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Human exposure to heavy metals in the vicinity of Portuguese solid waste incinerators – Part 3: Biomonitoring of Pb in blood of children under the age of 6 years

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Abstract

As a part of environmental health surveillance programs related to Portuguese solid waste incinerators (SWI), two biomonitoring projects have been established to investigate additional exposure to lead in children under the age of 6 years living in the vicinity of those facilities. The above-mentioned programs, being the only ones in the country that integrate systematic observations on human exposure to heavy metals, have to provide systematic data from Portuguese regions on the extent and pattern of human exposure to heavy metals, namely to lead. The present paper is the third of a series of papers prepared to accomplish that objective in regards to lead exposure as evaluated by measuring lead levels in children under the age of 6 years. Altogether, 250 children from Lisbon and 247 from Madeira Island have already been involved in the investigation. The present study evaluates spatial and temporal trends of lead exposure, based on comparisons of children's blood lead levels, either stratified by living area (exposed and control groups), or by time of exposure (T0, the baseline time, and T1, after approximately 2 years of regular operation of the facilities). The results obtained correspond to a relatively reduced number of individuals. Possibly for this reason, they are not fully conclusive in relation to whether living in the vicinity of SWI represents an additional risk of higher exposure to lead. Time trends of lead exposure as evaluated by blood lead levels in children also do not show any clear pattern. These conclusions and the fact that altogether around 3% of children from the whole group have blood lead levels $\geqslant 10\,\mu g/dl$ warrant further investigation in order to clarify the contribution of incinerator emissions to the levels of lead in children and to identify alternative sources for preventive purposes, taking into consideration the relevance of even low lead exposure from a public health perspective, mainly in relation to children.

Keywords: Incinerators; Biomonitoring; Children; Blood; Lead; Exposure; Portugal

Introduction

Nowadays, it is known that serious health consequences can occur not only from heavy exposure to environmental toxicants, but also from low-level chronic exposures. Although these exposures and their adverse

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consequences are often insidious, in particular for children and at an individual level, the damage can be substantial at the population level, especially when the exposure is prevalent (Lanphear and Bearer, 2005). Human exposure to lead can result in a wide range of biological effects depending on the level and duration of exposure. Individuals whose bodies are still developing (such as children or developing foetuses) are more at risk than adults (Canfield et al., 2003). While some aspects of lead poisoning are reversible in adults, in children it can interfere with normal development (Brown et al., 2005). The developing brain is especially vulnerable to some environmental toxicants, particularly lead. For example, Needleman et al. (1979) found that children with a higher lead body burden were more likely to have problems at the level of distractibility, organizational ability, dependence, impulsivity, daydreaming, and ability to follow directions. In a follow-up study, these children evidenced lower reading scores, lower class rank, and, in adolescence, increased absenteeism and higher risk of dropping out of school than children with lower body lead concentrations.

Lead is a metal that has been associated with human activities for the last 6000 years (Papanikolaou et al., 2005). The main sources of lead exposure are paints, water, food, dust soil, kitchen utensils, and leaded gasoline. Waste incineration is also responsible for metal emissions (Dempsey, 1993). In Portugal and in recent years, municipal solid waste incineration has been preferred to other waste treatment or disposal alternatives, due to the several advantages of this type of waste management. Since the potential health impact associated with emissions from incineration processes continues to be a major subject of concern, environmental health surveillance programs, relative to new and updated incinerators, were established during the construction or renovation of the main national incineration facilities. Most of these programs include assessment of human exposure to lead in several risk groups, in particular children under age of 6 years, since this period is a window of vulnerability of particular concern.

Human biomonitoring (HBM) has become an important tool in environmental health. Having the main added value that biomarkers are more directly linked to the adverse health effects that one attempts to prevent than is environmental monitoring (through air, water and soil monitoring programmes), HBM provides a possibility to assess human exposure to environmental pollutants and potential health effects of such exposure.

As part of two environmental health surveillance programs – one connected to an updated solid waste incinerator (SWI) at Meia Serra, Madeira Island, operating since June 2002, and another connected to the Municipal SWI of VALORSUL, near Lisbon, in operation since 1999 – biomonitoring of lead in the blood of children under the age of 6 years has been carried out, mainly to provide indicative data on the extent and pattern of lead exposure in this age group (Miguel et al., 2001; Reis et al., 2003, 2004).

