The aim of this analysis was to examine the association between tea intake during pregnancy and maternal and infant metal exposures. Data from the Maternal-Infant Research on Environmental Chemicals (MIREC) Study, a pan-Canadian pregnancy cohort, were used. All participants with a gestational age of ≥ 20 weeks (n = 1954) with available biomarkers were included. Geometric means (GMs) for lead, arsenic, cadmium and manganese in maternal (first and third trimesters) and cord blood, as well as speciated arsenic in maternal urine in the first trimester, were calculated for participants who drank regular, green or herbal tea and for those who did not. Differences between groups were examined using chi-square tests. Adjusted least squares geometric means (LSGMs) were estimated by tea intake, controlling for factors such as country of birth, coffee intake and maternal smoking.

Concentrations of all metals were above the limits of detection in most participants in the first trimester: lead (GM): 0.62 μg/dl, mercury (GM: 2.99 nmol/l); cadmium (GM 1.93 nmol/l), arsenic (GM 9.75 nmol/l) and manganese (GM 160.1 nmol/l). Adjusted LSGMs for lead in the first trimester were higher for tea drinkers than for those who were non-tea drinkers (LSGM 0.65 μg/dl, 95%CI: 0.62, 0.69 and 0.61 μg/dl, 95%CI: 0.59, 0.62), and there was evidence of a dose–response relationship for green and herbal tea. Those who consumed herbal tea in the third trimester had significantly higher third trimester maternal and cord blood lead concentrations than non-herbal tea drinkers. This study provides evidence of an association between blood lead concentrations and green or herbal tea consumption. However, the GM blood lead concentrations of the highest tea consumers were still less than 1 μg/dl and within the normal range of blood lead concentrations in the Canadian population.

**Keywords:** lead; metals; MIREC; tea
variable was derived to describe frequency as number of cups per week (none to < 1; 1 to < 7; ≥ 7) for each type of tea, as well as all types combined. Since the majority of participants in the “none to < 1 cup/week” category reported consuming tea “never” or “less than 2 times/month” and because a sensitivity analysis examining women with no tea consumption at all as a category did not change the results of the analyses, we collapsed these two categories into the “none to < 1 cup/week” category.

Metals Analysis
Metal concentrations of lead, cadmium, arsenic, total mercury and manganese in maternal whole blood were measured in the first and third trimester visits. Cord blood concentrations of these metals were also measured. Urine analysis for speciated arsenic was conducted in the first trimester.

Maternal and cord blood were analysed by sample dilution followed by inductively coupled plasma mass spectrometry (ICP-MS) analysis [ICP-MS DRC-II; Elan Perkin Elmer]. Urinary analysis for speciated arsenic was carried out by HPLC coupled to a Varian 820 MS ICP-MS. All chemical analyses were carried out by the Toxicology Laboratory, located in the Institut national de santé publique du Québec, which is accredited by the Standards Council of Canada under ISO 17025 and CAN-P-43. The accuracy and precision of the analyses are evaluated on a regular basis through the laboratory’s participation in external quality assessment programmes.

Statistical Analysis
Analyte results below the limits of detection (LOD), defined as results indistinguishable from zero, were counted as half the detection limit. Descriptive statistics were used to characterize the population by intake of

Table 1. Characteristics of study participants (n = 1954), by tea intake in the first and third trimesters, MIREC, Canada, 2009–2012.

