ความเสี่ยงต่อการรับสัมผัสจากตะกั่วและแคดเมียมในเด็กก่อนวัยเรียนในชุมชนรีไซเคิลขยะอิเล็กทรอนิกส์

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บทคัดย่อ

ตะกั่วและแคดเมียมเป็นโลหะหนักที่พบได้ในขยะอิเล็กทรอนิกส์ โดยระดับตะกั่วและแคดเมียมในเลือดสัมพันธ์กับความผิดปกติของการพัฒนาทางร่างกายในเด็ก การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อตรวจวัดระดับตะกั่วในเลือด (blood lead levels; BLLs) และระดับแคดเมียมในเลือด (blood cadmium levels; BCLs) และศึกษาผลของ BLLs และ BCLs ต่อการพัฒนาทางร่างกายในเด็ก รวมทั้งศึกษาปัจจัยที่ส่งผลต่อ BLLs และ BCLs ในเด็กในชุมชนเสือใหญ่อุทิศ เขตจตุจักร ชุมชนรีไซเคิลขยะอิเล็กทรอนิกส์ที่ใหญ่ที่สุดในกรุงเทพมหานคร โดยการตรวจวัด BLLs และ BCLs จากเลือดปลายนิ้วด้วยเครื่อง inductively couple plasma—mass spectrometry (ICP-MS) เปรียบเทียบ BLLs และ BCLs ของเด็กในชุมชนเสือใหญ่อุทิศ อายุระหว่าง 6 เดือนถึง 6 ปี จำนวน 22 คน (กลุ่มรับสัมผัส) กับเด็กที่อาศัยนอกเขตจตุจักร จำนวน 22 คน ที่มีอายุเท่ากันและเพศเดียวกันกับเด็กในกลุ่มรับสัมผัส จากคลินิกผู้ป่วยนอก สถาบันสุขภาพเด็กแห่งชาติมหาราชินี (กลุ่มอ้างอิง) ผลการศึกษา พบว่าค่าเฉลี่ยของ BLLs และ BCLs ในกลุ่มรับสัมผัส มีค่าเท่ากับ 8.60 ± 1.58 ไมโครกรัมต่อเดซิลิตร และ 2.01 ± 0.20 ไมโครกรัมต่อลิตร ซึ่งสูงกว่าในกลุ่มอ้างอิงที่ 3.07 ± 0.27 ไมโครกรัมต่อเดซิลิตร และ 0.58 ± 0.12 ไมโครกรัมต่อลิตร ค่า *p*-value เท่ากับ 1.3×10^{-4} และ 0.4×10^{-5} ตามลำดับ การศึกษานี้ไม่พบความผิดปกติของพัฒนาการทางร่างกายและภาวะโลหิตจางตามมาตรฐานเด็กไทยในกลุ่มรับสัมผัส ปัจจัยที่ส่งผลต่อ BLLs และ BCLs ในกลุ่มรับสัมผัสมากที่สุด ได้แก่ การที่เด็กอยู่ในบ้านที่ผู้ปกครองกำลังคัดแยกขยะอิเล็กทรอนิกส์ และการเก็บขยะอิเล็กทรอนิกส์ไว้ในบ้าน การศึกษานี้แสดงให้เห็นว่า

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เด็กในชุมชนรีไซเคิลขยะอิเล็กทรอนิกส์มีความเสี่ยงต่อการได้รับพิษจากโลหะหนัก เพื่อลดความเสี่ยงดังกล่าว การรีไซเคิลขยะอิเล็กทรอนิกส์และกิจกรรมที่เกี่ยวข้อง ควรได้รับการควบคุมทั้งในระดับชุมชนและระดับชาติ

คำสำคัญ: ขยะอิเล็กทรอนิกส์ แคดเมียม ตะกั่ว ระดับตะกั่วในเลือด ระดับแคดเมียมในเลือด

Risk of Lead and Cadmium Exposure in Preschool Children in Bangkok E-waste Recycling Area

