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Lead exposure in starter battery production: investigation of the correlation between air lead and blood lead levels

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Abstract The threshold limit value (TLV) for lead (in Germany, the MAK value) is based on a certain blood lead concentration (in Germany BAT value = biological tolerance value for working materials) that is not to be exceeded; thereby a statistically significant association between air lead (PbA) and blood lead (PbB) is assumed. On the basis of a 10-year period of (1982–1991) biological and ambient monitoring of 134 battery factory staff and their workplaces, a PbA/PbB correlation with the regression equation PbB = 62.183 + 21.242 × Log 10 (PbA) (n = 1089, r = 0.274, P < 0.001) was calculated. These results are in line with those of several other investigations. The shape of the regression curve and the wide scattering of values led to the assumption that PbA values above the MAK value (0.1 mg/m³) do not necessarily result in increased PbB values. Similarly, PbA values lower than the MAK value do not guarantee PbB levels below the BAT value in every case. These observations are influenced by numerous confounders and intervening variables. It is concluded that lowering MAK values as a consequence of lowering BAT values is not mandatory.

Key words Biological monitoring · Air lead · Blood lead · Battery factory

Introduction

In 1977, the Senate Committee of the German Association for Research into Hazardous Industrial Materials reduced the TLV (in Germany, the MAK value) for lead from 0.2 to 0.1 mg/m³. In a comprehensive investigation taking into account both toxicological and health aspects (Henschler 1977), the MAK value was based on a blood lead concentration that should not be exceeded (biological tolerance value for working materials = BAT value in Germany = 70 μg/dl). The MAK value was determined from the results of a number of experimental and theoretical studies which showed on the basis of sufficient evidence that blood lead concentrations of 60 μg/dl only occurred in isolated cases (Henschler and Lehnert 1983). Although a massive amount of literature on the toxicology of lead was already available at that time, it is striking that only a small number of studies had dealt with the relationship between the air lead concentration and the lead load of the human organism on a quantitative basis (Henschler 1977).

Due to the broad application of medical monitoring of workers exposed to lead in their occupational environment, a large number of empirical results are now available on the correlation between the air lead level and the blood lead level. Unfortunately, in many factories such routine data are either not prepared statistically at all or to only a limited extent. In addition, the information has not been published in many cases. One of the main reasons for this might be the fact that the available data have usually not been collected within the scope of a planned study. This means that, in order to appraise the required amount of data, scientific analysis of the relationship between the external and the internal lead exposure has to be carried out through a retrospective linkage of these two parameters. This procedure, however, often leads to many problems, because assignment of the employee’s blood lead value to the air lead level in the workplace becomes more imprecise with the passage of time.

In the present study we had to face similar problems. But based on the available high-quality documentation of the measurement results and taking advantage of all the existing aids for data collection in the factory, we finally managed to achieve highly expressive regressions. By taking into consideration the latest literature sources we hope that we will at least partially be able to fill the gap mentioned above.
Materials and methods

This work is based on the results of a retrospective cohort study for the biomonitoring of industrial lead exposure over a 10-year observation period from 1982 to 1991. In total, 134 employees from the production area of an accumulator factory were monitored (Kentner and Fischer 1993). A sample of venous blood was taken from exposed employees at least once a year within the scope of the preventive checkup stipulated in German industrial medicine regulations. Blood samples were taken only after at least a 1-month period of occupational lead exposure. Whole blood (PbB) analyses were carried out at the Institute of Occupational Medicine at the University of Hamburg. Flameless atomic absorption spectrometry was used for this purpose under quality assurance conditions that remained identical throughout the period reported. The analytical method has been described by Schaller (1974). 

In addition, measurements of the lead air concentration (PbA) were carried out at defined measuring points at least once a year. All air samples were taken using a stationary air sampler with a suction rate of 1.25 m³/s. The cellulose-nitrate membrane filter (Sartorius) had a working diameter of 20 mm with a filter pore size of 0.8 μm. The air samples were taken over a period of 40 min each, corresponding to a suction volume of 1 m³. After wet oxide treatment, lead analyses were carried out by emission spectral analysis (JY 38 plus, Jobin-Yvon, Switzerland).

