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ORIGINAL ARTICLE

Elevated blood lead levels and sources of exposure in the population of Kinshasa, the capital of the Democratic Republic of Congo

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The objective of this study was to determine blood lead levels (BLLs) and the possible sources of exposure in the population of Kinshasa, the capital of the Democratic Republic of Congo. A cross-sectional survey was carried out from January to May 2008 in a representative sample of the Kinshasan population. BLL was measured in 275 individuals (53.4% women) aged 1–70 years in the urban area of Kinshasa and from 60 additional subjects in the rural area. Pb was also determined in environmental specimens (air and soil, indoor and outdoor). BLL in the study population ranged from 2.9 to 49.3 μg/dl (median, 9.9 μg/dl). The median BLL among children aged <6 years was 11.5 μg/dl (range: 3.0–37.8 μg/dl). Of these children, 71% had elevated BLL (≥ 10 μg/dl) and 22% had BLL ≥ 20 μg/dl. The proportion of elevated BLL (≥ 10 μg/dl) was higher for children aged <3 years than for children aged 3 to 5 years (97% *vs* 56%). A higher prevalence of elevated BLL was observed in urban compared with rural children (71% *vs* 20%). Significantly higher BLLs were also found in children whose mother consumed fired clay during pregnancy. Residential informal activities in the recycling of car batteries also contributed to elevated BLL in children. The elevated background of Pb exposure in the Kinshasan population indicates a public health issue that requires corrective actions. Pb-contaminated dust and air in children's home is an issue of public health concern. The use of leaded gasoline and the activities of car battery recycling in certain residences appear to constitute the main sources of exposure in the city of Kinshasa. The traditional use of fired clay for the treatment of gastritis by pregnant women is another significant contributor for elevated BLL in children.

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INTRODUCTION

Pb is a cumulative toxicant that adversely affects the neurologic, hematologic, gastrointestinal, cardiovascular, renal and reproductive systems.[1–3] Pb and its inorganic compounds are considered as probable carcinogens for humans (Group 2A, IARC classification).[4]

Pb exposure has been continuously declining in most industrialized countries because of the phase-out of leaded gasoline, the ban of Pb in paint and consumer products, the removal of Pb from plumbing and so on. Environmental sources of Pb exposure vary, however, according to the local context, and some populations continue to be at greater risk of exposure to Pb. The Democratic Republic of Congo (DRC) is a developing country where leaded gasoline is still used despite a process of phasing out that started in December 2005 (Declarations of Dakar in June 2001 and Johannesburg in 2002). Moreover, residential informal activities in recycling used Pb-acid batteries are widespread in the DRC.

It is well established that children are both more vulnerable to Pb poisoning and more sensitive to its neurotoxic effects than adults.[5] Between 1960 and 1990, the Centers for Disease Control and Prevention (CDC) lowered the blood lead level (BLL) for individual intervention in children from 60 to 25 μg/dl. In 1991, the CDC recommended lowering this level to 15 μg/dl and implementing community-wide primary lead poisoning prevention activities in areas where many children have BLLs >10 μg/dl.[6] Although the CDC recognized that a BLL of 10 μg/dl did not define a threshold for the harmful effects of Pb, this level, which was originally intended to trigger community-wide prevention activities, has often been misinterpreted as a "definitive toxicologic threshold".[7] Research conducted since 1991 has strengthened the evidence that children's physical and mental development can be affected at BLLs of <10 μg/dl.[8–15] Childhood Pb poisoning appears to be of great concern in developing countries.[16] Although it was estimated that 15 to 18 million children living in developing countries suffer from permanent cerebral lesions due to Pb intoxication,[17] insufficient attention is still paid on the affect of Pb on human health in developing countries.

The objective of the present study was to assess Pb exposure through the measurement of BLL in a representative sample of the Kinshasan population, and to investigate the possible sources of exposure.