| Prevalence tea drinkers, n (%) | N (%) | First trimester | Third trimester | First trimester | Third trimester | First trimester | Third trimester |
|-------------------------------|-------|----------------|----------------|----------------|----------------|----------------|----------------|
| Overall                       | 1954  | 290 (14.8)     | 280 (14.8)     | 118 (6.0)      | 83 (4.4)       | 69 (3.5)       | 56 (2.9)       |
| Maternal age (years)          |       |                |                |                |                |                |                |
| ≤ 29                          | 592   | (30.3)         | 94 (15.9)      | 70 (11.8)      | 35 (5.9)       | 22 (3.7)       | 12 (2.0)       | 14 (2.4)       |
| 30–34                         | 699   | (35.8)         | 94 (13.5)      | 109 (15.6)     | 37 (5.3)       | 37 (5.3)       | 19 (2.7)       | 22 (3.2)       |
| ≥ 35                          | 663   | (33.9)         | 102 (15.4)     | 108 (16.3)     | 46 (6.9)       | 30 (4.5)       | 38 (5.7)       | 20 (3.0)       |
| Maternal country of birth     |       |                |                |                |                |                |                |
| Canada                        | 1590  | (81.4)         | 231 (14.5)     | 230 (14.5)     | 79 (5.0)       | 58 (3.7)       | 53 (3.3)       | 45 (2.8)       |
| Other                         | 364   | (18.6)         | 59 (16.2)      | 57 (15.7)      | 39 (10.7)      | 31 (8.5)       | 16 (4.4)       | 11 (3.0)       |
| First pregnancy               |       |                |                |                |                |                |                |
| No                            | 561   | (28.7)         | 75 (13.4)      | 84 (15.0)      | 34 (6.1)       | 23 (4.1)       | 22 (3.9)       | 14 (2.5)       |
| Yes                           | 1393  | (71.3)         | 215 (15.4)     | 203 (14.6)     | 84 (6.0)       | 66 (4.7)       | 47 (3.4)       | 42 (3.0)       |
| Marital status                |       |                |                |                |                |                |                |
| Single, divorced or widowed   | 91    | (4.7)          | 17 (18.7)      | 10 (11.0)      | 6 (6.6)        | 2 (2.2)        | 3 (3.3)        | 1 (1.1)        |
| Married or common law         | 1863  | (95.3)         | 273 (14.7)     | 277 (14.9)     | 112 (6.0)      | 87 (4.7)       | 66 (3.5)       | 53 (3.0)       |
| Maternal education            |       |                |                |                |                |                |                |
| College educated or less      | 735   | (37.6)         | 111 (15.1)     | 100 (13.6)     | 41 (5.6)       | 30 (4.1)       | 21 (2.9)       | 12 (1.6)       |
| Completed university          | 716   | (36.6)         | 98 (13.7)      | 101 (14.1)     | 39 (5.5)       | 29 (4.1)       | 26 (3.6)       | 17 (2.4)       |
| Graduate university           | 503   | (25.7)         | 81 (16.1)      | 86 (17.1)      | 38 (7.8)       | 30 (6.0)       | 22 (4.4)       | 27 (5.4)       |
| Household income ($)          |       |                |                |                |                |                |                |
| < 50,000                      | 338   | (18.1)         | 56 (16.6)      | 42 (12.4)      | 20 (5.9)       | 22 (6.5)       | 10 (3.0)       | 9 (2.7)        |
| 50,001–100,000                | 778   | (41.8)         | 117 (15.0)     | 117 (15.0)     | 52 (6.7)       | 33 (4.2)       | 26 (3.3)       | 21 (2.7)       |
| > 100,000                     | 747   | (40.1)         | 104 (13.9)     | 119 (15.9)     | 43 (5.8)       | 34 (4.6)       | 31 (4.2)       | 25 (3.4)       |
| Maternal pre-pregnancy body mass index |       |                |                |                |                |                |                |
| < 25                          | 1150  | (63.5)         | 183 (15.9)     | 171 (14.9)     | 75 (6.5)       | 70 (6.1)       | 46 (4.0)       | 40 (3.5)       |
| 25–29.9                       | 396   | (21.9)         | 50 (12.6)      | 62 (15.7)      | 26 (6.6)       | 8 (2.0)        | 12 (3.0)       | 7 (1.8)        |
| ≥ 30                          | 265   | (14.6)         | 42 (15.9)      | 41 (15.5)      | 11 (4.2)       | 7 (2.6)        | 5 (1.9)        | 5 (1.9)        |
| Smoking during pregnancy      |       |                |                |                |                |                |                |
| Daily or occasionally         | 80    | (4.2)          | 20 (17.7)      | 14 (12.4)      | 4 (3.5)        | 6 (7.5)        | 3 (2.7)        | 2 (2.5)        |
| Never                         | 1818  | (95.8)         | 270 (14.7)     | 274 (14.8)     | 114 (6.2)      | 83 (4.4)       | 66 (3.6)       | 54 (2.9)       |
| Exposure to second hand smoke |       |                |                |                |                |                |                |
| Yes                           | 884   | (45.2)         | 136 (15.4)     | 143 (16.2)     | 74 (6.9)       | 34 (3.9)       | 33 (3.7)       | 20 (3.4)       |
| No                            | 1070  | (54.8)         | 154 (14.4)     | 144 (13.5)     | 44 (5.0)       | 55 (5.1)       | 36 (3.4)       | 36 (2.3)       |
| Alcohol during pregnancy      |       |                |                |                |                |                |                |
| Never or < 1/week             | 1890  | (96.7)         | 280 (14.8)     | 279 (14.8)     | 112 (5.9)      | 86 (4.6)       | 65 (3.4)       | 54 (2.9)       |
| ≥ 1/week                      | 64    | (3.3)          | 10 (15.6)      | 8 (12.5)       | 6 (9.4)        | 3 (4.7)        | 4 (6.3)        | 2 (3.1)        |