The specific objectives of both programs (acronyms ProVEpA-Ms and ProVEpA-Lx, derived from the Portuguese designations for that of Meia Serra and of Lisbon) are (1) to determine if living in the vicinity of an SWI increases children's environmental exposure to lead; (2) to monitor temporal trends of human exposure to this pollutant. To accomplish these objectives, two cross-sectional surveys for each of the environmental health survey programs have already been carried out. The first, before the SWIs started operating, to establish baseline levels, and another, after approximately a 2-year period of regular operation, to determine potential specific impacts of the facilities in relation to the baseline levels.

These programs are the only systematic collection of data through HBM currently being performed in Portugal in relation to the pollutants potentially emitted by incineration processes. As such, although regional, they represent the only source of systematic data on human exposure to heavy metals in the country, making it important to publish the results of the ongoing projects. The present paper, the third in a series of three, reports and discusses the data on human exposure to lead obtained by biomonitoring of lead levels in the blood of children under the age of 6 years.

Material and methods

Study group

Apparently healthy children, aged between 1 and 6 years, non-twin, born from a normal pregnancy, with birth weight higher than 2500 g, without previous known environmental lead exposure, and living at the study area for over 1 year, participated in the blood biomonitoring studies, after written informed consent from at least one parent or a legal guardian. Participants were classified as exposed and controls, depending on their living at a greater or smaller than predefined distance from each SWI facility (5 km for Lisbon community and 3 km for Madeira community). In relation to both communities (from here on designated as Lisbon and Madeira) and for each of the groups (control and exposed), similar relevant socio-demographic characteristics were ensured in order to avoid between-group bias.

Sample and data collection

In total, 497 children were included in the two biomonitoring studies (250 from Lisbon and 247 from

Madeira). Samples were collected by nurses in Hospitals (Lisbon) and health centers (Madeira) of studied exposed and control areas. In Madeira, samples collected from each participant included scalp hair for heavy metal determinations (Pb and Hg) and venous blood ($\approx$4 ml), for determination of lead and clinical hematological and biochemical parameters. In Lisbon, only venous blood samples were collected due to logistical constraints. Immediately after collection, blood samples were frozen until analysis. Simultaneously with blood collection, a questionnaire was administered to the child's guardian to gather relevant individual and family characteristics, as well as data on potential alternative lead sources. A small gift was offered to the children after blood collection and, for hair sample collection, a financial compensation to cover hairdresser expenses to correct possible damage to the child's hair. Sampling was based on "convenience samples" due to the enormous difficulty in recruitment and sample collection from children.

Analytical procedures

Blood lead levels were determined by atomic absorption spectrometry (AAS) at Clínica Médica e Diagnóstico Dr. Joaquim Chaves, Lisbon, Portugal.

Statistical analyses

Database management was performed using Microsoft Access 2000 (9.0.3821 SR-1) and, for statistical analyses, SPSS software version 12.0 for Windows. Significance level was fixed at 0.05. Numerical variables were described by their arithmetic means or medians, percentage of results above them or above action level for lead as defined by CDC (1991), and variation intervals. Appropriate tests (Mann–Whitney and χ^2-tests) were used to compare means, medians and proportions across the two areas of residence, and between age and other relevant related groups. The association between age and lead levels was estimated by computing Spearman's correlation coefficient.

Results and discussion

Study group

In relation to the specific living area, no statistically significant differences have been found for variables such as age and sex, which seems to confirm a relative homogeneity between the exposed and control groups included both in Lisbon and Madeira biomonitoring projects and along the observational periods (T0 and T1). These findings led to the conclusion that results are not likely to be confounded by a selection bias. For Lisbon, the global population was characterized by mean age values and standard deviation of 36 ± 18 and 45 ± 22 months for T0 and T1, respectively, while for Madeira mean age values for the baseline period and for the first observational period of potential specific impacts of the incinerator were 40 ± 18 and 39 ± 18 months, respectively.

