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Urinary Metals as a Marker of Exposure in Men and Women in the Welding and Electrical Trades: A Canadian Cohort Study

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Abstract

Objectives: Men and women working in the welding trades undergo the same apprenticeship training but it is unknown whether, once in the trade, their exposures differ. Comparison of urinary metal concentrations, having adjusted for estimated airborne exposure, may provide an answer.
Methods: Men and women were recruited to a cohort study of workers in the welding and electrical trades (the Workers Health in Apprenticeship Trades-Metal working and Electrical [WHAT-ME study]). They completed a recruitment questionnaire and further questionnaires every 6 months for up to 5 years. At each follow-up, they gave details on employment and, if welding, answered trade-specific questionnaires. Urine samples were collected by mail. Welding exposure matrices were developed to estimate metal exposures from welding process, base metal, and consumables. Urinary metal concentrations, determined by ICP-MS, were compared by trade (welding or electrical). Within welding, the relation of urinary concentrations to estimated airborne exposure was examined, with adjustment for potential confounders including sex, use of respiratory protective equipment (RPE), and time spent outdoors. Natural logarithms were taken of exposure estimates and urinary concentrations, to reduce skew. All regression analyses included creatinine concentration.
Results: Urinary metal concentrations were analysed for 12 metals in 794 samples. Antimony, arsenic, lead, and mercury had a high proportion of samples with no metal detected and were not considered further. The urinary concentrations of aluminum, cadmium, chromium, cobalt, copper, manganese, nickel, and zinc were compared for welders (434 samples) and electrical workers (360). After adjustment for potential confounders, welders had higher urinary concentrations for aluminum (β = 0.13 95%CI 0.03–0.24) and chromium (β = 0.66 95%CI 0.55–0.77). Of 434 welder urines, 334 could be matched securely to detailed information about the most recent day welding. For these, an estimate of airborne exposure was made for aluminum, chromium, manganese, and nickel. Male welders were estimated to have higher airborne exposure to chromium and nickel than women welders. No difference was seen in the estimated exposures for aluminum or manganese (or total dust). Regression analyses of the relation of urinary metals to estimated exposure showed a good

concordance for aluminum (β = 0.09 95%CI 0.04–0.15 ($P < 0.001$) and chromium (β = 0.11 95%CI 0.05–0.17 $P < 0.001$). The concordance for manganese and nickel was positive, but much weaker. Urinary concentrations of aluminum and nickel were somewhat lower with increasing time wearing RPE and, for chromium and nickel, with time working outdoors. Having adjusted for estimated exposure, creatinine and other confounders, male welders had lower urine concentrations of aluminum (β = −0.35 95%CI −0.51 to −0.19 $P < 0.001$) chromium (β = −0.38 95%CI −0.57 to −0.19 $P < 0.001$) and manganese (β = −0.36 95%CI −0.49 to −0.23 $P < 0.001$) than female welders.

Conclusion: Welders had higher urinary concentrations of aluminum and chromium than electrical workers. Exposure estimates of aluminum and chromium for welders were a valid representation of the airborne exposures to these metals. Although male welders were estimated to have higher exposures of chrome and nickel than female welders, the higher urinary metal concentrations in women welders is of concern, particularly for women who may conceive while in the trade.

Keywords: exposure matrix; sex differences in exposure; urinary metals; validation; welding; WHAT-ME study

Introduction

In a cohort study set up in 2011 to study the effects of welding on pregnancy (Cherry *et al.*, 2018), estimating exposures to potentially fetotoxic metals was a major challenge. Collection of timed workplace samples was not feasible as women welders were recruited from across Canada and the event of greatest interest (conception) was known only retrospectively. As such, exposures were estimated from questionnaires recording details of tasks, working conditions, and respiratory protection on the most recent day of carrying out trade tasks, completed at each contact for up to 5 years. The validity of the welder's exposure questionnaire had been tested before starting the main study (Cherry *et al.*, 2011) and predictions from it compared with the results of laboratory replications (Galarneau, 2021). The analysis of urinary metals, from mailed-in urine samples, provided an independent estimate of exposure and an additional tool to validate questionnaire-based exposure algorithms.