METHODS

Study Design

In the absence of reliable population registers in Kinshasa, we applied a two-stage systematic sampling approach.[18] In the first stage, the 22

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administrative entities of Kinshasa were listed in alphabetical order and 11 out of them were selected as follows: a first entity was drawn randomly from the list and every other subsequent entity was then included, thus ensuring a comprehensive coverage of the entire urban area of Kinshasa. In the second stage, we aimed to recruit ~30 male and female subjects between 1 and 70 years from each entity. In a mobilization campaign (mainly by word of mouth), healthy subjects were invited to visit the local health center to take part in this survey. After exclusion of 13 individuals because of possible direct occupational exposure to Pb, 275 individuals provided a blood sample and were included in the present study (83% of the target number was reached). These individuals were not hospitalized and were free of disease as assessed by interview and clinical examination. Informed consent was obtained from each subject and information on age, gender, place of residence and smoking habits, housing conditions (type of indoor floor, presence of painting, outdoor soil), use of traditional cosmetics or remedies and environment was recorded. Sixty additional subjects living in the rural area were also included using the same sampling approach. The 17 administrative entities of the two rural districts of Kinshasa (N'sele et Maluku) were listed alphabetically and six out of them were systematically selected (nos. 2, 5, 8, 11, 14 and 17). In each of these entities, 10 individuals were recruited after informed consent and filling of the questionnaire. Subjects aged >5 years also provided a urine sample, the results of these analyses are presented elsewhere.

In order to characterize the potential exposure of children to Pb-contaminated household, interviews with family members (parents or relatives) were conducted and environmental samples were collected for each tested child. A total of four indoor wipe dust samples were collected from the child's principal playing area (1 m^2 area in living room using baby wipes). The most common flooring materials in the homes were dirt floors or cement. Airborne particulates were sampled during 24 h in the main living room using air sampling pumps (2 l/min) equipped with a nitrocellulose filter (0.8 μm); paint chips from indoor house and two drinking water samples were collected after flushing followed by 30 min stagnation. A sample of 0–1 cm surface soil was taken from the perimeter of the children's outdoor playing area, homogenized and sieved (2 mm) to obtain a coarse fraction.[19] In addition, as Pb may be adsorbed onto clays that are used as a traditional remedy by pregnant women in DRC, samples of fired clay were collected from different markets of Kinshasa.

The study was approved by the National bio-ethic committee.

Laboratory Methods

Blood was drawn in metal-free tubes (EDTA anticoagulated) in the local health centers after careful cleaning of the skin at the venipuncture site. After sampling, the tubes were frozen and transported in a cool box to the Catholic University of Louvain, Belgium, for analysis. Pb was measured by graphite furnace atomic absorption spectrophotometry (GFAAS) by the method of Miller et al.[20] with Zeeman effect background correction on a Perkin-Elmer Model 5100 (Perkin-Elmer, Norwalk, CT, USA). Analysis of each specimen was performed in duplicate, and the mean of duplicates is reported. Determinations were calibrated with Pb standards prepared of Pb nitrate (99.99% Pb(NO3)2; Aldrich, Milwaukee, WI, USA). The limit of quantification (LOQ) was 1 μg/dl. For quality control, internal standards and reference materials were run together with the samples on a daily basis. External quality control for the analysis of blood was achieved by regular participation in intercomparison programs organized by the Institute for Occupational, Environmental and Social Medicine of the University of Erlangen, Germany (G-EQUAS program) and the Institut National de Santé Publique, Québec (PCI and QMEQAS programs). For environmental specimens, all samples were mineralized in a microwave preparation system (A Paar Multiwave V3.20.5), except drinking water. Pb was quantified in these samples by inductively coupled argon plasma mass spectrometry (ICP-MS Agilent 7500ce) and the LOQ was 0.095 μg/l.

Statistical Analyses

All analyses were carried out with NCSS statistical software package, version 2004 (NCSS Institute, 2004). The distribution of BLL was log-normal upon visual inspection; therefore, medians or geometric means were used as measure of central tendency. The *t*-test, analysis of variance (ANOVA) and multiple-comparison test (Dunnett's test) on log-transformed values or χ^2 test were used for comparing subgroups according to age, gender, smoking habits and region of residence. Simple linear correlation analyses between log-transformed data were used to estimate the relationship between parameters (Pearson's *r* coefficient). Stepwise multiple linear regression analyses of log-transformed data were used to estimate the influence of independent variables on the BLL (stepwise procedure, criteria: *F* probability to enter ≤ 0.05 and *F* probability to remove ≥ 0.10). Potential explanatory variables were assessed for collinearity (variance inflation factor and condition indices). Differences were considered as significant for $P < 0.05$.