Blood lead levels for Lisbon

As can be seen in Table 1, the differences observed between the exposed and control groups for blood lead levels are statistically significant for both T0 ($p = 0.001$) and T1 ($p < 0.001$). Therefore, it is not possible to conclude on the effective control of the facility in relation to lead emissions, as was also evident from studies (not published) performed in other risk groups included in these ongoing surveillances. Comparison of results during the monitoring period shows a significant decline of mean lead levels in the exposed group (from 4.6 μg/dl in T0 to 2.5 μg/dl in T1), while in the control group an opposite trend can be observed (mean lead levels varies from 2.9 to 5.1 μg/dl). When the global population is considered, lead levels ranged from 0.1 to 19.8 μg/dl, with a mean value of 3.4 ± 3.4 μg/dl in T0, and from 0.1 to 22.9 μg/dl, with a mean value of 3.9 ± 3.3 μg/dl in T1. However, levels did not change significantly over time ($p = 0.060$). Nevertheless, it is important to notice that there are still 13 children in the whole group that showed blood lead levels equal to or higher than the action level of 10 μg/dl (CDC, 1991; ATSDR (Agency for Toxic Substances and Disease Registry), 2000), justifying further investigation in relation to this public health problem.

Levels of lead in blood for Madeira

Similarly to what happens in Lisbon, observed blood lead levels in the exposed and the control groups in Madeira are also different, being slightly ($p = 0.710$) higher in controls for T0 and significantly higher ($p = 0.002$) for exposed in T1 (Table 2). The global population can be characterized by mean lead values of 4.1 ± 2.2 and 2.3 ± 1.3 μg/dl for T0 and T1, respectively, ranging from 0.1 to 11.0 μg/dl in T0 and from 0.1 to 8.8 μg/dl in T1. Along the monitoring period, lead levels seem to have a tendency to reduction ($p < 0.001$), although more observations are needed to better define the trend. In relation to blood lead levels equal or higher than the 10 μg/dl limit, it has to be noticed that there is only one case in the whole group. This is, however, relevant enough to justify further investigation.

When compared to global lead levels in Lisbon, results from Madeira suggest that lower road traffic and reduced industrial density can be responsible for the

Table 1. Levels of Pb (μg/dl) in children per study area and in succeeding observational periods for Lisbon

	Exposed	Control	Global population	p^a
T0 – baseline period				
n	36	84	120	0.001
Mean	4.6	2.9	3.4	
Median	3.5	2.2	2.5	
Standard deviation	3.6	3.2	3.4	
Min.–Max.	0.1–15.0	0.1–19.8	0.1–19.8	
T1 – 1st observational period				
n	61	69	130	<0.001
Mean	2.5	5.1	3.9	
Median	1.6	4.7	3.4	
Standard deviation	3.1	3.0	3.3	
Min.–Max.	0.1–17.8	0.1–22.9	0.1–22.9	
	$p^a = 0.060$			

[a]Mann–Whitney test.

Table 2. Levels of Pb (μg/dl) in children per study area and in succeeding observational periods for Madeira

	Exposed	Control	Global population	p^a
T0 – baseline period				
n	66	67	133	0.710
Mean	3.9	4.3	4.1	
Median	4.1	4.4	4.2	
Standard deviation	2.0	2.5	2.2	
Min.–Max.	0.1–9.5	0.1–11.0	0.1–11.0	
T1 – 1st Observational period				
n	58	56	114	0.002
Mean	2.6	1.9	2.3	
Median	2.4	1.8	2.0	
Standard deviation	1.5	1.0	1.3	
Min.–Max.	0.1–8.8	0.1–4.9	0.1–8.8	
	$p^a = <0.001$			

[a]Mann–Whitney test.

apparently more effective control of lead exposure in Madeira, since conclusions relative to residing in the vicinity of an incineration facility are not yet possible for any of the population groups, taking into consideration only the results of both cross-sectional surveys. In order to clarify spatial and temporal trends, it is necessary that monitoring of lead exposure be repeated periodically. Evaluation of another observation period for both communities is already in progress and the results will be published as soon as they are available.

Age-dependence of lead levels in blood

No statistical associations have been found between children's blood lead levels and age, either for global populations from Lisbon and from Madeira, or for specific groups (stratified by sex or living area, for example) in either of the two periods (T0 or T1).

Comparison of lead levels in blood with action level

From analysis of all results obtained in this study it is possible to conclude that lead levels in the blood of the study children are relatively low and that only 14 cases (13 in Lisbon and 1 in Madeira), corresponding to 2.8% of the whole studied group, had blood lead levels equal to or higher than the action level of 10 μg/dl (CDC, 1991).

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