (86.8)	112 (4.1)	2,652 (95.9)	<0.001
Type of industry related to children's exposure to lead				
Manufacture of machinery and motor vehicles				
Yes	337 (10.6)	18 (5.3)	319 (94.7)	
No	2,847 (89.4)	137 (4.8)	2,710 (95.2)	0.669
Demolition and construction of buildings				
Yes	191 (6.0)	11 (5.8)	180 (94.2)	
No	2,993 (94.0)	144 (4.8)	2,849 (95.2)	0.555
Paint manufacturing				
Yes	177 (5.6)	6 (3.4)	171 (96.6)	
No	3,007 (94.4)	149 (5.0)	2,858 (95.0)	0.347
Battery storage				
Yes	92 (2.9)	3 (3.3)	89 (96.7)	
No	3,092 (97.1)	152 (4.9)	2,940 (95.1)	0.467
Electronic waste				
Yes	73 (2.3)	6 (8.2)	67 (91.8)	
No	3,111 (97.7)	149 (4.8)	2,962 (95.2)	0.178
Fishing tackle manufacturing				
Yes	44 (1.4)	16 (36.7)	28 (63.3)	
No	3,140 (98.6)	139 (4.4)	3,001 (95.6)	<0.001
Jewelry manufacturing				
Yes	37 (1.2)	3 (8.1)	34 (91.9)	
No	3,147 (98.8)	152 (4.8)	2,995 (95.2)	0.357
Shot and ammunition manufacturing				
Yes	20 (0.6)	5 (25.0)	15 (75.0)	
No	3,164 (99.4)	150 (4.7)	3,014 (95.3)	<0.001
Ship manufacturing				
Yes	12 (0.4)	2 (16.7)	10 (83.3)	
No	3,172 (99.6)	153 (4.8)	3,019 (95.2)	0.057

*†This column displays the number and column percentage; *Chi-square test*

Table 3. Results of multilevel* univariable and multivariable analysis identifying factors associated with elevated blood lead levels among children aged 1–5 years, Thailand (n=3,184)

Characteristic	Blood lead level		Crude OR	95% CI	Adjusted OR	95% CI
	≥5 µg/dL	<5 µg/dL				
Age group (years)						
3–5	89	1,367	1.70	1.18–2.43	1.28	0.81–2.02
<3	66	1,662	Ref.		Ref.	
Attending school						
Yes	109	1,699	1.84	1.23–2.76	1.54	0.93–2.57
No	46	1,330	Ref.		Ref.	
Parent's or guardian's occupations related to lead						
Yes	43	563	1.64	1.10–2.46	1.03	0.63–1.69
No	112	2,466	Ref.		Ref.	
Work related to lead at home						
Yes	32	319	2.23	1.39–3.57	1.16	0.63–2.12
No	123	2,710	Ref.		Ref.	
Home located near a lead factory or enterprise						
Yes	43	377	2.87	1.87–4.41	2.09	1.27–3.42
No	112	2,652	Ref.		Ref.	
Exposure to electronic waste						
Yes	6	67	2.23	0.86–5.79	1.46	0.53–4.00
No	149	2,962	Ref.		Ref.	
Exposure to fishing tackle manufacturing						
Yes	16	28	7.53	2.97–19.05	4.39	1.54–12.50
No	139	3,001	Ref.		Ref.	
Exposure to shot and ammunition manufacturing						
Yes	5	15	12.07	3.67–39.64	6.30	1.81–21.93
No	150	3,014	Ref.		Ref.	
Exposure to ship manufacturing						
Yes	2	10	3.49	0.65–18.65	2.67	0.48–14.75
No	153	3,019	Ref.		Ref.	