Abbreviations: BMI, body mass index; MIREC, Maternal-Infant Research on Environmental Chemicals. Missing data not shown, 7.3% of sample for maternal pre-pregnancy BMI. *Significantly different from tea intake at the first trimester visit, McNemar test (P < 0.05). †Reference. ‡Significantly different from reference (P < 0.05).
RESULTS
Population Characteristics
MIREC participant characteristics, by prevalence of reported tea drinking (regular, green or herbal) in the first and third trimesters, are described in Table 1. The majority of the women were Canadian born (81%), 30 years of age or older (70%), non-smokers (92%), first pregnancy (71%) and had an annual household income of $>50,000 (78%). Less than 1% of tea-drinking women reported consuming all three types of tea in either the first or third trimester, with no difference observed between the first and third trimesters for reported intake of regular or herbal tea.

At the first trimester visit, a significantly higher proportion of green tea drinkers were not Canadian born, and this was also observed at the third trimester. Women ≥35 years of age had a higher prevalence of herbal tea intake compared with those <29 years of age at the first trimester. At the third trimester visit, prevalence of herbal tea intake was higher for those with graduate level university education than for those who had a college education or lower. Those with a pre-pregnancy BMI of <25 had a higher prevalence of green tea intake than for those who were overweight or obese (BMI ≥25).

Metals in Maternal and Cord Blood and Speciated Arsenic in Maternal Urine
Most maternal blood metal concentrations were above the LOD in the first trimester: lead (GM): 0.62 μg/dl (0.03 μmol/l), 100% detected), mercury (GM 2.99 nmol/l, 90% detected), cadmium (GM 1.93 nmol/l, 97% detected), arsenic (GM 9.75 nmol/l, 92% detected) and manganese (GM 160.1 nmol/l, 100% detected).
Figure 1. Cumulative distribution of maternal whole blood lead concentrations in first and third trimesters, and cord blood, by type of tea consumed in MIREC participants, Canada, 2009–2012. MIREC, Maternal-Infant Research on Environmental Chemicals.
Higher blood lead was also observed for those who reported green tea than those who did not drink regular tea (0.61 μg/dl). More significantly different for third trimester green tea (0.86 μg/dl) and herbal tea (1.00 μg/dl) drinkers in comparison with non-tea drinkers (0.73 μg/dl for both types of tea).

A significant difference for mean cadmium concentrations between regular tea drinkers (2.12 nmol/l) and non-tea drinkers (1.90 nmol/l) was observed in the first trimester, but this did not persist into the third trimester nor was it observed in cord blood.

Concentrations of Metals by Reported Tea Intake

Table 3. Adjusted least squares geometric means of blood lead concentrations, by tea drinkers in the first or third trimester, in MIREC participants, Canada, 2009–2012.

| Concentrations of Metals by Reported Tea Intake |

Higher blood lead concentrations for tea drinkers compared with those who did not drink these types of tea (0.61 μg/dl for both types of tea). The difference in blood lead concentrations between tea drinkers and non-drinkers persisted for green (0.66 and 0.57 μg/dl, respectively) and herbal tea (0.70 and 0.57 μg/dl, respectively) in the third trimester. Cord blood lead concentrations were also significantly different for third trimester green tea (0.86 μg/dl) and herbal tea (1.00 μg/dl) drinkers in comparison with non-tea drinkers (0.73 μg/dl for both types of tea).

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| Concentrations of Metals by Reported Tea Intake |
Table 4. Adjusted least squares geometric means of blood lead concentrations, by frequency of tea intake in the first or third trimester, in MIREC participants, Canada, 2009–2012.