Few of the metals to which welders and those in the electrical trades are exposed have a biological exposure index (BEI; ACGIH, 2020). Chromium does have a BEI (of 25 µg/l in an end of week sample) but other metals of interest in welders (aluminum, manganese, nickel) do not, and measurement of urine concentrations for these may be less helpful. There are well-designed studies in the literature that have examined urine concentrations pre- and post-shift in relation to air monitoring for metal in fume (Weiss *et al.*, 2013; Stanislawska *et al.*, 2020) but these do not translate easily to spot samples from trades people exposed daily over months or years where, at least for some metals, urinary concentrations will reflect accumulated body burden rather than exposures attributable to any one day. Accepting these limitations, we examined differences in urinary metal concentrations between trades and between men and women. We also sought to quantify the extent to which ventilation and respiratory protection reduced internal exposure. Few studies have reported, quantified, or analyzed exposures to airborne contaminants by gender for those in the same work (Kennedy and Koehoorn, 2003; Howse *et al.*, 2006; Eng *et al.*, 2011; Curtis *et al.*, 2018). The WHAT-Me study (Workers Health in Apprenticeship trades-metal working and electrical) provided the opportunity to make gender comparisons in estimated exposure and absorption for the welding trades. An additional prime goal of the analysis reported here was to further

What's Important About This Paper?

There remains a need to improve on exposure assessment methods for metals among welders, and explore potential differences in exposures among male and female welders. This study found that urinary concentrations, particularly of chromium and aluminum, among welders are associated with airborne exposure estimates derived from a novel algorithm based on a survey. Further, this study demonstrated that airborne exposures and urinary metal concentrations differ between male and female welders. In particular, higher urinary excretion of aluminum and chromium among women relative to men, suggesting higher absorption in women welders.

validate, by urinary metal concentrations, the exposure algorithms developed to estimate exposure to metals in the welder cohort (Galarneau, 2021) and to give confidence for their use in the analysis of pregnancy outcome.

Methods

Four linked cohorts were set up, comprising women who had started an apprenticeship in a welding trade (welding, boiler making, steam fitter/pipefitter) or an electrical trade after 2005 in any Canadian province or territory. Men in the same trades were recruited only in the province of Alberta (Cherry *et al.*, 2018). Each participant completed a recruitment questionnaire, which included details of all jobs and training since leaving high school and, subsequently, follow-up questionnaires every 6 months for up to 5 years. Spot urine samples were collected as a direct request of all currently working in their trade, for women in Alberta at the time of completing their first follow-up questionnaire in October 2011 through September 2012 and for both men and women in September 2014 through June 2016. It was requested that these samples be collected at the end of the working week. In addition, throughout the period of data collection, women who notified the team they were pregnant were asked for a pregnancy urine sample. At each request, the participants were sent a kit to collect and mail back the sample: they were assured that it would be analyzed only for metals and creatinine. On receipt, samples were stored at −80°C. Metal concentrations were determined at the University of Alberta Hospital laboratory by ICP-MS. This clinical laboratory was the provincial centre for metals analysis of biological samples and participated in multiple external quality assurance schemes including those of the College of American Pathologists (CAP) and the Institut national de santé publique du Québec (INSPQ). The metals analyzed were 11 that were included in a standard metal screen (namely, aluminum, antimony, arsenic, cadmium, cobalt, copper, lead, manganese, mercury, nickel, and zinc). Chromium, not part of the standard screen, was added for this project. Samples found to have values below the limit of quantification (LOQ) were replaced, using the beta substitution method developed by Ganser and Hewett (2010). Creatinine was analyzed using the Beckman Jaffe method.

The job at the time of urine sample collection was determined from the cumulative job history compiled for each participant and was normally the current job reported in the most recently completed questionnaire. Exceptionally, with a job change reported later, a different job might be identified. Occupational exposures were determined first by trade (welding or electrical), then by exposure factors (such as the proportion of time spent working outdoors or using respiratory protection) collected for all jobs, and finally, for welders only, from detailed information given in welding-specific questionnaires, completed at each contact, which asked about the tasks, processes, metals, and consumables on the most recent day welding.

