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Lead exposure in an urban community: Investigation of risk factors and assessment of the impact of lead abatement measures ☆

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Abstract

Introduction: A battery recycling plant located in an urbanized area contaminated the environment with lead oxides. The Secretary of Environment of the State of São Paulo demanded an evaluation of lead exposure among the population in the vicinity of the plant.
Objectives: To assess the lead exposure of children, to propose control measures and evaluate the impact of these measures.
Methods: Cross-sectional study of all children < 13 years old in a radius of 1 km from the plant responsible for the contamination. Blood lead levels (BLL) were determined for each child and questionnaires were applied to their parents. Mean BLL were compared before and after control measures were implemented. Logistic regression identified risk factors of lead exposure.
Results: Of the 850 investigated children, 311 presented BLL above the action limit established by the World Health Organization. Overall, the median BLL was 7.3 μg/dL and it varied according to age of children (higher among 1–5 years old) and distance of the residence from the plant. Risk factors identified for BLL > 10 μg/dL were: to live in unpaved areas, parent working in the plant, distance from the plant, to play on the ground, pica, and to drink locally produced milk. After control measures were implemented (closing the plant, soil removal, dust vacuum-cleaning in the households, etc.), a reduction of 46% in BLL was observed considering the 241 re-evaluated children with levels > 10 μg/dL.
Conclusions: This study showed that combined abatement measures were effective in reducing BLL in children living close to a contaminating source. These results informed the decision-making process regarding management of contaminated areas in Brazil.

Keywords: Lead; Child; Contaminated areas; Surveillance; Intersectorial approaches

1. Introduction

Lead, even in low concentration, can affect the children central nervous system, causing retarding psychomotor development, reducing hearing capacity, and impairing learning and cognitive capabilities (Bellinger et al., 1987; Needleman et al., 1990). Nutritional factors and personal habits can influence lead absorption, increasing risk of

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intoxication especially in low income family children (Mahaffey, 1995; Gallicchio et al., 2002).

Since 1979 Brazil has progressively substituted tetra-ethyl-lead in gasoline by ethanol (Paoliello and De Capitani, 2005). It has also replaced lead-based soldering in food cans by heating and electronic soldering (Brasil, 1999), and has been recycling most of the used acid-lead batteries. An enforcement act regulating lead plants installation was put into effect in the 1980s (Brasil, 1986).

Despite those official efforts in reducing environmental lead contamination during the last three decades, very little effort has effectively been made to controlling lead oxides airborne emissions from old primary and secondary smelting plants.

A battery recycling plant located in Bauru, West of the state of São Paulo, Brazil, started its activities in 1974 at what was considered a rural area at that time. In 1997, a low economic population started to occupy the area in a process of urbanization around the plant. That population lives in poorly constructed houses, mostly in unpaved roads. Due to the absence of effective anti-emissions equipments, the plant contaminated its neighboring residential area with lead oxides during the last 8 years. The environment lead contamination has recently been assessed by CETESB (State Authority for Environmental Control), which notified the State Health Authority in February 2002, when the plant had its operations suspended (Companhia de Tecnologia de Saneamento Ambiental (CETESB), 2002). Average airborne lead measured in samples collected around the plant was 9.7 $\mu g/m^3$ (mean of 3 months) and maximum value of 37.3 $\mu g/m^3$ from June 2001 to September 2001 (EPA limit value = 1.5 $\mu g/m^3$) (United States Environmental Protection Agency (USEPA), 2000).

The city of Bauru has a tropical temperate weather with average temperature of around 26 °C (13 °C in winter and 32 °C in summer). It is relatively dry with average humidity ranging from 60% to 75% and annual rainfall of 100 mm. These climatic conditions favors that children play outdoors in a rather dusty environment.

Children are known to be more susceptible to lead toxic effects because of their higher rate of gastrointestinal absorption and because of their hand–mouth behavior (Davies et al., 1990; Centers for Disease Control (CDC), 1991; Lanphear and Roghmann, 1997; Lanphear et al., 1998; Baghurst et al., 1999; Lane and Kemper, 2001).

Aiming to assess children lead exposure around the plant, a multidisciplinary team was set including epidemiologists and toxicologists from environmental agencies and Universities, together with local and regional technical and political health authorities.

