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Toxic trace elements in maternal and cord blood and social determinants in a Bolivian mining city

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This study assessed lead, arsenic, and antimony in maternal and cord blood, and associations between maternal concentrations and social determinants in the Bolivian mining city of Oruro using the baseline assessment of the ToxBol/Mine-Niño birth cohort. We recruited 467 pregnant women, collecting venous blood and sociodemographic information as well as placental cord blood at birth. Metallic/semimetallic trace elements were measured using inductively coupled plasma mass spectrometry. Lead medians in maternal and cord blood were significantly correlated (Spearman coefficient = 0.59; $p < 0.001$; 19.35 and 13.50 μg/L, respectively). Arsenic concentrations were above detection limit (3.30 μg/L) in 17.9 % of maternal and 34.6 % of cord blood samples. They were not associated (Fischer's $p = 0.72$). Antimony medians in maternal and cord blood were weakly correlated (Spearman coefficient = 0.15; $p < 0.03$; 9.00 and 8.62 μg/L, respectively). Higher concentrations of toxic elements in maternal blood were associated with maternal smoking, low educational level, and partner involved in mining.

Keywords: environmental exposure; metallic trace elements; maternal exposure; prenatal exposure; risk factors

Introduction

Mining is an important activity in the Andean regions. Mining activities may contaminate the environment with metallic and semimetallic elements and other pollutants, as shown in studies from Colombia (Cordy et al. 2011), Ecuador (Guimaraes et al. 2011), Peru (van Geen et al. 2012; Yacoub et al. 2012), Chile (Oyarzun et al. 2006), and Bolivia (Hudson-Edwards et al. 2001; Cooke et al. 2011). In Bolivia, mining activities have been carried out for over 3000 years, before Incan times (Abbott & Wolfe 2003; Cooke et al. 2011). Oruro has been one of the most important mining cities for over

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400 years, particularly for the exploitation of silver and tin and, later, also gold, zinc, and lead (Torres 1890; Bouton 1998; Banks et al. 2002).

The area is naturally rich in multiple metallic and semimetallic elements, including gold, silver, tin, copper, zinc, antimony, lead, cadmium, and arsenic (Keutsch & de Brodtkorb 2008; Bundschuh et al. 2012). The mining waste may contain a combination of several potentially toxic elements depending on the exploited material and the technique employed. Some of the central districts of Oruro are located in close vicinity to mining pits or smelters, sometimes even on top of abandoned mining waste.

Located in the Bolivian plateau at ~ 3700 m of altitude above sea level, Oruro is cold and arid, with long dry seasons and strong winds, which contribute to making it a dusty city (SENAMHI http://www.senamhi.gob.bo/sismet/index.php). Besides, many roads in Oruro are unpaved and most mining tailings and waste piles remain exposed subject to wind erosion and leaching processes. This constitutes a source of pollution, especially when these materials are used as bulk-fill in improvised construction projects (Yáñez et al. 2002).

Previous studies have shown both outdoor and indoor environmental contamination with a combination of several metallic and semimetallic trace elements in Oruro, such as lead, arsenic, antimony, cadmium, and others (Banks et al. 2002; Fonturbel et al. 2011; Goix et al. 2011). Children from the mining and metallurgical districts seem particularly at risk, with higher concentrations of toxic elements in hair, mainly lead, arsenic, antimony, and cadmium (Barbieri et al. 2011; Barbieri et al. 2014).

Several of these metallic and semimetallic trace elements are associated with toxic health effects. Lead in particular is often associated with cardiovascular risk (Gump et al. 2011), impaired fertility (Buck Louis et al. 2012), nephrotoxicity (Cabral et al. 2012), and neurotoxicity (Liu et al. 2013), the latter also associated with arsenic, mercury, and antimony. Arsenic is also associated with genotoxicity (Niedzwiecki et al. 2013). Children are the most vulnerable population as these elements often affect early human development (Al-Saleh et al. 2011; Cace et al. 2011; Hawkesworth et al. 2013; Al-Saleh et al. 2014). Toxic trace elements, especially lead, often impair neurological development (Liu et al. 2013; Parajuli et al. 2013), intellectual performance (Bellinger et al. 1992; Riojas-Rodríguez et al. 2010; Mazumdar et al. 2011; Yorifuji et al. 2011), and behavior (Needleman 1982; Min et al. 2007; Surkan et al. 2007) in children. In particular, prenatal exposure can be harmful to the early development (Yorifuji et al. 2011; Xie et al. 2013; Al-Saleh et al. 2014).

Our objective was to assess maternal and neonatal exposure to lead, arsenic, and antimony in the city of Oruro, Bolivia, as well as to determine the associations between social determinants and maternal exposure to toxic trace elements.

Methods

Setting and study design

The city of Oruro is placed in the central Bolivian highland. It counted approximately 220,000 inhabitants in 2009 (INE).

