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Prevalence of elevated blood lead levels among pregnant women and sources of lead exposure in rural Bangladesh: A case control study

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ABSTRACT

Prenatal and early childhood lead exposures impair cognitive development. We aimed to evaluate the prevalence of elevated blood lead levels (BLLs) among pregnant women in rural Bangladesh and to identify sources of lead exposure. We analyzed the BLLs of 430 pregnant women randomly selected from rural communities in central Bangladesh. Fifty-seven cases were selected with the highest BLLs, $\geq 7\ \mu g/dL$, and 59 controls were selected with the lowest BLLs, $< 2\ \mu g/dL$. An exposure questionnaire was administered and soil, rice, turmeric, water, traditional medicine, agrochemical, and can samples were analyzed for lead contamination. Of all 430 women, 132 (31%) had BLLs $> 5\ \mu g/dL$. Most women with elevated BLLs were spatially clustered. Cases were 2.6 times more likely than controls to consume food from a can (95% CI 1.0–6.3, p = 0.04); 3.6 times more likely to use Basudin, a specific brand of pesticide (95% CI 1.6–7.9, p = 0.002); 3.6 times more likely to use Rifit, a specific brand of herbicide (95% CI 1.7–7.9, p = 0.001); 2.9 times more likely to report using any herbicides (95% CI 1.2–7.3, p = 0.02); and 3.3 times more likely to grind rice (95% CI 1.3–8.4, p = 0.01). Five out of 28 food storage cans were lead-soldered. However, there was minimal physical evidence of lead contamination from 382 agrochemical samples and 129 ground and unground rice samples. Among 17 turmeric samples, one contained excessive lead (265 μg/g) and chromium (49 μg/g). Overall, we found evidence of elevated BLLs and multiple possible sources of lead exposure in rural Bangladesh. Further research should explicate and develop interventions to interrupt these pathways.

1. Introduction

As a potent neurotoxin, lead (Pb) poses a serious threat to public health and human intellectual capital worldwide (Tong et al., 2000). After exposure via inhalation or ingestion, lead circulates in blood and is either excreted via urine or deposited in soft tissue or bone. The mean half-life of lead in blood is approximately 21–28 days, whereas lead accumulates in bones with a mean half-life of 5–19 years (Rabinowitz et al., 1976). During pregnancy, lead is mobilized from bones back into maternal blood and readily crosses the placenta into the blood of the developing fetus (Silbergeld, 1991; Röllin et al., 2009). Prenatal and early childhood lead exposures affect the developing central nervous system and produce irreversible cognitive damage that leads to adverse outcomes in adulthood (Bellinger, 2013).

Before the removal of lead in gasoline between the 1970–1990s, global blood lead levels (BLLs) were so high that the adverse effect of low levels of lead exposure was impossible to study (Bridbord and Hanson, 2009). For example, population mean BLLs dropped more than 75%, from 13–25 μg/dL to 2–3 μg/dL, in the US and South Korea within two decades after phasing out leaded gasoline (Pirkle et al., 1994; Oh et al., 2017). Subsequent multi-year cohort studies conducted in the US, Mexico, Australia, and Yugoslavia generated new evidence showing that lead exposure irreversibly decreases IQ, even at levels below 10 μg/dL (Ernhart et al., 1989; Baghurst et al., 1992; Bellinger et al., 1992; Dietrich et al., 1993; Wasserman et al., 1997; Schnaas et al., 2000; Canfield et al., 2003). A re-analysis of these data indicated that children with BLLs 2.4–10 μg/dL had IQ scores that were 3.9 points lower than children with BLLs $< 2.4\ \mu g/dL$ (Lanphear et al., 2005). In response to such evidence, the U.S. Centers for Disease Control and Prevention has continually lowered the threshold for elevated BLLs from 60 μg/dL in the 1960s to 5 μg/dL in 2015 (CDC, 2012, 2015). However, there is no known safe level of lead in the body.

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Bangladesh phased out lead in gasoline in 1999, yet BLLs above 5 µg/dL persist across the country (Mitra et al., 2009, 2012; Gleason et al., 2014). BLLs are comparatively higher in urban versus rural areas, though BLLs are higher than expected in non-industrial rural agrarian regions. In Dhaka, the capital city of Bangladesh, studies since 2000 have shown mean BLLs between 11.5 and 15 µg/dL among children under 16 years of age (Kaiser et al., 2001; Linderholm et al., 2011; Mitra et al., 2012). A 2007 study found 10 times higher BLLs in children living in industrial versus non-industrial neighborhoods in Dhaka (Mitra et al., 2009). Two studies from a rural agrarian region of Munshiganj district found high BLLs among more than 500 children under 4 years of age. In one study, 84% of children had BLLs ≥ 5 µg/dL and in another, the median BLL was 7.3 µg/dL (Gleason et al., 2014; Rodrigues et al., 2016). In Dinajpur, a different rural agrarian district, two studies reported similar BLLs, with means of 7.2 µg/dL (Mitra et al., 2009) and 7.3 µg/dL (Mitra et al., 2012) among a total of 380 children under 16 years of age. In this region, 25% of 16 parents had BLLs > 10 µg/dL (Mitra et al., 2009). In rural Narayanganj district, one study of 303 children 8–11 years of age reported a mean BLL of 11.5 µg/dL (Wasserman et al., 2011).