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Abstract

Lead and cadmium are commonly found in electronic waste or e-waste. High blood lead levels (BLLs) and blood cadmium levels (BCLs) are associated with children's abnormal physical and mental development. This study aimed to determine BLLs and BCLs and examine the physiological effects of lead and cadmium exposure in children in Sue Yai Utit, Bangkok's largest e-waste recycling area. Additional factors that could influence children's BLLs and BCLs were also evaluated. Fingerstick blood samples were collected from 22 children aged 6 months to 6 years from the Sue Yai Utit e-waste recycling area (exposed group). Age and sex matched control fingerstick blood samples were collected from 22 children who lived outside Chatuchak areas in Bangkok from the Queen Sirikit National Institute of Child Health outpatient clinics (reference group). BLLs and BCLs from both exposed and reference groups were determined using inductively coupled plasma—mass spectrometry (ICP-MS). BLLs and BCLs were compared using Mann—Whitney *U* test with a significance level at $p < 0.05$. The mean BLLs and BCLs in the exposed group were 8.60 ± 1.58 µg/dL and 2.01 ± 0.20 µg/L, respectively, which were

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significantly higher than the mean BLLS and BCLS of the reference group (3.07 ± 0.27 μg/dL and 0.58 ± 0.12 μg/L, respectively) with $p = 1.3 \times 10^{-4}$ and $p = 0.4 \times 10^{-5}$, respectively. However, children living in the Sue Yai Utit area developed normally according to the Thai child developmental standards and did not show any sign of anemia. Factors influencing children's BLLs or BCLs in the exposed group included staying in a house that dismantled and stored e-waste and the parents' hygiene such as clothes changing and hand washing after work. To help protect Thai children living in the e-waste recycling area from heavy metals poisoning, the disposal of e-waste and other related activities should be regulated both at the community and national levels.

Keywords: E-waste, Cadmium, Lead, Blood cadmium levels (BCLs), Blood lead levels (BLLs)

Introduction

Electronic waste or e-waste has rapidly been increasing worldwide in several countries, including USA, Canada, Europe, Australia, Africa, and Asia such as China, India, Japan, Vietnam and Thailand. Several countries now have the e-waste legislation to regulate e-waste management and disposal but e-waste has remained unregulated in several countries.(1) The legislative enforcement to control and regulate e-waste is still pending parliament and government approval in Thailand. As a result, the e-waste recycling business has spread through several provinces in the Northeastern region of the country, including Buriram(2) and Kalasin.(3) It is well known that e-wastes often contain heavy-metals, such as lead (Pb), cadmium (Cd), mercury (Hg) and arsenic (As), that can contaminate the environment and cause heavy metal poisoning in humans. Lead and cadmium are heavy metals commonly found in e-waste and can induce multiorgan toxicity. Lead and cadmium enter the human body via skin absorption, inhalation and ingestion. Because of hand-to-mouth behavior or poor personal hygiene found in young children, such as not washing hands before eating or playing in e-waste dump areas, both inhalation and ingestion are important routes for lead and cadmium to enter a child's body. Lead is more harmful in children than in adults, especially in children under six years of age. In children under 6-year-old, lead can damage the brain and nervous system leading to lower I.Q., impact learning and behavior problems.(4) Blood lead levels (BLLs) were found significantly associated with mild and severe anemia in children.(5) Furthermore, the high BLLs negatively affected certain essential elements, i.e., zinc, magnesium, and iron.(6)

Several studies found that children who lived in e-waste dismantling community had a higher level of lead and cadmium in blood than children in non-e-waste area. Studies in China and Taiwan showed that lead and cadmium from e-waste recycling activities affected children's health status, including a negative correlation between blood lead level and slowed growth, developmental delays, physical development and increasing of bone resorption.(7-9) Chronic exposure to lead is also associated with children's attention and executive function and academic performance.(10) Blood lead level is associated with a hearing loss(11) and olfactory memory impairment in children.(12) The high blood lead level was associated with elevated interleukin (IL)-6 level, high systolic blood pressure, and several other cardiovascular risk factors.(13) Additionally, both lead and cadmium can affect the number and percentage of innate immune cells(14) and interfere with immune homeostasis, promoting inflammation by increasing associated inflammatory cytokines in children.(15) Cadmium is classified by the International Agency for Research on Cancer (IARC) as carcinogenic to humans (Group 1). After ingested, cadmium is absorbed in stomach and intestines and enter the bloodstream while cadmium from inhalation is absorbed in the lung. Cadmium mainly affects kidney and bone resulting in renal tubular dysfunction, painful bone fractures, osteomalacia and osteoporosis which are characteristics of Itai-Itai disease.[16]

Damrongsiri, *et al* (2016)[17] found a high level of contaminating heavy metals in the surface soil samples at the dismantling site of Sue Yai Utit, an e-waste dismantling community in Bangkok. The levels of contaminated heavy metals, i.e., copper (Cu), lead (Pb), zinc (Zn) and nickel (Ni) were higher than the Thai and Dutch standards. In contrast, levels of cadmium (Cd) and selenium (Se) were not different from those found in non-dismantling area in the same community. Both lead and cadmium are the most health hazard and exert long-term health effects, especially in children. To our knowledge, no studies have compared age and sex-matched control preschool children's BLLs and BCLs in e-waste community and non-e-waste community and investigated the effect of associated risks of e-waste dismantling activity on children's BLLs and BCLs in e-waste recycling area in Bangkok.

