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Implications of different residential lead standards on children's blood lead levels in France: Predictions based on a national cross-sectional survey

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ABSTRACT

Despite the dramatic reductions in children's blood lead levels (BLLs), there is considerable evidence that low-level lead exposure is associated with intellectual deficits and behavioral problems, without apparent threshold. There are limited data, however, about the contribution of residential sources of lead to contemporary children's blood lead levels. The aim of this study is to calculate the contributions of residential sources of lead to assess the potential impact of setting new standards for lead levels in residential dust, soil and water. We enrolled 484 French children aged from 6 months to 6 years, and collected data on social, housing and individual characteristics. Lead concentrations in blood and environmental samples (water, soils, and dusts) were measured using inductively coupled plasma mass spectrometry. Data were analyzed using a multivariate generalized additive model accounting for the sampling design and the sampling weights. We found that exceedingly low concentrations of lead in dust, soil and water were significant predictors of children's BLLs, after adjustment for potential confounding variables. Lead-contaminated floor dust was the main source of lead in blood. BLLs (GM: 14 μg/L) increased by 65%, 13%, 25%, and 5% when lead content in floor dust, loose soil, hard soil and water increased from their 25th percentile to their 95th percentile, respectively. We also observed that the steepest increase in BLLs occurred at the lowest levels of lead-contaminated floor dust, which indicates that lead contamination should be kept as low as possible. Impact of different possible standards on children's BLLs was also tabulated and indicated that unless standards are set low, they will only benefit a small proportion of children who have the highest exposures.

Introduction

There is no known safe level of lead exposure. Indeed, there is mounting evidence of the adverse health effects of exceedingly low blood lead levels (BLLs) in children, including intellectual deficits, behavioral impairments, low birth weight and attention deficit hyperactivity disorder (Bellinger and Needleman, 2003; Canfield et al., 2003; Lanphear et al., 2005; Nigg et al., 2010; Zhu et al., 2010). Moreover, recent studies suggest that childhood lead exposure is a risk factor for conduct disorder and criminal behavior (Braun et al., 2008; Fergusson et al., 2008; Needleman et al., 2002; Wright et al., 2008). The European Food Safety Agency concluded that an increase of 12 μg/L in BLL was associated with 1-point IQ decrement and stated that there was no threshold for the neurodevelopmental toxicity of lead (EFSA Panel on Contaminants in the Food Chain (CONTAM), 2010). The Centers for Disease Control recently concluded that there is no safe level of lead in children's blood (Centers for Disease Control and Prevention, 2012).

In non-industrial areas, residential sources constitute the primary source of lead exposure for children with elevated BLLs (Jacobs et al., 2002). The contributions of residential sources

Abbreviations: CI, confidence interval; Bll, blood lead level; CMUc, complementary free health insurance; GM, geometric mean; LOD, limit of detection; LOQ, limit of quantification; μg/L, micrograms per liter; μg/m^2, micrograms per square meter; mg/kg, miligrams per kilogram.

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of lead, including lead-based paint, lead contaminated soil and subsequent contaminated house interior settled floor dust have become increasingly important to children's lead intake following the removal of lead from gasoline (Lanphear and Roghmann, 1997). The U.S. Environmental Protection Agency (EPA) established residential standards for floor dust (40 μg/ft^2), window sill dust (250 μg/ft^2) and soil in play areas (400 μg/g) (U.S.EPA United States Environmental Protection Agency, 2001), but several studies have suggested that lower levels are associated with substantial increases in children's blood lead concentrations (Dixon et al., 2009; Lanphear et al., 1996). Despite the progressive replacement of lead pipes in the public water supply, lead leached from water pipes could still constitute a significant source of exposure for some children in France. About 3% of dwellings where one or more child aged from 6 months to 6 years is living have water lead concentrations higher than 10 μg/L, the targeted European standard (Lucas et al., 2012).

There is no established quantitative relationship between lead in housing and children's BLLs in France. In France, standard exists only for tap water; the U.S. standards are currently in use for dust control after leaded paint removal. But U.S. standards may not be adaptable to the French context for several reasons, including differences in bioavailability of lead, housing occupation, children's behavior and, finally, analytical method of lead analysis. In France the leachable lead is used (Agence française de normalisation (AFNOR), 2008) while in the U.S. it is total lead (American Society for Testing and Materials (ASTM), 2004). More generally, there is a need to update and specify relationships between residential lead and BLLs at lower levels than those previously studied.

The objective of this paper is to quantify the relationship of children's BLLs with residential sources of lead exposures and calculate the impact of different lead standards on children's BLLs.