Exposure algorithms were developed for each combination of process, base metals, and consumables, using data extracted from the welding literature and samples collected for this project (Galarneau, 2021). Details are given in Supplementary Appendix 1 (available at *Annals of Occupational Hygiene* online). Exposures were estimated for four metals, aluminum, chromium, manganese, and nickel.

Statistical methods

Urinary metal concentrations and estimated metal exposures were log transformed to reduce skew: the antilog of the log transformed mean approximates the geometric mean. Creatinine was entered into the analysis as an independent variable rather than using creatinine-corrected concentrations. Creatinine excretion differs markedly between men and women, with difficulties in interpretation of creatinine-corrected results (Barr *et al.*, 2005). Correcting for creatinine statistically rather than *a priori* allowed direct comparison of urinary concentrations in male and female participants. A descriptive table showing creatinine-corrected individual values is included as Supplementary Material (available at *Annals of Occupational Hygiene* online). Multilevel regression models were used to allow for clustering within participant for those who gave samples at different periods during the study. The analysis first examined differences in mean log urinary concentrations between trades by analysis of variance. It then considered the relation to urinary metal concentration of potential confounders, both personal (sex, age, body mass index [BMI], smoking) and work place (proportion of time working outside, with area ventilation, local exhaust ventilation [LEV], and use of respiratory protective equipment (RPE)). Each analysis included creatinine as a factor and allowed for clustering. Confounders associated with urinary metals with $P < 0.10$ were included in the multivariate models developed to examine the difference in urinary metals in those in the welding and electrical trades. Further analysis was restricted to welders and to the four metals of prior interest (aluminum, chromium, manganese, and nickel). The analysis of the relation of confounders to urinary concentrations was repeated for samples from welders for the four metals of prior interest and final multivariable models constructed. These models included estimates of exposure to airborne metals. The relation between predicted urinary concentration and estimated airborne exposure was plotted for each of the metals for which a significant relation was found.

Results

A total of 794 urines were collected while the participant was working in their trade, 434 from welders (183 from women) and 360 from those in the electrical trades (179 from women). Of these, 91 were collected as pregnancy samples. Samples came from 706 different individuals. Of these 794 samples, 767 could be well matched to an occupational questionnaire (419 for a welder) and 334 welder samples to a questionnaire in which detailed welding information had been collected. Analysis of the urine samples found concentrations above the LoQ for at least half the samples for aluminum, cadmium, chromium, cobalt, copper, manganese, nickel, and zinc and these metal results were retained for further analysis (Table 1). The relation of trade to mean urinary metal concentrations is shown in Table 2, with and without log transformation. Welders were found to have higher log concentrations than those in electrical work for urinary aluminum and chromium. Those in electrical work had a higher log concentration of cobalt. No difference was seen for manganese and nickel. Results for creatinine-corrected individual results are tabulated by trade and sex in Supplementary Appendix Table B1 (available at *Annals of Occupational Hygiene* online). The relation between trade and potential confounders is shown, by sex, in Table 3. In both trades, women were younger and less likely to report use of LEV or any use of a respirator. Women were less likely than men in electrical work to report any area ventilation and women in welding, but not electrical work, to have a lower BMI. Welders of both sexes were more likely than those in the electrical trades to be current smokers. Overall, those in electrical work were more likely than welders to report some outdoor work on the most recent workday. Those in welding were more likely than those in electrical work to report some time working with area ventilation, use of LEV and RPE. Supplementary Appendix Table B2 (available at *Annals of Occupational Hygiene* online) shows the univariate analysis of the relation of each of the potential confounders to the three metals (aluminum, chromium, and cobalt) where urinary concentrations differed between trades, together with manganese and nickel. Table 4 gives the final, multivariable models examining the difference between trades in urinary metal concentrations. After adjustment for all significant confounders, welders had higher concentrations of urinary aluminum and chromium. Cobalt was only marginally higher in electrical work and again no difference was seen for manganese and nickel. Urinary concentrations were significantly lower in male workers for metals other than nickel. Although years in the trade were positively related to urinary chromium and nickel in the univariate analysis (Supplementary Appendix Table B2, available at *Annals of Occupational Hygiene* online) these did not retain significance in the multivariate model.