Thus, this study was aimed to evaluate the effect of e-waste dismantling activity on lead and cadmium exposures in preschool children by comparing BLLs and BCLs in children who lived in e-waste dismantling community and non-e-waste community using age and sex-matched control. In addition, the physiological effects of lead and cadmium exposure in 6 months to 6 years old children in Sue Yai Utit community, the largest e-waste recycling area in Bangkok were examined. Furthermore, factors that might influence BLLs and BCLs in children whose parents were e-waste dismantling workers were also investigated.

Materials and Methods

Chemicals and reagents

Nitric acid (Trace Metal™ Grade) was from Fisher Chemical and Triton® X-100 from PRS Panreac®. Water was generated from a Millipore pure water system (Millipore Co., Ltd., USA). Cadmium standard solution (1 mg/L in 2% HNO_3) and Rh internal standard solution (1 mg/L in 2% HNO_3) were from SPEX CertiPrep®, lead standard solution (100 μg/dL) from AccuStandard® and certified reference material human blood (lead and cadmium) BCR® - 634 and BCR® - 635 from European Commission, Joint Research Centre (JRC).

Participants

Forty-four children aged six months to six years were enrolled in this study and equally divided into two age and sex-matched groups. The exposed group, consisted of children who lived in Sue Yai Utit, e-waste dismantling community, Chatuchak District, Bangkok, was further divided into direct- and indirect-exposed groups. The direct exposed children were defined as children whose parents work as e-waste dismantling workers. While the indirect exposed children were defined as children whose parents lived in Sue Yai Utit community and worked in other types of businesses other than e-waste dismantling workers. Age and sex-matched children who did not live in Chatuchak District were defined as reference group. For reference group, children with anemia, renal diseases, hepatitis B/C infection, or receiving blood transfusions within three months were excluded. For exposed group, children with renal diseases, hepatitis B/C infection, or receiving blood transfusions within three months were also excluded from the study. All parents of children participating in this study provided written informed consent before enrolling in the study. Children's physiological parameters such as height, weight, and head circumferences were measured by registered nurses. Additionally, information on children whose parents were e-waste dismantling workers and factors that might influence children's BLLs and BCLs, including place for e-waste dismantling, place of e-waste storage, place for child stay while parents dismantle e-waste, clothes changing and hands washing behavior after work, were also collected by using questionnaires.

Blood specimen collection

Blood samples used for BLLs and BCLs evaluations were collected by finger-pricking. Blood specimens from children in the exposed and referene groups were collected in 0.5 mL EDTA collection tubes at the Foundation for Slum Child Care, Bann Sue-Yai (Under the Patronage of Her Royal Highness Princess Galyani Vadhana Krom Luang Naradhiwas Rajanagarindra) and Queen Sirikit National Institute of Child Health (QSNICH), respectively. Blood hematocrit was determined to screen for anemia that might occur in children chronically exposed to lead. The study protocol was approved by The Research Ethics Review Committee for Research Involving Human Research Participants, Group 1, Chulalongkorn University (reference number COA No. 168/2558) and Office of Research Ethics, Queen Sirikit National Institute of Child Health (QSNICH), Thailand (reference number EC.166/2557 and EC.121/2558).

Sample preparation for ICP-MS analysis

Samples were prepared as described in a previous study[18] with slight modifications. Briefly, lead and cadmium were extracted from EDTA blood using acid digestion protocol with the ratio of EDTA blood: 15.8 M HNO_3: water at 1: 2: 7. The reaction was incubated at room temperature for 30 minutes. Finally, 400 µL of supernatant was removed and diluted with 1,600 µL of diluent solution containing 0.5% (v/v) HNO_3, 20 µg/L Rh (internal standard) and 0.005% (v/v) Triton® X-100.