2. Population and methods

Initially a pilot study was designed to confirm the exposure of the local population and to evaluate the need of a deeper investigation. Following the guidelines proposed by Kjellström and Mage (1995), a small group of 29 children living close to the plant, and a control group of 30 children living about 11 km farther away from the plant were evaluated. Blood lead levels (BLL), measured by graphite furnace atomic absorption spectrometry (GF-AAS), using Zeeman background correction (Model SIMMAA 6000-Perkin-Elmer), were compared and showed to be statistically different, with much higher levels in the group of children living close to the plant, warranting an investigation of a larger sample of children.

A cross-sectional study of the whole children population (857 children eligible, age 0–12 were) living within 1000 m from the plant was carried out from February to November 2002 (Landrigan and Baker, 1981). The study protocol was approved by an Ethical Committee and a written informed consent was signed by all children's parents or legally responsible adult.

All households within 1000 m from the plant were visited and interviews were performed using a standardized questionnaire with questions assessing variables and factors which could be related to children lead exposure and absorption. After the parent's consent, blood samples were collected from each children less than 12 years old using heparin vaccuntainers for BLL measurements. When children were not present at the moment of the interview a new visit was agreed and scheduled with the parents.

The municipal and state health authorities guaranteed comprehensive medical care for the whole population in the area (AAP, 1998), and children with BLL above 10 $\mu g/dL$ had blood reassessed and if levels were confirmed were appointed for pediatric, neurological, and neurobehavioral specialized assessments.

When BLL were below the quantification limit of the method (2 $\mu g/dL$), the value of the detection limit (0.54 $\mu g/dL$) was assumed for calculation purposes.

During the whole period of investigation the plant remained closed. A new BLL evaluation was performed 1.5 years later, after environmental controlling actions were performed which consisted of indoor vacuum-cleaning of households, removal of a 5 cm deep layer of soil around the houses, paving of nearby streets, and establishment of specific hygiene and educational programs targeted to the local population.

Lead concentrations in soil, water, and in vegetables, eggs, dairy products and poultry grown in the area were analyzed by GF-AAS (CETESB, 2002; AOAC, 1995; APAH, 1998).

3. Statistical analysis

For continuous variables means and medians were calculated. Correlation between distance from the contaminating source, age, and BLL was tested. The information about age and the distance from the contaminating source were categorized and χ^2-tests for trend were performed.

Logistic regression models were used to estimate the association between BLL and age, sex, hand–mouth habit, playing on the ground, period of time dwelling in the area, distance from the plant, type of drinking water source, parents working at the plant, etc. In the univariate analysis all these variables, except age, were classified as dichotomous. Children were classified according to BLL higher than or equal to 10 μg/dL, and lower than 10 μg/dL (CDC, 1991). All those variables that reached a $P<0.20$ in the univariate analysis were selected for inclusion in the multivariate model and its adequacy was assessed by the maximum likelihood ratio test. Interactions were always tested when a variable included in the model changed the value of the previous ones by 10% or more. Variables entered the multivariate model following its level of significance observed in univariate analysis. A non-parametric test was used to compare medians of BLL before and after implementation of environmental control measures.

A significant level of 5% was used throughout the study. Data was analyzed using the statistic packages EPI-INFO version 6.4 and SPSS version 10.0.

4. Results

The study enrolled all the 857 children from 0 to 12 years old living within 1000 m from the plant. Four children belonging to the same family could not be contacted after several attempts and three other children from another family were excluded as they have an indoor lead exposure source. One of these children had BLL above 90 μg/dL and was admitted to hospital for clinical evaluation and specific treatment.

The remaining 850 children dwelling in 503 different households participated in the study (mean number of children per house: 1.69). The mean age was 6.2 years old (SD = 3.5) and the median value of BLL was 7.3 μg/dL. Among them 311 (36.6%) exhibited BLL equal to or higher than 10 μg/dL (median 14.7 μg/dL). The distribution of BLL in children according to demographic characteristics and distance from the exposure source is displayed in Table 1.

Just over half (52%) of the 311 children with BLL ⩾ 10 μg/dL presented levels between 10 and 14 μg/dL, 25% had levels between 15 and 19 μg/dL, 21% between 20 and 39 μg/dL, and less than 1% (three children) showed BLL of 40 μg/dL or higher.

Overall analysis showed no differences in BLL according to sex. However, when children from 6 to 12 years were evaluated, a significantly higher BLL was detected among boys. Children less than 1-year old exhibited the lowest BLL.

BLL in children were correlated with the distance from their homes to the plant (Spearman $r = 0.51$). Nearly 72% of the children living within 200 m range from the plant exhibited BLL above 10 μg/dL and there was a marked decrease in this percentage when houses were farther away (χ^2-test for trend, $P<0.05$).