The analysis then considered urinary concentration in the smaller group of 312 welders who gave

Table 1. Urinary metals assayed with LoQ, value substituted where below LoQ and proportions below the LoQ by trade.

Metal	LoQ (µg/l)	Value substituted (µg/l)	Welder		Electrician		Overall	
			N	%	*N*	%	*N*	%
Aluminum	1.349	0.852	39	9.0	30	8.3	69	8.7
Antimony			377	87.1	329	91.1	706	88.9
Arsenic			274	63.3	241	66.8	515	64.9
Cadmium	0.112	0.072	118	27.3	78	21.6	196	24.7
Chromium	0.151	0.080	128	29.5	213	59.2	341	42.9
Cobalt	0.118	0.074	44	10.1	21	5.8	65	8.2
Copper	6.355	4.527	81	18.7	54	15.0	135	17.0
Lead			390	90.1	339	93.9	729	91.8
Manganese	0.440	0.314	31	7.1	25	6.9	56	7.1
Mercury			426	98.4	354	98.1	780	98.2
Nickel	0.293	0.150	52	12.0	29	10.8	91	11.5
Zinc	19.263	10.974	9	2.1	2	0.6	11	1.4
N			434		360		794	

Table 2. Urinary metal concentrations in men and women in welding and electrical trades.

Urinary metal concentrations (µg/l)	Welding			Electrical			Log transformed concentration				Relation of log transformed to welding		
							Welding		Electrical				
	Mean	SD	95%tile	Mean	SD	95%tile	Mean	SD	Mean	SD	β	95% CI	*P**
Aluminum	7.20	8.38	19.99	6.25	9.42	14.26	1.59	0.88	1.48	0.80	0.13	0.02 to 0.23	0.021
Cadmium	0.27	0.29	0.73	0.25	0.22	0.67	−1.68	0.81	-1.68	0.73	0.03	-0.06 to 0.12	0.504
Chromium	0.45	1.01	1.20	0.20	0.40	0.52	−1.40	0.96	-2.03	0.73	0.65	0.54 to 0.76	<0.001
Cobalt	0.48	0.41	1.05	0.53	0.42	1.41	−1.01	0.75	−0.88	0.72	−0.11	−0.20 to −0.01	0.022
Copper	13.24	12.52	25.42	13.07	8.48	25.42	2.37	0.61	2.41	0.57	−0.03	−0.09 to 0.03	0.385
Manganese	1.54	1.47	3.25	1.46	0.92	3.07	0.22	0.64	0.20	0.62	0.03	−0.05 to 0.12	0.424
Nickel	1.97	1.71	4.93	1.99	1.88	5.28	0.28	1.01	0.29	1.00	−0.00	−0.14 to 0.13	0.964
Zinc	372.53	313.72	923.30	350.78	283.90	817.30	5.55	0.97	5.54	0.87	0.04	−0.06 to 0.14	0.481
Creatinine g/l	1.20	0.69	2.43	1.22	0.68	2.39					-	-	
N		434			360		434		360				

*Adjusted for creatinine and repeat samples.

Table 3. Relation of potential confounders to trade and sex.