Table 1. Demographic characteristics of the participants.

	Urban	*Rural*	*P-value*[a]
Number of subjects	275	60	
Age, years[b]	27 ± 23 [1–70]	31 ± 25 [1–60]	0.871
1–5, *n* (%)	55 (20.0%)	10 (16.6%)	0.554
6–11, *n* (%)	18 (6.5%)	26 (43.3%)	**<0.001**
12–19, *n* (%)	45 (16.4%)	9 (15%)	0.793
≥20, *n* (%)	157 (57.1%)	15 (25%)	**<0.001**
Sex			
Male, *n* (%)	128 (46.5%)	29 (48.3%)	0.802
Female, *n* (%)	147 (53.4%)	31 (51.6%)	
Current smokers			
Total, *n* (%)[c]	79 (39.1%)	6 (25.0%)	0.129
Men, *n*	38	3	
Women, *n*	41	3	

[a]Student's *t*-test or χ^2 test.
[b]Arithmetic mean ± SD [range].
[c]Percentage of individuals ≥12 years old.
Statistically significant differences are shown in bold.

RESULTS

The demographic characteristics of the urban and rural samples are shown in Table 1. In the urban sample, 20% were aged <6 years. Men and women were equally represented. Smoking habits did not differ according to gender, and smokers were equally prevalent in the urban and the rural samples.

Table 2 provides the results of the BLL measurements including the geometric means (GMs) and selected percentiles for the overall urban individuals studied, as well as after stratification according to gender, age and smoking habits. Overall, all BLLs exceeded the limit of quantification, and ranged between 2.9 and 49.3 μg/dl, with a GM of 9.6 μg/dl and a 95th percentile at 25 μg/dl. Similar BLLs were found in current smokers and non-smokers. The mean BLL was significantly higher in men than in women (GM 10.4 *vs* 9.0 μg/dl) and in children aged <6 years by comparison with the other age subgroups.

The BLLs of children <6 years are also shown in Table 2 as a whole group and stratified according to age, gender, consumption of fired clay by the mother while pregnant and the presence of informal residential activities in the recycling of lead-acid car batteries. Among children aged <6 years, those born from mothers who consumed fired clay during pregnancy and those living in a domestic environment where car batteries were recycled had significantly higher BLL. Children <3 years old showed the highest BLL when compared with children aged 3–5 years and with the other age subgroups.

Table 3 presents the prevalence of elevated BLL in urban children aged 1–5 years. A significantly higher prevalence was observed among children 1 to <3 years of age than among

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Table 2. Lead in blood (μg/dl) in a representative sample of the urban Kinshasa population.

	N	*P25*	*P50*	*P75*	*P95*	*Min*	*Max*	*GM (CI 95%)*	*P-value*[a]
Total	275	6.8	9.9	13.8	25.0	2.9	49.3	9.6 (9.0–10.3)	
Gender									
Men	128	7.5	10.3	15.2	25.4	3.0	49.3	10.4 (9.4–11.4)	**0.03**
Women	147	6.0	9.4	12.8	24.8	2.9	37.8	9.0 (8.2–9.9)	
Smoking[b]									
Current smokers	79	7.3	8.9	12.6	18.4	3.3	25.9	9.3 (8.4–10.3)	0.89
Non-smokers	123	6.5	9.4	13.1	22.7	2.9	49.3	9.1 (8.3–10.0)	
Age									
1–5 years	55	9.2	11.5	18.9	31.9	3.0	37.8	11.2 (10.3–14.4)	**0.006**
6–11 years	18	6.7	9.9	13.1	19.6	3.6	19.6	9.1 (7.2–11.5)	
12–19 years	45	6.9	9.4	12.8	19.1	3.3	20.1	9.0 (7.7–10.4)	
≥20 years	157	6.4	9.4	12.8	22.7	2.9	49.3	9.1 (8.4–9.9)	
Children <6 years									
Gender									
Boys	26	7.3	10.9	16.9	27.3	3.0	28.6	10.7 (8.4–13.6)	0.154
Girls	29	9.3	13.9	22.8	35.8	3.7	37.8	12.0 (9.6–15.0)	
Age									
1–2 years	30	10.6	17.0	25.0	35.6	3.7	37.8	15.6 (12.6–19.3)	**<0.001**
3–5 years	25	5.8	10.2	13.4	22.0	3.0	23.8	9.0 (7.2–11.4)	
Clay eating in pregnancy									
Yes	17	11.7	17.6	22.3	37.8	8.3	37.8	16.6 (13.2–20.8)	**0.015**
No	38	6.3	10.7	17.0	30.7	3.0	31.4	10.6 (8.6–13.1)	
Residential IARCB									
Yes	14	11.4	15.9	30.9	37.8	8.7	37.8	17.6 (13.1–23.6)	**0.009**
No	41	7.5	10.7	17.7	27.1	3.0	28.6	10.7 (8.8–13.0)	

