Childhood Blood Lead Reductions Following Removal of Leaded Ceramic Glazes in Artisanal Pottery Production: A Success Story

Donald E. Jones[1], MS; Mario Covarrubias Pérez[2]; Bret Ericson[3]; Daniel Estrada Sánchez[3], Sandra Gualtero[3]; Andrea Smith-Jones, MS[1]; Jack Caravanos, DrPH, CIH[4]

1 Quality Environmental Solutions, 40 Hudson Street, Suite 107, Annapolis, MD 21401
2 Fondo Nacional para el Fomento de las Artesanías (FONART), Av. Paseo de la Reforma No., 333 1er Piso, Col Cuauhtémoc, México D.F. C.P. 06500
3 Blacksmith Institute, 475 Riverside Drive, Suite 860, New York, NY, USA 10115
4 City University of New York School of Public Health, 2180 Third Avenue, NY, NY USA 10035

Corresponding Author:
Bret Ericson
Blacksmith Institute
475 Riverside Drive, Suite 860
New York, NY 10115
USA

phone: +1 212 647 8330
email: bret@blacksmithinstitute.org

Background. Lead exposure within artisanal ceramics workshop communities in Mexico continues to be a major source of childhood lead poisoning. Artisanal ceramics workshops expose children through direct ingestion, contaminated soil, and food prepared in lead-glazed pottery. Conversion to non-lead glazes alone may not effectively reduce exposure. This paper describes a model comprehensive intervention and environmental remediation of an artisanal ceramics workshop in the state of Hidalgo, Mexico.
Objectives. The purpose of the project was to evaluate the effectiveness of environmental interventions—including removal of lead-contaminated equipment, soil and pottery—on childhood blood lead levels.
Methods. A typical artisanal workshop using lead glaze was identified and assessed for lead contamination. Baseline blood lead levels (BLL) were taken from 5 children inhabiting the workshop prior to remediation. Follow-up paired BLL were taken 3- and 12-months post-remediation and results compared.
Results. A mean 54% decrease in BLL within 3 months of remediation and a 57% decrease within 1 year was observed.
Conclusions. This project shows the effectiveness of environmental lead remediation at artisanal Mexican ceramics workshops for purposes of sustained BLL reductions. Application of the methods presented in this paper to other ceramics workshops using lead glaze in central Mexico will likely help to further reduce childhood lead poisoning.
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Introduction

Lead-based ceramic glazes are widely used by traditional ceramicists in Mexico. The Mexican government agency Fondo Nacional para el Fomento de las Artesanías (FONART) has a database of 9,640 small-scale producers that utilize such glazes, but estimates that there may be an additional 40,000.[1] Similar to other artisanal industries in low and medium income countries, the majority of this work takes place within the home, with various family members engaged at different points in the production process.[2] Lead (Pb) is a neurotoxin with well-known cognitive developmental effects in children and cardiovascular effects in adults.[3, 4, 5, 6, 7, 8]

While there is extensive research on the health risks posed by lead-based ceramic glazes, few studies examine the efficacy of public health interventions designed to mitigate these risks. An exception is Counter et al., who suggests a decline in BLLs of children in Ecuadorian Andean village populations as a result of public education campaigns.[9] However, to our knowledge no studies have been published demonstrating the results of engineering interventions aimed at the artisans themselves.

This paper reports on the environmental intervention implemented jointly by New York-based Blacksmith Institute and FONART in the state of Hidalgo. The intervention relied on environmental remediation in the workshop and home following the successful adoption of modern lead-free ceramic glazes.

Background

Historical Context

Lead was one of the first metals to be extracted and reformed by humans for a variety of uses.[10] Given its low melting point and other properties, lead and its oxide have been used in ceramic glazes for a millennia. The earliest known uses of lead in ceramics occurred in the ninth century BC in Greece[11] and continues into the present day. Lead acts as a flux, helping promote the formation of glass coating by lowering the melting point of silica. Often, colorants are simultaneously added to the liquid glaze for decorative purposes. Ceramic colorants have also been reported to contain lead and may further exacerbate toxic exposure.[12]

