Bull. Environ. Contam. Toxicol. (1996) 56:543-550

Bulletin of Environmental Contamination and Toxicology

Impact on Blood Lead in Children and Adults Following Relocation from Their Source of Exposure and Contribution of Skeletal Tissue to Blood Lead

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Received: 15 May 1995/Accepted: 7 September

The goal of hazard abatement is the identification and systematic elimination of lead hazards in the community, which should ultimately result in lowering of blood lead (PbB), especially in children. Such a goal may be achievable in some communities but is a daunting task in mining or smelting communities such as Broken Hill or Port Pirie in Australia, where in the case of Broken Hill, industrial activities operating for more than 100 years and natural weathering over millennia have resulted in widespread contamination. *“The single most important factor in managing of childhood lead poisoning is reducing the child’s exposure to lead ..." (CDC, 1991, p.59).*

Millions of dollars have been spent in remediation programs in mining and smelting communities with varying degrees of success in achieving lower PbB levels in children. Luke (1991) reviewed the remediation programs in seven large smelter operations outside Australia using environmental and biological indices, before and after intervention, to gauge the success of such measures. He concluded that outcomes varied from temporary improvements in Kellog, Idaho to apparently more successful outcomes in El Paso and Dallas, Texas.

Remedial programs can involve: actions by the industries to minimize “emissions”, replacing soil, decontamination of houses, provision of “safe” houses, forming barriers to the pollutants, education, diet, and many others (Luke 1991; Maynard et al. 1993). At Port Pirie, Luke (1991) identified that the most significant predictor of a reduction in PbB levels was permanent relocation out of the high risk areas, whereas in a later assessment Maynard et al. (1993) identified, in addition to permanent relocation, level of expenditure on house dedusting and refurbishment, improved dust hygiene practices, and improved early morning diet as likely to reduce PbB levels.

The aim of this study was to evaluate the impact on PbB of relocation of two families from their source of lead, in this case from the Broken Hill mining community. To gauge the impact of relocation, the results are compared with twenty seven children who relocated within the Broken Hill community from high to low risk areas.

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MATERIALS AND METHODS

One family (House A) which relocated from Broken Hill comprised a male adult, a female adult, and three boys aged 6 years and 3-year old twins. The other family (House B) comprised a single parent female adult and girls aged 3-½ and 1-½ years and twins aged 6 weeks. Both families moved to rural communities in which agriculture and light industry are the primary activities.The children who relocated within Broken Hill are aged from 1 to 4 years.

Venous blood and environmental samples were obtained when the House A and B families were resident in Broken Hill and then again ~8 months later. The reason for the 8-month time interval was because of the delay in obtaining final results for the major investigation described by Gulson et al. (1994a) and the belated recognition of the importance of follow-up. Parents were measured in the families to act as controls for environmental variables such as food, water and air.

Venous blood samples were collected from two adults and the 3-year-old twins from House A and the mother and older daughter from House B. Data for the 6-year-old male from House A in the new location are unavailable because the sample spilt during transportation. Environmental sampling for House A in Broken Hill involved house dust (vacuum cleaner, surface wipes) and cold drinking water and in House B involved house dust (vacuum cleaner, dust fall accumulation), water, soil and a 6-day duplicate diet. In their new locations, environmental sampling was restricted to vacuum cleaner dust. More detailed protocols for blood and environmental sampling are described in Gulson et al. (1994a). Sampling protocols, blood lead and environmental lead data for the families who moved within Broken Hill are similar to the above protocols and have been described in Phillips and Hall (1994).

Isotopic compositions of lead were measured in the families from Houses A and B to assist in interpretation of changes in environmental parameters and their impact on PbB, and to estimate the proportion of skeletal lead in blood after the families moved away from Broken Hill. Proportions of lead from skeletal and environmental sources can be calculated from the isotopic compositions by simple proportionality, if it is assumed that the end-members are lead in the skeleton and environmental factors. The validity of these calculations are described in Gulson et al. (1995). In the case of Broken Hill, the calculations are based on the assumption that the isotope value measured in Broken Hill is blood in equilibrium with skeletal tissue, that the isotope ratio for vacuum cleaner dust from the new environment for House A is 17.25 and for dust fall accumulation is 16.91, giving an average value of 17.08. Vacuum cleaner dust for House B has a $^{206}Pb/^{204}Pb$ value of 16.52, which is slightly lower than the value measured in the mother's blood. The basis of the calculation for House B is given in the following section.

