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Analysis and reduction of the uncertainty of the assessment of children's lead exposure around an old mine

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Abstract

Exposure to lead is a special problem in children, because they are more highly exposed than adults and because this pollutant, which accumulates in the body, induces neurobehavioral and cognitive effects. The objective of this study was to determine the probability density of the lead exposure dose of a 2-year-old child around an old mine site and to analyze its uncertainties, especially those associated with the bioavailability of lead in soil. Children's exposure was estimated indirectly from environmental samples (soils, domestic dust, water, air) and parameters (volume inhaled, body weight, soil intake rate, water intake, dietary intake) from the literature. Uncertainty and variability were analyzed separately in a two-dimensional Monte Carlo simulation with Crystal Ball® software. Exposure doses were simulated with different methods for accessing the bioavailability of lead in soil.

The exposure dose per kilogram of body weight varied from 2 μg/kg day at the 5th percentile to 5.5 μg/kg day at the 95th percentile (and from 2 to 10 μg/kg day, respectively, when ignoring bioavailability). The principal factors of variation were dietary intake, soil concentrations, and soil ingestion. The principal uncertainties were associated with the level of soil ingestion and the bioavailability of lead. Reducing uncertainty about the bioavailability of lead in soil by taking into account information about the type of mineral made it possible to increase our degree of confidence (from 25% to more than 95%) that the median exposure dose does not exceed the Tolerable Daily Intake. Knowledge of the mineral very substantially increases the degree of confidence in estimates of children's lead exposure around an old mining site by reducing the uncertainty associated with lead's bioavailability.

Keywords: Lead exposure; Health risk assessment; Lead bioavailability; Monte Carlo simulation; Lead mining

1. Introduction

Lead is a cumulative pollutant that induces neurobehavioral and cognitive effects in children (IPCS (International program on Chemical Safety), 1995). Harmful effects, especially on intellectual quotients (Canfield et al., 2003), have been reported for relatively low blood lead levels, below 100 μg/L (10 μg/dL). The studies so far published do not appear to show any threshold blood lead level below which there is no health effect (INSERM, 1999).

Exposure to lead occurs principally through the lungs and the gastrointestinal tract: the cutaneous pathway is considered negligible in humans (IPCS, 1995).

Young children (0–6 years), because of their behavior, especially their hand–mouth habits, are particularly exposed to lead. Such exposure may take place in homes with a history of lead-based paints but also around industrial sites that release or once released lead (Hivert et al., 2002).

In France, an INSERM (National Institute for Health and Medical Research) expert advisory group (INSERM, 1999) recommends screening children in at-risk areas, especially those identified around industrial sites. As screening for lead poisoning requires a blood sample, which is an invasive procedure, especially in young children, the Institute for Health Surveillance

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recommends (Glorennec et al., 2002) a preliminary assessment to examine population exposure around an industrial site before determining the need for a screening program.

This procedure was followed in Trémuson, France, a site where lead, silver, and zinc ore were mined from 1690 through 1931. Although active mining no longer takes place on the site, exposure from soil and dust continues; studies (Bjerre et al., 1993; Gulson et al., 1994; Murgueytio et al., 1998; Sterling et al., 1998; Malcoe et al., 2002) conducted around old mines have observed higher mean blood lead levels in such communities. Many studies (Xintaras, 1992; Mielke and Reagan, 1998; White et al., 1998) stress the importance of soil and dust in population exposure to lead. Soil particles (either directly or indirectly after transformation into house dust (Mielke and Reagan, 1998; White et al., 1998)) can be ingested by adults and children through unintentional hand–mouth contact, geophagia, or dust inhalation. A study (Lanphear et al., 1996) among children in Rochester (NY, USA) indicates that dust lead content explains most of the variance in blood lead levels. A review (Mielke and Reagan, 1998) found a positive correlation between lead levels in soils and those in blood.

At Trémuson, an exposure assessment had already been conducted (Glorennec et al., 2001) and submitted to the local health authorities to determine the usefulness of screening for childhood lead poisoning. The aim of the work presented here is to help identify the types of information that should be collected in priority in this type of situation. A means of describing the sensitivity with respect to different exposure factors is the technique of Monte Carlo simulation. In this probabilistic approach, all variables and parameters used in risk assessment may be regarded as distributions throughout the analysis. A process of repeated simulations is then used, during which the estimated quantity (risk in this case) is calculated many times with randomly chosen values of variables and parameters, covering their range of variability and reproducing the assumed distribution density. The final result is given in the form of a probability distribution of risk (Biesiada, 2001). Beyond ranking the sources of uncertainty and variability, this study presents the probability density of the exposure dose of a 2-year-old child with its degree of certainty, according to the extent of consideration and knowledge of lead bioavailability.

2. Material and methods

2.1. Population studied

The village of Mines, a subdivision of Trémuson, is a rural hamlet of approximately 400 inhabitants in a wooded valley. The homes are old single-family houses, packed densely together. Public premises are limited to a cafe/bar, a sports field, footpaths, and a children's playground.

The area that may have been contaminated by air pollution from the mining activities is limited to the village of Mines, downhill from the buildings used for mineral extraction and treatment. We initially studied the population of children aged 0–6 years ($N = 20$) who regularly spent time in the area. The probability density of the exposure dose is presented here for a 2-year-old child, the most exposed in that kind of environment (INSERM, 1999).

2.2. Exposure by ingestion to outdoor soils and indoor dust

Samples were taken from the houses ($N = 14$) where young children lived; no indoor samples were taken from 1 house (refusal) and no outdoor samples from another (no courtyard or garden). For indoor house dust, three samples were taken for each home, from dust collected from all smooth surfaces in rooms (average 15–20 m^2/room) used by the children (according to the parents): living room, kitchen, and bedroom. Samples were taken with a rubber blade, so that all of the dust on the room's surfaces could be collected without scratching. Outside soil samples were taken with a trowel at a depth of 0–0.01 m. Three soil samples were taken at each house. Each sample was the mixture of one primary sample and four peripheral samples 1 m away from the places most used by the children, according to their parents. The distributions of the concentrations were interpolated with Crystal Ball® software, based on concentrations measured by the following procedure (US EPA, 1997): graphic choice of the shape of the distribution and verification that it is not rejected by the Anderson–Darling test, which is appropriate for considering the values of the distribution tail.

The ingestion rates that we used for soils and dust are those recently proposed by Stanek et al. (2001) for a two-dimensional Monte Carlo simulation. This is a normal distribution *N* (31, 31) of soil ingestion with its associated uncertainty, in the form of a deviation correlated with soil ingestion (the uncertainty is higher for higher ingestion rates) with normal distribution *N* (4;0). This is, to our knowledge, the only published study that separates variability and uncertainty and presents an estimate of long-term soil ingestion. This distribution is consistent with the recommendations for point estimates of soil intake rates of the US Environmental Protection Agency (2001) for this age group.

2.3. Dietary exposure

Because of the low transfer rate of lead toward fruits and vegetables (IPCS, 1995) and the absence of