In artisanal production, lead remains a key base for glazes. In addition to Mexico, lead is still widely used in several Latin American and Caribbean countries, the Middle East, North Africa, and other regions.[13] In most high-income countries, the sale of ceramics used for food preparation or storage is monitored for leachable lead with tight restrictions.[14,15,16,17]

In Mexico, the sale of lead oxide to ceramicists is similarly prohibited by law. Regulations passed in 1993 state that pottery containing certain levels of lead oxide (.05 μg/mL to 2 μg/mL, depending on use) should be labeled "Not for Human Use" or perforated to prevent it from being used in food preparation. However, the purchase and use of lead oxide by artisanal ceramists remains widespread and routine. Indeed fewer than 50 ceramists are estimated to operate in completely lead-free workshops.[13]

Artisans do not typically use protective personal equipment (PPE) such as gloves, masks, or goggles. Thus, the very fine particles of lead oxide are easily inhaled or ingested during production.[18]

Abbreviations

μg/dl	Micrograms per deciliter	*mg/kg*	Milligrams per kilogram
BLL	Blood lead level	*NIST*	National Institute of Standards and Testing
CDC	Centers for Disease Control and Prevention	*Pb*	Lead
EPA	Environmental Protection Agency	*PPE*	Personal protective equipment
		PPM	Parts per million
FONART	Fondo Nacional para el Fomento de las Artesanías	*USAID*	United States Agency for International Development
IEUBK	Integrated Exposure Uptake Biokinetic model	*XRF*	X-ray fluorescence

Human Exposure Pathways

The primary human exposure pathways are the inhalation and ingestion of lead-contaminated soil. Acute skin exposure associated with the handling of lead oxide is likely to be a less critical risk factor because production volume is relatively low. By contrast, soil containing lead will continue to pose a risk long after it initially becomes contaminated because, under most natural conditions, lead oxide is highly immobile in soil.[19] Due to the low solubility of the lead compound, it tends to remain in the surface soil.[20] Many homes and most workshops of artisans have earthen floors, thus presenting a chronic exposure risk.

A third possible exposure pathway is the contamination of food during preparation. Because artisans rarely use PPE and are often unaware of the risk, they potentially contaminate food during handling. FONART has anecdotally demonstrated elevated lead levels by testing the hands of artisans for lead using sodium rhodizonate as many as 4 days after glaze application.

The inhalation of lead vapors is unlikely to pose a risk. Lead vaporizes at 1,750°C, well above the operating temperature of the kilns used by traditional artisans.

Lead-free Alternatives

There are unleaded glaze alternatives. Some lead-free glazes, however, require kilns that can fire at much higher temperatures than those available to artisans: ie, a range of 1200°—1800°C.

Several agencies have subsidized the construction of gas-fired kilns to help encourage the use of lead-free glazes. The United States Agency for International Development (USAID), the World Bank and FONART conducted several serious efforts to subsidize gas kiln manufacturing. However, given the scale of the issue (approximately 50,000 producers) and high cost of kiln manufacture (around US$20,000 per kiln), progress has been limited. To date, 48 kilns have been constructed by FONART through subsidies.

Perhaps the most pragmatic approach

involves the development of a safe low-temperature ceramic flux. Researchers from glaze-producing companies (i.e. Dal Tail, Ferro Mexicana, Cerámicos San José, Procerama), working closely with FONART, have developed several such alternatives. These include a completely lead-free, boron-based option, as well as glaze that contains lead made insoluble by bonding with other metals in the firing process. Both of these options are in fact more affordable than lead oxide and are widely available. Their adoption, however, has been slow, with few producers opting to utilize solely lead-free (or lead-insoluble) glazes. When they are utilized, it is often done for export or to reach a niche market, rather than for broad domestic consumption

Even in the event that an artisan fully converts to lead-free production, the workshop and household may still contain high levels of lead oxide. This is particularly the case with earthen floors, where it is extremely difficult to remove all traces of lead. In such cases, an assessment of risk is required. In those cases where elevated levels are identified, environmental remediation by professionals is essential to remove the chronic risk.

Materials and Methods

Study Location

A team of experts from Blacksmith Institute worked jointly with FONART to identify a typical home for the study. The key parameter for inclusion was an active artisanal ceramic workshop with willingness to convert to using a lead-free glaze. A second parameter involved geography. Finally, priority was placed on those households where children were potentially at risk. FONART identified several candidate workshops and chose the best applicant for this study.