Univariate logistic regression analysis (Table 2) identified several variables associated with high BLL. Although there was a statistically significant difference in BLL according to race (see also Table 1), there was nearly 30% missing information for this variable. Therefore, race was not considered in further analysis.

Multivariate logistic regression models were used to identify risk factors for high BLL in children (Table 3). From this model it can be seen that living in non-paved streets is the most important risk factor (OR = 5.06, 95% Cl: 3.15–8.12). No significant interactions were observed.

Among the 311 children with BLL equal to or above 10 μg/dL, 276 were reevaluated 75 days later when the plant was still closed but no environmental control measures were performed. Overall, there was a statistically significant 12% decrease in mean BLL (from 16.8 to 14.7 μg/dL) although there was a subgroup of 55 children for whom BLL increased in the period.

After these assessments a series of lead abatement activities were performed including indoor vacuum-cleaning of all households with children with BLL ⩾ 10 μg/dL,

Table 1
Blood lead levels according to children demographic characteristics and distance of residences to the plant, Bauru, Sao Paulo, 2002

		n (%)	Median (Pb) (μg/dL)	25% percentile (μg/dL)	75% percentile (μg/dL)	*P*-value
Sex	Masc.	449 (52.8)	7.6	3.9	13.1	0.08
	Fem.	401 (47.2)	7.0	2.1	12.0	
Age (years)	<1	55 (6.5)	<2.0	<2.0	9.9	0.00
	1–5	364 (42.8)	8.6	5.0	14.3	
	6–12	431 (50.7)	6.9	2.7	11.2	
Race	White	511 (85.6)	6.8	<2.0	11.3	0.00
	Non-white	86 (14.4)	10.2	6.2	15.4	
Distance from the plant (m)	0–200	50 (5.9)	13.4	9.9	17.4	0.00
	201–400	74 (8.7)	13.1	8.7	16.8	
	401–600	127 (14.9)	10.6	6.2	17.4	
	601–800	155 (18.2)	9.5	6.5	14.9	
	801–1000	444 (52.2)	5.1	<2.0	8.0	

Table 2
Odds ratio (95% CI) for variables examined as potential risk factors for high blood lead levels—univariate analysis, Bauru, Sao Paulo, 2002

Variables	OR	IC 95%	*P*-value
To live in non-paved street	11.20	7.17–17.62	0.00
Father working in the company	5.04	2.88–8.88	0.00
To live less than 500 m of the company	4.72	3.26–6.88	0.00
To play on the ground	3.92	2.67–5.76	0.00
Children with pica	3.19	2.09–4.87	0.00
More than two children at household	2.71	1.98–3.71	0.00
To drink local milk (non-industrialized)	2.27	1.47–3.50	0.00
To play in the local river or lake	2.07	1.22–3.53	0.00
To stay in the area more than 18 h a day	1.52	1.13–2.03	0.00
Race (white as reference)	0.37	0.23–0.61	0.00
To play with imported toys	0.58	0.43–0.79	0.00
Age in years (as continuous)	0.94	0.90–0.98	0.00
To use alternative drink water source	1.80	0.83–3.87	0.07
Parents working in another factory that uses lead	0.70	0.43–1.15	0.08
To use lead based corrosion-resistant paint	0.70	0.41–1.16	0.09
To use ceramic dishes	1.56	0.74–3.30	0.14
Gender	1.15	0.86–1.54	0.18
Children with health problems	0.86	0.62–1.19	0.19
Contact with vehicle lead batteries at the household	0.81	0.39–1.67	0.33
To eat from the kitchen garden or orchard	1.03	0.76–1.39	0.45
Residence time longer than 1 year	0.97	0.62–1.53	0.49
To wash working clothes at home	0.83	0.21–3.41	0.49

Table 3
Odds ratio (95% CI) for variables examined as potential risk factors for high blood lead levels—multivariate analysis, Bauru, Sao Paulo, 2002

Variables	OR	IC 95%	*P*-value
To live in non paved street	5.06	3.15–8.12	0.00
Father working in the company	3.81	2.09–6.92	0.00
To live less than 500 m of the company	2.54	1.69–3.82	0.00
To play on the ground	2.09	1.30–3.35	0.00
Children with pica	1.81	1.08–3.00	0.02
To drink local milk (non-industrialized)	1.73	1.07–2.81	0.02
More than two children in the household	1.68	1.18–2.39	0.00
Age in years (as continuous)	0.94	0.89–0.99	0.03

removal of the upper layer of soil around the houses in unpaved streets, and other specific hygiene and educational programs targeted to the whole local population.