Materials and methods

Study population

Survey and sampling procedures have been previously described (Etchevers A. et al., 2010; Lucas et al., 2012;Oulhote et al., 2011). A national survey called "Saturn-Inf" involving 3831 children was carried out in 2008–2009 by the French Institute for Public Health Surveillance (InVS) to estimate the prevalence of lead poisoning in children. A two stage sampling design was implemented with (1) hospitals sampling and (2) hospitalized children aged from six months to six years. Exclusion criteria were severe diseases (e.g. kidney damage) and hospitalizations for lead poisoning. We intentionally oversampled hospitals in communities with a higher prevalence of old and deteriorated housing and industrial activity. To account for this oversampling, a sampling weight (the inverse of the probability of sampling) was assigned to each child. Region, sex, age and the presence of a free complementary health insurance (Couverture Médicale Universelle complémentaire) as an indicator of poverty, were chosen as auxiliary variables to adjust the sampling weights, to account for the discrepancies between the sample and the whole population of French children. The parents of children who took part in the study were informed about the purposes of the study and gave their consent. They received an individual written results report. Approval was obtained from the French Ethics Committees (Commission Nationale de l'Informatique et des Libertés (CNIL), Comité de Protection des Personnes (CPP) and Comité Consultatif sur le Traitement de l'Information en matière de Recherche dans le domaine de la Santé (CCTIRS)) before enrolment of study participants.

Data collection

A nested environmental survey was carried out by the scientific and technical building institute (CSTB) in a subsample of 484 enrolled children. The first step of this housing survey was to interview one adult who was living with the child about demographic, housing and behavioral characteristics. The second step was an environmental survey to identify and quantify the main sources of residential sources of lead intake among children. In each dwelling, up to five rooms were selected using the US-HUD protocol (U.S. Department of Housing and Urban Development, 1995) in the following order: child's bedroom, living room, hall, kitchen and bedroom of the brother/sister immediately younger or older. Finally, wipe samples of floor dust were collected from a 0.1 m^2 surface area of the floor where the child was reported to play. In addition, one or two dust samples were collected in common parts for apartments or multiunit dwellings.

If the child was reported to play outdoors in a garden or playground in the close vicinity of the home, the ground was sampled by taking a core sample (2 cm deep) of soil surfaces or a wipe sample (0.1 m^2) for hard surfaces. A sample of tap water was systematically collected: after 30 min without using any water, 2 L were drawn, homogenized in a 2 L flask and then poured into a 0.25 L flask acidified (with 1% of HNO_3 to ensure pH < 2).Finally, when appropriate, cosmetics (kohl) or traditional dishes known to be potential sources of lead were also collected.

Chemical analyses

Environmental samples

Samples analyses were performed with inductively-coupled plasma mass spectrometer (ICP-MS) Agilent Technologie 7500ce equipped with a quadrupole mass filter and an octopole reaction cell). To compare results from leachable (regulatory method in France) and total lead digestion, all environmental samples (except for water) were analyzed with both methods (Le Bot et al., 2011). The limits of quantification (LOQ) were 1 μg/L for water, and 1 μg/m^2 and 2 μg/m^2 for both dust and hard soils, respectively for leachable and total lead. For outdoor loose soil, the LOQ were 0.5 mg/kg and 1.3 mg/kg, respectively for leachable and total lead. Quality controls were performed with analytical blanks and standard reference materials SRM 2583 and SRM 2584 for dust, certified reference material CRM 013-050 for paint, CRM SS2 for soil and National Institute of Standards and Technology NIST 1643 for water. These control samples were inserted in all digestion series or analyses series (for water) for lead determination in the same manner as real samples. The lab has French accreditation (COFRAC-Comité Français d'accréditation) for lead in water, dust and soil. The intra-laboratory relative standard deviation for lead in all types of sample was lower than 10%.

Blood samples

Blood samples were diluted with a matrix modifier solution containing nitric acid, triton and butanol. BLLs were measured using ICP-MS. All assays were above the LOQ of 0.037 μg/L. Blood samples above 80 μg/L were confirmed with a second analysis. For quality control, blanks and internal quality controls from reference materials (Utak blood samples 27.91 μg/L and 394.92 μg/L) were analyzed for every 10 samples. External quality control included successful (deviation between expected and measured values were less than 10%) AFSSAPS (French Agency for medical care safety) inter-laboratory control (2007 and 2009) and the use of external samples from the Institut National de Santé Publique du Québec.