The ToxBol project was conceived as a multidisciplinary research project to study the origin of polymetallic contamination in Oruro and its impact on the environment, health, and society (Goix et al. 2011; Moya et al. 2011; Ruiz-Castell et al. 2012; Goix et al. 2013; Ruiz-Castell et al. 2013). The health component of the ToxBol project was the "Mine-Niño" pregnancy cohort, which took place between 2007 and 2010. For the present study, we analyzed cross-sectional data from the Mine-Niño cohort: the baseline assessment of the mothers during pregnancy and their newborns at birth.

Ethics statement

The National Bioethics Committee of Bolivia evaluated and approved each component of the Mine-Niño cohort prior to the recruitment of the participants (Appendix 1: Letter of Acceptance). Participating women signed a written informed consent after receiving written information and detailed explanations about the project. Parents or legal guardians signed the informed consent form on behalf of underage participants (under 18 years of age according to Bolivian law). A member of the team read and explained the text to adult illiterate women. Members of our local staff translated the text to either Quechua or Aymara for non-Spanish speaking women. Personal data was protected according to international recommendations regarding anonymity and privacy.

Study population

We worked in cooperation with two health care centers: the "Barrios Mineros" Hospital (HBM) is a basic facility with a small maternity ward, located in a mining district. It admits women mostly from that neighborhood, although not necessarily miners' families. It provides modest mother–infant primary health care services, free of charge, and financed by the State. The "10 de Febrero" Clinic (CNS) is part of the Bolivian statutory health insurance provided to registered workers. It admits women from all over the city as long as they, their parents, or husbands are insured.

Between 2007 and 2008, we invited healthy women at any stage of pregnancy, who attended their prenatal care at one of the two health care centers. A total of 467 women were initially registered. Exclusion criteria were: living in Oruro less than a year, age below 16 years old, and multiple pregnancies (twins, triplets, etc.).

We obtained venous blood samples from 419 women during pregnancy and cord blood sample from 240 newborns. We recorded the location of each household (or the closest reference point) using a Global Positioning System device (Figure 1).

Social and environmental determinants

We applied structured questionnaires in Spanish, Quechua, or Aymara to obtain personal and sociodemographic information. We registered the women's pregnancy stage in weeks, as stated on her prenatal care chart. When this information was not in the chart, we calculated it using the woman's recollection of her last menstrual period. We classified pregnancy stage in three categories (first/second/third trimester). We obtained a short health history, with particular interest in smoking habits and the presence of metallic dental fillings. These variables were dichotomous (yes/no).

We classified marital status in three groups (married/cohabiting/single), placing the only two widow women in the "single" group. We categorized the maternal educational level according to the Bolivian educational system in effect (elementary: 8 schooling years; secondary: 12 schooling years; tertiary: more than 12 schooling years).

We registered the main occupation of each woman and that of her husband or partner. When single women lived at the parental home, we registered the occupation of her

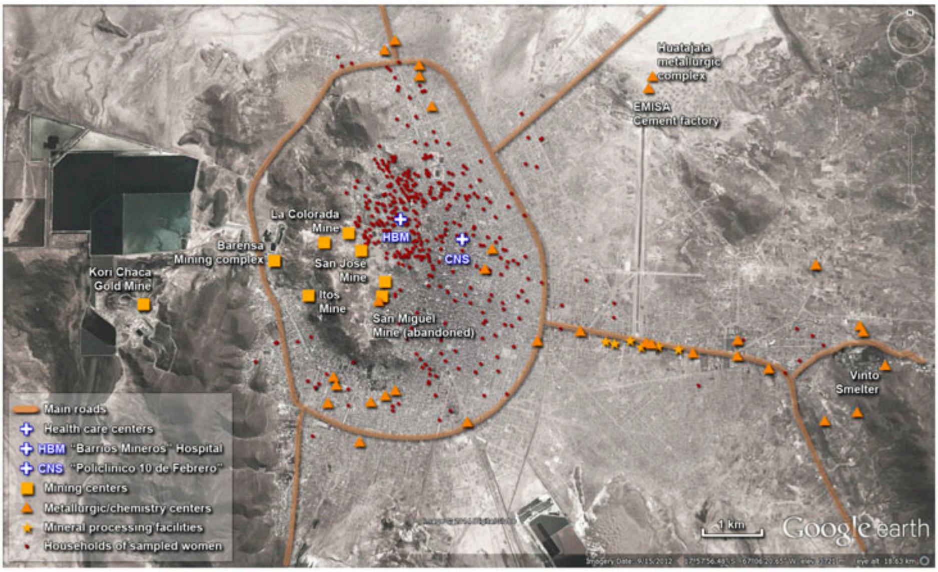

Figure 1. (Color online) Map of the city of Oruro.
Notes: Location of the two health care centers where the cohort took place, the main mining and metallurgical facilities, and the location of the households of the participating families.

father. We grouped occupations based on the Classification of Occupations of Bolivia (INE 2009) and ordered them by skill levels according to the National Occupational Classification Matrix 2006 (Canada) (HRSDC 2006).

We asked if anyone in the household, especially the woman or her husband, partner or father, worked in mining, either as miners or other occupations (engineers, cleaning personnel, or others at a mining or metallurgical site). We recorded this information separately as yes/no variables. If a family member worked in mining, we assessed whether or not they brought home their working clothes, tools, or minerals.