Confounder	Welding					Electrical work					Total				
	Men		Women		*P*	Men		Women		*P*	Welding		Electrical		*P*
	Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Age	35.3	9.3	31.2	8.4	<0.001	34.6	8.8	31.1	6.7	<0.001	33.5	9.1	32.8	8.0	0.272
Body mass index	27.8	5.0	24.9	3.9	<0.001	27.0	4.1	26.3	4.8	0.121	26.5	4.8	26.7	4.5	0.660
	n	%	*n*	%		*n*	%	*n*	%		*n*	%	*n*	%	
Current smoker Yes	66	26.3	56	30.6	0.333	11	6.1	27	15.1	0.006	122	28.1	38	10.6	<0.001
N	251		183			181		179			434		360		
	n	%	*n*	%		*n*	%	*n*	%		*n*	%	*n*	%	
Any work outdoors? Yes	109	44.7	67	38.3	0.194	105	60.7	103	58.9	0.744	176	42.0	208	59.8	<0.001
Any area ventilation? Yes	164	67.2	114	65.1	0.676	111	64.2	79	45.1	<0.001	278	66.3	190	54.6	0.001
Any local exhaust ventilation? Yes	78	32.0	39	22.3	0.036	36	20.8	17	9.7	0.004	117	27.9	53	15.2	<0.001
Any use of respirator Yes	122	50.0	71	40.6	0.060	27	15.6	15	8.6	0.049	193	46.1	42	12.0	<0.001
N (samples)	244		175			173		175			419		348		

Table 4. Relation of (log) urinary related concentration (µg/l) to trade allowing for creatinine concentration, confounders, and clustering.

	Aluminum		Chromium		Cobalt		Manganese		Nickel	
	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI
Welder	0.13	0.03 to 0.24	0.66	0.55 to 0.77	−0.08	−0.17 to 0.01	0.05	−0.02 to 0.13	0.02	−0.10 to 0.17
P	0.013		<0.001		0.077		0.176		0.748	
Sex (male)	−0.25	−0.36 to −0.14	−0.28	−0.39 to −0.16	−0.21	−0.31 to −0.12	−0.36	−0.45 to −0.28		
P	<0.001		<0.001		<0.001		<0.001			
Age	-		-		-		-		0.01	0.01 to 0.02
P									0.001	
Body mass index	−0.01	−0.03 to −0.00	-		-		-		-	
P	0.016									
Current smoker	-		-				-		−0.20	−0.37 to −0.03
P									0.022	
% of time in outdoor work	−0.20	−0.33 to−0.07	−0.25	−0.39 to −0.12	-		-		-	
P	0.002		<0.001							
Creatinine	0.59	0.51 to 0.67	0.55	0.47 to 0.63	0.58	0.51 to 0.65	0.43	0.37 to 0.48	0.21	0.32 to 0.51
P	<0.001		<0.001		<0.001		<0.001		<0.001	
Constant	1.35	1.02 to 1.67	−2.47	−2.62 to −2.33	−1.49	−1.59 to −1.38	−0.14	−0.23 to −0.04	−0.62	−0.92 to −0.31
P	<0.001		<0.001		<0.001		0.005		<0.001	
N										
Samples		767		767		767		767		767
Participants		686		686		686		686		686

Table 5. Estimated (log) exposure (µg/m³ * hours) by sex in welders (*N* = 334).

	Aluminum	Chromium	Manganese	Nickel	Total dust
Men					
Mean	4.26	2.65	6.49	3.20	8.22
SD	1.39	1.41	1.26	1.26	1.20
N	199	199	199	199	199
Women					
Mean	4.23	2.25	6.26	2.87	8.64
SD	1.52	1.51	1.31	1.16	1.23
N	135	135	135	135	135
Total					
Mean	4.25	2.49	6.40	3.07	8.75
SD	1.44	1.46	1.28	1.23	1.21
N	334	334	334	334	334
Difference between means					
P	0.823	0.013	0.111	0.015	0.192

334 urine samples that could be linked to detailed exposure questionnaires and for whom a prediction of exposure could be made (Galarneau, 2021; Supplementary Appendix A, available at *Annals of Occupational Hygiene* online). The univariate analysis of confounders with these urine concentrations is shown in Supplementary Appendix Table B3 (available at *Annals of Occupational Hygiene* online). Women were again found to have higher urinary concentrations than men for aluminum, chromium, and manganese. Examination of the estimates of airborne metal concentrations showed no difference in estimated exposure for aluminum and manganese in male and female welders, but higher airborne concentration of chromium and nickel in men (Table 5). Total dust estimates did not differ between men and women. The final models including the exposure estimates and significant confounders are given in Table 6. Urinary concentrations of aluminum and chromium were related to the estimates of airborne exposure concentration. The regression coefficients for estimated manganese and nickel were positive, but their relation to urinary concentration did not approach statistical significance. For chromium and nickel, the urinary concentration decreased with the time spent working outside and, for nickel and, less strongly, aluminum, there was decrease in urinary concentration with time wearing RPE. Urinary chromium concentration increased with years spent in welding. The relation between estimated airborne and urine concentration from the models in Table 6 are shown in Fig. 1, with clearly increasing urinary concentration with estimated exposure to aluminum and chromium.

