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A simple lead dust fall method predicts children's blood lead level: New evidence from Australia

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ABSTRACT

We have measured dust fall accumulation in petri dishes (PDD) collected 6 monthly from inside residences in Sydney urban area, New South Wales, Australia as part of a 5-year longitudinal study to determine environmental associations, including soil. with blood lead (PbB) levels. The Pb loading in the dishes (n = 706) had geometric means (GM) of 24 μg/m^2/30d, a median value of 22 μg/m^2/30d with a range from 0.2 to 11,390 μg/m^2/30d. Observed geometric mean PbB was 2.4 μg/dL at ages 2–3 years. Regression analyses showed a statistically significant relationship between predicted PbB and PDD. The predicted PbB values from dust in our study are consistent with similar analyses from the US in which floor dust was collected by wipes. Predicted PbB values from PDD indicate that an increase in PDD of about 100 μg/m^2/30d would increase PbB by about 1.5 μg/dL or a doubling PbB at the low levels currently observed in many countries. Predicted PbB values from soil indicate that a change from 0 to 1000 mg Pb/kg results in an increase of 1.7 μg/dL in PbB, consistent with earlier investigations. Blood Pb levels can be predicted from dust fall accumulation (and soil) in cases where blood sampling is not always possible, especially in young children. Petri dish loading data could provide an alternative or complementary "action level" at about 100 μg Pb/m^2/30 days, similar to the suggested level of about 110 μg Pb/m^2 for surface wipes, for use in monitoring activities such as housing rehabilitation, demolition or soil resuspension.

1. Introduction

Investigations into blood lead (PbB) and environmental levels in industrial sites such as mining and smelting are routinely undertaken and the acquisition of blood samples in young children is an accepted practice. This is not always the case, however, in non-industrial or remediated locations where there may be concern over exposure, especially to young children. In these cases there may be reluctance of the parent/guardian/child to concede to blood sampling, usually arising from concern over the invasiveness of venous blood sampling and possible stigma of implied health effects of Pb and other metals (a "leaded" child). Nevertheless, blood lead testing is widely practiced, especially in the US, without causing significant harm to children.

Many studies over several decades have found a strong association between house dust and PbB (e.g., Buchet et al., 1980; Charney et al., 1980; Duggan and Inskip, 1985; Harrison, 1979; Lanphear and Roghmann, 1997; Lanphear et al., 1998; Lanphear et al., 2002; Laxen et al., 1987; Mielke et al., 2010; Rabinowitz et al., 1985; Thornton et al., 1990; Dixon et al., 2009). Drawing conclusions about the relationships between PbB and dust is complicated by the variable methods of sampling house dust and lack of internationally accepted guidelines for dust Pb values. Some of these sampling methods, summarised in USA EPA (2013) include vacuum cleaner dust (Clark et al., 1995; Farfel et al., 1994), surface wipes (Clark et al., 1995), and entry mats (Farfel et al., 2001). These sampling methods have various limitations including lack of information about deposition rates, unless resampling over specific time periods is specifically undertaken; some of the advantages and disadvantages of these methods are given in the section on Results and Discussion. With respect to guidelines, Duggan (1983) wrote: "There is a strong case for a lead-in-dust standard.", then in 1987 Laxen et al. suggested that for a population with a mean PbB of 10 μg/dL a dust Pb concentration of 1000 mg/kg could give an increase of 1.9 μg/dL. More recently Dixon et al. (2009) suggested that for a pre-1978 home, the year that Pb paint was banned for residential use in the US, with a floor dust value of 6 μg/ft^2 (64.6 μg/m^2) their models predicted that the GM PbB was 3.4 μg/dL and 16.5% would have PbB ≥ 5 μg/dL. Further discussion of the Dixon et al. (2009) paper is presented later.

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Lead in paint and in soil is well correlated with settled lead dust and PbB (Jacobs, 1995; National Academy Press, 1993).

Several studies have shown that dust lead loading is a better predictor of PbB concentrations in children than dust lead concentration (Lanphear et al., 1995, 1998). Lead in dust is usually expressed in one of two ways (US EPA, 1995). The Pb concentration, sometimes called a mass concentration, is usually expressed as micrograms of Pb per gram of dust (μg/g) or the equivalent expression, parts per million Pb by weight (ppm). The amount of dust on a surface can be expressed as grams of dust per unit area and is usually called dust loading (g/m^2 or g/ft^2). The Pb concentration, multiplied by the dust loading on a surface, gives a Pb loading value and is commonly expressed as micrograms of Pb per unit area ($\mu g/m^2$ or $\mu g/ft^2$). The dust loading and Pb loading measurements are both area concentrations, that is, the concentration of dust or Pb per unit area.

