Brief Report

Indirect Lead Exposure Among Children of Radiator Repair Workers

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Background Secondary exposure to lead has been identified as a public health problem since the late 1940s; we investigate the risk of lead exposure among families of radiator repair workers.

Methods A sample of the wives and children, aged 6 months to 6 years (exposed children) (n = 19), of radiator repair workers and a sample of children whose parents were not occupationally exposed to lead (non-exposed children) (n = 29) were matched for age and residence; their geometric mean blood lead levels are compared. Blood samples were obtained by the finger stick method and environmental dust samples by the wipe method; both were analyzed using a portable anodic stripping voltameter.

Results Dust lead levels were significantly higher in the houses of exposed children (143.8 vs. 3.9 μg/g; P < 0.01). In crude analyses, the highest lead levels were observed among children whose fathers worked in home-based workshops (22.4 μg/dl)(n = 6). Children whose fathers worked in an external workshop (n = 13) also had high levels (14.2 μg/dl) (P < 0.01), while blood lead levels in non-exposed children were significantly lower (5.6 μg/dl)(P < 0.01). The observed differences remained significant after adjustment for age and gender.

Conclusions This study confirms that children of radiator repair workers are at increased risk of lead exposure and public health interventions are needed to protect them. Am. J. Ind. Med. 00:1–6, 2003. © 2003 Wiley-Liss, Inc.

KEY WORDS: children; secondary exposure; parental occupational lead exposure; pediatric lead exposure; Mexico

INTRODUCTION

The health effects of lead exposure have been described, from neurological problems and alterations in growth at relatively low blood lead levels, to enzymatic alterations, anemia, nephropathies, encephalopathies, and even death at extremely high blood lead levels [U.S. ATSDR, 1992a,b; WHO, 1995; Sanín et al., 2001]. In recent years, we have seen significant advances in the control of lead exposure due to the elimination of leaded gas and other sources of exposure. Little attention, however, has been given to lead poisoning that occurs by secondary exposure [McDiarmid and Weaver, 1993].
Secondary exposure to lead and various compounds has been identified as a public health problem since the late 1940s. This exposure occurs among workers’ families, relatives, or neighbors by: (a) contact with clothes, shoes, automobiles, or other articles that are contaminated in the work place and then taken to their homes; (b) personal contact with the worker; or (c) when the workshop is home-based (cottage industry) [McDiarmid and Weaver, 1993].

A meta-analysis of 10 secondary exposure studies from the USA, published between 1987 and 1994 showed that 139 secondarily exposed children had a geometric mean blood lead level of 9.3 µg/dl compared to a U.S. population geometric mean of 3.6 µg/dl ($P < 0.01$) [Roscoe et al., 1999]. Currently, in the USA, cases of secondary pediatric poisoning continue to occur [Materna, 2001].

Automobile radiators are frequently repaired with lead and tin welding recycled from old radiators. In Mexico, a study recently undertaken by our group to characterize lead exposure in Mexican workers suggested that the wives and children of radiator repair workers are at an increased risk of lead exposure [Dykeman et al., 2002]. We have expanded our previous work on the lead exposure of families of workers in this industry.

**MATERIALS AND METHODS**

From October 1999 to March 2000, recruitment was performed by consulting available directories and by visually identifying workshops in the automotive repair areas of three major cities of Morelos, Mexico. A total of 39 workshops were identified. Radiator repair workers were considered eligible to participate in the study if they had children between 6 months and 6 years of age.

Twenty-three radiator repair workers were eligible and of these 20 agreed to participate, 6 of who had workshops based in the home. The final study population included 48 children and 47 wives distributed as follows: 19 children of radiator repair workers (exposed children) and 29 children and their mothers selected at random from the same residential areas, always living on the same street at a distance between 100 and 150 m from the home of an exposed child, and with parents who were not occupationally exposed to lead (non-exposed children). One exposed participant was excluded because the child was on chelation therapy.