Blood lead levels (BLLs) and blood cadmium levels (BCLs) determination

BLLs and BCLs were quantified using matrix-matched calibration curve. Seven points calibration curves of lead and cadmium were prepared daily in duplicates over the ranges of 0 - 27.3 µg/dL for lead and 0 - 15.7 µg/L for cadmium. Lead and cadmium levels in samples, CRM Human Blood (lead and cadmium) BCR® - 634 and BCR® - 635 were analyzed in triplicates using inductively coupled plasma-mass spectrometer (ICP-MS) (iCAP Qc, Thermo Scientific) at Scientific and Technological Research Equipment Centre, Chulalongkorn University. Performances of the method, including linearity, the lower limit of detection (LLOD),% accuracy, interday and intraday precisions, were evaluated.

Statistical analysis

The results were expressed as the mean ± standard error. All statistical analyses with $p < 0.05$ were considered statistically significant and performed using SPSS software version 22. All variables were tested for normal distribution using Shapiro-Wilk test. Comparison between the mean of BLLs and BCLs from two groups were performed using Mann-Whitney *U* test. The factors that might affect children's BLLs and BCLs were evaluated using a generalized linear model.[19]

Results

Sample preparation for ICP-MS analysis

The sample preparation was performed as described in a previous study with slight modifications[18] before being analyzed by ICP-MS. Fifty microliters of calibrators, CRMs, and blood samples were used. Samples were extracted in duplicates using acid digestion protocol and were analyzed in triplicates by ICP-MS. The matrix-matched calibration curves of lead and cadmium with seven concentration levels of standards were constructed. Lead standard concentrations ranged from 0, 2.3, 4.8, 7.3, 12.3, 17.3, 27.3 µg/dL, whereas cadmium standard ranged from 0, 0.7, 1.7, 2.7, 5.7, 10.7, 15.7 µg/L. The linearity of lead and cadmium calibration curves had the coefficient of determination (R^2) value of 0.999. The lower limit of detection or LLOD of lead and cadmium detected by ICP-MS were 0.011 µg/dL and 0.135 µg/L, respectively. The CRM BCR® - 634 (low level) and BCR® - 635 (high level) were used to assess % accuracy and interday and intraday precisions. The % accuracy (mean ± % S.D.) of lead determination for low and high levels were 98.88 ± 6.87 and 90.05 ± 2.55, respectively. While the % accuracy of cadmium determination for low and high levels were 97.56 ± 7.19 and 94.31 ± 4.00, respectively. The interday and intraday precisions of BLLs determined from BCR® - 634 were 6.95% and 7.64% and in BCR® - 635 were 2.83% and 2.92%, respectively. The interday and intraday precisions of BCLs determinations in BCR®-634 were 7.35% and 9.46%, and in BCR®-635 were 4.25% and 4.81%, respectively. All samples were analyzed using inductively coupled plasma-mass spectrometer (ICP-MS) (iCAP Qc, Thermo Scientific) at Scientific and Technological Research Equipment Centre, Chulalongkorn University. The results showed that this modified method's performance was acceptable and verified for quantification of BLLs and BCLs in children.

Blood lead levels (BLLs) and blood cadmium levels (BCLs) determination and relevant factors

A total of 44 preschool children were investigated and equally divided into two age and sex- matched groups: exposed group and reference group. Characteristics of the study population regarding sex, age, blood lead levels (BLLs), blood cadmium levels (BCLs), and % hematocrit are shown in **Table 1.** There were significant differences for lead and cadmium among reference and exposed groups with $p = 1.3 \times 10^{-4}$ and $p = 0.4 \times 10^{-5}$ as shown in **Fig. 1** and **2**, respectively. The highest BLLs found in the direct exposed group was 29.17 μg/dL, while the highest BLLs found in the reference group was only 5.61 μg/dL. The lowest BLLs detected in the reference group was also significantly lower than that in the exposed group (**Table 1**). There was statistically significant difference in BLLs between reference and exposed groups with $p = 1.3 \times 10.^{-4}$, 36.36% of children in the reference group had BLLs higher than the CDC normal reference value of 3.5 μg/dL.[20] In comparison, 81.82% of children in the exposed group had BLLs higher than the CDC reference value. The highest BCLs found in the exposed group was 4.08 μg/L, while the highest BCLs in the reference group BLCs was only 1.94 μg/L. The lowest BCLs found in reference group was lower than LLOD of this method. BCLs between the reference and the exposed groups were significantly and statistically different with $p = 0.4 \times 10.^{-5}$ All of the children in the e-waste dismantling community had BCLs higher than the CDC normal reference value of 0.15 μg/L.[21] In contrast, 77.27% of the non-e-waste dismantling community had BCLs higher than the CDC normal reference value.