Multiple hypotheses have been explored in the literature for reasons why lead levels are high in rural Bangladesh but none have been conclusive. An analysis of lead exposure and BLLs among 919 children from both Dinajpur and Dhaka found that the mean BLL was 3.7 µg/dL higher for children whose families lived in close proximity to industries ($p < 0.001$) and 2.3 µg/dL higher for children whose families used certain traditional medicines compared to those who did not ($p = 0.004$) (Mitra et al., 2012). BLLs were also inversely correlated with body mass index ($r = -0.23$, $p < 0.001$) and hemoglobin levels ($r = -0.10$, $p = 0.02$). Low body mass index and low hemoglobin levels are indicators of poor nutrition. Nutrient deficient individuals, especially those lacking divalent metals like iron and calcium, absorb lead more readily, making them prone to lead poisoning (Goyer, 1995; Ahamed and Siddiqui, 2007). Other possible exposure sources included water source, metal taps, and melamine dinner plates, but were not significantly associated with BLLs after controlling for confounders.

Additional studies suggested agricultural and food-related exposure routes. Bergkvist et al. conducted a study of 408 pregnant women and 331 children in rural Chandpur district, concluding that rice may be an important source of lead due to contamination from agrochemicals (Bergkvist et al., 2010). The median rice lead concentration from 63 households was 0.013 µg/g. Based on an estimated consumption of 0.5 kg rice per day, median intake of lead from rice alone would be 6.5 µg/day, exceeding the established maximum daily intake limit set by the US Food and Drug Administration in 1993 (FDA, 2017). The 2013 Munshiganj study identified turmeric as a potential exposure route since 8 of 18 samples contained greater than 100 µg/g Pb (Gleason et al., 2014). Water, rice, and soil did not contain elevated lead concentrations in household samples and researchers did not attempt to draw statistical associations between BLLs and risk factors.

In an effort to evaluate the prevalence of elevated BLLs among pregnant women in rural Bangladesh and to identify the sources of lead exposure, we conducted a cross-sectional BLL assessment and a case control study.

2. Materials and methods

2.1. Study design and study population

The case control study was nested within the WASH Benefits Bangladesh trial that began in 2012 and followed 5551 women from their first or second trimester of pregnancy through the first few years of their children's lives (Arnold et al., 2013). A sample size of 500 individuals was calculated to assess the prevalence of elevated BLLs among pregnant women enrolled in the WASH Benefits trial. For budgetary reasons, the sample was reduced to 430. A geographically stratified random sampling approach was used to select women from among all those who reported primarily consuming rice grown in their own field (Fig. 1, $n = 1269$). This inclusion criterion was chosen because our main hypothesis was that elevated BLLs in rural communities resulted from exposure to lead arsenate pesticide, and restricting to households who could report their own agrochemical use might provide a clearer signal of exposure. Study participants lived in Mymensingh, Tangail, and Kishoreganj districts. Based on the distribution of BLLs from the 430 women, 57 cases were selected who had the highest BLLs, ≥ 7 µg/dL, and 59 controls were selected who had the lowest BLLs, < 2 µg/dL. Our sample size of 116 provided 80% power to detect an odds ratio of 2.85 assuming 40% of controls are exposed. We based these power calculations on the hypothesis of a single predominant exposure pathway, that is lead arsenate pesticides.

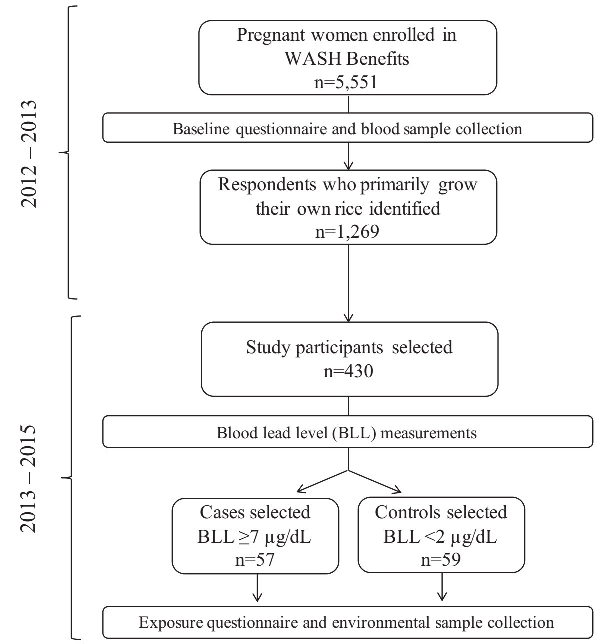

Fig. 1. Overview of participant selection and research activities in Mymensingh, Tangail, and Kishoreganj districts between 2012 and 2015.

2.2. Blood sampling and analysis

Between June 2012 to July 2013, before mothers were randomized to an arm of the WASH Benefits trial (Table 1, SI), research assistants collected 10 mL whole blood from all 5551 pregnant mothers using trace metal-free certified needles and tubes. Blood samples were diluted with reagent grade nitric acid and then BLLs were analyzed using Graphite Furnace Atomic Absorption Spectrophotometry (Shimadzu EX7, AA-6800) in the Nutritional Biochemistry Laboratory at icddr,b. We analyzed for spatial clusters of high and low BLLs by conducting an Optimized Hotspot Analysis using geographic information systems software.

2.3. Exposure questionnaire data collection and analysis

In November and December 2013, research assistants conducted an in-depth anthropological investigation involving semi-structured interviews with 10 heads of household and 10 women with BLLs > 10 µg/dL along with observations inside and outside each house to understand possible lead exposures and household characteristics in order to develop an exposure questionnaire. None of the houses were painted, inside or outside, which was typical of the study area. Between February and March 2014, research assistants administered the exposure questionnaire to all 116 case and control households. The