Measurement of trace elements in maternal and cord blood

We took a venous blood sample of 5 mL from the pregnant mother during the recruitment interviews using a BD® vacutainer tube free of trace elements. After placental delivery, we took blood samples (25 mL) from the clamped placental cord using the same BD® vacutainer tubes.

We stored the blood samples at 4 °C at the local hospital and transported them in iceboxes to the Environmental Quality Laboratory (LCA) in La Paz, where they were digested, mineralized, and stored at −20 °C. Then, these samples were sent to the Hydrosciences Montpellier Laboratory, France, where they were analyzed using Inductively Coupled Plasma Mass Spectrometry (Q-ICPMS X série II + CCTTM – Thermo Fisher-). The trace elements initially measured were lead, calcium, iron, copper, zinc, arsenic, selenium, rubidium, strontium, cadmium, mercury, antimony, and cesium. The quantification of trace elements concentrations was performed establishing calibration curves by linear regression. Lead concentration values were calculated using bismuth as internal standard, while the other trace elements were determined using indium as internal standard, providing an accurate measure to normalize potential variations of the ICP-MS response. Quality control was performed on every set of 24 digested whole blood samples. It consisted in measuring a calibration blank, all calibration standard solutions, one reference river water sample SLRS-4, two reference materials from SERO AS (Norway) -Seronorm Trace Elements Whole Blood, Level 1 (lowest available concentrations) and Level 2 (elevated concentrations)- two digestion blanks and two subsamples of the pooled blood control sample from this study. The repeated analyses of reference materials allowed accessing the accuracy of the applied analytical procedures. Detection limits were calculated following the International Union of Pure and Applied Chemistry (http://www.iupac.org/) criterion based on three times the standard deviation of 10 consecutive measurements of the blank digestion method solution (3σ) divided by the experimental slope of the calibration graph.

For the present study, we selected the elements with known toxicity and relevance in the mining context that were detectable in the blood samples. The detection limits for these elements were: lead – 3.26 µg/L, arsenic – 3.30 µg/L, and antimony – 0.70 µg/L. Blank values were subtracted from the samples.

Statistical analysis

We used Fisher's exact test to assess possible differences in social and environmental determinants in the women with and without blood sample taken. In women with blood sample, we also compared the social and environmental determinants by health care center.

We observed the distribution patterns of lead, arsenic, and antimony concentrations in blood and tested normality using the Shapiro-Francia test. In the absence of normality, we used non-parametric tests. The eight newborns with lead below detection limit (3.33 %) were assigned the value of the detection limit (3.26 µg/L). Arsenic was treated as a dichotomous variable, divided in two groups (below/above detection limit), because of the low percentage of concentrations above that level (17.90 % mothers and 34.58 % newborns).

Both in maternal and cord blood, we tested the association between lead and antimony using Spearman rank correlations. We used the Mann-Whitney-Wilcoxon test to test lead/arsenic and antimony/arsenic associations (arsenic as dichotomous variable). To test the associations between maternal blood and cord blood, we used Spearman rank correlations for the continuous variables lead and antimony, and Fisher's exact test for the dichotomous variable arsenic.

For a secondary analysis, we dichotomized the distributions of toxic elements in maternal blood as "higher/lower," using as cut-off the 75th percentile for lead and antimony and detection limit for arsenic. We tested the associations between the toxic trace elements in maternal blood and all social determinants using separate logistic regressions for each element. We adjusted for maternal age and health care center. For lead, we added pregnancy trimester as a potential confounder because of its maternal bone release and placental transfer during the second trimester (Moura & Valente 2002; Gulson et al. 2003; Manton et al. 2003a; Ettinger et al. 2007).

For the multivariate analysis, we created an ordinal outcome variable indicating the cumulative high exposure of lead, arsenic, and antimony. This variable was the sum of the toxic elements as dichotomous variable classified as "higher." We classified this ordinal outcome variable in three categories: "none/one/two or more" because only four samples had three elements classified as "higher." We included all the social and environmental determinants in an ordinal logistic regression model and adjusted for maternal age and health care center.

We considered statistical significance α error < 0.05 for all our analysis. We used STATA® version 10.0 for all the statistical analyses.

Results

Characteristics of the population

From the 467 recruited women, 48 refused to give a blood sample (47 at the HBM and one at the CNS), four suffered spontaneous abortions or still births and 106 abandoned the project before birth, leaving 357 women who registered a newborn in our study. We could not obtain cord blood samples for 117 newborns. There were no significant differences in age, social, or environmental determinants between the mother–infant pairs with blood samples taken and those without blood samples. Mean age at the start of the study was 25 years (range 16–44 years).

Women from the HBM were on average younger, less often married, had lower educational level and social status, and were in earlier stages of pregnancy than the women from CNS (Table 1).

