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Health surveillance of employees on a lead mine, 1979-1989

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Summary

Health surveillance of employees at a lead mine in the northern Cape, employing about 1 400 people, is specifically aimed at early detection of excessive lead absorption, which is the main chemical hazard. Over a period of 9 years the blood lead level distribution showed very few values (2,5%) that exceeded 60 μg/100 ml. The predictive validity (calculated according to the method of Alessio) of zinc protoporphyrin (ZPP) levels, at a cut-off level of 4 μg/g haemoglobin, to screen exposed workers in order to determine whether their blood lead level would exceed 50 μg/100 ml proved to be high (198).

In 1988 a significant correlation between ZPP and blood lead levels was found in 195 employees at a low level of absorption manifested by an incidence of only 4% exceeding the cut-off level of 4 μg ZPP/g haemoglobin and only 2% exceeding a blood lead level of 50 μg/100 ml in that year. Monitoring by ZPP provides a high degree of safety for workers and is a relatively inexpensive, well-accepted and effective method.

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The draft lead regulations published by Notice 821 of 1987 in *Government Gazette* No. 11028 of 13 November 1987, prescribe, in addition to air monitoring under section 8, medical surveillance and biological sampling of employees exposed to lead. Measurement of blood lead concentration and haemoglobin and other relevant biological tests at the appointed medical practitioner's discretion were proposed. Since then a second draft has been published for comment and the final promulgation of lead regulations is expected in the near future. They would apply to any workplace 'where lead is produced, processed, used, handled or stored when such lead is in a form in which it is likely to be inhaled, ingested or absorbed by an employee'.

In the USA biological monitoring (blood lead and zinc protoporphyrin (ZPP)) is prescribed for all employees who are exposed to lead-in-air levels higher than the action level of 30 $\mu g/m^3$ for more than 30 days in the year, while medical examination is mandatory for any worker whose blood lead level exceeds 40 μg/100 g (OSHA — 29 CFR — 1910. 1025).

In the UK the approved code of practice 'Control of lead at work' (revised June 1985, Health and Safety Commission) prescribes medical surveillance, including biological monitoring tests, for all workers whose exposure to lead is significant (par. 105). This is defined as the level of airborne lead being in excess of 75 $\mu g/m^3$ as 8-hour time-weighted average or 'when biological monitoring reveals a blood level of greater than 40 μg/100 m' (par. 10).

For occupational health reasons, medical surveillance of workers potentially exposed to lead in air was instituted on the Black Mountain Broken Hill Mine, Aggeneys, CP, early in 1979. Dornan[1] has shown that, in a group of miners working

in the Peak District of Derbyshire where galena (PbS) is found, blood lead values were much lower (mean 20 μg/100 ml, range 10 - 46 μg/100 ml) than in groups of workers employed in the flotation treatment plant (mean 52 - 57 μg/100 ml, range 30 - 80 μg/100 ml with 1 individual 150 μg/100 ml). In the mineral extraction treatment plant and in the grinding and despatch sections, workers were also exposed to lead carbonate (PbCO) and lead oxide (PbO), which are much better absorbed. Blood lead values exceeding 80 μg/100 ml were found in a number of employees working in the latter sections.

Lead sulphide concentrate, zinc concentrate and copper concentrate are the principal products of the mine. Before the results of medical monitoring are reported, a short description of the mine and extraction plant is included.

Mining and extraction methods

Mining activities at Aggeneys started in 1978. The Black Mountain Broken Hill Mine at Aggeneys is one of four large base metal deposits occurring in a 10 × 30 km area approximately 100 km north-east of Springbok in the north-western Cape Province.

The deposit consists of two ore bodies, which are separated by several metres of barren schist. Each ore body is made up of weakly mineralised ferruginous quartzite, magnetite and well-mineralised massive sulphide. High lead-to-zinc ratios characterise the several massive sulphide lenses in the upper ore body, while in the lower ore this ratio is < 3:1. The principal sulphides are pyrrhotite, galena, sphalerite, pyrite and chalcopyrite. Significant amounts of silver are found in both the copper and the lead concentrates.

Mining is a destructive operation with hazards to safety and health. Although these hazards are controlled as best as possible, people, machinery and equipment are exposed to such adverse factors as poor soil conditions, darkness, noise, confined spaces, dust, smoke, heat, etc., which all contribute to the risk factors in operations. The mine has an established environmental control department that monitors noise levels, dust levels, air temperatures, etc., guided by the standards set by government regulations that lay down acceptable levels for all these factors, but not specifically for lead in air. No environmental exposure levels to lead are available for the mine and plant. In Black Mountain Broken Hill Mine, the most important hazard is the intake of lead particles by inhalation or through eating and drinking food and liquids underground. Most dangerous is the burning of lead particles by smoking or welding, since this causes the lead sulphide to turn into lead oxide, which is easily absorbed into the human blood stream. Areas where this is liable to happen are the underground workshops, and places where cutting or welding is done in ore passes. The highest risk lies with the welding and cutting being done in these ore passes of which there are two sets, each about 140 m long. Continuous work is carried out in these passes of which welding or cutting takes up about 7 days per month. When cutting or welding is being done only the welder and one helper stay inside the ore pass and they are therefore most likely to be affected.

