ORIGINAL ARTICLE

Declining blood lead levels among small-scale miners participating in a safer mining pilot programme in Nigeria

Perry Gottesfeld,[1] Gabriella Meltzer,[2] Sadie Costello,[3] Jane Greig,[4] Natalie Thurtle,[4] Karla Bil,[4] Benjamim Janeiro Mwangombe,[4] Manti Michael Nota[1]

[1]Occupational Knowledge International, San Francisco, California, USA
[2]College of Global Public Health/ Department of Epidemiology, New York University, New York City, New York, USA
[3]Division of Environmental Health Sciences, UC Berkeley School of Public Health, Berkeley, California, USA
[4]Doctors Without Borders Operational Centre Amsterdam, Amsterdam, The Netherlands

Correspondence to
Perry Gottesfeld, Occupational Knowledge International, San Francisco, CA 94118, USA; pgottesfeld@okinternational.org

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ABSTRACT

Objectives Our objective was to monitor blood lead levels (BLLs) of miners and ore processors participating in a pilot programme to reduce lead poisoning and take-home exposures from artisanal small-scale gold mining. A medical surveillance programme was established to assess exposures as new methods aimed at reducing lead exposures from ore were introduced in a community in Nigeria where children experienced substantial lead-related morbidity and mortality.

Methods Extensive outreach and education were offered to miners, and investments were made to adopt wet methods to reduce exposures during mining and processing. We conducted medical surveillance, including a physical exam and repeated blood lead testing, for 61 miners selected from among several hundred who participated in the safer mining pilot programme and consented to testing. Venous blood lead concentrations were analysed using the LeadCare II device at approximately 3-month intervals over a period of 19 months.

Results Overall geometric mean (GM) BLLs decreased by 32% from 31.6 to 21.5 µg/dL during the 19-month project. Women had a somewhat lower reduction in GM BLLs (23%) compared with men (36%). There was a statistically significant reduction in log BLLs from baseline to the final test taken by each participant ($p<0.001$).

Conclusions The observed reductions in GM BLLs during the pilot intervention among this representative group of miners and ore processors demonstrated the effectiveness of the safer mining programme in this community. Such measures are feasible, cost-effective and can greatly improve health outcomes in mining communities.

Key messages

What is already known about this subject?

- There are known health benefits from reducing blood lead levels (BLLs) among occupationally exposed adults, but there have not been any concerted efforts to reduce exposures among artisanal small-scale miners exposed to lead.

What are the new findings?

- A pilot intervention to introduce safer mining among small-scale gold miners in Northern Nigeria resulted in a statistically significant 32% reduction in geometric mean BLLs over a 19-month period.

How might this impact on policy or clinical practice in the foreseeable future?

- As small-scale mining is a rapidly growing enterprise, there is an immediate need to introduce safer mining practices among gold miners throughout a large area of Northern Nigeria and to apply these same practices to small-scale lead miners everywhere.

INTRODUCTION

Artisanal, small-scale mining is a growth industry in many countries around the world and is estimated to employ more than 40 million people.[1] Most of these miners are exposed to silica dust and other hazards, but few studies have been conducted to test ore for lead or other contaminants. In Northern Nigeria, artisanal small-scale gold mining (ASGM) has been associated with extensive environmental contamination and acute lead poisoning from the lead present in the ore. Small-scale lead mining is also taking place in these communities and is a growing activity in Nigeria yielding approximately 50 000 tons of lead in the 4-year period between 2013 and 2017.[2]

In 2010, Doctors Without Borders/Médecins Sans Frontières (MSF) first diagnosed children with severe lead poisoning in several villages in Zamfara State, Nigeria, and since then have treated thousands of children with acute lead poisoning.[3] These exposures were linked to the informal mining and processing of gold in this region.

In April 2015, severe lead poisoning cases were reported in two villages in an area in Niger State approximately 250 km south of where the initial emergency was identified. An investigation by the Federal Ministry of Health indicated that approximately 80% of the children tested had BLLs greater than 45 µg/dL, and at least 28 reported deaths among young children were attributable to lead poisoning.[4]

In 2016, MSF formed a partnership with Occupational Knowledge International to demonstrate the feasibility and effectiveness of safer mining practices in this community in Niger State. The motivation for conducting this pilot intervention was to reduce environmental lead contamination in homes and villages and thereby reduce community lead exposures by changing work practices.