RESULTS AND DISCUSSION

The family from House A lived over 1.5 km from the central mining activities in a new well-maintained house with limited exposure to lead. The low levels of exposure are illustrated by the concentration of 220 ppm Pb for the bulk vacuum cleaner dust, one of the lowest measured by us in over 40 houses from Broken Hill (Gulson et al. 1994a). The male adult worked underground at the time of first sampling for 6 hours per day for ~2 years in a non-operational mining area.

The family from House B lived in rental accommodation of very low standard in a high risk area of south Broken Hill. Bulk soils from the yard contained ~2000 ppm, and the -53 + 38 µm fraction, 4600 ppm Pb; the lead in both the bulk and fine fraction consisted wholly of orebody lead (Gulson et al. 1994a). Vacuum cleaner dust contained ~4500 ppm Pb in the bulk sample and up to 7400 ppm Pb in the finer fractions. A small additional component (~10%) of lead, besides that from an orebody source, is present in the house dust (Gulson et al. 1994a).

Lead concentrations and isotopic ratios (expressed as the $^{206}Pb/^{204}Pb$ ratio) are summarised in Table 1. Only lead concentrations are available for the children who relocated within Broken Hill.

For House A there was a decrease in PbB of ~50 - 63% in the male members of the family with the largest decrease for the adult and a ~20% decrease for the female adult. The isotopic shift away from Broken Hill values was largest for the male adult and smallest for the twins. Vacuum cleaner dust from the new location contained 42 ppm Pb and the -100 µm and -53 µm fractions contained 40 ppm and 36 ppm Pb, respectively.

For House B, there was a similar decrease by ~69% in PbB for the mother and ~69% for the daughter. The isotopic shift was similar to that for the twins from House A. The value in the mother's blood indicates that she has a significant contribution from environmental sources, such as food, with a higher $^{206}Pb/^{204}Pb$ value. Hence, in the calculations for skeletal contribution to PbB for the mother and child from House B, the mother's rural blood lead isotope value is used.

For the 27 children who moved from high risk to low risk areas within Broken Hill, the mean decrease in PbB was 0.31 µm/L (6.37 µg/dL; 95% CI 3.05-9.69) (Phillips and Hall 1994). The change in "mean" soil lead was from ~1300 to 800 ppm; the soil lead values are based on the general level of soil lead contamination for a zone rather than for the soil where the child lived. The largest decrease in PbB was 1.30 µm/L (27 µg/dL; 62 to 35 µg/dL) for a "decrease" in soil lead from ~1200 to 400 ppm. The largest increase in PbB was 0.68 µm/L (6 µg/dL; 14 to 20 µg/dL) for a "decrease" in soil lead from ~2400 to ~800 ppm (Phillips and Hall 1994).

For the 15 children who moved from a low risk to high risk zone within Broken Hill, the mean decrease in PbB was 0.16 µm/L (3.4 µg/dL; 95% CI 0.75-6.05), for a change in "mean" soil lead level from ~400 to ~800 ppm. The largest decrease in PbB was 0.48 µm/L (10 µg/dL; 17 to 7 µg/dL) for an "increase" in soil lead from ~400 to ~600 ppm. The largest increase in PbB was 0.29 µm/L (6 µg/dL; 6 to 12 µg/dL) for a "increase" in soil lead of ~300 to ~400 ppm (Phillips and Hall 1994).

For the 417 children who did not move within Broken Hill, the mean decrease in PbB over the same 12-month interval was 0.17 µm/L (3.61 µg/dL; 95% CI 3.02-4.20) (Phillips and Hall 1994).