Abbreviations: GM, geometric mean (CI, 95% confidence interval); IARCB, informal activities in the recycling of car batteries; Max, maximum value; Min, minimum value; P25, P50, P75, P95, percentiles.
[a]*P*-value (*t*-test or ANOVA on log-transformed values).
[b]Individuals ≥12 years old.
Statistically significant differences are shown in bold.

children 3–5 years of age. The prevalence of BLL ≥10 μg/dl in urban children aged <6 years was 3.5 times higher than in children living in the rural area (20%). None of the BLL measured in rural children reached 20 μg/dl (GM: 7.7 (95% CI 6.2–9.1); range: 3.9–10.7; $n = 10$).

The Pb content in samples collected in the environment of the tested children is presented in Table 4. The Pb concentration in indoor dust and air samples from homes where lead-acid batteries were stored, reconditioned or recycled was ~2 and 1.6 times higher, respectively, than in other homes. Pb concentrations in indoor dust and indoor air were correlated ($r = 0.386$; $P = 0.004$). No other significant relationship was found between the different environmental samples.

Outdoor air samples showed high Pb concentrations in Kinshasa city with an arithmetic mean (SD; range) of 1.78 (1.75; 0.57–5.22) μg/m^3. The corresponding values measured in the rural area were 0.20 (0.05; 0.15–0.21) μg/m^3.

Bivariate correlation models showed good associations between Pb content in indoor dust and BLL ($r = 0.449$; $P = 0.0006$) as well as between Pb content in indoor air and BLL ($r = 0.488$; $P = 0.0002$). These correlations were slightly better when considering only children <3 years old ($r = 0.476$; $P = 0.008$ and $r = 0.636$; $P = 0.0002$, respectively) and were non-significant in children aged 3–5 years. No relationship was found between BLL and the presence of paint chipping, the Pb concentration in paint or in soils.

Results of the multiple linear regression analyses are presented in Table 5. Considering the group of children <6 years, BLL was found to be significantly influenced by age, the Pb content of indoor house air and the ingestion of fired clay by the mother during pregnancy. The model explained ~41% of BLL variation. Gender was not a predictor of BLL. A separate model run with Pb content in indoor dust instead of indoor air explained only 28% of the variance (not shown).

Table 3. Prevalence (%) of elevated BLL among children aged 1–5 years.

Blood lead level (μg/dl)	*Urban area*		
	1–5 years	*1–2 years*	*3–5 years*
≥10	70.9	96.6	56.0
≥15	38.2	56.6	16.0
≥20	21.8	26.6	4.0

Table 6 compares the values measured in the rural and urban Kinshasan populations to those measured in 2003–2004 in the same urban area of Kinshasa ($n = 385$; age <1 to 70 years,[21]) and to reference values from databases involving American ($n > 2500$),[22], Canadian ($n > 400$; age = 18–65 years)[23,24] and German[25–28] populations. A higher BLL was found in the overall urban population than in the rural population. This area-related difference was seen when comparing the three age subgroups <20 years of age, but not in adults >20 years of age.

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Table 4. Environmental Pb exposure in the home of children aged 1 to 5 years (urban area).