The safer mining pilot combined training programmes and worksite improvements. The project was initiated with a robust health promotion programme and a community engagement approach that included formal training programmes for miners and the community to raise awareness of the hazards and to explain the routes of exposure that could impact their health and that of their children. We then introduced new work practices to lower airborne lead exposures and improve personal hygiene measures to reduce take-home exposures.

We previously reported on our progress in reducing airborne lead levels by 95% following the introduction of wet spray misting at this site.[5] However, blood lead testing is considered the best overall measure of occupational exposure. At the outset, there was no data on BLLs among those mining and processing gold ore in this region. Given the lack of any blood lead measurements from any similar population and the subtle health effects associated with lead poisoning, a medical surveillance programme was needed to assess overall exposures to these miners during the pilot. The aim of this effort was to monitor the health and BLLs of miners during the implementation of a safer mining programme in this community.

METHODS

This safer mining intervention project was conducted in the Shikira community in Niger State starting in 2016 after severe lead poisoning was detected in children, and two villages in the area underwent extensive soil remediation. We first conducted outreach meetings with mining leaders, traditional leaders, religious authorities and local government to explain the project objectives and our desire to work cooperatively with the community to introduce safer mining practices. With encouragement from the mining leaders and community, we initiated formal training programmes and conducted air sampling to characterise exposures in various mining and processing tasks.

The training curriculum emphasised measures to reduce exposures with personal hygiene practices and the importance of not taking home ore or dust on clothing and footwear. We also provided information on the hazards of silica dust, mercury, cyanide and safety issues.

Separate training sessions were held with women whose children were being monitored and/or treated for lead poisoning and other community members to explain the purpose of these workplace interventions and how to minimise exposures to children from mining activities. When new miners came into the area, additional training courses were provided.

Following the initial training, but before the initiation of worksite improvements, we initiated a medical surveillance programme to monitor potential health effects of lead exposure and to provide feedback on exposures with quarterly blood lead testing. A protocol was prepared by MSF to address testing, counselling, potential treatment and the assessment of blood test results.

Baseline air samples demonstrated that the ore processors who used mechanical methods to grind the ore into a fine powder had approximately 10-fold higher exposure to airborne lead than the miners. In designing a medical surveillance programme, we hoped to include all the highly exposed processors and a sample of the much larger pool of several hundred miners.

After completing initial training with most of the active miners in the intervention area, we used the list of approximately 240 miners who had attended initial training sessions to select every fifth miner to invite to participate in the medical surveillance programme. The list was arranged by date of training course attended to obtain a representative sample from those who came forward for training earlier and those who attended later. This systematic random sampling was designed to include a minimum of 51 individuals to provide sufficient statistical power and to include all 14 ore processors if they consented.[6]

We invited those selected to attend a meeting where the content and purpose of the medical surveillance would be explained. Following the orientation meetings conducted in the local language, we asked the selected participants if they were willing to have their blood drawn every 3 months during the 19-month intervention. If they verbally consented, they were asked to come to the medical clinic to meet with the staff and be tested. Any selected participant who declined to attend an orientation session or to participate was replaced by the next miner on the list until a willing volunteer was identified.

At the clinic, each miner was given further counselling on the hazards of lead exposure before verbal consent was confirmed and a medical questionnaire was completed. Female miners were advised that their lead exposure could cause lead poisoning to their unborn children, and therefore, women should not be involved in mining in this area where there is high lead content in the ore. All participants provided a signed informed consent. Each participant underwent a physical examination including a blood pressure measurement and neurological examination.

Blood samples were collected from a venous puncture after skin cleaning with soap and water following a well-established sample testing and analysis protocol developed by MSF and the US Centers for Disease Control and Prevention for testing children in these communities and subject to ongoing validation. Samples were stored and then analysed at a temporary laboratory located in the community using LeadCare II point-of-care testing device (Meridian Bioscience).