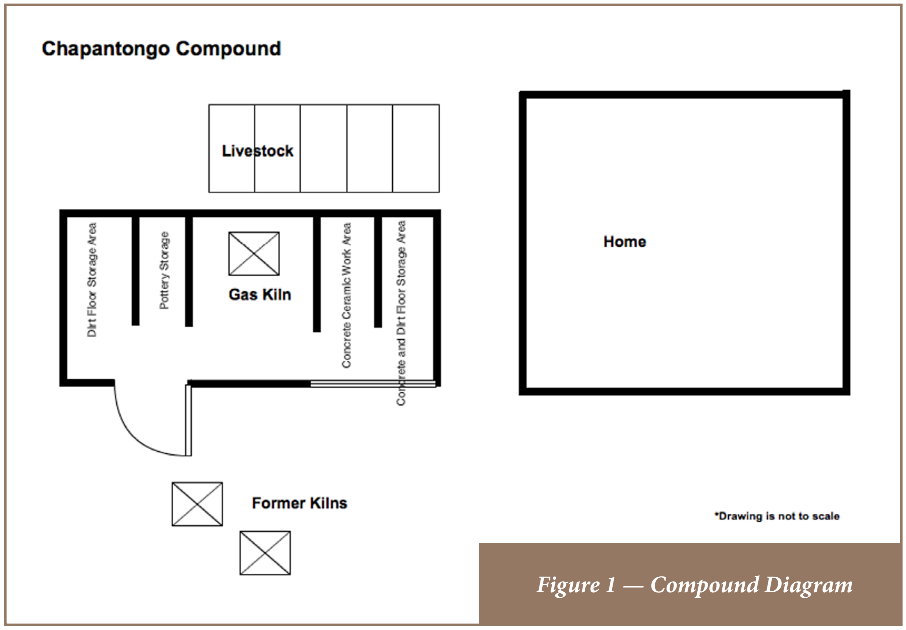

Figure 1 — Compound Diagram

The project participant was a workshop located in Chapantongo, Hidalgo, approximately 130 km north of Mexico City. The workshop was located in a rural, primarily agricultural area with a concentration of approximately 130 artisanal ceramists. The owner-occupied property consisted of a residence, a separate workshop building, an agricultural field and covered area for farm animals. A graphical depiction of the area is provided as Figure 1.

The household comprised a father, mother and 5 children ranging in age from 9 to 18 years (*Table 1*), all of whom were involved in some stage of the production process. The workshop, which was separate from the home, had a mixture of earthen and concrete flooring. The family were recipients of a FONART-subsidized gas kiln, housed in the workshop. They had ceased using lead-based glazes 6 months earlier, but no environmental remediation had been implemented at that time.

Environmental Lead Assessment

Lead-in-soil measurements were taken with an Innov-X® Alpha handheld X-ray fluorescence analyzer (XRF). While this unit is capable of measuring 21 elements in soil up to several centimeters in depth, only lead (Pb) was recorded. An automatic internal calibration check ensured proper functioning, as well as periodic testing using an external National Institute of Standards and Testing (NIST) lead-in-soil standard. Concentrations are reported as mg/kg (ppm) and all data is stored internally. The unit operated within manufacturer's parameters throughout the study.

ID	Gender	Age
CH1	Female	9
CH2	Male	9
CH3	Male	13
CH4	Female	15
CH5	Female	18

Table 1 — Demographics of Study Population

The lead-in-soil assessment protocol involved testing bare soil with the potential for child contact with a range of 3 to 5 readings per testing area (front yard, workshop, garden, etc.) as per U.S. Housing and Urban Development lead testing guidelines.[21]

Biological Sampling

Blood samples were tested on-site in a secure contamination-free area using a LeadCare II analyzer (Magellan Diagnostics, MA USA). High and low standards provided by the manufacturer ensured the unit was operating properly before and after testing. This field unit provided adequate analytical sensitivity and was operated by trained staff. The caretakers (mother and father) were informed, in their native language, of the study objectives and risks, and verbally consented to the participation of the children. Prior to the study, arrangements were made with the local health office should blood lead values reach levels warranting immediate medical attention (i.e. ≥40 µg/dl).