Toxic trace elements in maternal and cord blood

Table 2 displays the concentrations of lead, arsenic, and antimony in maternal blood and cord blood. Arsenic was above detection limit (3.30 μg/L) in 18 % of maternal blood samples and 35 % of cord blood samples. Eight cord blood samples (3.33 %) were below detection limit for lead. They were assigned the detection limit value (3.26 μg/L).

In maternal blood, lead, arsenic, and antimony were not associated with each other. In cord blood, lead and antimony were inversely associated with arsenic, with higher concentrations of lead and antimony in samples below detection limit of arsenic (Mann-Whitney-Wilcoxon $p = 0.056$ for lead, $p = 0.022$ for antimony).

We could match 223 mother–infant pairs with both samples taken. Lead in maternal blood and cord blood showed a stronger correlation (Spearman ρ coefficient = 0.59; $p < 0.001$) than antimony (Spearman ρ coefficient = 0.15; $p < 0.027$) (Table 2, Figure 2). We found 13 mother–newborn pairs with both samples above detection limit. No association was found between maternal and neonatal arsenic as dichotomous variable (Fisher's exact test – $p = 0.72$).

Social and environmental determinants and maternal exposure

Women with lower educational level and women whose husband/partner/father was involved in mining activities were significantly more likely to be in the higher exposure category for all three toxic elements adjusted for maternal age and health care center (and for pregnancy trimester for lead). Smoking was associated with high exposure for lead and antimony, but not arsenic. Women with lower social status were more likely to be in the higher exposure category of lead and arsenic (Table 3).

About 53 % of the women in this study were in the higher exposure group of at least one toxic element and approximately 13 % of them were in the higher exposure group of at least two of them simultaneously.

Table 1. Characteristics of the included women with blood sample taken, stratified, and compared by health care center.

	N (%)			
	CNS[a]	HBM[b]	TOTAL	*P* value[c]
Maternal age				
15–25 years old	51 (37.0 %)	163 (58.0 %)	214 (51.1 %)	< 0.001
25–35 years old	70 (50.7 %)	98 (34.9 %)	168 (40.1 %)	
35–45 years old	17 (12.3 %)	20 (7.1 %)	37 (8.8 %)	
Pregnancy trimester				
First	0 (0 %)	83 (29.8 %)	83 (20.0 %)	< 0.001
Second	3 (2.2 %)	182 (65.2 %)	185 (44.6 %)	
Third	133 (97.8 %)	14 (5.0 %)	147 (35.4 %)	
Smoking				
No	118 (85.5 %)	239 (85.1 %)	357 (85.2 %)	0.514
Yes	20 (14.5 %)	42 (15.0 %)	62 (14.8 %)	
Dental amalgams				
No	54 (39.7 %)	137 (57.8 %)	191 (51.2 %)	0.001
Yes	82 (60.3 %)	100 (42.2 %)	182 (48.8 %)	
Marital status				
Married	87 (63.0 %)	95 (33.8 %)	182 (43.4 %)	< 0.001
Cohabiting	31 (22.5 %)	141 (50.2 %)	172 (41.1 %)	
Single	20 (14.5 %)	45 (16.0 %)	65 (15.5 %)	
Maternal schooling[d]				
Tertiary	87 (64.4 %)	93 (33.7 %)	180 (43.8 %)	< 0.001
Secondary	38 (28.2 %)	134 (48.6 %)	172 (41.9 %)	
Elementary	10 (7.4 %)	49 (17.8 %)	59 (14.4 %)	
Maternal occupation[e]				
Professional	39 (28.9 %)	11 (3.9 %)	50 (12.1 %)	< 0.001
Technical	36 (26. 7 %)	55 (19.6 %)	91 (21.9 %)	
Administrative	7 (5.2 %)	32 (11.4 %)	39 (9.4 %)	
Basic/manual	53 (39.3 %)	182 (65.0 %)	235 (56.6 %)	
Paternal occupation[f]				
Professional	36 (27.3 %)	23 (8.4 %)	59 (14.5 %)	< 0.001
Technical	24 (18.2 %)	49 (17.3 %)	73 (17.9 %)	
Administrative	23 (17.4 %)	85 (30.9 %)	108 (26.5 %)	
Basic/manual	49 (37.1 %)	118 (42.9 %)	167 (41.0 %)	
Father works in mining[f]				
No	119 (89.5 %)	237 (85.9 %)	356 (87.0 %)	0.196
Yes	14 (10.5 %)	39 (14.1 %)	53 (13.0 %)	

[a] CNS: Caja Nacional de Salud (statutory health insurance).

[b] HBM: Hospital Barrios Mineros (mining district hospital).

[c] Fisher's exact text to test for differences between health care centers.

[d] Bolivian educational system (elementary: 8 schooling years; secondary: 12 schooling years; tertiary: more than 12 schooling years).

[e] Occupations were categorized based on the Classification of Occupations of Bolivia (INE 2009) and adapted by skill levels according to the National Occupational Classification Matrix (HRSDC 2006).

[f] Refers to the husband or partner or father of the interviewed woman. Otherwise, the data from the woman's father was collected, provided that the woman lived at her father's household.