Following the sample analysis, miners were asked to individually visit the clinic to obtain their results and discuss any recommended actions with the medical staff. Individuals with results exceeding 50 µg/dL were advised to stop mining until their BLL was reduced. Notably, none of the miners agreed to stop mining and none received chelation treatment.

After the initiation of the medical surveillance programme, we worked in cooperation with miners and ore processors to convert dry mining and processing techniques to wet methods to reduce dust exposures. We installed a bore well at the processing site along with a tower to supply pressurised water to water spray misting nozzles, and the processors contributed a generator to power the electric well pump. A separate lunch facility and hand washing station were erected where food vendors gathered and workers ate during lunch breaks. A small changing area was constructed for miners to change clothing and wash at the end of the work day. Miners and processors contributed labour, financial resources and some equipment to these efforts.

Statistical analysis

Variables were analysed using Stata SE V.15. The geometric mean (GM) and range for BLLs were calculated. The change in BLL from baseline to the final test was calculated for each participant. Since the observed change in BLLs were not normally distributed, we log transformed all BLLs for bivariate and multivariate analyses. Two-sample, paired t-tests were conducted to assess overall differences in log-transformed arithmetic mean BLLs among the samples at baseline and at the final round of testing that each individual participated in.

Table 1 Blood lead levels (BLLs) for the first and final round of testing and t-test results for differences by gender and job classification for log-transformed mean values

	N (%)	Mean age	GM BLL first round	95% CI	GM BLL final round*	95% CI	Per cent change (first vs final)	P value (first vs final)†
Males	41 (67)	28.2	30.3	23.1 to 39.8	19.5	15.7 to 24.2	−36	<0.001
Females	20 (33)	20.9	34.4	29.1 to 40.7	26.5	22.6 to 31.0	−23	0.001
Miners	47 (77)	26.0	28.5	23.0 to 35.3	20.1	16.7 to 24.3	−29	<0.001
Ore processors	14 (23)	24.9	44.7	30.6 to 65.2	27.0	20.9 to 35.0	−40	0.002
Total participants	**61**	**25.8**	**31.6**	**26.1 to 38.1**	**21.5**	**18.4 to 25.2**	**−32**	**<0.001**
Total (1st–7th testing round)	**58**	**25.5**	**31.4**	**25.7 to 38.3**	**21.4**	**18.2 to 25.2**	**−32**	**<0.001**

*Final round indicates the 7th round of testing for all except for three individuals who were last tested in the 6th round.
†Significance tests were conducted based on logged values due to non-normal distribution.
GM, geometric mean.

To compare differences among subsets of participants (miners or ore processors and male or female), we conducted independent t-tests on the change from baseline to the final test for log-transformed BLLs in the subgroups, assuming equal and unequal variances. We conducted linear regression to predict changes in log BLLs controlling for age and sex, in the entire sample, and then only among those who identified as miners.

RESULTS

Most participants in the programme had significant lead exposures that were reduced over the 19 month intervention. Our sample consisted of 61 mostly young miners and ore processors with a mean baseline age of 26 years (see table 1). The baseline GM BLL was 31.6 µg/dL, and only four (7%) initial BLLs were less than 10 µg/dL. No ore processors and fewer miners were female, and therefore, our sample included 67% men and 33% women (see table 1).

Only one miner who had participated in the initial testing was unavailable to be retested at any time and was therefore dropped from this analysis. The 61 individuals who had participated in at least two of the seven testing rounds had a statistically significant 32% reduction in GM BLL from their initial to their final test ($p<0.001$) (see table 1). Three participants were not present for testing at the seventh round but had last been tested in the sixth round. Exclusion of their results had little impact on the decrease in GM BLL from 31.4 µg/dL to 21.4 µg/dL ($p<0.001$) in the more restricted group of 58. The mean decrease in BLLs was not significantly different for miners compared with the ore processors ($p=0.28$ not shown in table 1). Linear regression analysis showed that neither age (ß −0.01; 95% CI −0.02 to 0.00) nor sex (ß −0.25; 95% CI −0.52 to 0.02) were statistically significant predictors of change in BLLs.