To further examine the effect of e-waste dismantling activity in young children, the exposed group was equally divided into the direct and indirect exposed groups. There were statistically significant differences in BLLs and BCLs between direct exposed and age and sex-matched reference groups with $p = 1.9 \times 10^{-4}$ and $p = 0.002$, respectively. Also, BLLs and BCLs between age and sex-matched indirect exposed group and the reference group were statistically significant different with $p = 0.010$ and $p = 0.004$, respectively. Interestingly, there were no statistically significant differences in BLLs and BCLs between the direct and indirect exposed groups.

Table 1 Participant characteristics and comparison of BLLs and BCLs from exposed and reference groups

Characteristics	Exposed group (n=22)	Reference group (n=22)	*p*-value
Age (average, months)	30	30	-
(Min, Max)	(6, 53)	(9, 60)	
Sex			
- Male	12	12	-
- Female	10	10	-
[1]BLLs (μg/dL)	8.60 ± 1.58	3.07 ± 0.27*	1.3×10^{-4}
(Min, Max)	(1.34, 29.17)	(0.61, 5.61)	-
< 3.5	4 (18.18)	14 (63.67)	-
> 3.5	18 (81.82)	8 (36.36)	-
- Direct Exposed (n = 11)	12.99 ± 2.52	3.23 ± 0.34*	1.9×10^{-4}
- Indirect Exposed (n = 11)	4.21 ± 0.47	3.13 ± 0.46*	0.010
[2]BCLs (μg/L)	2.01 ± 0.20	0.58 ± 0.12*	0.4×10^{-5}
(Min, Max)	(0.67, 4.08)	(ND, 1.94)	-
< 0.15	-	5 (22.73)	-
> 0.15	22 (100)	17 (77.27)	-
- Direct Exposed (n = 11)	1.90 ± 0.29	0.64 ± 0.19*	0.002
- Indirect Exposed (n = 11)	2.12 ± 0.28	0.79 ± 0.30*	0.004
[3]Hct (%)	34.8 ± 0.9	34.9 ± 0.6	-
(Min, Max)	(28, 40)	(29, 40)	-
< 33 (0.5 – 2 yrs)	4 (18.18)	3 (13.64)	-
< 34 (2 – 6 yrs)	4 (18.18)	3 (13.64)	-

Data expressed as Mean ± SE or the number (percent). ND means not detectable with the value lower than LLOD or 0.135 μg/L.

* Significant difference compared between paired age, sex-matched reference and exposed groups using Mann–Whitney *U* test, $p < 0.05$.

[1] Cut off point for BLLs from CDC reference value (2021).[20]

[2] Cut off point for BCLs from CDC reference value (2017).[21]

[3] Cut off point for Hct (%) from Clinical Practice Guideline of The Royal College of Pediatricians of Thailand & Pediatric Society of Thailand.[22]

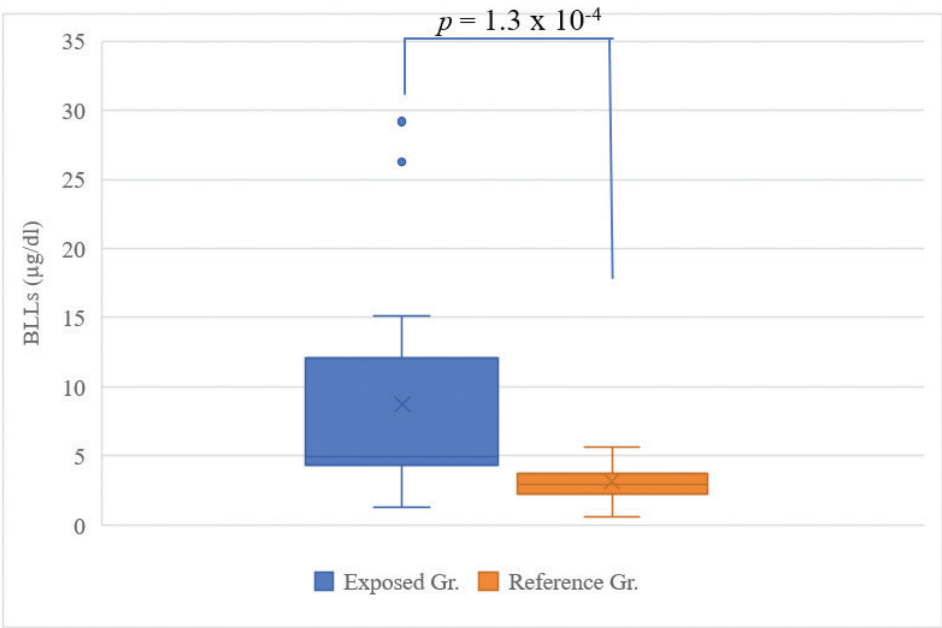

Fig. 1 Box plots of BLLs between exposed and reference groups. $p < 0.05$ was considered statistically significant