The adjusted ordinal logistic regression showed that women with more toxic elements in the higher exposure group were more likely in their second trimester of pregnancy (OR = 2.28; $p = 0.007$), smoked (OR = 1.77; $p = 0.05$), were single (OR = 2.19; $p = 0.03$), and had husbands/partners/fathers involved in mining activities (OR = 2.16; $p = 0.037$) (Table 4).

Table 2. Lead, arsenic, and antimony concentrations in maternal blood and cord blood (μg/L). Associations between maternal blood and cord blood concentrations.

	N	Geometric mean (SD[a])	Range	Median	P_5–P_{95}[b]	Spearman coefficient	*p* value
Lead							
Maternal blood	419	26.53 (48.71)	4.38–801.60	19.35	7.78–51.14		
Cord blood	240	22.57 (57.44)	3.26–707.15	13.50	3.83–42.96	0.59	< 0.01
Antimony							
Maternal blood	418	13.55 (12.89)	2.48–111.41	9.00	4.59–37.79		
Cord blood	240	20.18 (37.76)	3.69–369.18	8.62	4.32–71.66	0.15	0.03
Arsenic[c]							
Maternal blood	419	3.81 (1.66)	<DL–14.33	<DL	<DL–7.22		
Cord blood	240	4.25 (3.11)	<DL–44.77	<DL	<DL–6.48	–	0.72[d]
Arsenic (above DL only)[c]							
Maternal blood	75	6.14 (2.98)	3.32–14.33	4.87	3.37–13.02		
Cord blood	83	6.06 (4.81)	3.32–44.77	5.06	3.54–12.11	–	–

[a] SD = Standard Deviation.
[b] Percentiles 5th and 95th of the distribution.
[c] DL = Detection Limit (DL = 3.30 μg/L).
[d] Fisher's exact test using arsenic as dichotomous variable: 0 = below detection limit/1 = above detection limit.

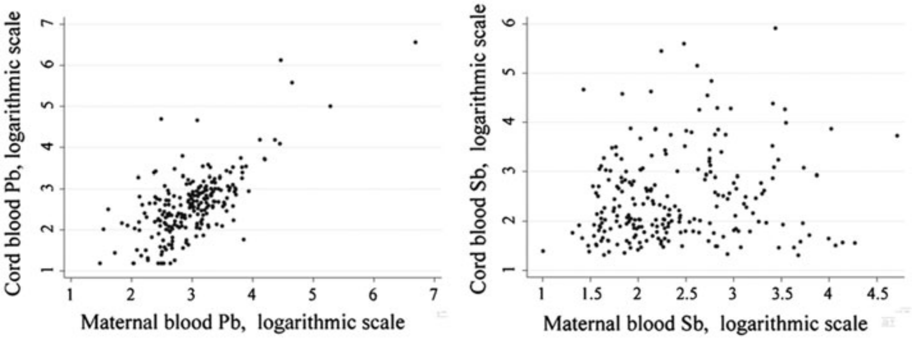

Figure 2. Associations between the concentrations of lead and antimony in maternal blood during pregnancy and cord blood at birth (µg/L) using logarithmic scales.
N = 223 mother-newborn pairs.

Discussion

Main findings

Our study showed different degrees of exposure to toxic trace elements for both pregnant women and their newborn children in the Bolivian mining town of Oruro. Blood lead concentrations were relatively low, but antimony concentrations were elevated. Even though arsenic was detectable in only a third of cord blood samples and a fifth of maternal blood samples, the levels detected were also elevated.

We found a good correlation between lead concentrations in maternal and cord blood, whereas for antimony concentrations, the correlation was weak. It was not possible to properly assess associations between maternal and cord blood arsenic because of the limited statistical power. Independent risk factors for higher concentrations of toxic elements were maternal smoking, lower maternal educational level, and a close family member involved in mining activities.

Maternal and neonatal exposure

With regard to lead, 5 % of the maternal and cord blood samples had levels above the current recommended level of 50 µg/L suggested by the Center for Disease Control and Prevention (CDC 2013). In other Andean mining or metallurgical sites, lead concentrations in maternal and neonatal blood were higher compared to the city of Oruro (Conklin et al. 2008; Pebe et al. 2008; Fonturbel et al. 2011; van Geen et al. 2012). The median levels of blood lead from our study were comparable to those in non-exposed populations (CDC 2005; Goullé et al. 2005; Plusquellec et al. 2007; Xie et al. 2013). The significant correlation between maternal and cord blood suggests placental transfer of lead (Manton et al. 2003b; Lin et al. 2010; Al-Saleh et al. 2011), with potential harmful effects on fetal development (Yorifuji et al. 2011).

The detection limit for arsenic in our study was rather high (3.3 µg/L). Therefore, we could not assess how many samples were above the reference level (1 µg/L) recommended by the United States Agency for Toxic Substances and Disease Registry (ATSDR). The population above detection limit had arsenic concentrations at least threefold higher than these recommended levels (ATSDR 2007).

Table 3. Logistic regression between individual elements (lead, antimony, and arsenic) in maternal blood and the covariates included in the analysis.