The largest decrease in BLLs among the sampled population was 83.8 µg/dL (70.8%), and the largest increase was 10.6 µg/dL (82.8%). Only two (3%) miners had an increase in BLL greater than 5 µg/dL. Figure 1 shows the distribution and median BLLs in each testing round. The largest decrease occurred between round #1 and #2 (see figure 1) with individual BLLs in each round varying somewhat.

Field observations indicated that men and women generally performed different tasks in mining, with most women working in the shallow pit mines or in alluvial mining areas adjacent to rivers. Men generally worked in deeper open pit mining areas and in ore processing. Women had higher initial GM BLLs than men (see table 1) and experienced a smaller decrease in BLLs over the project period, but the difference was not statistically significant ($p=0.1$ not shown in table 1).

DISCUSSION

Results from the exposure surveillance of this group of miners and ore processors conducted over a 19-month pilot intervention demonstrate the feasibility of safer mining measures in significantly reducing BLLs among these highly exposed individuals.[7] The temporal pattern of declining BLLs, the strength of the effect size and the separately reported 95% reduction in airborne lead levels following the installation of wet spray misting equipment and other worksite improvements provide evidence of the effectiveness of these measures.[6] Had we initiated blood lead testing before offering the training programmes, it is possible that baseline exposures would have been higher than those reported here and could have strengthened our findings.

A small investment of approximately US$5000 covered the capital costs for introducing wet methods and personal hygiene measures at the worksites. Given the large number of miners and processors benefiting from these improvements, this investment would not impact the long-term economics of these mining operations.

The final blood lead tests from this group were well below levels where medical intervention would be considered, despite three initial BLLs >100 µg/dL. Only two (3%) of the participants

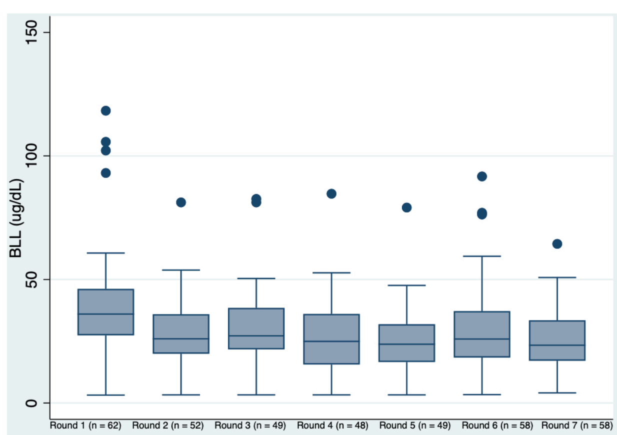

Figure 1 Distribution of blood lead levels (BLLs) (µg/dL) for the participating miners by quarterly testing round (#1–7).

had final BLLs ≥50 µg/dL, the level at which medical removal protection would be required under the US Occupational Safety and Health Administration Lead in Construction Standard.[8] During the initial round of testing, 3 (21%) of the 14 ore processors had BLLs exceeding the criteria (BLL >100 µg/dL) for considering chelation treatment for asymptomatic participants under our protocol. None agreed to stop working so were not provided medical treatment, but all three had final BLLs less than 65 µg/dL.

Since 2016, the US National Institute for Occupational Safety and Health has characterised elevated BLLs in adults as levels greater than or equal to 5 µg/dL.[9] In our sample, only two (3%) of the participants had BLLs below this level during the seventh round of testing. BLLs even below 10 µg/dL in adults are associated with increased cardiovascular mortality, decreased auditory function and increased hypertension.[10] Our experience indicates that exposures can be controlled but are still likely to contribute to subclinical effects and increased cardiovascular disease in this community.

The rate of decrease in BLLs in occupationally exposed adults following a reduction in exposure has been shown to have considerable interindividual variation.[11] In adults, most lead in the body is stored in the bone and released over many years as other exposure sources are reduced. In general, premenopausal women tend to experience a slower reduction in BLLs following removal from occupational exposure.[12] These observed differences in other studies are consistent with our finding that women had a somewhat lower reduction in GM BLLs (23%) compared with men (36%).