Parents of the participating children were informed of the study’s purpose and were asked to sign an informed consent form. The protocol was reviewed and approved by the Human Subjects Committee of the National Institute of Public Health of Mexico. All participants received information on how to reduce lead exposure.

The blood samples were taken at home from the children of both groups and dust samples were collected from their homes (entrance, laundry room, and living room). Other potential lead sources, such as previously documented socio-economic, behavioural, and cultural predictors of blood lead levels (e.g., use of leaded glazed pottery) were evaluated using a questionnaire. All questionnaire information was provided by the mothers of participating children.

**Laboratory Analysis**

The blood samples were obtained by a nurse trained in the collection of finger-stick blood samples according to a protocol that minimized external lead contamination of the sample. Children’s fingers were washed with surgical soap. They were instructed to keep their hands in a prayer-like position to avoid contamination. Blood samples, obtained via a prick of the ring finger, were placed in capillary tubes with heparin, and were analyzed using a LeadCare™ portable anodic stripping voltameter [ESA, 1997]. This voltameter is simple to use, requires neither manual calibration nor refrigeration, and provides a blood lead level in a few minutes. The detection limit of this instrument is reported to be 1.4 µg/dl and it has a working range from 0 to 65 µg/dl [Taylor et al., 2001].

Environmental sampling was carried out in accordance with the PaceScan 3000™ operator’s manual [PaceEnvirons, 1997] following the procedures recommended by the Environmental Sciences Technology Laboratory of the Georgia Technical Research Institute, as has been previously described in other studies in Mexico [Romieu et al., 1995]. For each sample, new latex gloves were used to avoid cross-contamination. When sampling for each house was finished, new gloves were used to fold and place a clean towel in a container to serve as a field blank.

The dust lead wipe samples were microwaved, subjected to 15% technical grade nitric acid, and analyzed by anodic stripping voltametry (ASV) with the PaceScan 3000™ voltameter [PaceEnvirons, 1997]. The sampling method has been validated [Ashley et al., 1996] using the method for lead in surface wipe samples of the National Institute for Occupational Safety and Health (NIOSH) (Method 9100) [Eller and Cassinelli, 1994], and the ASV method with atomic absorption analysis [Ashley, 1995].

**Statistical Analysis**

Depending on the distribution of the variable under study, we did an exploratory and descriptive analysis to compare summary statistics among the study groups. This comparison was performed using a t-test for comparing means or the Kruskal Wallis test, depending on the variable distribution. Prior to this, the homogeneity of variances was verified using an F test.

Next, we did multivariate linear regression to adjust for potential confounders. The blood lead levels were log-e transformed to satisfy the assumption of normality of the residuals. The fit of the model and influential points were...
evaluated with standard techniques using studentized residuals. In addition, we used the robust regression with cluster option specific for grouped data by matched design. All the analyses were conducted using the STATA 6.0 program for statistical analysis [STATA Corporation, 1999].

RESULTS

Dust lead concentration was significantly higher ($P < 0.05$) in the exposed children’s homes (Table I). All the field blanks ($n = 48$) were under the lead detection limit of the PaceScan3000TM [1.4 µg/g].

The mean age (standard deviation (SD)) in exposed children ($n = 19$) was 2.9 (1.4) vs. 3.2 (1.7) years in non-exposed children ($n = 29$), ($P = 0.43$). The mean (SD) education level in the exposed group was 8.2 (2.9) years vs. 9.5 (3.6) years in non-exposed mothers ($P = 0.32$).

The mean (SD) blood lead levels in crude analyses for exposed and non-exposed children were 16.3 (1.8) and 5.6 (2.2) µg/dl, respectively. Girls showed higher blood lead levels than boys in the exposed group (20.1 vs. 11.6 µg/dl) and the non-exposed group (7.4 vs. 4.5 µg/dl) (Table II).