All ore is tipped by underground haul trucks and although ore passes are kept under negative pressure, dust inevitably contaminates the mine air. Tipping, crushing, conveyor-belt transport, loading and face drilling are the major causes of dust generation. High dust levels occur in the crusher chambers and passages nearby.

The crushed ore from the mine is transported by a conveyor belt to the plant where it is further crushed. The fine ore is then sludged and, with the aid of a computer, concentrate is extracted by flotation methods.

Lead concentrate, containing lead sulphide and zinc concentrate, and copper concentrate, partially dried, are then stored, loaded onto road transport vehicles and conveyed to Loop 10, which is a facility where the concentrates are transferred to railway trucks. To reduce the risk of inhaling dust, wetting down, housekeeping and ventilation methods are used. The water content of the concentrate is restricted by maximum prescriptions laid down for shipping the concentrate in holds in order to prevent undue shifting. For lead concentrate this is set at 6,2%.

Medical monitoring programme

From the inception of the mine the health and safety of the employees was regarded as very important. Pre-employment medical examinations, induction lectures emphasising the dangers, risks and hazards, and ways to control these by safety measures were given to all staff. The mine employs approximately 1 400 people in total, including in the plant. An ongoing educational programme, using lectures and video films, teaches employees the use of respirators and the importance of hygiene, good housekeeping and the proper use of facilities and is part and parcel of a worker's life.

The principal author developed a medical monitoring system in consultation with staff of the Universities of Stellenbosch and Cape Town. The general protocol consists of a pre-employment medical examination, which includes a detailed medical and occupational history, laboratory tests of blood (haemoglobin and blood lead) and urine (general and urinary aminolaevulinic acid (ALA) level) and 6-monthly examinations.

The organisation of blood lead monitoring received particular attention. After many false starts and mainly because few laboratories could cope with processing about 60 blood samples on a weekly basis, the mine's own assay laboratory was charged to do the blood lead determinations. For validation and quality control duplicate samples were initially sent to the Government Chemical Laboratory in Cape Town (Mr M. Stokol) and to the National Centre for Occupational Health (NCOH) in Johannesburg. At present, the mine's laboratory is a member of the National Quality Control Scheme for lead run by the NCOH.

Blood lead is determined according to the method of Hessel.[2] The results for the period 1981 - 1989 were very encouraging in that levels exceeding 60 μg/100 ml were rarely found. (Results before 1981 were of an experimental nature and are not regarded as reliable.)

Blood samples are taken before a workshift in a clean, uncontaminated area, such as the hospital or clinic. The total number of blood samples reported on in this article is 3 614. Since no signs of clinical or chemical lead poisoning had been found and blood lead levels were generally low, in 1983 it was decided to restrict blood tests to random samples of high-risk personnel categories.

The cut-off level for removal from work was set at 60 μg lead/100 ml blood. Whenever this value was exceeded by 1 worker, all exposed personnel in his category were again tested and the person himself was medically evaluated and retested.

Results

The distribution of blood lead levels over the period 1981 - 1988 is shown in Table I and graphically presented in Fig. 1. These are test results and employees may be represented more than once. The lowest level found was 3 μg/100 ml (the duplicate reading was 1,96 μg, the average of all determinations was 23,7 μg/100 ml. Only once, in 1982, was the level of 79 μg/100 ml exceeded, when the highest test result, 80 μg/100

ml occurred, validated on repeat testing. The worker, a welder's assistant who had suffered an acute high exposure to lead oxide fumes when working in an ore pass, was medically examined and removed from exposure. On re-evaluation 2 weeks later his blood lead had already dropped to 34 μg/100 ml. The fast drop confirmed the short duration of exposure reported when taking his history.

Table I and Fig. 1 clearly show that nearly all test results (99,5%) were below 70 μg/100 ml. Only 2,5% exceeded the arbitrary cut-off point of 60 μg/100 ml used as criterion for removal from exposure, while less than 20% exceeded the acceptable level as recommended by the World Health Organisation study group in 1980,[3] which is 40 μg/100 ml for men.