Discussion

The analysis reported here confirmed higher urinary concentrations of aluminum and chromium in welders than in electrical workers. Within welders, the estimates from the exposure models were related to the urinary concentrations for these two metals, supporting the validity of the models. The results for manganese and nickel were less striking, with only a weak relation to urinary concentrations, which moreover did not differentiate welders and those in electrical work. This does not mean that these airborne exposure models were not valid, but rather that urinary concentrations of manganese and nickel may not be a good reflection of the dust and fume inhaled. Previous studies of manganese alloy workers have failed to demonstrate a clear relation between airborne manganese and end of shift (Barrington *et al.*, 1998) or delayed urine concentration (Ellingsen *et al.*, 2006). Urinary excretion accounts for only about 1% of manganese absorption (Lauwerys and Hoet, 2001). The evidence for a relation between airborne and urinary nickel is more mixed. Stridsklev *et al.* (2004) and Gube *et al.* (2013) failed to find a relation between urinary and airborne nickel but Weiss *et al.* (2013) reported that airborne nickel was related to end of shift spot samples in 241 welders. Lauwerys and Hoet (2001) commented that nickel in fumes from stainless steel welding may be poorly absorbed by the lung but progressively released. In the current study, no difference was found between urinary nickel concentrations in welding and electrical workers, suggesting only low nickel absorption or retention in these welders.

A strength of the study was that all urinary concentrations used in the study were measured in the same

Table 6. Final models for the relation of urinary metals to estimated exposure adjusted for repeat samples in welders.

	Aluminum			Chromium			Manganese			Nickel		
	β	95% CI	*P*	β	95% CI	*P*	β	95% CI	*P*	β	95% CI	*P*
Estimated exposure (μg/m³ * h)[a]	0.09	0.04 to 0.15	0.001	0.11	0.05 to 0.17	<0.001	0.01	−0.03 to 0.06	0.552	0.04	−0.04 to 0.12	0.313
Sex (male)	−0.35	−0.51 to −0.19	<0.001	−0.45	−0.64 to −0.25	<0.001	−0.36	−0.49 to −0.23	<0.001			
Age										0.01	−0.00 to 0.02	0.059
Years in trade				0.02	0.01 to 0.04	0.006						
% of time wearing respirator	−0.19	−0.39 to 0.01	0.065							−0.37	−0.64 to −0.10	0.008
% of time outdoors				−0.34	−0.57 to −0.10	0.005				−0.30	−0.57 to −0.03	0.032
Creatinine g/l	0.66	0.54 to 0.78	<0.001	0.79	0.65 to 0.92	<0.001	0.41	0.31 to 0.50	<0.001	0.42	0.26 to 0.57	<0.001
Constant	0.74	0.47 to 1.02	<0.001	−2.33	−2.59 to −2.08	<0.001	−0.14	−0.46 to 0.19	0.409	−0.50	−0.99 to −0.01	0.044
N												
Samples		334			334			334			334	
Participants		312			312			312			312	

[a]Adjusted for repeat samples.