Six months after environmental lead abatement measures were performed, a second re-assessment of BLL was carried out. This was around 1.5 years after the first assessment. We observed a 46% decrease in BLL ($P<0.05$) among the 241 children who had previous BLL equal or above 10 μg/dL. The median BLL found in this second re-assessment was 8 μg/dL (Table 4). There was no statistically significant difference in the first BLL assessment between those who were re-assessed and those who were not (70 children). There was a greater reduction in BLL among children 1–5-year old (52%) than among those less than 1-year old (32%).

All measurements performed on drinking water samples lay within the standards for human consumption (0.01 mg/L). Among the food items analyzed only mint, eggs and milk produced locally had lead levels above the standards (0.050 mg/kg, 0.10 mg/kg and 0.05 mg/L, respectively) and their production and consumption was prohibited. Analysis of soil revealed that samples collected between 0 and 2 cm deep had levels higher than the standards set by CETESB (2001).

5. Discussion

Compared to other lead contaminated areas in Brazil, BLL found in this study were rather low (median of 7.3 μg/dL). Silvany-Neto et al. (1989), studying children living close to a primary lead smelting plant in Bahia (Northeast of Brazil) found mean BLL of 36.7 ± 20.7 μg/dL. In that area soil lead concentration showed values reaching up to 10,000 mg/kg. In this study the maximum lead concentration in upper layer of soil was 350 mg/kg (0–2 cm deep sample). Santos-Filho et al. (1993), investigating one of the most industrialized areas in Brazil, located in Cubatão, state of São Paulo, found mean BLL of children from 4 to 10 years old of 17.8 μg/dL, in spite of the environmental control measures concerning the industrial emissions that had been put into effect since 1985. Paoliello et al. (2002), studying a lead mining area in the Ribeira river valley, in the border of the states of São Paulo and Paraná, where a primary smelting plant was in operation for the last 50 years up to 1995, found a BLL median value of 11.25 μg/dL. Among the 94 children examined, 59.6% exhibited BLL higher than 10 μg/dL. In our study we found 36.6% of the children with BLL equal or higher than 10 μg/dL.

Fossil fuel combustion is the most important source of lead in the atmosphere (WHO, 1995). Countries where lead

Table 4
Comparison of blood lead levels (BLL) of children who presented BLL $\geqslant$ 10 μg/dL, before and after abatement measures were implemented, Bauru, Sao Paulo, 2002–2004

	N	Mean/(SD) (μg/dL)	Median (μg/dL)	% difference	*P*-value
1st assessment (all children)	311	16.52 (6.36)	14.70	—	
1st assessment (only those who were re-assessed)	241	16.63 (8.52)	15.00	—	
1st assessment (only those who were *not* re-assessed)	70	15.43 (5.67)	14.00		0.30
2nd assessment (after control measures)	241	9.05 (4.82)	8.00	46.23	0.00

in fuel was phased out showed a marked decrease in BLL in children (USEPA, 1998). In the state of Sao Paulo lead in fuel has been replaced by ethanol since 1979 and a declining trend in atmospheric concentration was observed reaching 0.30 μg/m^3 in the Metropolitan Region of Sao Paulo in 1987 (Romano et al., 1992; Paoliello and De Capitani, 2005).

Brazil has no reference values for BLL in unexposed population but studies that examined unexposed populations have generally showed low levels. Paoliello et al. (2002) found a median of 4.4 μg/dL in a control group of children from 7 to 14 years of age living in an area free of any environmental lead contamination in Paraná, São Paulo. Ushirobira et al. (2004) evaluated a non-exposed group of children from 0 to 12 years old in a rural area in Jacareí, São Paulo, and found most of the results below the quantification limit of the method (2 μg/dL). However, none of these studies used strict methodology to obtain general population reference values.

According to data from NHANES III, median BLL found in children from 6 to 11 years of age in the USA from 1988 to 1991 was 2.5 μg/dL (Brody et al., 1994). In Sweden two studies designed to obtain population reference values in 1995 and 2000 showed medians of 2.7 and 1.9 μg/dL, respectively (Stromberg et al., 1995; Berglund et al., 2000).