The existing standard for measuring dust lead loading is the wipe sampling method, a simple and inexpensive tool that only measures loading (US EPA, 1995, 2013). An alternative method is to collect dust over extended periods by use of trays (Bornschein et al., 1985; van Alphen, 1999), polystyrene cups (Meyer et al., 1999), beakers (Seifert et al., 2000), plastic buckets (Farfel et al., 2003; Jacobs et al., 2013; Mucha et al., 2009) or petri dishes (Gulson et al., 1995; all references denoted by * in the reference list) although these have not been universally accepted and rarely undertaken in longitudinal studies. The plastic buckets of Mucha et al. (2009) contain 1 L of deonized water to assist in sample capture and avoid resuspension (D. Jacobs, written communication, 2017). Material collected in these vessels is via airborne pathways and may derive from such sources as activities in the house (e.g., renovation, smoking), tracked in dust, windblown through doors and windows, or cavities in the house construction (Davis and Gulson, 2005) and demolition of housing with interior or exterior Pb paint. The exterior sources may be resuspended soil and dust which may contain a legacy of past leaded-gasoline use or leaded paint (Laidlaw and Filippelli, 2008; Laidlaw et al., 2012), a fact that is often misinterpreted by people who think Pb is no longer an issue because Pb has been removed from gasoline and paint in most countries. However, there are many reports of new lead-based paint being manufactured in a number of countries and that some of that new lead paint is being manufactured by major paint companies (Clark et al., 2015).

We have evaluated our observed PbB and PDD data from a 5-year longitudinal study of young children in Sydney to determine if PbB levels can be predicted from the dustfall data. As soil data were also available, we compared the soil-PbB relationships with those obtained from the dust-PbB values. The study was undertaken from 2002 to 2006 to coincide with the cessation of use of Pb in petrol in 2002 and introduction in 2002 and then termination of methyl-cyclopentadienyl manganese tricarbonyl (MMT) in 2006. Mixed model analyses and structural equation (or path) modelling of Pb and manganese were carried out for data from the blood of children and environmental measures of handwipes, 6-day duplicate diet, drinking water, interior and day-care dust-fall accumulation using PDD, exterior dust sweepings, soil, paint and urban air. These data have been published for two time periods (Gulson et al., 2006, 2014).

2. Methods

Samples were collected every 6 months from children, whose age ranged from 0.29 to 2.4 years at the time of first sample collection, in residences located at varying distances from major traffic thoroughfares in Sydney and in the surrounding suburbs.

Dustfall accumulation in two frequented areas of the house (child's bedroom, living/play room) were collected over 6-month periods by the petri dish method (Gulson et al., 1995) to provide ongoing monitoring of dust Pb loadings (weight of Pb/area/time). The dishes were placed at heights of 1–2 m in areas accessible to air flow but not where they could be disturbed such as on the tops of cupboards, television sets, etc. The petri dishes were 85 mm diameter and depth 10 mm. After several trials, the PDD from the main locations was combined for a single analysis. Although other sites such as day care centres and exterior locations were also monitored, the data sets for these were not as comprehensive as the residence interior dust and have not been modelled separately. Soil from 0 to 2 cm depth was collected using a stainless steel trowel from garden beds and bare patches in the front and back yards and sand pits where available. Venous blood samples were collected by a trained phlebotomist into ultra-trace metal free Vacutainer tubes using a 23G ¾ Vacutainer blood collection set consisting of 12″ tubing with multiple sample Luer adapter ("butterfly"). A questionnaire was administered at the time of the first sampling and updated throughout the study. Information was obtained about the location of the residence with respect to traffic, age and condition of the residence, metal exposure, and more personal details relevant to the parents and child. Details of sample preparation and total Pb analyses are given in Gulson et al. (2006).

2.1. Data handling methods

The data consisted of observations collected over varying periods for 108 participants. The number of observation-occasions ranged from 2 to 13 per subject, with a mean of 9.

Details of how the data were managed in the original longitudinal analyses have been given in Gulson et al. (2014); (2017). In brief, because measurements of some elements were missing at some timepoints, a multiple imputation procedure was used. This provided values which allowed analyses to proceed, and estimates which reflected the uncertainty inherent in imputed values, and which were taken into account in the analyses (Sinharay et al., 2001; Chen et al., 2011; Lubin et al., 2004). A mixed model was used in the original analyses to take account of the correlations between the repeated measures for each subject. The intraclass correlations for the intercept-only analyses of the measures used in the current study were 0.31 for blood lead, 0.40 for the PDD and 0.41 for soil. The mixed model was not needed for the present analysis, as the data for each individual were aggregated over time points within each of the 10 imputed datasets. This meant that individuals rather than the time points for each individual were the units of analysis but that variability due to the uncertainty of the imputed values could be taken into account.

The analyses were carried out using the *mi* facility in Stata 14 (Stata Corp, 2015) and in SPSS 24. The logarithms of PbB levels were regressed on the logarithm of Pb measurements obtained from dust and from soil in separate bivariate analyses. Pooled outcomes were based on the results for the 10 imputed datasets, which were combined according to the rules given by Rubin (1987). In order to further assess the association between the Pb measurements and the dust and soil measurements, partial correlations were calculated (Edwards, 1976). Designated r_p, the partial correlation coefficient, shows the correlation $r_{A.B}$ between pairs of residuals, one set obtained by regressing Y on B, and the other set by regressing A on B, where Y is an outcome variable and A is an independent variable and B is a covariate for which the association between Y and A is to be adjusted. The partial correlation coefficient shows the association between Y and A with the effect of B "held constant" (Edwards, 1976).

The predicted values of PbB were obtained, along with the standard errors of prediction (which incorporated both within- and between-imputed dataset variability). Ninety-five percent confidence limits for mean predictions were calculated using a value from the *t*-distribution (approximately 2.0 in each case) with degrees of freedom adjusted according to the variability of the MI datasets. The figures show the observed and predicted values as the log-transformed values used in the analyses and also in terms of the original observed dust and soil measurements and the anti-logs of predicted Pb values.