Blood samples were analyzed for all residents 3 times over the course of a year. Initial baseline BLLs were done at the time of environmental remediation, followed by 3- and 12-month testing intervals. Samples were taken from both parents and all 5 children. In addition, blood samples were taken from both paternal grandparents who lived in an adjacent property and were themselves artisanal ceramists utilizing lead-based glazes.

Environmental Remediation Activity

Based on the XRF lead-in-soil data, specific areas were identified for surface soil and dust removal. Remediation was accomplished by mechanically loosening and removing impacted soil, followed by vacuum collection of residual dust. Once impacted soil was removed, the walls and floor were power washed with water and re-vacuumed. All remediation workers wore proper personal protective equipment. The total volume of excavated material was $0.5m^2$. This material was collected and disposed off-site in a secure area. XRF samples were taken during remediation to ensure complete removal and after to monitor the effectiveness of the remedial activity.

Results

Environmental Lead Assessment

A total of 71 surface soil samples were tested with the XRF prior to remediation. Potable water and earthenware were not tested. The lead concentrations ranged from 30 (±5) to 28,635 (±514) mg/kg with a mean of 1,600 mg/kg. Within the workshop, the mean concentration of 34 samples was 2,652 mg/kg. The U.S. Environmental Protection Agency (EPA) standard for lead in bare soil where there is child contact (i.e. play) is 400 mg/kg.[22] Thus, the mean soil lead level in the workshop exceeded the EPA standard by approximately 6.6 times.

Samples taken after the remedial activities in the workshop exhibited a low of 12 (±4) and a high of 1,538 (±34) mg/kg of lead in soil. The mean lead in soil concentration was 322 mg/kg.

Biological Sampling

All analyzed samples exceeded the U.S. Centers for Disease Control and Prevention's (CDC) level of concern of 5 µg/dL (*Table 2*).[23] While this level is not an enforceable regulatory value, it is generally regarded as such and accepted by various international environmental agencies.

The lowest initial BLL was 12.1 µg/dL (18-year-old female), while the highest was 27.5 µg/dL in the 9-year-old male. The mean initial BLL for all participants was 19.3 µg/dL. Biological sampling results are presented graphically in Figure 2.

Blood samples taken 3 months after remediation showed a considerable decrease in BLLs for all 5 children. The lowest BLL at this point was 6.9

		Initial BLL	3-Month BLL*	12-Month BLL**
CH1	Female, 9 yrs	20.0	8.7	9.2
CH2	Male, 9 yrs	27.5	9.3	10.8
CH3	Male, 13 yrs	23.0	10.2	9.0
CH4	Female, 15 yrs	13.9	6.9	5.7
CH5	Female, 18 yrs	12.1	9.3	6.6
	Mean	19.3	8.88	8.26
	Std Deviation	6.37	1.23	2.07

Table 2 — Pre- and Post-Remediation Children's Blood Lead Levels
$^{*}p \le 0.008$ (paired t-test initial and 3-month)
$^{**}p \le 0.002$ (paired t-test initial and 12-month)