| N (%) | LSGM | 95% CI | P-value |
|-------|------|--------|---------|
| First trimester blood concentration | | | |
| Regular tea (cups/week) | | | |
| None to < 1 | 1626 (85.1) | 0.61 | 0.60, 0.63 |
| 1 to < 7 | 197 (10.3) | 0.62 | 0.58, 0.66 |
| ≥ 7 | 87 (4.6) | 0.68 | 0.61, 0.75 |
| Green tea (cups/week) | | | |
| None to < 1 | 1795 (94.0) | 0.61 | 0.60, 0.62 |
| 1 to < 7 | 101 (5.3) | 0.71 | 0.64, 0.77 |
| ≥ 7 | 14 (0.7) | 0.78 | 0.60, 0.98 |
| Herbal tea (cups/week) | | | |
| None to < 1 | 1847 (96.7) | 0.62 | 0.60, 0.63 |
| 1 to < 7 | 58 (3.0) | 0.72 | 0.64, 0.81 |
| ≥ 7 | 5 (0.3) | 0.52 | 0.33, 0.81 |
| All tea (cups/week) | | | |
| None to < 1 | 1511 (79.1) | 0.61 | 0.59, 0.62 |
| 1 to < 7 | 294 (15.4) | 0.65 | 0.61, 0.68 |
| ≥ 7 | 105 (5.5) | 0.67 | 0.62, 0.74 |
| Third trimester blood concentration | | | |
| Regular tea (cups/week) | | | |
| None to < 1 | 1398 (83.6) | 0.57 | 0.55, 0.58 |
| 1 to < 7 | 206 (12.3) | 0.56 | 0.52, 0.60 |
| ≥ 7 | 69 (4.1) | 0.56 | 0.50, 0.63 |
| Green tea (cups/week) | | | |
| None to < 1 | 1588 (94.9) | 0.57 | 0.55, 0.58 |
| 1 to < 7 | 74 (4.4) | 0.61 | 0.55, 0.69 |
| ≥ 7 | 11 (0.7) | 0.57 | 0.43, 0.77 |
| Herbal tea (cups/week) | | | |
| None to < 1 | 1617 (96.7) | 0.56 | 0.55, 0.58 |
| 1 to < 7 | 48 (2.9) | 0.71 | 0.61, 0.82 |
| ≥ 7 | 8 (0.5) | 0.51 | 0.36, 0.74 |
| All tea (cups/week) | | | |
| None to < 1 | 1306 (78.1) | 0.56 | 0.55, 0.58 |
| 1 to < 7 | 281 (16.8) | 0.58 | 0.55, 0.62 |
| ≥ 7 | 86 (5.1) | 0.56 | 0.50, 0.62 |
| Cord blood concentration | | | |
| Regular tea (cups/week) | | | |
| None to < 1 | 1182 (84.6) | 0.74 | 0.72, 0.76 |
| 1 to < 7 | 162 (11.6) | 0.75 | 0.69, 0.81 |
| ≥ 7 | 54 (3.9) | 0.82 | 0.71, 0.96 |
| Green tea (cups/week) | | | |
| None to < 1 | 1333 (95.4) | 0.74 | 0.72, 0.76 |
| 1 to < 7 | 57 (4.1) | 0.82 | 0.70, 0.94 |
| ≥ 7 | 8 (0.6) | 0.79 | 0.54, 0.87 |
| Herbal tea (cups/week) | | | |
| None to < 1 | 1356 (97.0) | 0.74 | 0.72, 0.76 |
| 1 to < 7 | 38 (2.7) | 0.92 | 0.77, 1.10 |
| ≥ 7 | 4 (0.3) | 0.89 | 0.81, 1.63 |
| All tea (cups/week) | | | |
| None to < 1 | 1112 (79.5) | 0.73 | 0.71, 0.76 |
| 1 to < 7 | 220 (15.7) | 0.77 | 0.72, 0.83 |
| ≥ 7 | 66 (4.7) | 0.82 | 0.72, 0.94 |

Abbreviations: CI, confidence interval; LSGM, least squares geometric mean; MIREC, maternal-infant research on environmental chemicals. Each model controlled for age, household income, highest level of maternal education, country of birth, maternal smoking, maternal coffee intake, exposure to second hand smoke and maternal pre-pregnancy body mass index. *Defined in questionnaire as 6 ounces.

Tea intake and maternal blood metal concentrations
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(1991–1992), which did not find that tea intake was independently associated with first trimester blood lead concentrations (GM 3.43 μg/dl).18 However, in the ALSPAC, caffeinated coffee was a stronger predictor of blood lead levels than decaffeinated coffee when the model was adjusted for tea consumption. There are several possible explanations for this disparity, including the following: the tea sold in the United Kingdom during that time period may have differed in lead content from that in Canada (e.g., increase in industrialization in tea growing regions), variance in the frequency of tea intake in the two populations, or dissimilar predictors because of the higher blood lead concentrations in the ALSPAC cohort (GM 3.67 μg/dl) as compared with MIREC women (GM 0.62 μg/dl).