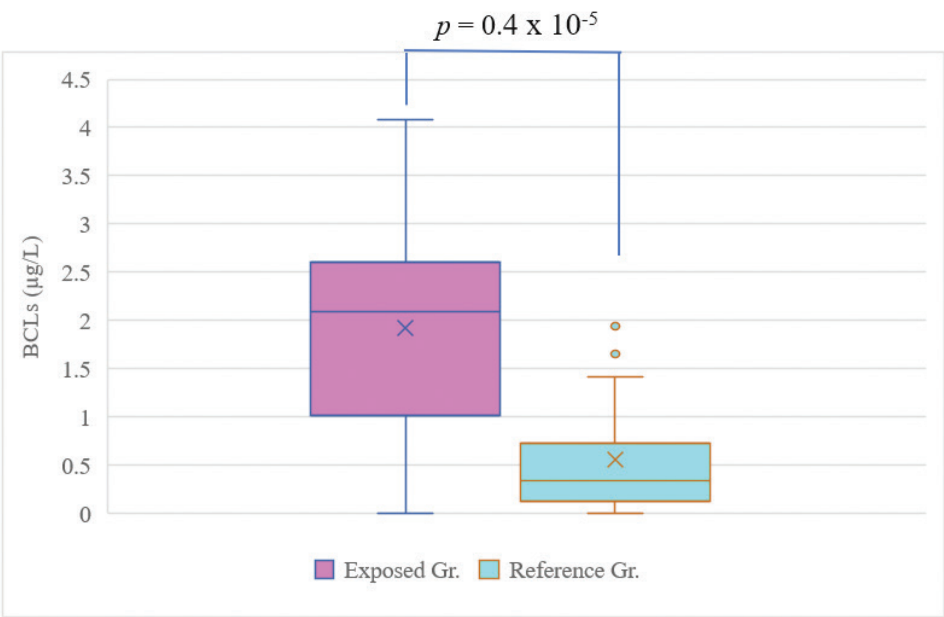

Fig. 2 Box plots of BCLs between exposed and reference groups. $p < 0.05$ was considered statistically significant

Factors that might influence BLLs and BCLs in children were evaluated by questionnaire. The questionnaire focused on e-waste dismantling and storage sites, clothes-changing and hands-washing after work, and where the children were while parents worked in the dismantling e-waste sites. Almost all factors significantly influenced BLLs in children except parents' clothes-changing and hands-washing behavior after work **(Table 3).** Interestingly, all factors evaluated in the questionnaire significantly affected children's BCLs **(Table 4).**

The physiological effects of lead and cadmium exposure

The blood hematocrit (%Hct) was used to screen for anemia condition in children exposed to lead in this study. However, no significant difference in %Hct was found between exposed and reference groups (Table 1). The number of children with Hct (%) lower than the normal range was also comparable between the two groups. To evaluate children's physical growth in the e-waste dismantling community, the WHO child growth standard (2006) was used. Lower weight than WHO standard indicated acute malnutrition, while the lower height indicated chronic malnutrition in children.[(23)] Three children, or 18.18%, had lower weight than the WHO standard in the exposed group, whereas five children, or 22.73%, had lower height than the WHO standard. All children in the study had normal head sizes **(Table 2)**. No significant correlation between BLLs and BCLs and physical effects was found.

Discussion

To our best knowledge, this report was the first study examining the effect of e-waste dismantling activities on lead and cadmium exposures in preschool children by BLLs and BCLs in Sue Yai Utit e-waste recycling community in Bangkok. BLLs and BCLs in age and sex-matched children who lived in Sue Yai Utit e-waste recycling community and non-e-waste recycling communities were compared. BLLs was accepted as the best way to evaluate lead exposure in children. The United States Centers for Disease Control and Prevention (CDC) recommend two types of BLLs sample collection methods for evaluation of Pb exposure in children, including finger-pricking (capillary) for screening and venous blood draw for confirmation. The finger-prick test may give a falsely high result from skin contamination. Nonetheless, the finger-pricking method takes only a small amount of blood from a child's finger and is more appropriate for young children aged 6 months to 6 years. Thus, finger-pricking collection method was used to determine BLLs and BCLs in this study. To minimize contamination from lead and cadmium on the children's fingers, participants' hands were thoroughly washed with soap and dried with a clean towel before finger-pricking to collect blood samples in a 0.5 mL EDTA

Table 2 Physiological parameters of children in the exposed group

Range of weight and height	Total (22)
Weight for age (Kg)	
Median ± 1.5 SD	18 (81.82)
Less than Median - 1.5 SD(1)	4 (18.18)
Height for age (cm)	
Median ± 1.5 SD	17 (72.27)
Less than Median - 1.5 SD(2)	5 (22.73)
Head circumference (cm)	
Typical head size(3)	22 (100.00)

Data expressed as the number (percent).