Table 1. Changes in PbB and isotopic compositions for families relocating from Broken Hill (Houses A, B) or within Broken Hill (House C)

Subject	Age (years)	PbB (μg/dL) B Hill	PbB (μg/dL) Rural	$^{206}Pb/^{204}Pb$ B Hill	$^{206}Pb/^{204}Pb$ Rural	Fraction of PbB from skeleton (μg/dL)
House A						
Male Adult	37	12.6	4.6	16.21	16.82	1.4
Female Adult	38	4.1	3.3	16.61	17.03	0.35
Male Child	3	17.7	8.9	16.24	16.47	6.5
Male Child	3	15.5	6.6	16.25	16.47	4.9
House B						
Female Adult	-	13.7	4.2	16.39	16.62	<0.4
Female Child	3-½	27.9	10.1	16.17	16.31	7.0
House C						
Male Child-1	4	47.1		16.35		
-2*		39.8		16.29		
-3		34.6		16.35		

+ Assuming isotope value measured in Broken Hill is blood in equilibrium with skeletal tissue; isotope ratio for vacuum cleaner dust from new environment for House A is 17.25 and for dust fall accumulation is 16.91 giving an average value of 17.08. Vacuum cleaner dust from new environment for House B has isotope ratio of 16.52, lower than female adult PbB, indicating that other environmental sources such as food with higher ratio are significant contributors to PbB. For skeletal calculation in House B, mother's PbB is used.
* Second blood measurement 1 month later, and third was 15 months after the first

The change in PbB versus the change in isotopic composition exhibits a negative relationship with a correlation coefficient of 0.95 (not shown); the aberrant value for the male adult from House A is excluded from this calculation.

The decrease in PbB by a factor of between 2 and 3 in the children over an 8-month period when relocated completely from their source of exposure is highly encouraging from a public health viewpoint. The decrease in the female adult's PbB from House A was relatively small and is possibly related to her low initial PbB.

These changes are far greater than for most of the children who relocated within Broken Hill from high to low risk zones. The smaller decreases in PbB for children who relocate within Broken Hill may not be unexpected. This is possibly because of the ubiquitous contamination of soil and house dust even in areas distant from mining activities in Broken Hill, and lower "bioavailability" of the lead in the other communities to which the two families shifted compared with Broken Hill. The "bioavailability" of the -53 μm-vacuum cleaner dust from House A in the rural area is ~30% compared with values generally from 50 to 100 % in Broken Hill (Gulson et al. 1994b). The "bioavailability" for House B in Broken Hill was 50 - 60% for the -53 + 38 μm fraction for soils containing 4600 and 7300 ppm Pb, and ~100% for the same-sized fraction of vacuum cleaner dust (Gulson et al. 1994b). There was a minimum 10-fold difference in lead concentrations in the house dust for House A in Broken Hill compared with their current environment. Nevertheless, the decreases observed in the children who relocated within Broken Hill from high risk to low risk zones are encouraging and probably reflect not only the lower exposures but also altered household practices arising from visits by the primary health care staff.

Decreases in PbB where families moved away from their sources of exposure have also been observed in Christchurch, New Zealand (Hinton 1988; and written communication, 1994). She presented data for 4 families who moved from older lead-painted wooden houses whose paint had been removed by sandblasting or burning, or both, to brick and stone dwellings with no lead paint. Maximum PbB levels ranged up to 30 µg/dL. The decreases in PbB in subjects from Christchurch can be of a similar order to those measured in Broken Hill subjects. For example, PbB in a 4-year old female decreased from 26 to 7 µg/dL over 44 months. Many of the Christchurch PbB measurements were up to 4-5 years apart and the decreases in PbB may just reflect the recognized changes of decreasing PbB with increasing age (Dietrich et al. 1993; Baghurst et al. 1993).

A community-based program in the smelting community of Trial, British Columbia involving education, case management and interventions resulted in the average PbB of children aged 6-72 months declining by 13.8% from the fall of 1991 to the fall of 1992. However, a further decline of only 6% was registered from 1992 to 1993 (Hilts and Ames 1994). These changes compare with the decrease of ~1 µg/dL/year in USA children aged 1-5 years, determined for NHANES III (Pirkle et al. 1994).