Children between 6 and 18 months of age had higher blood lead levels in the exposed group 24.5 (1.3) µg/dl as compared to 9.6 (1.6) µg/dl in the non-exposed group ($P < 0.01$). In neither group were there significant differences related to chewing toys or pencils, nor for the use of lead glazed pottery (LGP) to cook or store food (Table II). However, we do not have information regarding the consumption by the child of food prepared or stored in LGP.

Blood lead levels in exposed mothers were higher than in non-exposed mothers, but this difference was not found to be significant (Table II). In the exposed children, the mean blood lead level was about two times higher if the mother washed the work clothes at home (18.9 vs. 10.2 µg/dl, $P = 0.04$), the child visited the workshop more than once a month (21.1 vs. 11.6 µg/dl, $P = 0.02$), or a household member in addition to the father worked in the workshop (25.3 vs. 12.7 µg/dl, $P < 0.01$) (Table III).

Mean (SD) blood lead levels of the exposed children who lived in a cottage industry ($n = 6$) reached 22.4 (1.5) µg/dl, compared to 14.2 (1.8) µg/dl for those who did not live in cottage industry ($n = 13$) (Table III).

In the multivariate linear regression, after adjusting for age and gender, in comparison to the control group the exposed group that did not live in a cottage industry had a relative increase in blood lead level of 2.32 µg/dl, 95% CI: (1.62–3.42 µg/dl). Those living in a cottage industry had a relative increase in blood lead level of 4.57 µg/dl, 95% CI: (2.65–7.85 µg/dl) (Table IV).

DISCUSSION

Our results document that children of radiator repair workers in the state of Morelos, Mexico, have an increased risk of lead exposure. The blood lead levels observed in the exposed group were close to three times higher than those observed in the reference group, and almost four times higher for those living in a cottage industry.

We assume that the study groups are comparable because the exposed and non-exposed children come from the same source population. They were paired by place of residence to control for other potential environmental lead pollution sources and there were no statistically significant differences regarding children’s age, maternal age, nor maternal education. In addition, although our study sample was limited, we believe that the workshops studied were similar to those in other parts of the country.

Dust lead levels in the comparison group were found to be under the 10 µg/g reference level [CDC, 1985Q4; U.S. ATSDR, 1992a]. Dust lead levels were significantly higher in the exposed group and similar to the levels found in previous studies on polluted sites [CDC, 1985Q5; McDiarmid and Weaver, 1993; Lanphear et al., 1998; Materna, 2001]. The field blanks and the Lead-Care were not contaminated.

### TABLE I. Dust Lead Levels (µg/ft²) in Three Sites in Homes of Children Under 7 Years of Age in the State of Morelos, Mexico (1999–2000)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Exposed group</th>
<th></th>
<th></th>
<th>Non-exposed group</th>
<th></th>
<th></th>
<th>P&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean&lt;sup&gt;a&lt;/sup&gt;</td>
<td>SD&lt;sup&gt;b&lt;/sup&gt;</td>
<td>n</td>
<td>Mean&lt;sup&gt;a&lt;/sup&gt;</td>
<td>SD&lt;sup&gt;b&lt;/sup&gt;</td>
<td>P&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Laundry room</td>
<td>18&lt;sup&gt;d&lt;/sup&gt;</td>
<td>140.8</td>
<td>328.7</td>
<td>26&lt;sup&gt;d&lt;/sup&gt;</td>
<td>10.2</td>
<td>16.2</td>
<td>0.01</td>
</tr>
<tr>
<td>Entrance</td>
<td>19</td>
<td>143.8</td>
<td>287.4</td>
<td>27&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.9</td>
<td>11.6</td>
<td>0.02</td>
</tr>
<tr>
<td>Living room</td>
<td>19</td>
<td>43.0</td>
<td>75.9</td>
<td>28&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.3</td>
<td>7.0</td>
<td>0.02</td>
</tr>
</tbody>
</table>

