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Environmental determinants of different blood lead levels in children: A quantile analysis from a nationwide survey

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ABSTRACT

Blood lead levels (BLLs) have substantially decreased in recent decades in children in France. However, further reducing exposure is a public health goal because there is no clear toxicological threshold. The identification of the environmental determinants of BLLs as well as risk factors associated with high BLLs is important to update prevention strategies. We aimed to estimate the contribution of environmental sources of lead to different BLLs in children in France.

We enrolled 484 children aged from 6 months to 6 years, in a nationwide cross-sectional survey in 2008–2009. We measured lead concentrations in blood and environmental samples (water, soils, household settled dusts, paints, cosmetics and traditional cookware). We performed two models: a multivariate generalized additive model on the geometric mean (GM), and a quantile regression model on the 10th, 25th, 50th, 75th and 90th quantile of BLLs.

The GM of BLLs was 13.8 μg/L (=1.38 μg/dL) (95% confidence intervals (CI): 12.7–14.9) and the 90th quantile was 25.7 μg/L (CI: 24.2–29.5). Household and common area dust, tap water, interior paint, ceramic cookware, traditional cosmetics, playground soil and dust, and environmental tobacco smoke were associated with the GM of BLLs. Household dust and tap water made the largest contributions to both the GM and the 90th quantile of BLLs. The concentration of lead in dust was positively correlated with all quantiles of BLLs even at low concentrations. Lead concentrations in tap water above 5 μg/L were also positively correlated with the GM, 75th and 90th quantiles of BLLs in children drinking tap water.

Preventative actions must target household settled dust and tap water to reduce the BLLs of children in France. The use of traditional cosmetics should be avoided whereas ceramic cookware should be limited to decorative purposes.

1. Introduction

Blood lead levels (BLLs) in young children have considerably declined in developed countries over the past 15 years. The geometric mean of BLLs in children decreased from 36 to 15 μg/L between 1996 and 2009 in France (Etchevers et al., 2013). Similar BLLs have been reported in Germany (Becker et al., 2013), the USA (CDC, 2013a), Croatia, the Czech Republic, Poland, Slovakia, Slovenia (Hruba et al., 2012) and Sweden (Stromberg et al., 2008) in recent years.

Many scientific publications have shown adverse health effects associated with BLLs below 50 μg/L (=5 μg/dL) (National Toxicology Program, 2012) and there is currently no defined toxicity threshold (Canfield et al., 2003; Jusko et al., 2008; Lanphear et al., 2005). As a consequence, the German Federal Environmental Agency and the Centers for Disease Control and Prevention (CDC) have recently revised the blood lead 'levels of concern' of 100 μg/L. It was lowered from 100 μg/L to 35 μg/L (Wilhelm et al., 2010) in Germany and from 100 μg/L to 50 μg/L (CDC, 2012) in the USA. Similarly, in France, a reduction of the current level of 100 μg/L to an as-yet undetermined threshold is under revision.

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Since the removal of lead from gasoline, residential sources have become the biggest sources of lead exposure for children in developed countries (Lanphear et al., 2003). Levallois et al. (2013) and Oulhote et al. (2011, 2013) recently demonstrated that exposure to several sources of lead including tap water, home and exterior dust and soil is associated with BLLs in children.

It is essential to evaluate the contribution of each individual source to BLLs in children both to design prevention strategies and to limit environmental exposure. Such prevention strategies must target both children with low BLLs (the most frequent) and children with elevated BLLs. The identification of environmental factors that contribute to elevated BLLs will facilitate both the design of effective screening programs and strategies to remove these sources. Identification of the contributors to low BLLs is important because they contribute to the main burden of IQ loss (Lanphear et al., 2005) and have the largest economic impact (Pichery et al., 2011).

The first objective of the study was to identify the contribution of lead sources to BLLs in young children living in France 1) for the whole population (corresponding to the geometric mean) and 2) for the most exposed children (corresponding to the 90th quantile of BLLs). The second objective was to compare the contribution of dust and tap water lead levels at different points of the BLL distribution (geometric mean, 10th, 25th, 50th, 75th and 90th quantiles of BLLs).

2. Methods

2.1. Population and sampling

Between 2008 and 2009, the French Institute for Public Health Surveillance (InVS) implemented a nationwide (n = 3831) cross-sectional survey to estimate BLLs in children (6 months to 6 years of age) in France (Etchevers et al., 2013). Between November 2008 and August 2009, the Scientific and Technical Building Institute (CSTB) carried out a nested environmental survey in homes of a random subsample of 484 children in mainland France (Etchevers et al., 2013; Lucas et al., 2012). Hereafter, only the main features will be recalled. We used a two-stage probability sample design: in the first stage, the primary sampling units were hospitals and in the second stage, we included hospitalized children. The hospitals were stratified by administrative regions and the risk of lead poisoning, the extent of old and poor housing in the catchment area, and industrial activity related to lead. Hospitals in high risk areas were intentionally oversampled. The sampling weights were then adjusted by post- stratification based on auxiliary variables (region, sex, age and eligibility for complementary free health insurance (CMUc)) to increase the precision of estimates and to make the sample more representative of the population (Lumley, 2010). The participation was 83% for hospitals. The participation for parents was 97% at hospitals and 62% at home.