The PbB and PbA values were combined (with regard to both location and time) using the best available information (details from the personnel department, reports from workshop managers, mailing plus, data from medical records). For this purpose, the production area was divided into seven independent production and activity areas with different organizational structures and work contents: casting, Pb oxide production, bunker, pasting, plate stacking, formation, and assembly (Kentner et al. 1994). Each of the 134 employees was assigned yearly to the production area in which he had worked for most of the time. Those PbB and PbA values showing the smallest time difference were then combined. If several measurements were available, the arithmetic mean was calculated first.

Results

A total of 1089 PbB/PbB value pairs was available from the 10 observation years. The measured PbB values ranged from 1.0 to 98.0 μg/dl; the arithmetic mean was 39.44 (± 15.32) μg/dl, and the median, 38.0 μg/dl. The PbA values ranged from 0.015 to 0.289 mg/m³, with an arithmetic mean of 0.094 (± 0.04) mg/m³ and a median of 0.0935 mg/m³. For both the PbA and the PbB values, an approximate normal distribution can be assumed.

The PbA/PbB correlation with a linear regression function showed a correlation coefficient of 0.259; this is lower than that with the non-linear regression with the logarithm taken from PbA (r = 0.274; cf. Fig. 1).

With an error probability of 0.1%, both regression functions are statistically significant. The usually vertical arrangement of the values in Fig. 1 is due to the fact that the mean was taken from the PbA values within the individual work areas.

When considering the logarithm not only of the x-axis but also of the y-axis, the resulting correlation coefficient was 0.241 (P < 0.001). It is thereby quite obvious that the regression in Fig. 1 with the logarithm taken only from the PbA values best describes the relationship between PbA and PbB. Here, the MAK value of 0.1 mg/m³ corresponds to a PbB value of approximately 47 μg/dl.

The indication of the MAK and BAT values in Fig. 1 leads to a four-quadrant representation; the values of the individual quadrants are shown in Table 1. In accordance with the PbA/PbB measurement results shown in Fig. 1, these values lead to (a) a sensitivity of 0.759, (b) a specificity of 0.599, (c) a positive predictive value of 0.049 and (d) a negative predictive value of 0.989. The lowest PbA value exceeding the BAT limit was 0.067 mg/m³.

What is especially striking in the aggregation of points in Fig.1 is the vertical line in the PbA section between 0.175 and 0.200 mg/m³. These results solely originate from the “plate stacking” production area. From experience we know that a large number of the old workplaces in this area presented high lead load values that exceeded the BAT value by a greater than average degree. Hence, especially in this production area employees were temporarily shifted to workplaces without or with only limited lead exposure. The aggregation of points mentioned above represents all employees who returned to their original workplace in the plate stacking area after their blood lead values had fallen again. As a consequence, it is possible that the PbA/PbB regression might lead to wrong results in that a slope degradation might occur. For this reason, a four-quadrant presentation to calculate the validity of an air lead value (PbA) of 0.1 mg/m³ on the basis of a blood level (PbB) of 70 μg/dl when estimating the health risk for employees exposed to lead at work. The values are based on the results shown in Fig. 1.

Table 1: Four quadrant presentation to calculate the validity of an air lead value (PbA) of 0.1 mg/m³ on the basis of a blood level (PbB) of 70 μg/dl when estimating the health risk for employees exposed to lead at work. The values are based on the results shown in Fig. 1.

<table>
<thead>
<tr>
<th>PbB (μg/dl)</th>
<th>PbA (mg/m³)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.1</td>
<td>(0.067)</td>
<td></td>
</tr>
<tr>
<td>≥ 0.1</td>
<td>(0.094)</td>
<td></td>
</tr>
<tr>
<td>&lt; 70.0</td>
<td>635 (58.31)</td>
<td>425 (39.03)</td>
</tr>
<tr>
<td>≥ 70.0</td>
<td>7 (0.64)</td>
<td>22 (2.02)</td>
</tr>
<tr>
<td>Total</td>
<td>642 (58.95)</td>
<td>447 (41.05)</td>
</tr>
</tbody>
</table>