<sup>a</sup>Arithmetic mean.<br>
<sup>b</sup>Standard deviation.<br>
<sup>c</sup>Kruskal Wallis test; for not satisfying the normality assumption.<br>
<sup>d</sup>One, two, or three missing data.<br>

Indirect Lead Exposure<sup>Q1</sup>
Children between 6 and 18 months showed significantly higher blood lead levels in both the exposed group and the non-exposed group than children in other age groups. This was probably due to increased contact with lead-polluted waste and dust resulting from the tendency for hand to mouth activity in children at this age, as reported in previous studies [Roels et al., 1980; Angle and McIntire, 1982; Mielke and Reagan, 1998].

### TABLE II. Mean Blood Lead Levels (μg/dl) and Their Predictors in Children Under 7 Years of Age in the State of Morelos, Mexico (1999–2000)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Exposed group</th>
<th></th>
<th></th>
<th>Non-exposed group</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean*</td>
<td>SD b</td>
<td>n</td>
<td>Mean*</td>
<td>SD b</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----</td>
<td>--------</td>
<td>----------</td>
<td>----</td>
<td>--------</td>
<td>----------</td>
</tr>
<tr>
<td>Children</td>
<td>19</td>
<td>16.3</td>
<td>1.8</td>
<td>29</td>
<td>5.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Girls</td>
<td>12</td>
<td>20.1</td>
<td>1.8</td>
<td>13</td>
<td>7.4</td>
<td>1.6</td>
</tr>
<tr>
<td>Boys</td>
<td>7</td>
<td>11.6</td>
<td>1.5</td>
<td>16</td>
<td>4.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Mothers</td>
<td>19</td>
<td>8.3</td>
<td>1.9</td>
<td>29</td>
<td>6.4</td>
<td>2.0</td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5–1.5</td>
<td>4</td>
<td>24.5</td>
<td>1.3</td>
<td>7</td>
<td>9.6</td>
<td>1.6</td>
</tr>
<tr>
<td>&gt;1.5–4</td>
<td>9</td>
<td>12.3</td>
<td>1.9</td>
<td>13</td>
<td>4.4</td>
<td>2.5</td>
</tr>
<tr>
<td>&gt;4–6</td>
<td>6</td>
<td>19.1</td>
<td>1.4</td>
<td>9</td>
<td>5.3</td>
<td>1.9</td>
</tr>
<tr>
<td>Cook with LGP^c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>11</td>
<td>16.5</td>
<td>1.6</td>
<td>18</td>
<td>6.2</td>
<td>2.5</td>
</tr>
<tr>
<td>No</td>
<td>8</td>
<td>16.1</td>
<td>2.0</td>
<td>11</td>
<td>4.9</td>
<td>1.6</td>
</tr>
<tr>
<td>Place where child plays</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yard</td>
<td>2</td>
<td>12.8</td>
<td>1.0</td>
<td>9</td>
<td>5.10</td>
<td>2.8</td>
</tr>
<tr>
<td>Living room</td>
<td>15</td>
<td>16.1</td>
<td>1.8</td>
<td>20</td>
<td>5.9</td>
<td>2.0</td>
</tr>
<tr>
<td>Workshop</td>
<td>2</td>
<td>24.3</td>
<td>1.6</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chewing toys or pencils</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>13</td>
<td>17.0</td>
<td>1.8</td>
<td>8</td>
<td>5.4</td>
<td>3.0</td>
</tr>
<tr>
<td>No</td>
<td>6</td>
<td>15.2</td>
<td>1.6</td>
<td>21</td>
<td>5.7</td>
<td>2.0</td>
</tr>
</tbody>
</table>

NA, not applicable.
^aGeometric mean.
^bStandard deviation.
^cLead glazed pottery.