	Odds ratio (95 % Confidence interval)			
	N (%)	Lead[a,c]	Antimony[a,d]	Arsenic[b,d]
Smoking				
No[e]	357 (85.2)			
Yes	62 (14.8)	2.14 (1.19–3.85)	1.86 (1.04–3.34)	0.80 (0.38–1.68)
Dental amalgams				
No[e]	191 (51.21)			
Yes	182 (48.79)	0.58 (0.36–0.95)	0.87 (0.53–1.44)	1.01 (0.55–1.86)
Marital status				
Married[e]	182 (43.44)			
Cohabiting	172 (41.05)	1.15 (0.67–1.97)	0.76 (0.45–1.30)	0.77 (0.42–1.40)
Single	65 (15.51)	1.66 (0.83–3.30)	1.05 (0.53—2.09)	0.83 (0.38–1.82)
Maternal schooling[f]				
Tertiary[e]	180 (43.8)			
Secondary	172 (41.85)	1.33 (0.78–2.26)	1.01 (0.60–1.69)	1.68 (0.91–3.10)
Elementary	59 (14.36)	2.51 (1.27–4.98)	2.00 (1.04–3.83)	2.86 (1.36–6.03)
Maternal occupation[g]				
Professional[e]	50 (12.05)			
Technical	91 (21.93)	0.60 (0.25–1.41)	0.76 (0.30–1.92)	1.02 (0.29–3.57)
Administrative	39 (9.4)	0.48 (0.15–1.50)	1.27 (0.45–3.60)	1.89 (0.49–7.24)
Basic/manual	235 (56.63)	1.45 (0.69–3.03)	1.37 (0.60–3.11)	1.93 (0.62–6.03)
Paternal[h] occupation[g]				
Professional[e]	59 (14.5)			
Technical	73 (17.94)	1.10 (0.45–2.95)	0.79 (0.32–1.94)	1.26 (0.35–4.51)
Administrative	108 (26.54)	1.73 (0.77–2.43)	1.36 (0.62–3.01)	3.18 (1.02–9.88)
Basic/manual	167 (41.03)	1.87 (0.88–4.40)	1.39 (0.66–2.93)	2.71 (0.89–8.20)
Father[h] works in mining				
No[e]	356 (87.04)			
Yes	53 (12.96)	2.00 (1.06–3.75)	1.82 (0.98–3.39)	2.04 (1.05–3.97)

[a] Dichotomous transformation for Pb and Sb: 0 = first three quartiles of the distribution/1 = last quartile of the distribution.

[b] Dichotomous transformation for As: 0 = below detection limit/1 = above detection limit (DL = 3.30 μg/L).

[c] Adjusted for maternal age and pregnancy trimester.

[d] Adjusted for maternal age and health care center.

[e] Reference category.

[f] Bolivian educational system (elementary: 8 schooling years; secondary: 12 schooling years; tertiary: more than 12 schooling years).

[g] Occupations were categorized based on the Classification of Occupations of Bolivia (INE 2009) and adapted by skill levels according to the National Occupational Classification Matrix 2006 (HRSDC 2006).

[h] Refers to the husband or partner of the interviewed woman. Otherwise, the data from the woman's father was collected, provided that the woman lived at her father's household.

In Oruro, the median concentrations of antimony in both maternal and cord blood were comparable to high occupational exposure (ATSDR 1992; Kentner et al. 1995). Previous studies in Oruro suggested that household dust (Fonturbel et al. 2011), soil and airborne particles (Goix et al. 2011) were contaminated with antimony. Most studies and official recommendations for antimony exposure refer to the occupational context (ATSDR 1992). Very few studies have addressed antimony exposure from environmental sources and the obtained blood concentrations tended to be low (Bazzi et al. 2005; Goullé et al. 2005).

Table 4. Multivariate ordinal logistic regression between the sum of toxic trace elements in maternal blood considered higher exposure[a] and the covariates included in the analysis, adjusted by health care center and maternal age.

	N (%)	Odds ratio	Confidence interval 95 %	*p* value
Pregnancy trimester				
First[b]	83 (20)			
Second	185 (44.58)	2.28	(1.25–4.14)	0.007
Third	147 (35.42)	1.81	(0.53–6.26)	0.346
Smoking				
No[b]	357 (85.2)			
Yes	62 (14.8)	1.77	(1.00–3.15)	0.050
Dental amalgams				
No[b]	191 (51.21)			
Yes	182 (48.79)	0.93	(0.59–1.45)	0.745
Marital status				
Married[b]	182 (43.44)			
Cohabiting	172 (41.05)	1.12	(0.67–1.90)	0.663
Single	65 (15.51)	2.19	(1.08–4.44)	0.030
Maternal schooling[c]				
Tertiary[b]	180 (43.8)			
Secondary	172 (41.85)	0.86	(0.46–1.59)	0.632
Elementary	59 (14.36)	1.26	(0.55–2.88)	0.592
Maternal occupation[d]				
Professional[b]	50 (12.05)			
Technical	91 (21.93)	0.54	(0.24–1.20)	0.131
Administrative	39 (9.4)	0.48	(0.16–1.43)	0.189
Basic/manual	235 (56.63)	1.31	(0.57–3.01)	0.520
Paternal[e] *occupation*[d]				
Professional[b]	59 (14.5)			
Technical	73 (17.94)	1.18	(0.24–2.66)	0.683
Administrative	108 (26.54)	2.22	(0.99–4.95)	0.052
Basic/manual	167 (41.03)	1.52	(0.71–3.26)	0.284
Father[e] *works in mining*				
No[b]	356 (87.04)			
Yes	53 (12.96)	2.16	(1.05–4.44)	0.037