TABLE I. DISTRIBUTION OF BLOOD LEAD TEST RESULTS (*N* = 3 614)

Pb level (μg/100 ml)	No. of cases (n)	% distribution	Cumulative % 1981-88
0-10	650	18,0	18,0
11-20	903	25,0	43,0
21-30	903	25,0	68,0
31-40	489	13,5	81,5
41-50	325	9,0	90,5
51-60	254	7,0	97,5
61-70	72	2,0	99,5
71-80	18	0,5	100,0

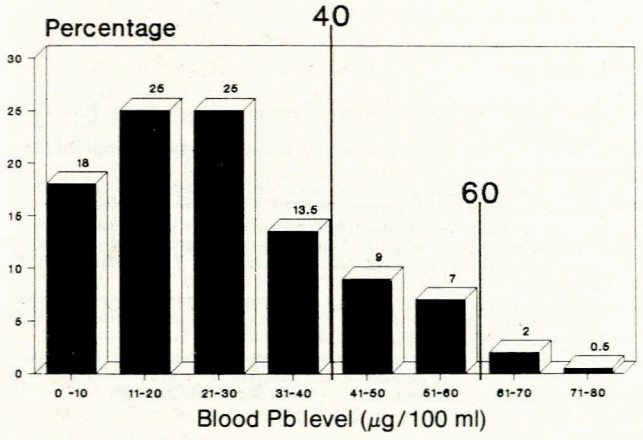

Fig. 1. Percentage distribution of blood lead test results, 1981-1988 (*N* = 3 614).

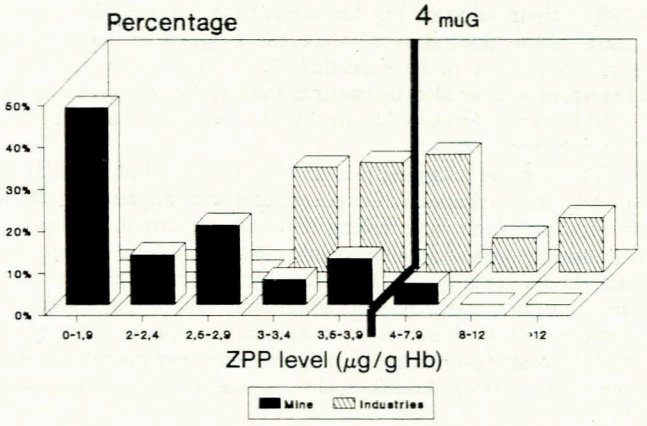

Fig. 2. Percentage distribution of ZPP values (mine *N* = 195; industries *N* = 348).

In 1988 an Aviv haematofluorometer was acquired and monitoring of all employees was started using zinc protoporphyrin determinations. The test is simple — a drop of blood is placed on a clean glass cover slip, which is inserted into the instrument. A reading in SI units (μmol ZPP/mol haemoglobin) is available within seconds and converted into either μg/g haemoglobin (conversion factor = 25) or μg/100 ml blood. The first mode was selected and values are thus expressed as μg ZPP/g haemoglobin.[4]

Wildt *et al.*[5] stated that in the lead in blood range of 10 - 80 μg/100 ml the relationship between log ZPP and blood lead level may be regarded as linear. They determined, as a regression equation for men, that log ZPP = 1,48 + 0,0113 blood lead level, in which ZPP is expressed as μg/100 ml. The conversion factor for ZPP to obtain values in μg/g haemoglobin is division by 13,94. Their correlation coefficient was 0,72 and the expression accounted for 52% of the total variance. Their equation corresponds well with other published equations quoted in their article as well as with the one calculated by Alessio and Foa.[6]

Alessio and Foa,[6] in their authoritative chapter on lead in the Commission of the European Communities series on human biological monitoring, reported a high predictive validity of 177 (defined as the sum of specificity (79%) and sensitivity (98%)) for screening of workers exposed to lead when using a cut-off point of ZPP = 7,1 μg/g haemoglobin to predict that blood lead levels would not exceed 60 μg/100 ml blood. Only 2% false-negative results were noted where men with a ZPP level < 7,1 μg/g haemoglobin showed a blood lead level higher than 60 μg/100 ml ($N = 211$).

In the Cape Town area results of a study[7] of a group of 364 workers exposed to metallic lead in a number of small workplaces, i.e. a battery manufacturing plant and a secondary smelter, showed a correlation coefficient of 0,76 ($P < 0,005$) for blood lead values and ZPP values of 16 - 105 μg/100 ml (mean 54,5 ± 21,63 μg/100 ml) and 4 - 31 μg/g haemoglobin (mean 5,7 ± 5,73 μg/g) respectively. These workers, exposed to lead fumes and lead dust that mostly contained salts other than lead sulphides, showed higher levels of absorption than the lead-mine workers (Fig. 2): only 51% had ZPP values < 4 μg/g haemoglobin v. 96% of the miners. However, 79% had ZPP levels < 8 μg/g and 87% had levels lower than 12 μg/g haemoglobin. This close and significant correlation was confirmed for 58 men when their ZPP values were compared with blood lead samples taken 8 - 12 weeks earlier ($r = 0,73$, $P < 0,005$).