Children less than 1-year old showed lower BLL than other age groups. This might be due to children at this age having little contact with contaminated soil and dust (Tavares et al., 1989; Bjerre et al., 1993; Trepka et al., 1997). No overall significant sex difference of BLL was found. However, when children were stratified by age, those between 6 and 12 years showed higher BLL among boys, probably due to preferences in playing outdoors in contact with contaminated soil and dust (Roels et al., 1980; Trepka et al., 1997; Paoliello et al., 2002). Paoliello et al. (2002) also found higher BLL in boys 7–14 years old than in girls.

Multivariate logistic regression analysis pointed some variables out as predictors of children BLL, such as living in non-paved streets, residence located at short distance from the contaminating source, habit of playing on the ground, pica, and consumption of milk produced in the area.

Cook et al. (1993), evaluating the type of yard pavement as an indicator of the level of children lead contamination detected a positive correlation between the absence of yards pavement with high BLL. Pica, hand-to-mouth activity and proximity of residence to the lead source have also been studied and showed good correlation with BLL in children (Landrigan and Baker, 1981; Silvany-Neto et al., 1989, 1996; Tavares et al., 1989; Cook et al., 1993; Leroyer et al., 2000; Paoliello et al., 2002; Albalak et al., 2003). According to Roels et al. (1980) children's BLL correlates better with the concentration of the metal in the superficial soil and in the children's hands than with lead in the air, emphasizing the risk of transferring lead from dust to hands and from them to the gastrointestinal tract. Good correlations were also found between lead in indoor dust and BLL in children (Baker et al., 1977; Grandjean and Bach, 1986; Laxen et al., 1987).

The correlation found between parents' lead working activities and children BLL has already been shown in other studies, pointing out to the difficulties related to controlling the workers clothes contamination (Silvany-Neto et al., 1989; Tavares et al., 1989; Cook et al., 1993; Trepka et al., 1997; Leroyer et al., 2000; Paoliello et al., 2002). Although the company provided separated bathrooms and lockers, 20% of the studied workers said they used to bring home the clothes they had worked with.

From food produced locally only mint, milk and eggs showed lead levels above permitted limits. However, in the multivariate logistic regression analysis to identify risk factors for high BLL only milk presented statistical significance, probably due to its greater consumption among children than eggs or mint.

Drinking water supply, either from the public system or from backyard wells, did not show to be a source of lead contamination, presenting lead concentrations below Brazilian permitted levels (0.01 mg/L for drinking water; 0.03 mg/L for superficial waters, and 0.5 mg/L effluents) (Brasil, 2004; Brasil, 1986).

In this study, a significant difference was found between children BLL obtained during the first evaluation, and BLL obtained after the implementation of a program for lead abatement. The first campaign blood samples were collected along 2002, and the second campaign was developed during the end of the dry season and the first rains of 2003 (September–November) when one expects to have higher dust lead levels. No significant differences were found between groups regarding age, which could explain BLL decrease, although a smaller rate of decrease in BLL was seen among 1-year-old children. No other similar situation involving such methods of lead abatement measures has been studied so far in the country. Silvany-Neto et al. (1996) compared levels of children zinc protoporphyrin (ZPP) measured in 1980 prior to and after implementation of controlling measures of lead air emissions from a primary smelting plant in 1985, in Bahia, and after the closure of the plant in 1995. The authors found a significant decrease in the median ZPP levels, although the proportion of children with ZPP above the recommended limits varied from 92.2% to 98.4% and 97.0%, respectively.

Roels et al. (1980) showed that isolated controlling measures of lead air emission from primary smelting plants can reduce children BLL during the first year of implementation, but did not establish a stable decreasing rate along the years. Few studies using the same methods of reducing secondary lead sources (indoor dust control by water-sealed vacuum cleaners; personal hygiene and nutritional education programs; backyard soil covering or replacement) as implemented in this study were published so far. Lindern et al. (2003) investigating a lead contaminated area in Plata river valley, where a lead plant was in operation until 1981, found a median children BLL of 40 μg/dL in 2001, vs. 4 μg/dL after controlling of the secondary lead sources were implemented.

6. Conclusion

This study tried to investigate all factors that could have contributed to the high BLL found among children living around a secondary lead smelting plant. As the plant was closed at the time of the investigation, secondary lead sources were assessed involving drinking water, food, soil and indoor dust. Lead abatement measures were established and implemented according to these results, and a significant decrease in BLL has then occurred which suggests the efficacy of those measures.

Despite the significant decrease in the median BLL, a regular blood lead monitoring is planned to be running in the next years, as many of children still have BLL above 10 μg/dL.

The epidemiological design, and the institutional and operational logistic approach used in this study could be of value in dealing with similar situations in the country.

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