(1) Lower weight than WHO child growth standard indicated the acute malnutrition.[23]

(2) Lower height than WHO child growth standard indicated the chronic malnutrition.[23]

(3) WHO Child Growth Standards.[24]

Table 3 Factors from parents' e-waste dismantling activity influenced BLLs in children who lived in Sue Yai Utit community

Risk factor from parents' e-waste dismantling activity	n (%)	95% CI	*p*-value
E-waste dismantling in house			
- Yes	10 (90.9)	(0.96-29.33)	0.036
- No	1 (9.1)		-
E-waste storage in house			
- Yes	8 (72.7)	(0.14-17.09)	0.046
- No	3 (27.3)		-
Changing clothes and washing hands after work			
- Yes	8 (72.7)		-
- No	3 (27.3)	(-5.62-11.33)	0.509
Child stays with parents during daytime			
- Yes	6 (54.5)	(6.60-21.76)	0.001
- No	5 (45.5)		-

Data collection through questionnaire from 11 e-waste dismantling workers who lived in Sue Yai Utit community. Data expressed as the number (percent). Associated risk factors were tested using generalized linear model.

Table 4 Factors from parents' e-waste dismantling activity influenced BCLs in children who lived in Sue Yai Utit community

Risk factor from parents' e-waste dismantling activity	n (%)	95% CI	*p*-value
E-waste dismantling in house			
- Yes	10 (90.9)	(1.75-4.45)	$0.7x10^{-5}$
- No	1 (9.1)		-
E-waste storage in house			
- Yes	8 (72.7)	(1.16-2.78)	$0.2x10^{-5}$
- No	3 (27.3)		-
Changing clothes and washing hands after work			
- Yes	8 (72.7)		-
- No	3 (27.3)	(0.04-1.66)	0.039
Child stays with parents during daytime			
- Yes	6 (54.5)	(0.56-2.00)	0.001
- No	5 (45.5)		-

Data collection through questionnaire from 11 e-waste dismantling workers who lived in Sue Yai Utit community. Data expressed as the number. Associated risk factors were tested using generalized linear model.

tube. Additionally, the modified sample preparation method used only 50 μL of the blood sample to determine BLLs and BCLs by ICP-MS. The sample collected by the finger-pricking was sufficient to accurately determine BLLs and BCLs by ICP-MS and a suitable method for sample collection in young preschool children instead of a more invasive venopuncture method.

An increase in BLLs is directly correlated with an increase in the severity of lead toxicity symptoms. To reduce the child's future exposure to lead earlier, CDC has recently reduced a blood lead reference value in children from 5 μg/dL to 3.5 μg/dL. Lead affects children more than adults, especially in children under six years of age. Lead damages the brain and nervous systems and can lower I.Q., leading to learning retardation and other behavior problems. In addition, high BLLs is also associated with anemia in children. A previous study found that the BLLs of 10-20 μg/dL was significantly associated with mild and severe anemia with decreased blood iron and ferritin levels [5]. In this study, Hct (%) was used to evaluate anemia in children, but no association between BLLs and Hct (%) was found.