laboratory, and that comparisons could be made between those exposed to welding fume with electrical trade workers as a reference group. Comparison of the mean urinary concentration of metals in these two trades with those in the general Canadian population (aged 20–39) (Health Canada, 2010) was possible for many of the metals in Table 2. The mean concentration for copper was higher in both welders (13.2 μg/l) and electrical workers (13.07 μg/l) than in the general population (with a population 95%CI of 10.55–12.36 μg/l). Cadmium concentrations were somewhat lower (welders 0.27 μg/l: electrical 0.25 μg/l) than in the population (95%CI 0.39–0.47 μg/l). Zinc was within the population range for both trades. For the four metals of particular interest, Canadian population data were available only for manganese and nickel. As previously reported for women welders in this study (Arrandale *et al.*, 2015), manganese levels for welders (mean 1.54 μg/l) were considerably elevated above the population mean of 0.13 μg/l (95%CI 0.11–0.15) with the electrical workers also having higher than expected levels (1.46 μg/l). Mean nickel levels were also elevated above the population mean of 1.43 μg/l (95%CI 1.28–1.58) in both trades (welders 1.97 μg/l: electrical 1.98 μg/l). A population mean of 0.22 μg/l for chromium urinary concentration was found in early data from the US NHANES study (Paschal *et al.*, 1998), consistent with the level found here for electrical workers (0.20 μg/l) but far below that (0.45 μg/l) for welders. Population data for aluminum urinary concentration were less readily available. Data from northern France with mean concentrations of 4.25 μg/l (95%CI 4.01–4.49) (Nisse *et al*, 2017) would suggest that the means in both welders (7.20 μg/l) and electrical workers (6.25 μg/l) were high but other estimates of 6.47 μg/l (Wang *et al.*, 1991) and 8.89 μg/l (Valkonen and Aitio, 1997) might indicate that the aluminum concentrations were not importantly elevated.

A limitation of the present study was that collection of the urine sample and completion of the exposure questionnaire did not necessarily happen on the same day. Although it is reasonable to assume that the description of welding tasks reported on the 'most recent day' of welding was representative of welding on the day on which the sample was collected, there will have been more scope for misclassification of exposure than in a study with samples taken at the end of a shift with monitored exposures. Moreover, all the metals considered have a prolonged clearance rate and the urinary concentrations may reflect exposures over many weeks. The strong positive relation between urinary aluminum and chromium and estimated airborne exposure gives credence to the methods adopted.