[a] We dichotomized as “higher/lower” the trace elements distributions in maternal blood using as cut-off the 75th percentile for lead and antimony and detection limit for arsenic. The “mixed exposure” variable was the sum of the elements in the “higher” group.

[b] Reference category for each covariate.

[c] Bolivian educational system (elementary: 8 schooling years; secondary: 12 schooling years; tertiary: more than 12 schooling years).

[d] Occupations were categorized based on the Classification of Occupations of Bolivia (INE 2009) and adapted by skill levels according to the National Occupational Classification Matrix 2006 (HRSDC 2006).

[e] Refers to the husband or partner of the interviewed woman. Otherwise, the data from the woman’s father was collected, provided that the woman lived at her father’s household.

Factors involved in the exposure of the population to toxic trace elements

A factor explaining the variability of exposure could be the bioavailability of the metallic and semimetallic elements in the compounds where they are found (Glorennec 2006). The bioavailability of lead in some mining wastes may be lower than lead paint or lead vapors (Freeman et al. 1994). Studies have shown that blood concentrations of trace elements, particularly of lead in children, were lower than expected in populations exposed to mining wastes (Malcoe et al. 2002), even though the environment was strongly contaminated with these toxic elements (Zota et al. 2011). This could be a factor explaining the relatively low concentrations of lead found in our population as well as the toxic trace elements that were undetectable in our samples, such as mercury or cadmium.

In Oruro, it is complicated to identify more and less exposed areas. Some districts are located in clear contact with the mining centers or built on top of abandoned mining wastes, but also small furnaces and smelters are scattered all over the city (Figure 1). The mining districts are generally impoverished areas, where most streets are unnamed, unnumbered, and unpaved, and most households are built in precarious conditions. Thus, these houses are more likely to be contaminated by air particles and dust from the mining wastes and tailings, especially during the long dry/windy seasons. In combination with low educational level and the resulting lack of knowledge about prevention and general precautions, the differences observed in maternal blood of our population seem to point to socioeconomic inequalities as a possible risk factor for higher exposure to toxic trace elements, especially lead. This was also observed in other populations (Berglund et al. 2011; Liu et al. 2012).

Potential limitations

A potential limitation of our study was the assessment method to determine arsenic exposure. The biomarker most commonly used to monitor short-term arsenic and antimony exposure is urine (ATSDR 1992; ATSDR 2007; Sundar & Chakravarty 2010), whereas nails are typically used to determine chronic exposure (ATSDR 2007). In the case of antimony, blood concentrations were also correlated to occupational exposure (Kentner et al. 1995), which is why we do not consider that the biomarker of choice affected our study results.

The population included in our study is representative for the city of Oruro and other mining cities in Bolivian Andean regions but not of other Bolivian regions. Due to the high percentage of study participants without a blood sample, the generalizability of these results should be interpreted with caution. However, we found no significant differences between participants with and without a blood sample with regard to the risk factors: maternal smoking, educational level, and paternal mining.

Conclusions

Pregnant women and their unborn children in the Bolivian town of Oruro are exposed to various toxic trace elements, such as lead, arsenic, and antimony. Twelve percent of our cohort children were born with at least two of these toxic elements above recommendation limits. As exposure is expected to increase with age, these infants are at high risk of developing negative health effects. In order to protect children from potential harmful effects, preventive measures should focus on families with lower educational level, smoking mothers, and family members involved in mining activities.

Disclosure statement

There are no competing interests for the present study, financial or otherwise.