Owing to its biological effect on haemoglobin synthesis, the ZPP level reflects lead absorption over a period of 8 - 12 weeks, whereas blood lead levels correspond with exposure fluctuations over a range of a few weeks or even days, serving to indicate absorption rather than effect. Correlation of ZPP with blood lead levels can only be expected under stable exposure conditions and will be closest if taken with a time interval of 8 - 12 weeks.

Table II shows the results of ZPP level measurements on the mine. The 195 paired blood tests for lead and ZPP for this group of workers on the mine showed a mean level of blood lead of 30,85 ± 0,75 μg/100 ml (range 9 - 66 μg/100 ml) and a mean ZPP level of 2,19 ± 0,79 μg/g haemoglobin (range 1,3 - 9,5 μg/g). The correlation coefficient for all results was 0,478

and for all blood lead levels exceeding 40 μg/100 ml it was 0,704, both significant ($P < 0,001$). None of the persons whose ZPP level was less than 4 μg/g haemoglobin showed a blood lead level higher than 60 μg/100 ml. Of the few who exceeded that level, none showed any relevant signs or symptoms on clinical examination. Any person whose test results exceeds 4 μg ZPP/g haemoglobin is called up at once for medical evaluation, which includes blood lead determination.

TABLE II. DISTRIBUTION OF ZPP VALUES, 1988 ($N = 195$)

ZPP level (μg/g Hb)	No.	% distribution	Cumulative %
0 - 1,9	**92**	**47**	**47**
2,0 - 2,4	**23**	**12**	**59**
2,5 - 2,9	**37**	**19**	**78**
3,0 - 3,4	**14**	**7**	**85**
3,5 - 3,9	**22**	**11**	**96**
> 4	**7**	**4**	**100**

Discussion

If the ZPP level of 4 μg/g haemoglobin is taken as the cut-off point for screening workers so as not to exceed a blood lead value of 50 μg/100 ml there were 3 false-positive results, no false-negative results and only 4 true-positives in this group. This represents a 100% sensitivity and 98% specificity but a low predictive value of only 2%, which is explained by the very low prevalence — only 2% of the blood lead values exceeded 50 μg/100 ml. However, calculating the predictive validity according to Alessio and Foa,[6] as quoted earlier, this would be 198 v. their value of 177 for the cut-off point of ZPP at 7,1 μg/g haemoglobin for an expected blood lead value of 60 μg/100 ml not to be exceeded. The findings on this mine therefore appear also to confirm the validity of screening by ZPP for lower levels of absorption than occur and are reported for industries.

The clinical examination at the mine includes taking a history for indications of exposure and asking questions about symptoms, such as a feeling of weakness; tiredness; lack of appetite; vague abdominal pains; change of bowel habits, e.g. diarrhoea, constipation and colic; peripheral limb weakness; and central nervous system depression. The protocol specifies examination of blood pressure, general and specific urine tests, tests of motor power, checking for signs of peripheral neuritis, muscular wasting, and the colour of mucous membranes and gums, while haemoglobin and blood lead tests are repeated. No positive clinical signs of importance were ever recorded on the mine.

Since 1988 ZPP level is routinely determined when workers return after an annual leave period and are away from exposure for 4 - 6 weeks. This routine adds to the safety margin incorporated in the now adopted cut-off level of 4,0 μg/g haemoglobin, which prompts full medical evaluation if exceeded.

Conclusion

This report of the results of biological monitoring of workers on a lead mine, where the risk of potential exposure to low levels of lead dust (mainly in the form of lead sulphide) exists, indicates that these workers are at low risk of absorbing lead to an excessive degree. This was defined as reaching a blood lead level of 60 μg/100 ml, but the statement is true even when the recommended level of 40 μg/100 ml, as advocated by the WHO, is aimed at.

Over a period of about 1 year the use of ZPP determinations has proved to be a reliable method for monitoring these workers. Under the prevailing conditions of low-level exposure, with little fluctuation over time, the correlation of ZPP and blood lead levels was significant. No blood lead values higher than 60 μg/100 ml were ever found in individuals whose ZPP level did not exceed 4,0 μg/g haemoglobin, adopted as the cut-off level for removal from exposure and medical evaluation.

Health surveillance for exposure to lead, which includes this inexpensive method of determining ZPP levels, highly sensitive and specific and also readily accepted by the workforce, has become accepted practice on the mine, in addition to the statutory required medical examination which includes chest radiography.

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