2.2. Data and sample collection

Children gave venous blood samples (1.5 mL) during the hospital stay. At each child's home, we interviewed one adult who was living with the child, about demographic, housing and behavioral characteristics and we sampled residential sources of lead. In each dwelling, we collected wipe samples of floor dust from a 0.1 m^2 surface area of the floor where the child was reported to play, in up to five rooms (U.S.HUD, 2002). In addition, we collected one or two dust samples in the entrance hall and in the landing for apartments. If the child was reported to play outside, in a garden or playground in close vicinity to the home, the ground was sampled by coring (2 cm deep) for soil surfaces or by dust wiping (0.1 m^2) for hard surfaces. We collected a 2 L tap water sample after a 30 min stagnation time of water in the pipework. The water samples were homogenized and were poured into a 0.25 L flask acidified with 1% of HNO3 to ensure a pH <2. We performed paint measurements with portable X-ray fluorescence (XRF) lead-based paint analyzers (Niton) on each part of the room (wall, door, and window) accessible to the child, except on new parts of the room. Finally, if the family agreed, we also collected traditional cosmetics (kohl) or dishes known to be potential sources of lead.

2.3. Chemical analyses

2.3.1. Blood lead levels

Blood lead levels were analyzed by inductively coupled plasma mass spectrometry (ICP–MS). The blood samples were diluted (1:10) with an aqueous matrix modifier solution (0.2% butanol, 0.1% Triton and 1% nitric acid). The limit of quantification (LOQ) was 0.037 μg/L. In all cases, BLLs were above the LOQ. All blood samples with a BLL greater than 80 μg/L were analyzed for the second time to confirm the result. Quality control procedures were performed: blanks and internal quality controls from reference materials (Utak blood samples of 27.91 μg/L and 394.92 μg/L) were analyzed for every 10 samples. External quality control procedures included participation in the AFSSAPS (French Agency for medical care safety) interlaboratory control (2007 and 2009) and the use of external samples from the INSPQ (National Institute of Public Health of Quebec). The external control test was considered successful if there was less than 10% difference between the expected and observed values.

2.3.2. Lead measurements in environmental samples, kohl and traditional cookware

We analyzed environmental samples for lead content using an ICP–MS (Agilent Technology) 7500ce equipped with a quadrupole mass filter and an octopole reaction cell. We analyzed all environmental samples (except for water) for leachable (regulatory method in France) and total lead content (Le Bot et al., 2010, 2011). The LOQ were 1 μg/L for water, 1 μg/m^2 (0.09 mg/ft^2) for leachable lead in dust and 2 μg/m^2 (0.19 mg/ft^2) for total lead in dust. For soil, the LOQ were 0.5 μg/g and 1.3 μg/g, for leachable and total lead respectively. For traditional cosmetic (kohl), we used the same leachable digestion method as for soil. The LOQ was 1.3 μg/g. For traditional cookware, leachable lead was measured by contact with acetic acid (4%) for 24 h at room temperature (ISO 7086-1 2000). The LOQ was 1 μg/L. Quality control was 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 kohl, and the National Institute of Standards and Technology NIST 1643 for water and traditional cookware. Control samples were included in all digestion series or analyses series (for water) to determine lead concentration in a manner identical to that of the real samples. The lab has French accreditation (Comité Français d'accréditation (COFRAC)) for the analysis of lead in water and dust. The intra-laboratory relative standard deviation for lead in all types of sample was lower than 10%.

2.4. Statistical analyses

We used two different modeling approaches: 1) a generalized additive model (GAM) of expected geometric mean of BLLs to quantify the risk factors for the whole population and 2) quantile regressions for expected 10th, 25th, 50th, 75th and 90th quantiles of BLLs to study risk factors of specific areas of the BLL distribution. In the GAM model, we included the following variables: lead levels in interior dust, dust from common areas of the building, tap water, soil, playground dust, paints, cookware ceramics, traditional cosmetics (kohl, surma, tiro), along with children's sex, children's age, environmental tobacco smoke (ETS) exposure, tap water consumption and parents' occupational exposure to lead. In the quantile regression models, we removed some covariates (i.e. lead in paints, ceramics, traditional cosmetics, ETS) that were collinear with other risk factors at the 90th quantile of BLLs due to the absence or quasi-absence of these risks factors in children.