	N	*GM (95% CI)*	*Median*	*Min*	*Max*	*P-value*
Indoor dust, μg Pb/m²						
Total	55	720 (555–934)	822	89	11,170	
Without IARCB	41	606 (469–782)	568	89	11,130	**0.04**
With IARCB	14	1197 (597–2399)	996	131	11,170	
Indoor air, μg Pb/m³						
Total	55	0.89 (0.77–1.03)	0.78	0.42	2.04	
Without IARCB	41	0.79 (0.68–0.91)	0.78	0.42	2.04	**0.002**
With IARCB	14	1.28 (0.92–1.78)	1.75	0.42	2.04	
Playing area outdoor soil, μg Pb/g						
Total	55	39 (22–67)	19.6	3.3	2232	
Without IARCB	41	35 (18–67)	15.8	3.3	2232	
With IARCB	14	51 (15–181)	23.3	3.3	1351	0.55
House paint chips, μg Pb/g	55	24.9 (14.5–35.5)	13	9	1890	
Drinking water, μg Pb/l	50	0.24 (0.16–0.37)	0.18	0.05	32.0	
Fired clay, μg Pb/g	10	190 (142–255)	162	30	538	

Abbreviation: IARCB, informal activities in the recycling of car batteries.
P-value: comparison between houses with and without IARCB (*t*-test on log-transformed values); statistically significant results are shown in bold.

Table 5. Predictors of BLL in children aged 1–5 years ($n = 55$) in the urban area (log-transformed data)

Variable	β	*P-value*	*Partial R²*
Indoor air Pb levels	0.384	0.001	0.194
Age	−0.327	0.005	0.147
0: <3 years			
1: ≥3 years			
Fired clay[a]	0.265	0.018	0.069
0: no			
1: yes			
MODEL	0.412		

[a]Consumed by the mother during pregnancy.
β Standardized regression coefficients.
P-value for the term in the multiple linear regression model.

DISCUSSION

This study aimed at characterizing the BLL in a representative sample of the population of Kinshasa, and determining the prevalence and risk factors of elevated BLL in young, urban children. Great care was taken to select a representative sample of the Kinshasan population but, in the absence of reliable demographic data, it is not possible to assess the exact representativeness of our sample and a bias is not formally excluded. There is, however, no reason to suspect a bias caused by self-selection based on either high or low exposure to Pb.

The BLL measured in adults averaged (GM) 9.1 μg/l (P95 at 22.7 μg/dl), which is similar to the mean BLL measured in the 2003–2004 survey.[21] The urban population of Kinshasa displayed significantly higher BLLs than the rural population, and the overall BLLs of the Kinshasan population were at least twofold higher than those reported in the United States,[22] Quebec[23,24] or Germany.[25,26,28] In most European countries, the median BLL in the general population is below 5 μg/dl.[29]

The BLL in Kinshasa differed significantly between genders, being 13% higher in men than in women. Similar gender differences have been reported in most previous surveys.[23,30–37] Factors such as a higher exposure in men, a lower hematocrit in women, different behaviors and different Pb kinetics have been involved in this gender-related difference, but the exact reason is not clear.[3,38,39]

Smoking has been regularly reported to increase BLL,[31,40–45] but in this study, no difference was observed between current smokers and non-smokers. This is probably because of the fact that, for economical reasons, smokers in the present population were not heavy consumers, with one cigarette being often shared by several smokers.

Consistent with other studies, the present survey also found that the BLL was significantly higher in children than in adults.[46–50] Children <6 years of age had a 20% higher BLL than the older groups. Children are known to constitute a group at high risk of Pb poisoning; they ingest more Pb because of their hand/mouth activity, their digestive absorption rate is higher than adults and their developing nervous system is more sensitive to the adverse effects of Pb. According to the CDC definition of elevated BLL (≥10 μg/dl),[6] ~71% of Kinshasa children had elevated BLL, and 22% had ≥20 μg/dl, which is the medical intervention threshold as well as a level requiring an environmental investigation.