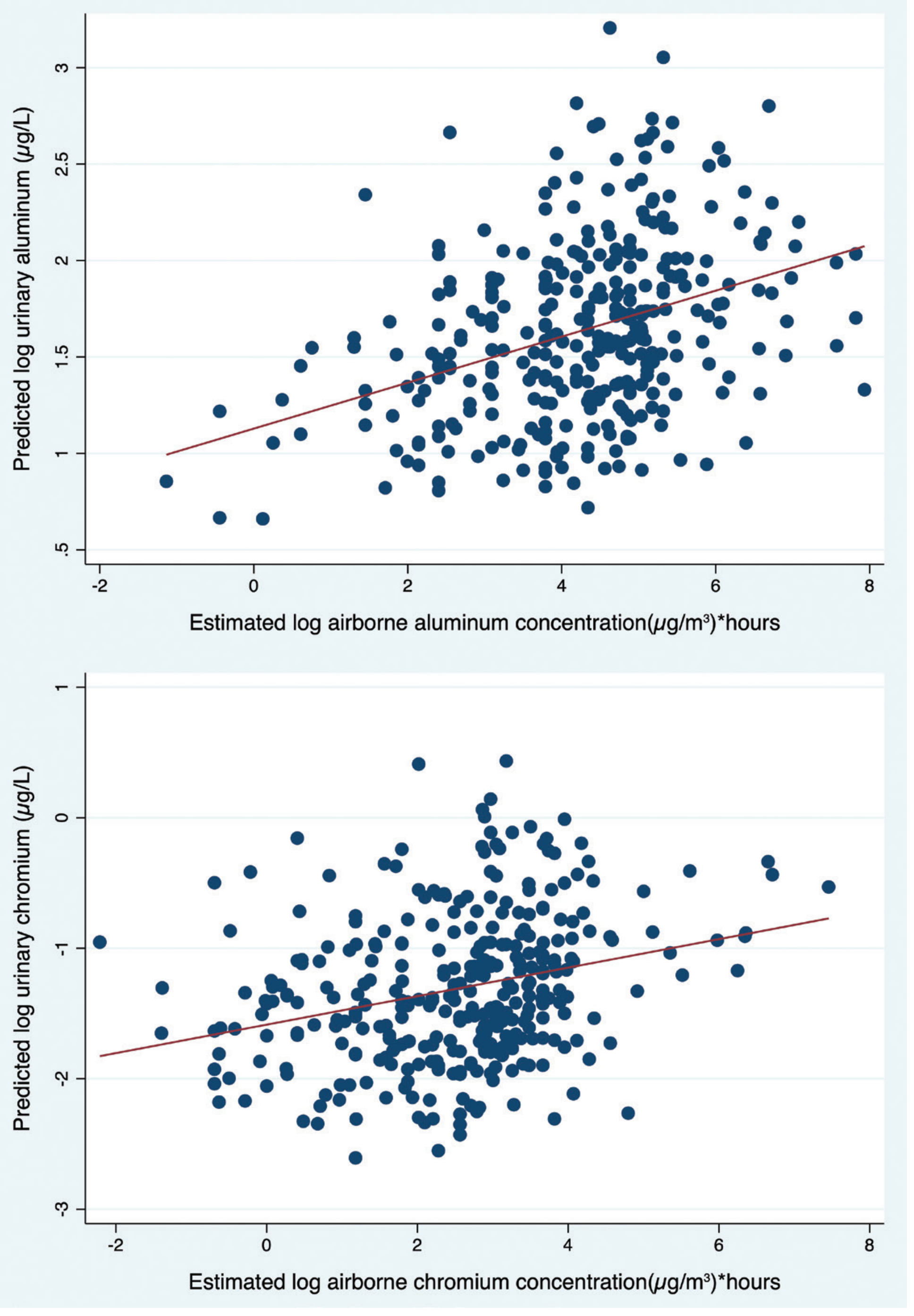

Figure 1 Log linear relation between predicted urinary metal concentrations and estimated exposures.

One focus of the WHAT-ME study was the examination of differences in exposures between men and women in the same trade and it was hoped that analysis of urinary metal concentrations would give further insight into this. As has been seen here, with statistical adjustment for creatinine in the final models, women were found to have higher urinary concentrations of aluminum, chromium, cobalt, and manganese. This was also seen, for both welders and those in electrical work, with individual adjustment for creatinine (Supplementary Appendix Table B1, available at *Annals of Occupational Hygiene* online). Interpretation of these data is problematic (Barr *et al*, 2005). In part, they reflect lower creatinine concentration in women. Moreover it has been observed that women absorb more manganese than men. (Findley et al, 1994; Health Canada, 2010; Berglund *et al*, 2011) The higher urinary concentration in women welders of aluminum and chromium (with higher estimated airborne chromium exposure in men) is unexpected: neither chromium nor aluminum appear to be absorbed more readily by women in the general population and so differences in other sources, such as diet, seem less likely. (Nisse *et al*, 2017) (St-Jean *et al*., 2018). Both aluminum and chromium accumulate in body tissues with repeated occupational exposures but male welders had been in the trade longer than females (Cherry *et al*., 2018) and any resultant body burden would be expected to be greater in men. Total months in trade did add significantly to urinary excretion of chromium (although not aluminum) in this study but inclusion of this factor to the model in Table 6 did not reduce the gender difference in chromium excreted. Women welders were less likely than men to report use of LEV and RPE, but adjustment for these did not fully account for the higher urinary concentrations in women. It remains unclear why the urinary concentrations in women are higher, but if this were to signify that they get dirtier jobs, less adequate PPE, or have more hazardous work practices, these are remediable, and interventions indicated.

The next phase of the analysis is to examine the effect on the fetus of estimated exposures at the time of conception and the relation of exposure to the new onset of asthma symptoms. The results of the present analysis, supporting the validity of the exposure algorithms for, particularly, chromium and aluminum, would give credence to any future conclusions about the effects of such exposures in this cohort.

Supplementary Data

Supplementary data are available at *Annals of Work Exposures and Health* online.

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Conflict of interest

The authors declare no conflict of interest relating to the material presented in this Article.

Ethical approvals

The research was reviewed by the Health Ethics Board at the University of Alberta (Pro00017851). All participants gave written informed consent.

Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

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