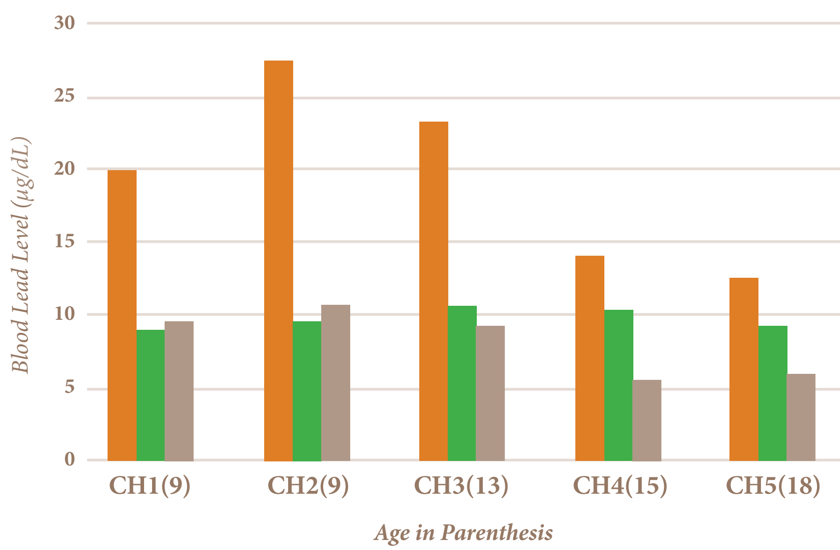

Figure 2: Blood Lead Sampling Results for Children

Initial BLL
3 Month BLL
12 Month BLL

µg/dL, in the 15-year-old female. The median BLL for the group had decreased to 8.8 µg/dL from 19.3 resulting in an average decrease of 54%. BLLs continued to decline 1 year after clean-up for 3 of the 5 children, though this was not statistically significant. However, this stabilization was expected given the biological purging of blood lead after eliminating exposure. The group, on average, experienced a decline of 57% in their BLLs over the initial time period and 12 months after. At the mean remediation level of 322 mg/kg, the observed mean BLL of the study population was 8.26 while the U.S. EPA's Integrated Exposure Uptake Biokinetic (IEUBK) model predicted a 9.2 µg/dl BLL for children. The IEUBK is a validated model used to forecast likely BLLs in children from different exposures, including soil, air, water, diet and maternal blood lead.[24]

Discussion

The results demonstrate a strong correlation between environmental lead levels and BLLs. Utilizing IEUBK and controlling for setting the remaining exposure variables at 0, the predicted BLL at a soil lead concentration of 2,652 mg/kg (the mean workshop soil lead level) resulted in 15.6 µg/dL. As a comparison, our observed in-situ measurements produced a mean BLL of 19.3 µg/dL. The IEUBK model uses biokinetic values for infants and children while our study population contained 3 adolescents. While our observed 19.3 µg/dL was higher than would be predicted by the model, other exposure pathways not entered into the model are likely influencing BLLs in this community (i.e. water and dietary sources).

The soil-lead concentrations and BLLs identified at our site were similar or lower than those found elsewhere in Mexico. Torres-Ortiz et al, for instance, found average BLLs of 52.5 µg/dL in ceramics-producing communities in the state of Veracruz.[25]

Elevated BLLs (i.e. > 5 µg/dl) can result in a number of serious health outcomes. In children, elevated BLLs can lead to neurological and cognitive developmental issues. In particular, elevated levels of lead in children's blood have been associated with decreased IQ. Lanphear et al and Schwartz et al, for instance, model potential IQ points lost from different environmental exposures. Both models find significant IQ loss in children at the levels identified during this study. Lanphear et al, for example, reviewed seven studies with 1,333 children in total participating. They noted a potential loss of 6.9 IQ points as a result of an increase in BLLs from 2.4 to 30 µg/dL.[8,26] They further note that the most significant IQ losses took place when BLLs increased from 2.4 to 10 µg/dL. Similarly, Schober et al, when reporting the results from the NHANES III Mortality Study, found increased risk of death in adults from cardiovascular disease in those with higher levels of blood lead.[27] Studies elsewhere have found a positive correlation between the use and manufacturing of lead-glazed pottery and BLLs.[10,28,29,30] Furthermore, Romieu et al. identified the use of lead-glazed ceramics as one of the major predictors of BLLs for different Mexican populations, as did Hernández-Ávila for Mexican women.[31,32]

Other health outcomes in children from lead exposure include anemia and gastrointestinal disorders. Fewtrell et al. demonstrate that perhaps 20% of children with BLLs above 70 µg/dL may have anemia. The same authors note that 10% of children with BLLs above 60 μg/dL likely have gastrointestinal disorders.[33]

Conclusions

The cessation of the use of lead-based glazes and removal of lead-contaminated soil at the Chapantongo workshop resulted in significant reductions in BLLs of the immediate family over a short period of time. These decreases will likely result in considerable reductions in health risks. Similar health risks are present in perhaps 50,000 workshops across Mexico. The methodology detailed in this paper provides a potential model for mitigating these exposures.

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