Although the mean BLL in children <6 years old was not statistically different from that found in the previous survey (12.4 μg/dl,[21]), the prevalence of children having an elevated BLL (≥10 μg/dl) was higher in the current survey (71% *vs* 63.0%, $P = 0.007$). No gender difference in BLL was found among children, which is in agreement with other studies.[30,47,51,52] Among children <5–6 years tested in developing countries, ~7% were reported to have elevated BLL (>10 μg/dl) in Nairobi,[53] 21% in the rural Philippines[54] and in Kampala,[55] 55% in Nigeria and Egypt[56,57] or even 81% in Pakistan.[58] The prevalence found in industrialized countries is much lower with, for instance, 1.4% in the United States.[47]

The lowest BLL value (2.9 μg/dl) determined in children of Kinshasa was higher than the 75th percentile in the US children aged 1 to 5 years[22] and German children aged 3 to 5 years.[48]

Younger children (1–2 years) showed significantly higher BLL than older children (3–5 years). This difference is not unexpected as a critical role of dust ingestion associated with the hand- or object-to-mouth behavior in the exposure pathway of children has been well documented.[3,59–63] Overall, indoor air and dust were identified as good predictors of BLL in children. The relationship between Pb in indoor dust and air is not surprising as part of the Pb content in air consists of resuspended dust particles, entailing both an inhalation and an ingestion risk.[64,65] The hot climate and the dusty conditions certainly contribute to amplify this pattern of exposure in the DRC.

In 2001, the US Environmental Protection Agency (EPA) established a Pb dust standard for the home environment of

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Table 6. Comparison between Kinshasan, Pb-B 2004 and Pb-B 2008 (μg/dl) populations and reference values (GM).

	Kinshasa, DRC					*Reference values*		
	Pb-B 2008[a]		*P-value*[b]	*Pb-B 2004*[c]	*P-value*[b]	*USA*[d]	*Québec*[e]	*Germany*[f]
	Rural area (n = 60)	*Urban area (n = 275)*		*Urban area*[g] *(n = 385)*				
Total	6.8	9.6	**<0.001**	10.1	0.21	1.3	1.4[h]	3.1
Sex								
Men	7.3	10.4	**<0.001**	10.5	0.89	1.5	2.7	9.0[i]
Women	6.0	9.0	**0.001**	9.7	0.18	1.1	1.9	7.0[i]
Age								
<6 years	7.7	11.2	**0.03**	11.3	0.45	1.5		
6–11 years	6.7	9.1	**0.01**	12.1	**0.01**	1.0		
12–19 years	5.7	9.0	**0.009**	10.1	0.23	0.80		
≥20 years	7.4	9.1	0.14	8.9	0.67	1.4	1.5[h]	3.1

[a]This study.
[b]*t*-test on log-transformed levels; statistically significant results are shown in bold.
[c]Tuakuila et al.[21]
[d]US National Health and Nutrition Examination Surveys: data from CDC[22] (values for total population of survey years 2005–2006).
[e]Institut National de Santé Publique du Québec: values for Quebec population of survey 2003.
[f]German Environmental Survey: data from GerES II (1990/192) and GerES III (1998–2003; values for total population).
[g]Recalculated after excluding individuals with high risk of occupational exposure to Pb ($n = 100$).
[h]Wong and Lye[24] (data from Statistic Canada).
[i]Schulz et al.[26] (data from GerES III).

430 μg/m^2. The Pb content measured in the indoor dust samples collected from Kinshasa homes clearly exceeded this level, with a geometric mean reaching 720 μg/m^2 (range 89–11,170). A number of different sources can contribute to Pb in house dust and air, both from outside and inside the home, including deteriorated lead-based residential paint, leaded gasoline, lead-emitting industries and landfills.

No industry or landfill known to release Pb existed near the study places.[66] The Pb content of paint chips collected in the homes of the tested children averaged 25 μg/g, with a maximum of 1890 μg/g. The US Department of Housing and Urban Development (HUD) recommends that action to reduce exposure should be taken when the Pb content in paint is >5 mg/g. No relationship was found between Pb in paint and BLL. Thus, lead-based paint does not appear to constitute a predominant source of indoor Pb pollution in Kinshasa.