### TABLE III. Mean Blood Lead Levels (μg/dl) and Their Main Determinants in Children Under 7 Years of Age in the State of Morelos, Mexico (1999–2000)

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Mean*</th>
<th>SD b</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-exposed children</td>
<td>29</td>
<td>5.6</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>Exposed children, but not in a cottage industry</td>
<td>13</td>
<td>14.2</td>
<td>1.8</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Exposed children living in a cottage industry</td>
<td>6</td>
<td>22.4</td>
<td>1.5</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Somebody from the household in addition to the father works in the workshop</td>
<td>7</td>
<td>25.3</td>
<td>1.3</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Yes</td>
<td>12</td>
<td>12.7</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>The wife washes the work clothes at home</td>
<td>14</td>
<td>18.9</td>
<td>1.8</td>
<td>0.04</td>
</tr>
<tr>
<td>No</td>
<td>4</td>
<td>10.2</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>Frequency with which the children visit the shop</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than once a month</td>
<td>8</td>
<td>11.6</td>
<td>1.6</td>
<td>0.02</td>
</tr>
<tr>
<td>More than once a month</td>
<td>11</td>
<td>21.1</td>
<td>1.7</td>
<td></td>
</tr>
</tbody>
</table>

^aGeometric mean.
^bStandard deviation.
^cKruskal Wallis test, for not satisfying the normality assumption or t-test.
TABLE IV. Predictors of Geometric Mean of log-e Blood Lead Variation in Children Under 7 Years of Age in the State of Morelos, Mexico (1999–2000)

<table>
<thead>
<tr>
<th>Variable</th>
<th>β</th>
<th>95% CI</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposedb (non-cottage industry)</td>
<td>2.32</td>
<td>(1.62 to 3.42)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Cottage industryb</td>
<td>4.57</td>
<td>(2.65 to 7.85)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Boys</td>
<td>−1.45</td>
<td>(−2.05 to −0.82)</td>
<td>0.03</td>
</tr>
<tr>
<td>&lt; 1.5 years</td>
<td>2.23</td>
<td>(1.50 to 3.35)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Constant</td>
<td>5.53</td>
<td>(4.01 to 7.61)</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

R² = 0.61
aRobust regression.
bReference category: non-exposed.
cConfidence interval.

Although dust lead concentration was significantly higher (P < 0.01) in the homes of the exposed group, we could not document a dose–response association between dust lead levels and blood lead levels as reported by others [Lanphear et al., 1998]. This might be explained by the small sample size of our study.

In the exposed group, blood lead levels were about two times higher when the wife washed the work clothes at home, the child visited the workshop more than once a month or a household member in addition to the father worked in the workshop. Although these variables were important predictors of blood lead levels in the bivariate models, they were not statistically significant in the multivariate analysis. This was probably due to the small size of our study population. This observation may suggest the most risky practices that can be emphasized in intervention programs to prevent lead poisoning in families exposed to lead.

In our non-exposed group, blood lead levels were highly consistent with the results of previous studies for Mexican populations that are not occupationally exposed [Hernandez-Avila et al., 1991; Romieu et al., 1994; Romieu et al., 1996].

Our results suggest that secondary lead exposure in Mexico may be an important public health problem. It is imperative to encourage the health authorities to compile a complete listing of the industries involved in the use of lead with the aim of identifying the population at risk and determining the most urgent priority in terms of prevention and control of pediatric lead poisoning in Mexico.

These activities should consider implementation of standards to limit the lead exposure at the source, such as: adequate workshop facilities for ventilation, installation of showers, provision of clothing and equipment exclusively for work. Moreover, it is necessary to implement educational programs for the population at risk as well as for educators and health providers to rise the awareness on the hazards of lead exposure.

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The authors thank Marie O’Neill, M.D., Sc.D., Betania Allen Soc. M.A., and Carl Reddy, M.B. Bch., for their helpful comments and suggestions on the English version of this paper. We also thank Dr. Stephen Rothenberg for his invaluable recommendations on the statistical analysis. Finally, a special thanks to the parents and children who participated in the study.

REFERENCES


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