A blood lead concentration considered as safe during pregnancy has not been established, though the American Congress of Obstetricians and Gynecologists recommends blood lead testing when any risk factor is identified, and follow-up testing if results exceed 5 μg/dl.19 Infants and children are undergoing rapid neurodevelopment, and absorb lead more easily and excrete lead less efficiently than adults; thus, sensitive adverse health end points in this sub-group have been associated with blood lead levels as low as >1.3 μg/dl.20 The GM blood lead concentrations of the MIREC population (tea and non-tea drinkers) were below these thresholds and were lower than for females 20–39 years of age in the 2007–2009 Canadian Health Measures Survey (CHMS) (MIREC: 0.62 μg/dl vs CHMS: 0.89 μg/dl).21 Though lead mobilization from bone, increased gut absorption and lead retention in soft tissue may result in higher concentrations as pregnancy progresses, the hemolysis that occurs in pregnancy may be partly responsible for the lower lead concentrations in the MIREC cohort in comparison with non-pregnant women in the CHMS study.22

Tea is produced from the Camellia sinensis, plant of the Theaceae family. Different processing methods are used to make different types of tea, including green tea (non-oxidized, non-fermented) and black tea (fully-oxidized, fermented). Herbal tea is commonly made from dried herbs, flowers or roots, and may not contain leaves from the Camellia sinensis. The soil where plants are grown may be exposed to metals through the application of fertilizers and pesticides, which are then available for uptake by the plant.23 Detectable levels of certain metals, including lead, arsenic and cadmium, have been observed in dried tea. For example, the Canadian Food Inspection Agency (CFIA) tested 100 samples of dried tea (including black, green and herbal) and found that metals, including manganese, lead, cadmium and arsenic, were detected in 100% of samples, at varying levels.23 Further, green tea had higher mean lead amounts (1.31 p.p.m.) than herbal tea (1.14 p.p.m.) and black tea (0.64 p.p.m).23 These dried tea samples do not indicate the amount of lead in prepared tea, as steeping time impacts the transfer of contaminants. For example, in a Canadian study, convenience samples of 30 steeped black, green, white and oolong tea were examined6 to determine the presence of metals; the study revealed that lead and arsenic were detected in all dried tea leaves and steeped tea, with Chinese oolong teas having the highest levels, followed by green tea and regular black tea. Though the study accounted for the amount of lead in the water used for preparation, the mean amount found in steeped tea — standard oolong tea with a steeping time of 3–4 min (3.05 μg/l) and 15–17 min (3.45 μg/l) — was below 10 μg/l, the current maximum acceptable concentration of lead in Canadian drinking water.23 Although mercury was detected in the dry tea leaves, none of the brewed teas had detectable levels, suggesting that mercury is bound in the leaf and does not leach into the brewed tea. Cadmium was measured in all dry tea leaves and steeped tea, with Chinese oolong teas having the highest levels, followed by green tea and regular black tea. The world’s top tea producing countries are China (1.94 million tonnes) and India (1.21 million tonnes), followed by Kenya (430,000 tonnes) and Sri Lanka (340,000 tonnes).23 In highly industrialized countries, tea leaves may be exposed to higher lead in the soil. For example, in a systematic review of Chinese surveillance data gathered from 2006 to 2012, it was determined that dried tea had the highest
lead concentration in the food samples studied, with an estimated weighted mean concentration of 1.937 mg/kg.10

The MIREC cohort has multiple strengths, including the large, national-level prenatal population with biomonitoring data on metal exposures at multiple time points in pregnant women. Further, chemical analyses for MIREC and the CHMS were conducted at the same laboratory, which minimizes potential inter-laboratory variation. As MIREC is not population based, participants differed from the Canadian population giving birth in 2009; for example, our population tended to be older, more educated and less likely to be a current smoker. Thus, our results may not be generalizable to the Canadian population.16 Though measured blood metal concentrations were available in early and late pregnancy, concentrations across time points were not compared as we could not control for hemodilution during pregnancy. Our sample included mostly low-to-moderate tea drinkers, which indicates the need for future studies to examine the association between blood lead concentrations in heavy tea drinkers. Further, other than general tea categories (e.g., regular and green) we did not collect specific data on the source of the tea consumed, such as country of origin. Studies indicate that the transfer of lead from dried to liquid tea increases with length of steeping time — though the amount transferred may be modest — and we did not have this information for the MIREC participants. A study examining the metal content of tea by type, country of origin and steeping time in relation to metal biomarkers may provide further insight needed to formulate appropriate guidance for pregnant women. This study suggests that green and herbal tea drinkers may have higher blood lead concentrations than non-drinkers. However, other environmental exposures that may contribute to this increase in blood lead levels and be correlated with tea intake should be investigated in future studies.

This study provides novel insight into tea intake as a potential route of exposure for metals in Canada. Lead was the only metal found to be related to intake of green and herbal tea, after adjusting for potential confounders. However, the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead found to be related to intake of green and herbal tea, after adjusting for potential confounders. However, the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead found to be related to intake of green and herbal tea, after adjusting for potential confounders. However, the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead concentrations of the highest tea consumers were still less than the GM blood lead.