**Intraclass correlation coefficient (ICC) province: 0.00; ICC hospital within province: 0.23*

OR: odds ratio, CI: confidence interval

Discussion

This is the first study to determine the blood lead reference value in Thailand using the 97.5th percentile of the population-based blood lead levels among children aged 1–5 years. The BLRV of 6.9 µg/dL from this study was slightly higher than that in the United States of 5 µg/dL (referenced from 2012–2021) and nearly twice as high as the BLRV of 3.5 µg/dL that was revised in 2021.[10] In the United Kingdom, data on lead exposure in the child surveillance system in 2021 led to a lowering of the BLRV to half the previous concentration, from 0.48 µmol/L (equivalent to 10 µg/dL) to 0.24 µmol/L (equivalent to 5 µg/dL).[14] There is no global standard BLRV. The United States and the United Kingdom are the only two countries that have provided large population-based lead surveillance data to give clear recommendations on the BLRV among children. Before the national survey in 2019, Thailand set the action level for BLL among children at 10 µg/dL.[12] Based on our findings, the BLRV for children in Thailand was 6.9 µg/dL. However, to be consistent with the recommendation from the United Kingdom, a BLL of 5 µg/dL may be more practical for use as the action level in Thailand.[14]

Regarding factors associated with elevated blood lead level, other studies reported that blood lead levels in children increase with increasing age, consistent with the results from our univariable analysis which showed that children aged 3–5 years had a significantly higher blood lead level than those aged <3 years, although the statistical significance disappeared in the multivariable analysis.[15–17] A possible explanation for this result is that children aged 3–5 years tend to be more active than those aged <3 years. This would increase their chance of lead exposure from the environment such as playgrounds. In 2019, a study surveyed the playground equipment in two popular parks in Bangkok and found that 14 of

24 selected pieces of equipment contained lead levels greater than 10,000 parts per million.[18]

Results of the univariable analysis demonstrated that the three main exposure variables (parent's or guardian's occupations were related to lead, living in a house where lead was used for manufacturing, and living in a house near a lead factory) increased the risk of having a high blood lead level. However, only house location was significant in the multivariable analysis. These findings are consistent with other studies. Children whose parents had lead-related occupations had a significantly higher risk of elevated BLL than other children.[19–21] Exposure can occur from contaminated clothing. A study from China showed that children's blood lead level decreased as the distance between the children's house and the lead factories increased.[22] Another study from Italy reported that blood lead levels among children living in communities free from factories that use lead were significantly lower than communities whose economy was based on home-operated artistic pottery production (using lead).[21]

According to lead-associated industries, we found that exposure to manufacturing of shot and ammunition and fishing tackle were statistically significant risk factors. This is consistent with reports in 2023 that children of employees at an ammunition plant in Anoka, Minnesota had higher BLL, possibly due to take-home lead.[23] A study in Thailand reported that the mean BLL among children residing in fishing communities was about 2.5 times higher than children in other communities.[24]

This study has some limitations. First, selection bias could have occurred because the data were derived from a hospital-based survey using quota sampling. However, the proportional quotas and weighted analyses based on the sampling process could minimize this problem since the method would help generate a sample that was more likely to match the geographical distribution of the population. Second, the study sample included children visiting hospitals and therefore could potentially have higher blood lead levels than those in community. However, this did not adversely impact the calculated BLRV. Third, subject recruitment may have varied by health region; however, the manual for project implementation was developed to be used as the standard operational protocol for every health region. Finally, data of some variables, such as weight and height, underlying disease, and children's behavior had many missing values and were therefore excluded from the analysis. These omitted variables may potentially be significant factors influencing elevated BLL.

Public Health Actions and Recommendations

Lead exposure can seriously affect children's health and wellbeing, causing brain damage and growth and development delay. Based on guidelines recommended by the Advisory Committee on Childhood Lead Poisoning Prevention, the BLRV for children in Thailand should be set at 6.9 µg/dL. However, to be consistent with the recommendation from the United Kingdom, a blood lead level of 5 µg/dL would be a more appropriate reference level to be used in Thailand. Additionally, in order to control and prevent children from lead exposure, health officials should work in collaboration with their network partners, such as the Ministry of Industry or the Ministry of Labor, to provide health literacy and increase awareness among parents working in factories or enterprises that use lead for manufacturing to prevent take home lead exposure in children. Exposure surveillance of blood lead levels should be set up in order to detect elevated blood lead levels among children living in high-risk areas or having a high risk of lead exposure, such as those whose parents or guardians have occupations related to lead.

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