The results showed that children who lived in the e-waste dismantling community had significantly higher BLLs and BCLs than children from other non-e-waste communities, similar to previous studies in China[9,13,25] and India.[11] The highest BLLs and BCLs of 29.17 μg/dL and 4.08 μg/L, respectively, were found in a child who lived in the Sue Yai Utit e-waste recycling community. This child had all risk factors associated with lead and cadmium exposure filled in the questionnaire, including staying at home while parents dismantled e-waste, e-waste storage on site, and the parents did not change clothes or wash hands after work. Interestingly, we found that all factors in the questionnaire were significantly associated with BCLs in children. Results from the questionnaire suggested that the parents' clothes-changing and hands-washing after work were not significantly associated with BLLs but associated with significantly lower BCLs as compared to other contributing factors. This could be due to the fact that children were directly and constantly exposed to heavy metals dust all the time when they lived at home. Thus, e-waste storage or dismantling at home could increase children's risk for heavy metals exposure due to heavy metals dust attached to mattresses, clothes, and hand-to-mouth behavior. In addition, children were still at risk for heavy metal exposure from parents' clothing contaminated with lead and cadmium regardless of whether e-waste dismantling activity was done at home or at a site away from home.[26] Lead and cadmium dust can contaminate the air, water, and environment. Interestingly, it was found that children of non-e-waste workers who lived in the e-waste dismantling community had significantly higher BLLs and BCLs than children in other areas of Bangkok, suggesting that lead and cadmium levels in the environment of the e-waste dismantling site could be higher than in the non-e-waste communities as described in a previous study.[17]

In this study, 36.33% and 77.27% of the non-e-waste dismantling community children had BLLs and BCLs higher than CDC reference values. No safety standard limit was set for blood lead and cadmium levels in Thai children. In 2021, new CDC blood lead reference value (3.5 μg/dL) was established from the 97.5th percentile of the blood lead values among U.S. children aged 1-5 years from the 2015-2016 and 2017-2018 National Health and Nutrition Examination Survey (NHANES) cycles.[20] Additionally, the U.S. Food and Drug Administration (FDA) has established the action plan to reduce exposure to toxic elements including lead and cadmium from foods eaten by babies and young children to as low as possible.[27] According to FDA and CDC guidelines, standard BLLs and BCLs limits were much lower as compared to BLLs and BCLs limits used in Thailand. Furthermore, environmental lead and cadmium contamination was strictly regulated in the US. Lead-based paints, banned in the U.S since 1978, are still widely available in Thailand. Lead was detected in paints chips inside building of nursery schools at a level higher than the reference level. Moreover, lead and cadmium were also detected from toy paints at higher than reference levels.[28] Due to these environmental factors children in Thailand are at a higher risk of exposing to environmental lead and cadmium and could contribute to high BLLs and BCLs as compared to those found in US children. Therefore, BLLs and BCLs in Thai children should be surveyed and established to help evaluate the risk of lead and cadmium exposure in Thai children in the future.

The association between BLLs and BCLs and other physiological parameters in the exposed group was not found. Interestingly, around 20% of children in the exposed group were identified as malnourished with an increased risk of lead toxicity, especially those who receive inadequate dietary calcium. Previous studies showed that calcium competitively inhibits the active transport of intestinal lead. Thus, dietary calcium could reduce exposure to dietary lead in children.[29-30] Thus, supplemental dietary calcium should be provided to these malnourished children in the e-waste community to help reduce the risk of lead toxicity.

Cadmium accumulates in the human body with a half-life of around 10-30 years and causes kidney dysfunction and bone fracture. High BCLs in children increase the risk of cadmium toxicity. Long-term cadmium exposure had been shown to be associated with kidney dysfunction in primary school children in Mae Sot District, Tak Province, Thailand.[31] However, most of the e-waste dismantling workers in the Sue Yai Utit community came and stayed in Bangkok for only a short period of time and would return to their hometown in other provinces with their children when the farming and growing season started. Thus, it is likely that children were not exposed to high levels of lead and cadmium from e-waste dismantling activity at all times. This could be the reason why we could not find any association between high BLLs and BCLs and other physiological effects in the exposed children group as other previous studies.[7, 9, 13]

Conclusion

This was the first study that demonstrated that the e-waste dismantling activity directly affects BLLs and BCLs in preschool children who lived in Sue Yai Utit e-waste dismantling community both directly and indirectly. High BLLs in preschool children could affect children learning abilities in the future. Comparison of BLLs and BCLs in age and sex-matched children who lived in e-waste recycling community and non-e-waste recycling community showed that both the direct- and indirect exposed children had significantly higher BLLs and BCLs than children from other non-e-waste communities. However, children living in the e-waste recycling area did not show any sign of anemia or physical development abnormality. Factors influenced children's BLLs or BCLs in the exposed group, including staying at home that dismantled and stored e-waste and the parents' hygiene such as clothes changing and hands washing after work. Our study demonstrated a direct association between e-waste dismantling activities and increased BLLs and BCLs of children living in the e-waste dismantling community. Thus, children who lived in the e-waste recycling community had elevated blood lead and cadmium levels and were at a higher risk of lead and cadmium poisoning, suggesting the disposal of e-waste and other related activities should be regulated both at the community and national levels.

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