Rapid decreases in PbB have been observed in female adults moving from one country to another (Gulson et al. 1995). For example, in the case of a female migrating from Bulgaria to Australia, PbB decreased from 20 to 6 µg/dL in 4 months. Using the stable isotope technique, Gulson et al. (1995) were able to show that after 6 months, and even up to 15 months, ~40 to ~70% of the lead in the residual blood of 10 female immigrants derived from skeletal tissues.

Similar estimations can be undertaken for the Broken Hill subjects who relocated to other communities. Assuming the values in blood measured while in Broken Hill represent lead in equilibrium with skeletal tissues, and another main source of lead in their new locations is house dust (vacuum cleaner plus dust fall accumulation), the contribution of skeletally-derived lead to PbB can be estimated (Table 1). Given the limited number of environmental measures in this study compared with the migrant study and uncertainties about lead distributions between compartments, especially in children, these estimations can only be considered approximate. Nevertheless, they suggest that in the children, whose PbB levels were elevated in Broken Hill, the amounts of lead in blood coming from skeletal tissues after 8 months is ~70%. In contrast, there appears to be a greater contribution of environmental lead to PbB for the female adults and perhaps the male adult.

The rapid decrease in PbB observed in the two Broken Hill families and the migrant cohort of Gulson et al. (1995) contrasts with the very slow decline in, or maintenance of, elevated PbB in several children, some of whom relocated within Broken Hill (Gulson et al. 1994a). Despite insistence from parents that their children were no longer exposed to lead, upon moving from high risk to low risk areas in Broken Hill, residual elevated PbB are probably explained by ongoing exposure or with a small contribution from skeletal mobilization or both.

In a study of exposed and non-exposed adults, Erkkila et al. (1992) suggested that a decrease in PbB and lead concentration in bone is controlled by the intensity of exposure versus duration of exposure. Cortical bone lead concentrations, represented by their tibia1 measurements, increased consistently both as a function of the intensity of exposure and duration of exposure to lead. Trabecular bone, represented by calcaneal measurements, was strongly dependent on the intensity of exposure rather than duration of exposure. Thus for acute exposure, there should be a more rapid exchange between blood and skeletal tissues, whereas for chronic exposure, such as employees in lead smelters or battery factories, lead concentration in bone is higher and slow mobilisation occurs over decades (O'Flaherty et al. 1982; Hyrhorczuk et al. 1985; Christoffersson et al. 1986; Schutz et al. 1987; Nilsson et al. 1991; Erkkila et al. 1992). The male adult from House A was exposed to lead-bearing dust over a two-year period in a non-operational part of the underground mine. If this is considered an acute exposure, compared with what the children suffered, then such an exposure could partly explain the more rapid decrease in PbB of the father. Such a simplistic explanation is complicated by the higher bone turnover rates in children compared with adults (Smith and Hursh 1977; Rabinowitz et al. 1976; Rabinowitz 1991; Silbergeld 1991).

Even though it is well recognized that diet can play a significant role in PbB (e.g., Mahaffey 1981), diet is probably a minor factor in reducing PbB in the two families studied here. The dramatic decrease in PbB appears to be a direct result of moving completely away from the sources of exposure. Even though large decreases were observed in some children who relocated from high risk to low risk zones within Broken Hill, the decrease in mean PbB of the 27 children was only ~6 µg/dL, compared with the mean decrease of ~3 µg/dL in the 417 children who did not shift.

Relocating families from their source of exposure is probably the most effective public health strategy for lowering PbB, but such dramatic action may be complicated, and even overridden by psychological effects and social factors such as employment, cost, friendships, etc.

We have shown that skeletal stores can be a major contributor to children's blood lead, even after relocation. Hence, as most of the children in Broken Hill have a dominant component of orebody lead in their blood, those with the highest blood leads will take the longest, toxicokinetically, to "flush" this lead from their system. Furthermore, the higher the original blood lead, the lower the relative impact on current lead intakes. For the adults, the contribution from environmental sources dominated blood lead.

Acknowledgments. We thank: the families who participated in this study; Marcia Lively and Angela Tinziani for their assistance in making contacts with some of the families and their untiring efforts to assist families at risk; Daphne Hinton for supplying information on New Zealand families; and Paul Mushak, Garth Alperstein, Daphne Hinton and Colin Luke for reviewing an earlier version of the manuscript.

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