Our intent in conducting this intervention was to initiate workplace improvements to reduce occupational exposures that was motivated by the acute lead poisoning among children in this community. One of the inherent limitations is that our study reports on results of medical surveillance data without a control group or other experimental design.

Previously reports on lead poisoning from mining in Nigeria only provided results from children residing in similar communities in Zamfara State.[13–15] There are no other published reports on BLLs among adults in any of these areas where extensive gold mining and ore processing has taken place.

Other efforts to assess hazardous exposures among small-scale miners have been largely focused on biological monitoring of mercury in urine and hair. One study conducted in Ecuador reported on lead exposures from environmental sources in communities where ASGM activities were present, but no attempt was made to determine the concentration in the gold ore.[16] Other studies have focused on lead exposures to children from mine waste tailings.[17 18] However, this is the first report that we are aware of that includes BLLs of artisanal gold miners.

The success of this intervention was dependent on developing a cooperative relationship with mining leaders, traditional leaders, religious authorities, government agencies and the miners themselves. The project was initiated with outreach to meet these stakeholders, explain our objectives and to build trust. The community readily volunteered labour to these efforts and collected funds for some of the equipment needed for the improvements in mining and processing. Likewise, most individuals selected to participate in the medical surveillance programme readily agreed and consented to regular clinic visits without receiving any monetary compensation. As these are informal workers who migrate to various mine sites, we had fluctuations in the participation during multiple rounds of blood lead testing.

Ongoing exposures from other sources may also have contributed to the BLLs we observed. Lead from both local water sources and diet may be an additional exposure source to miners in this community. However, to our knowledge, sources of food and water did not substantially vary during the 19-month surveillance period and could not account for the reduction in BLLs observed.

A limitation in our study is that this self-employed workforce is intermittently engaged in mining activities along with subsistence agriculture and other work. One possible contribution to reduced BLLs could be a result of reduced mining activities during this period. However, agriculture in this area is generally limited to the wet season and significant shifts would have resulted in a seasonal pattern in BLLs that were not evident in the quarterly testing (figure 1). In addition, mining activities take place in several locations where the ore may have variable lead content so results could possibly reflect an unrecognised change in lead concentrations in the source material. However, we have no information to suggest that the overall trend in lead concentration would have been reduced during this time.

It is very unlikely that working hours, changes in mining intensity or diet are confounding variables as our observations suggest that such factors are probably randomly distributed throughout the population of miners and processors. Furthermore, the previously reported reduction in airborne lead levels during this phase of the project provides a strong indication that occupational exposures are by far the most significant contribution to blood lead levels among these miners. Although there are seasonal patterns to dust levels generated from mining and processing, we account for the potential impacts of these fluctuations by monitoring miners over 19 months.

As governments look to small-scale mining as an economic driver and as a future revenue source, they should incorporate the lessons from this pilot project into outreach efforts and regulatory requirements for this activity. Existing regulations governing small-scale mining in Nigeria do not require health and safety training, the availability of water at mining or processing sites, nor are there any criteria for locating ore storage sites, mine tailings or processing machines. These types of dust controls, in combination with training programmes and improved hygiene practices, can contribute substantially to preventing severe lead poisoning among miners and children in these communities.

CONCLUSIONS

We documented a statistically significant reduction in log mean BLLs over a 19-month period among this representative group of miners and ore processors. Our pilot study demonstrated that the adoption of safer mining practices and resulting reductions in BLLs are possible even among highly exposed, artisanal small-scale miners working in very resource constrained environments. Although the measures employed significantly reduced exposures, it is important to characterise these activities as 'safer mining' practices but not 'safe mining' when messaging this approach to impacted communities.

Despite challenges in reducing BLLs among chronically exposed workers, this pilot provided significant public health benefits to both adults and children residing in this community. Improvements were accomplished with a small investment that would not impact the long-term economics of these mining operations. Nigeria and other African countries with large numbers of small-scale miners view this activity as an economic development strategy that should be formalised and regulated.

Investments in reducing these exposures are likely to have significant returns on investment when compared with the direct costs of treating severe lead poisoning in these communities. We hope that others will replicate these efforts, prioritising areas where lead is present in gold ore and everywhere lead ore is mined by informal small-scale miners.

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