Countries that have phased Pb out of gasoline have reported parallel dramatic decreases in Pb concentrations in air and human blood.[37,57,67–72] In spite of a voluntary program instituted since 2005 to reduce the Pb additives in gasoline, the ambient air levels remain high in Kinshasa, ranging from 570 to 5220 ng/m^3 in Kinshasa city, and 150 to 210 ng/m^3 in the rural area (J. Tuakuila, unpublished personal observations). Pb continues to be emitted in some countries such as DRC by the high number of vehicles burning leaded fuel. Pb-contaminated dust in high traffic areas is likely to contribute to the children's Pb intake in Kinshasa city. Considering the whole study population, the urban population had a significantly higher BLL than the rural population. Still, the mean BLL of urban children was only slightly higher than that in rural children and additional sources of exposures are, therefore, likely.

Informal residential recycling of lead-acid batteries can be a source of Pb exposure for nearby residents.[64] Because of the severe unemployment in RDC, some people develop irregular activities such as battery recycling. This consists in the reclamation of used or damaged batteries that are then repaired in improvised workshops established in private residencies. A recent report of mass Pb intoxication resulting from the recycling of used lead-acid batteries in Dakar redrew attention to this problem in developing countries.[73] The natural Pb content in soil typically ranges from <10 μg/kg soil up to 30 μg/g soil.[65] The maximum level of Pb recommended for residential soil is 140 μg/g according to the Canadian Council of Ministers of the Environment Guidelines.[74] The EPA established a hazard standard of 400 μg/g in residential play areas to help preventing Pb poisoning in children <6 years old.[75] In the present study, the Pb concentration in soils samples taken outside the home in the playing area of the children averaged 40 μg/g, a concentration below the level of concern. No difference was found in Pb soil content irrespective of whether informal recycling activities were carried out or not, but significantly higher Pb concentrations were found in indoor air and dust samples from homes where such activities were operated in comparison with the others. Accordingly, the BLL of the children living in these homes was also higher. No relationship was found between the lead content in indoor dust and in playing area soil. The greater impact of house dust than residential soil on the BLL of children has been widely demonstrated (see Lanphear et al.[63]). Another potential source of Pb in residential air is metal-cored candlewicks,[76] but such candles were not burned in the homes of children tested. Pb pipes, lead-glazed or lead-painted pottery and canned food can constitute other significant sources of Pb ingestion, but these risk factors did not appear from the analysis of responses in questionnaires. Drinking water was tested; a mean value well below the limit for Pb in drinking water established by the EPA (15 μg/l) and in EU (currently 25 μg/l to be reduced to 10 μg/l by 2013[77]) was measured.

Eating clay is a worldwide practice that is particularly common in pregnant women.[78] In Kinshasa, the number of pregnant women eating soil or clay was estimated to exceed 70%;[79] they mainly eat fired clay sticks for their nutritional mineral content or to provide relief for "pasi ya estoma", that is, the gestational gastritis (Figure 1b). Clay is sold in markets, or taken from termite mounds known to be rich in minerals, and eaten at an average quantity of 20–40 g per day. The results of the current survey indicated a significant difference in BLL between children whose mother consumed fired clay during pregnancy and the others (Table 2). The analysis of 10 samples of fired clay revealed a mean Pb concentration of 162 μg/g (SD 130; Table 4). The multivariate model demonstrated that indoor air, age and fired clay ingestion during pregnancy contributed to explain 43% of the variation in the BLL of children.

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Figure 1. Informal activities in the recycling of car batteries in the residences of Kinshasa (**a**) and fired clays consumed by some pregnant women as a remedy for the treatment of gestational gastritis (**b**).

Overall, living in the urban area of Kinshasa resulted in increased BLL as compared with a rural area. The BLL of children was associated with the Pb content of indoor dust and air, which are likely to be contaminated by the use of leaded gasoline and residential informal activities of recycling car batteries in the urban area of Kinshasa. This study also highlights the traditional practice of clay eating, which is found in Kinshasa, as an important risk factor for elevated BLL in young children.

Thus, children in developing countries continue to be at great risk of Pb exposure, which can have detrimental neurological effects. Although the phasing out of leaded gasoline is a main step in eradicating childhood Pb poisoning, other actions such as implementation of lead-battery recycling guidelines and public education are urgently needed.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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