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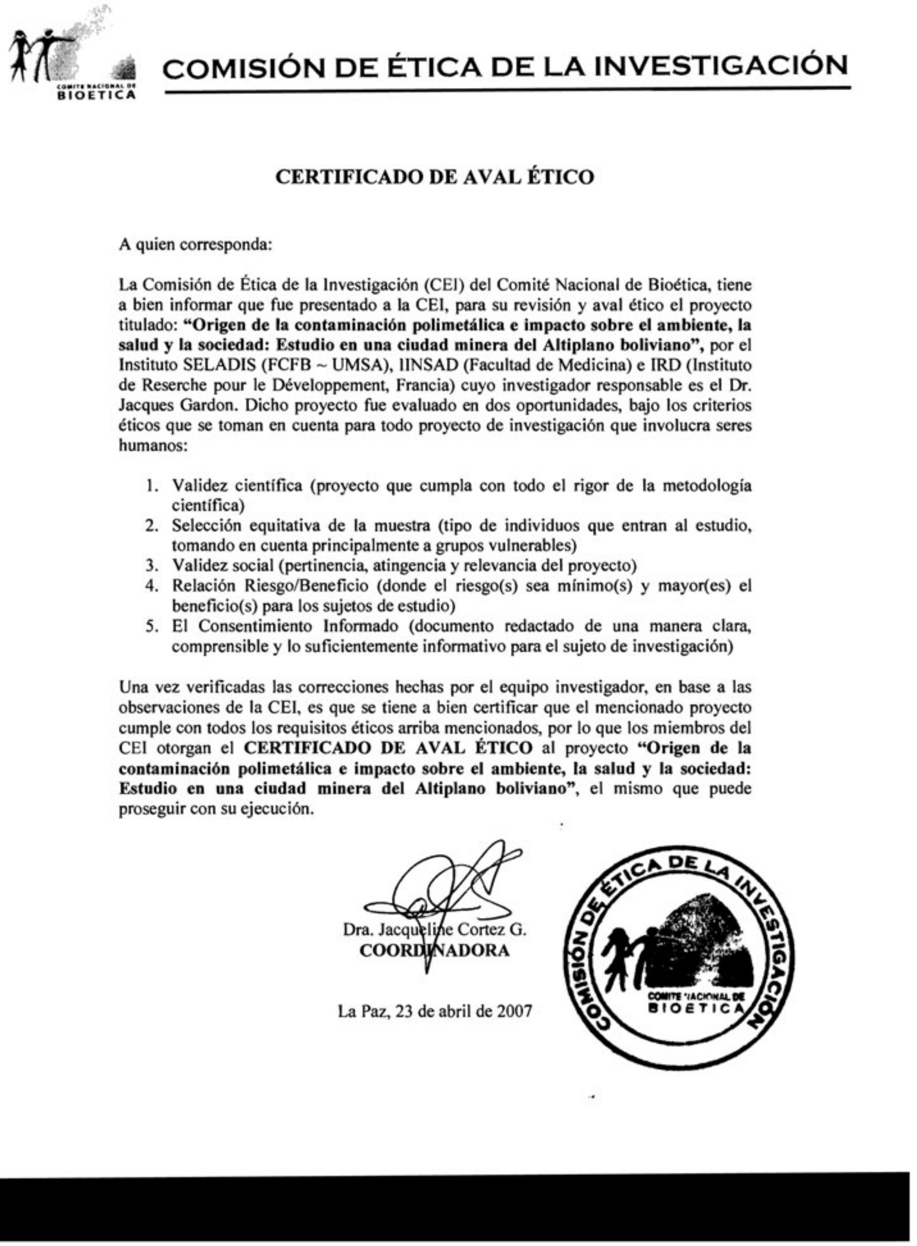
Appendix 1



COMITE NACIONAL DE BIOETICA

COMISIÓN DE ÉTICA DE LA INVESTIGACIÓN

CERTIFICADO DE AVAL ÉTICO

A quien corresponda:

La Comisión de Ética de la Investigación (CEI) del Comité Nacional de Bioética, tiene a bien informar que fue presentado a la CEI, para su revisión y aval ético el proyecto titulado: **"Origen de la contaminación polimetálica e impacto sobre el ambiente, la salud y la sociedad: Estudio en una ciudad minera del Altiplano boliviano"**, por el Instituto SELADIS (FCFB ~ UMSA), IINSAD (Facultad de Medicina) e IRD (Instituto de Reserche pour le Développement, Francia) cuyo investigador responsable es el Dr. Jacques Gardon. Dicho proyecto fue evaluado en dos oportunidades, bajo los criterios éticos que se toman en cuenta para todo proyecto de investigación que involucra seres humanos:

1. Validez científica (proyecto que cumpla con todo el rigor de la metodología científica)
2. Selección equitativa de la muestra (tipo de individuos que entran al estudio, tomando en cuenta principalmente a grupos vulnerables)
3. Validez social (pertinencia, atingencia y relevancia del proyecto)
4. Relación Riesgo/Beneficio (donde el riesgo(s) sea mínimo(s) y mayor(es) el beneficio(s) para los sujetos de estudio)
5. El Consentimiento Informado (documento redactado de una manera clara, comprensible y lo suficientemente informativo para el sujeto de investigación)

Una vez verificadas las correcciones hechas por el equipo investigador, en base a las observaciones de la CEI, es que se tiene a bien certificar que el mencionado proyecto cumple con todos los requisitos éticos arriba mencionados, por lo que los miembros del CEI otorgan el **CERTIFICADO DE AVAL ÉTICO** al proyecto **"Origen de la contaminación polimetálica e impacto sobre el ambiente, la salud y la sociedad: Estudio en una ciudad minera del Altiplano boliviano"**, el mismo que puede proseguir con su ejecución.

Dra. Jacqueline Cortez G.
COORDINADORA

La Paz, 23 de abril de 2007

[redacted]